Griffith Business School

Submitted in fulfillment of the requirements of the degree of

Doctor of Philosophy

by

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September 2016
Economies of Scale and Scope in Higher Education

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Submitted in fulfillment of the requirements of the degree of
Doctor of Philosophy

September 2016
Abstract

This thesis investigates economies of scale and scope in higher education. In a period of tighter budget constraints, declining government funding, and increasing competition for students, staff and non-commercial and commercial research funding, understanding the nature of any scale and scope economies in higher education is critically important for both policy change and ongoing institutional and structural reform. The thesis presents three separate but related research objectives to provide insights into this important area: first, an examination of new output sources of cost economies (including scale and scope) as they exist in the Australian higher education sector, second, an analysis of the link between university performance and cost economies, and finally, an evaluation of the factors affecting the estimated economies of scale and scope.

The first research objective focuses on revealing new output sources of cost economies. Previous studies generally proxy teaching outputs using the level of education (undergraduate and postgraduate) or the broad subject field (science and other subjects). Two other important outputs are rarely discussed, namely, distance education and internationalization, features of particular importance in the Australian sector. The analysis uses balanced panel data comprising 37 Australian public universities over the period 2003–12 to examine the potential cost economies. The results indicate strong overall scale and scope economies and product-specific scale economies for distance education. These findings further suggest a priority on distance education as a way to achieve significant cost savings for Australian universities.

As for the internationalization of higher education, the findings suggest that it is generally worthwhile to enroll additional overseas students due to their lower average and marginal costs and the significant economies of scale prevailing in higher education. Further, while
there is evidence of economies of scope for overseas students only in smaller institutions, there is no evidence of diseconomies of scope, implying the current number of overseas students and their joint production with domestic students does not at least lead to higher costs. The expectation is that these two outputs could be key drivers in the next expansion phase of higher education.

The second research objective tackles the potential relationship between global rankings and effects of scale and scope, that is, the relationships between scale (as measured by the number of enrollments) and scope (as measured by the number of teaching programs), research performance, and institutional reputation (measured by the ARWU and QS university ranking scores). The most important outcome of this work is that a significant component of the superior performance of many universities found in global rankings flows not from any superior performance per se, rather from the innate, often inherited, benefits of their superior scale and scope. These benefits enable institutions not only to produce teaching, research and other outputs more cheaply than smaller universities, but that they also benefit qualitatively from reputation, given their greater visibility and the larger number of their alumni targeted for the surveys extensively used in these surveys.

The final research objective addresses the mixed, even conflicting results from previous studies. Unlike a simple qualitative literature reviewing previous studies, this thesis explores not only the overall level of scale and scope economies across studies, but also those factors that potentially affect their presence in the higher education sector. The findings suggest that functional form, allowances for managerial efficiency, and the specification of teaching outputs have a significant impact on estimated scale economies. In contrast, for scope economies, the key factors appear to be when the analysis was undertaken, the diversity of the sample, and the national level of economic development in the chosen context.

The thesis does have a number of limitations, all pointing to future research directions. The
first is the data used for exploring new output sources of cost economies, whereby our sample employs purely Australian data. Whether these cost economies persist in other countries or over time awaits further inquiry. A second limitation is the lack of detail on the specific insights needed to adjust the scale and scope without sacrificing teaching quality. Research addressing this could employ qualitative methods, also left to future study.
This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

(Signed) Liang-Cheng Zhang
Table of Contents

Abstract ...................................................................................................................................... ii
Statement of Originality ............................................................................................................. v
Table of Contents ...................................................................................................................... vi
List of Tables .............................................................................................................................. x
List of Figures ........................................................................................................................... xi
List of Acronyms ...................................................................................................................... xii
Acknowledgements ................................................................................................................. xiv
Thesis Related Research Outputs ............................................................................................ xvi
Publications Included in the Thesis ....................................................................................... xviii
Chapter 1. Introduction .............................................................................................................. 1
  1.1 Thesis background ........................................................................................................... 1
  1.2 Thesis motivation ............................................................................................................ 4
  1.3 Thesis objectives and questions ..................................................................................... 5
  1.4 Thesis structure ............................................................................................................. 9

Chapter 2. The Australian university sector ............................................................................. 13
  2.1 Introduction .................................................................................................................... 13
  2.2 Development ............................................................................................................... 13
  2.3 Financial reform .......................................................................................................... 14
  2.4 Structural change .......................................................................................................... 17
    2.4.1 Amalgamations ..................................................................................................... 17
    2.4.2 Cooperation .......................................................................................................... 19
    2.4.3 Distance education ............................................................................................ 20
    2.4.4 Internationalization ........................................................................................... 21
  2.5 Concluding remarks ...................................................................................................... 24
Chapter 7. Conclusion ............................................................................................................ 159

7.1 Summary ...................................................................................................................... 159

7.2 Contribution .................................................................................................................. 161

7.3 Limitations .................................................................................................................... 163

7.4 Future research directions ............................................................................................ 164

Appendix ................................................................................................................................ 167

Appendix 1. Computer code for Chapter 3 (section 3.5). ..................................................... 167

Appendix 2. Computer code for Chapter 4 ......................................................................... 171

Appendix 3. Computer code for Chapter 5 ......................................................................... 178

Appendix 4. Computer code for Chapter 6 ......................................................................... 190

References ............................................................................................................................. 195
List of Tables

Table 1.1: Tertiary education enrollments, 2003 to 2012 .............................................................................................................. 2
Table 3.1: Summary results of empirical studies on economies of scale and scope in higher education.................. 35
Table 3.2: Economies of scale for public institutions ........................................................................................................... 62
Table 3.3: Economies of scope for public institutions ........................................................................................................... 63
Table 3.4: Studies included in the meta-regression analysis, by country................................................................. 75
Table 3.5: Descriptive statistics of literature on scale economies (n = 52) and scope economies (n = 37).......... 80
Table 3.6: Correlation matrix for literature on scale economies (n = 52) and scope economies (n = 37)........ 82
Table 3.7: MRA results: dependent variables SRAY and GSE .......................................................................................... 84
Table 3.8: MRA results: dependent variables D.SRAY and D.GSE............................................................................... 86
Table 4.1: Selected variable statistics, 2003–2012 ................................................................................................................. 99
Table 4.2: Cost function estimates ................................................................................................................................. 104
Table 4.3: Average incremental cost ($000s) at mean output ....................................................................................... 105
Table 4.4: Scale economies at percentage of current mean output ........................................................................ 107
Table 4.5: Scope economies at percentage of current mean output ........................................................................ 108
Table 5.1: Higher education delivery to international students in Australia ......................................................... 115
Table 5.2: International student enrollments in Australian higher education ....................................................... 116
Table 5.3: Selected Variable Statistics, 2003–2012 ................................................................................................. 122
Table 5.4: Cost Function Estimates ............................................................................................................................... 126
Table 5.5: Point Estimates of average incremental costs of teaching outputs by broad field of education .... 128
Table 5.6: Point estimates of marginal costs of teaching outputs by broad field of education .................. 130
Table 5.7: Point estimates of scale economies at percentages of current mean output ...................................... 132
Table 5.8: Point estimates of scope economies at percentages of current mean output ...................................... 134
Table 6.1: ARWU and QS ranking indicators .................................................................................................................... 145
Table 6.2: Summary statistics for top-100 universities in 2014 ARWU and QS .................................................. 148
Table 6.3: Regression results for ARWU scores .............................................................................................................. 151
Table 6.4: Regression results for QS scores ...................................................................................................................... 152
List of Figures

Figure 3.1: Marginal and average cost curves ................................................................. 28
Figure 3.2: Ray average cost curve ............................................................................... 30
Figure 6.1: The illustration of ray average cost ......................................................... 143
Figure 6.2: Dot plots for private institutions and their ARWU and QS scores ........ 154
Figure 6.3: Dot plots for public institutions and their ARWU and QS scores ......... 155
# List of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS</td>
<td>Australian bureau of statistics, Australian Government</td>
</tr>
<tr>
<td>AIC</td>
<td>Akaike information criterion</td>
</tr>
<tr>
<td>ARWU</td>
<td>Shanghai Jiao Tong academic ranking of world universities</td>
</tr>
<tr>
<td>ATN</td>
<td>Australian Technology Network</td>
</tr>
<tr>
<td>CES</td>
<td>Constant elasticity of substitution</td>
</tr>
<tr>
<td>DIISRTE</td>
<td>Department of industry, innovation, science, research and tertiary education</td>
</tr>
<tr>
<td>FFCQ</td>
<td>Flexible fixed cost quadratic</td>
</tr>
<tr>
<td>FFCQ-A</td>
<td>Flexible fixed cost quadratic function with input prices entering additively</td>
</tr>
<tr>
<td>FFCQ-M</td>
<td>Flexible fixed cost quadratic function with input prices entering multiplicatively</td>
</tr>
<tr>
<td>Go8</td>
<td>Group of Eight</td>
</tr>
<tr>
<td>GSE</td>
<td>Global scope economies</td>
</tr>
<tr>
<td>IC</td>
<td>Incremental cost</td>
</tr>
<tr>
<td>IRU</td>
<td>Innovative Research Universities</td>
</tr>
<tr>
<td>MC</td>
<td>Marginal cost</td>
</tr>
<tr>
<td>MRA</td>
<td>Meta-regression analysis</td>
</tr>
<tr>
<td>NSW</td>
<td>New South Wales</td>
</tr>
<tr>
<td>NT</td>
<td>Northern Territory</td>
</tr>
<tr>
<td>QCF</td>
<td>Quadratic cost function</td>
</tr>
<tr>
<td>QF</td>
<td>Quadratic function</td>
</tr>
<tr>
<td>QLD</td>
<td>Queensland</td>
</tr>
<tr>
<td>QS</td>
<td>Quacquarelli Symonds world university rankings</td>
</tr>
<tr>
<td>OLS</td>
<td>Ordinal least squares</td>
</tr>
<tr>
<td>OUA</td>
<td>Open Universities Australia</td>
</tr>
<tr>
<td>RFM</td>
<td>Relative funding model</td>
</tr>
<tr>
<td>PSCE</td>
<td>Product-specific scale economies</td>
</tr>
<tr>
<td>PSOE</td>
<td>Product-specific scope economies</td>
</tr>
<tr>
<td>RUN</td>
<td>Regional Universities Network</td>
</tr>
<tr>
<td>SA</td>
<td>South Australia</td>
</tr>
<tr>
<td>SFA</td>
<td>Stochastic frontier analysis</td>
</tr>
<tr>
<td>SRAY</td>
<td>Ray economies of scale</td>
</tr>
<tr>
<td>THE</td>
<td>The Times higher education world university rankings</td>
</tr>
<tr>
<td>TL</td>
<td>Hybrid translog</td>
</tr>
<tr>
<td>VIC</td>
<td>Victoria</td>
</tr>
<tr>
<td>UK</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>Code</td>
<td>Description</td>
</tr>
<tr>
<td>------</td>
<td>------------------------------</td>
</tr>
<tr>
<td>US</td>
<td>United States</td>
</tr>
<tr>
<td>USN</td>
<td>The US News best global universities ranking</td>
</tr>
<tr>
<td>WA</td>
<td>Western Australia</td>
</tr>
</tbody>
</table>
Acknowledgements

I have written this thesis while a full-time student in the Department of Accounting, Finance and Economics at Griffith University from 2013 to 2016, with the financial support of two International Postgraduate Research Scholarships from Griffith University. I sincerely appreciate the academic and administrative support of the department and the generous financial support of the university.

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Another tip learned from my candidate is to cooperate with experts. These experts have played a number of important roles in my journey, including as discussants, coauthors, reviewers, and colleagues. I would especially like to thank Professor Christopher O’Donnell at University of Queensland for being the discussant of my paper at the 2014 Asia-Pacific Productivity Conference.

I would also like to thank Ms. Mingyan Hu for contributing her knowledge and experience in international higher education to part of my thesis. Since the thesis consists in part of refereed journal articles, its quality has been greatly improved by anonymous reviewers for the target journals. Whoever you may be, I thank you for spending time on my drafts and providing useful comments. I also thank my friends and colleagues at other universities, especially Tzu-Hsien Yuan, for directing me to some interesting and useful research materials.
concerning the subject of my thesis.

Finally, I would like to extend my sincere gratitude to my family, my wife Dr. Jia-Jia Syu and my son Zhou-Yi Zhang. My wife is an excellent scholar as well as an amazing mother to our son. During my candidate, she gave birth to my son and takes great care of our family. Thank you Jia-Jia for all your loving support along the way and, most importantly, raising a gorgeous boy who is my inspiration and motivation in life.
Thesis Related Research Outputs

Journal Publications


Working Papers


Book Chapters


Conference Proceedings


Software

Conference Papers


Publications Included in the Thesis

Chapters 3 to 6 in this thesis are journal articles and book chapters (in part or in full) published by the candidate during candidature and co-authored with others. The candidate’s contribution to each publication involves the initial concept and empirical design, the collection and analysis of data, and the writing, preparation and submission of the manuscripts. The authors signify their approval for the publication to be included in the thesis below:

Chapter 3 (section 3.5).


(Signed) _________________________________ (Date)  6 March 2017

Liang-Cheng Zhang

(Countersigned) _________________________________ (Date)  6 March 2017

Andrew C Worthington
Chapter 4.


[SSCI; A* ranked in ERA; A ranked in ABDC]

(Signed) _________________________________ (Date) 6 March 2017

Liang-Cheng Zhang

(Countersigned) _________________________________ (Date) 6 March 2017

Andrew C Worthington

Chapter 5.


[SSCI; A ranked in ABDC]

(Signed) _________________________________ (Date) 6 March 2017

Liang-Cheng Zhang

(Countersigned) _________________________________ (Date) 6 March 2017

Andrew C Worthington

(Countersigned) _________________________________ (Date) 6 March 2017

Mingyan Hu
Chapter 6.


(Signed) _________________________________ (Date) 6 March 2017

Liang-Cheng Zhang

(Countersigned) _________________________________ (Date) 6 March 2017

Andrew C Worthington
Chapter 1. Introduction

1.1 Thesis background

In recent decades, national higher education sectors worldwide have been under the persistent pressure aimed toward their expansion. For the most part, strong needs for skilled labour and advanced technology have led to models of mass higher education around the world (OECD, 2009; Trow, 1972). According to UNESCO (2005), tertiary student numbers increased by 43% between 1995 and 2003 across the developed world, and even more significantly in developing countries, where students numbers grew by 77% over the same period.

Two factors help explain this expansion. First, the baby boom following World War II. This mainly accounts for the massification of domesticate higher education in Europe and North America (and Australia), and led to the rapid expansion of higher education providers in the 1960s (Bereday, 1973). Second, increasing demands by international students. From 1950 to 1980, the average annual growth rate of overseas students has doubled every decade (Mazzarol & Soutar, 2012). For the most part, the higher education market is now no longer limited by geographic space, but has extended to a global market.

Even in the last decade, there are still signs of the ongoing expansion trend. Table 1.1 depicts the trend in tertiary education enrollments in OECD countries over past ten years. As shown, the market for higher education continues to expand, not only nationally, but also globally (except for Japan) (UNESCO, 2005). Of these, the US has the largest tertiary enrollments (around 20 million after 2010) followed by several Asian countries such as Japan and Korea. Even the Netherlands and Switzerland experience a 4.5% annual growth rate in student numbers over this period. Elsewhere, the number of enrollments continues to grow, albeit at a
Economies of Scale and Scope in Higher Education

decreasing rate.

Table 1.1: Tertiary education enrollments, 2003 to 2012

<table>
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<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>1,006</td>
<td>1,003</td>
<td>1,025</td>
<td>1,040</td>
<td>1,118</td>
<td>1,200</td>
<td>1,276</td>
<td>1,324</td>
<td>1,364</td>
<td>1,364</td>
<td>3.06%</td>
</tr>
<tr>
<td>France</td>
<td>2,119</td>
<td>2,160</td>
<td>2,187</td>
<td>2,201</td>
<td>2,180</td>
<td>2,165</td>
<td>2,173</td>
<td>2,245</td>
<td>2,259</td>
<td>2,296</td>
<td>1.26%</td>
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<td>Germany</td>
<td>2,242</td>
<td>2,330</td>
<td>2,269</td>
<td>2,289</td>
<td>2,279</td>
<td>2,245</td>
<td>2,439</td>
<td>2,556</td>
<td>2,763</td>
<td>2,939</td>
<td>3.20%</td>
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<td>Italy</td>
<td>1,913</td>
<td>1,986</td>
<td>2,015</td>
<td>2,029</td>
<td>2,034</td>
<td>2,014</td>
<td>2,012</td>
<td>1,980</td>
<td>1,968</td>
<td>1,926</td>
<td>0.40%</td>
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<td>Japan</td>
<td>3,984</td>
<td>4,032</td>
<td>4,038</td>
<td>4,085</td>
<td>4,033</td>
<td>3,939</td>
<td>3,874</td>
<td>3,836</td>
<td>3,881</td>
<td>3,885</td>
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<td>Korea</td>
<td>3,223</td>
<td>3,225</td>
<td>3,210</td>
<td>3,204</td>
<td>3,209</td>
<td>3,204</td>
<td>3,219</td>
<td>3,270</td>
<td>3,356</td>
<td>3,357</td>
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<td>Mexico</td>
<td>2,237</td>
<td>2,323</td>
<td>2,385</td>
<td>2,447</td>
<td>2,529</td>
<td>2,623</td>
<td>2,705</td>
<td>2,847</td>
<td>2,981</td>
<td>3,161</td>
<td>3.95%</td>
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<td>Netherlands</td>
<td>527</td>
<td>543</td>
<td>565</td>
<td>580</td>
<td>590</td>
<td>602</td>
<td>619</td>
<td>651</td>
<td>780</td>
<td>794</td>
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<td>New Zealand</td>
<td>196</td>
<td>243</td>
<td>240</td>
<td>238</td>
<td>243</td>
<td>244</td>
<td>263</td>
<td>266</td>
<td>262</td>
<td>260</td>
<td>3.59%</td>
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<tr>
<td>Norway</td>
<td>212</td>
<td>214</td>
<td>214</td>
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<td>215</td>
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<td>219</td>
<td>225</td>
<td>230</td>
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<td>Spain</td>
<td>1,841</td>
<td>1,840</td>
<td>1,809</td>
<td>1,789</td>
<td>1,777</td>
<td>1,781</td>
<td>1,801</td>
<td>1,879</td>
<td>1,950</td>
<td>1,966</td>
<td>0.72%</td>
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<tr>
<td>Sweden</td>
<td>415</td>
<td>430</td>
<td>427</td>
<td>423</td>
<td>414</td>
<td>407</td>
<td>423</td>
<td>455</td>
<td>464</td>
<td>453</td>
<td>1.77%</td>
</tr>
<tr>
<td>Switzerland</td>
<td>186</td>
<td>196</td>
<td>200</td>
<td>205</td>
<td>213</td>
<td>224</td>
<td>233</td>
<td>249</td>
<td>258</td>
<td>270</td>
<td>4.73%</td>
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<tr>
<td>UK</td>
<td>2,288</td>
<td>2,247</td>
<td>2,288</td>
<td>2,336</td>
<td>2,363</td>
<td>2,329</td>
<td>2,415</td>
<td>2,479</td>
<td>2,492</td>
<td>2,496</td>
<td>1.10%</td>
</tr>
<tr>
<td>US</td>
<td>16,612</td>
<td>16,900</td>
<td>17,272</td>
<td>17,487</td>
<td>17,759</td>
<td>18,248</td>
<td>19,103</td>
<td>20,428</td>
<td>21,016</td>
<td>20,994</td>
<td>2.82%</td>
</tr>
</tbody>
</table>

Note: Figures in thousands. Some OECD countries are not included because of missing data.
Source: http://stats.oecd.org

While these figures imply the significant expansion in the scale of the higher education sector, there has been a corresponding increase in scope. Dating back to the 1960s, the existence of many smaller institutions, including colleges of advanced education (CAEs) in Australia, gradually became a financial burden for their respective governments. The increasing cost of education accompanied by inflation and economic decline promoted growing numbers of mergers (Goodlad, 1983). Merging two or more higher education institutions is considered an effective way to restructure education system and achieve financial sustainability for its institutions. During the 1970s and 1980s, mergers were extensively used in some developed
countries, including Australia, Germany, Sweden and the UK (Skodvin, 1999). From 1990 to 2005, over 400 mergers between higher education institutions had been performed in China (Cai & Yang, 2016). Even in the past decade, there have been about 100 higher education mergers throughout Europe (Estermann & Pruvot, 2015). Importantly, these have created larger and more comprehensive universities, which provide increasingly diversified services and programs.

Together, these global developments have accounted for both an increase in the size (scale) and provision (scope) of the services (including broadly research, teaching and research training) provided by higher education institutions. However, the World Bank (1994) has warned that they could also bring about a crisis in higher education, not least by imposing a serious cost burden on individual institutions, and especially when unaccompanied by corresponding budget growth. For example, the growth of the higher education sector throughout the OECD has dramatically driven up unit or per student costs for teaching and research and resulted in a decrease in dollar resources per student (Altbach, Reisberg, & Rumbley, 2009). Throughout the OECD from 2000 to 2012, the average share of government funding for higher education institutions decreased from 68.8% to 64.5% (OECD, 2015). Only a very few countries continue to increase the public share of university funding, including Chile, Ireland, Korea, and Poland.

Unfortunately, the existing literature provides little guidance about the costs of production (Cheslock, Ortagus, Umbricht, & Wymore, 2016) for higher education institutions, let alone the adjustments of scale and scope based on cost economies. Two main challenges are the assumption of single-output production and the untangling of joint products in higher education (Breneman, 2001), for which we may be able to respond using the theory of scale and scope economies first developed by Baumol, Panzar, and Willig (1982). Therefore, investigating scale and scope economies is an important topic in the field of higher education.
Economies of Scale and Scope in Higher Education

and the main purpose of this thesis.

1.2 Thesis motivation

Understanding the nature of scale and scope economies in higher education is critically important for future policy and for the economic rationale underpinning any structural change. Otherwise, diseconomies of scale and scope will result if the levels of outputs are too high or too low or their mix inappropriately broad or narrow. Institutions, therefore, need current information about their cost structures. To date, many studies have been conducted to provide such information about higher education. Unfortunately, many pertinent issues await further study.

The first research gap lies in the incomplete discussion regarding the output types used for calculating economies of scale and scope economies. Most previous studies have proxied teaching outputs for educational levels (undergraduate and postgraduate) or broad fields of subject (science and non-science subjects). However, the expansion of the labor-intensive nature of higher education generally limits these teaching outputs. Thus, it is not surprising that many past studies either did not find economies of scale in these outputs or that the economies are usually artificially capped at about 100% of mean output.

Another research gap could be the potential link between effects of scale and scope and performance in global university rankings. Raising the world ranking of higher education institutions has been increasingly one of the most important issues facing domestic industry stakeholders (Dearden, Grewal, & Lilien, 2014; Marope, Wells, & Hazelkorn, 2013) because better ranking results arguably lead to attracting more and better quality students and faculty. University spending aimed at improving results has accordingly increased (Ehrenberg, 2000). These expenses may include building laboratories and classrooms equipped with high-end
facilities, and paying a top salary to attract scholars and the department leaders (Times Higher Education, 2013). Effects of scale and scope could play an important role in the ranking performance because the associated cost advantages could enable some institutions to increase their university rankings relatively easier in terms of lower costs. Unfortunately, there is still no study providing relevant empirical evidence of the relationship between cost economies and ranking performance.

The final research gap concerning this thesis originates from the mixed, even conflicting, results of previous studies. For example, findings of cost economies vary with different types and locations of institutions. It will then be instructive to investigate the factors affecting the degrees of scale and scope economies. Nonetheless, there is still no study using such method to sort out the mixed results from previous studies regarding economies of scale and scope in higher education. These research gaps motivate this thesis to provide a more complete picture of cost structures in higher education as they currently exist, and to provide industry and policy suggestions that will ensure the sustainability of the industry and its key contributions to the education sector and global economies.

1.3 Thesis objectives and questions

In this thesis, we expect three core research objectives and their accompanying research questions to address this.

Question #1: What are the new output sources of scale and scope economies in higher education?

Instead of using traditional teaching output classifications such as educational levels
(undergraduate and postgraduate) and broad fields of subject (science and non-science subjects), this thesis identifies other possible output types for exploring new sources of scale and scope economies. Distance education and internationalization of higher education could be ideal candidates since both types of outputs might qualify the essential criteria of achieving at least scale economies: higher fixed costs but lower variable costs.

The nature of higher education teaching is labor intensive, especially for traditional face-to-face instruction. Distance education releases this labor-intensive nature by using new information and communication technology for course delivery and instruction. Notice that adopting distance education causes higher fixed costs at least at short run because a distance education instructor usually spends more time designing and producing instruction than does a face-to-face instructor. Once the courses are ready, cost of distance education comes from the maintenance of large files and multiple simultaneous users and considerable bandwidth (Archibald & Feldman, 2010). Fortunately, this type of output could be more unlimited by the space and time compared with the traditional classroom-based instruction. There is much less need to maintain classrooms, libraries and other campus building. The extra cost of adding another student is much lower compared with face-to-face teaching. These indicate the variable costs should be lower and further decrease with the growth of enrolled students.

There also could be potential existence of scope economies between face-to-face teaching and online delivery (Morris, 2008). Nowadays, institutions that teach in the conventional mode are usually in charge of distance education. These two types of courses can be taught by the same academic staffs that spend their time and energy on both course designs. Course materials could also be shared or adapted by the other courses (Ashenden, 1987). Face-to-face and distance courses have co-existed in higher education institutions for many years, but there is still little research discussing their cost relationship or the relationship between distance education and research output. There is only one relevant study (Li & Chen, 2012) and they
found the scope economies between distance education and other types of outputs.

Another new output source of economies of scale and scope might come from the internationalization of higher education. Internationalization in this thesis refers to integrating international dimensions into the hosting institutions, especially by means of recruiting overseas or international students. Over the past few decades, the additional revenues available via the export of higher education (through both relatively higher prices and increased enrollments) have attracted the attention of providers in many developed countries, especially for English-speaking countries such as the US, the UK, Canada, and Australia.

For hosting these overseas students, institutions usually have to pay a significant amount of money to build facilities and provide additional services specific to these students. These facilities and services might include language-learning centers, counselling, student accommodation, and employment services. However, these fixed costs are very likely to decrease with the increasing number of overseas students. One major reason could be due to their relevantly short completion time, especially given the recently increasing numbers of transnational or offshore programs on offer, contributing lower marginal costs compared with their domestic counterparts. Another intriguing question is whether institutions benefit from offering these international environments in terms of cost savings (i.e. scope economies). Unfortunately, the above potential cost economies underlying the provision of higher education services for international students remain relatively unknown at the sector level.

**Question #2: What is the relationship between effects of scale and scope and global university rankings?**

This research question mainly investigates the potential link between effects of scale and scope and university performance (measured by university rankings, QS and ARWU in this
thesis). This thesis defines scale as the number of student enrollments and scope as the number of research or teaching programs in a higher education institution. This enables us to understand how university scores and how their rankings may benefit from its inherent advantages in scale and scope.

These effects on ranking results are especially increasingly critical for universities operating in globally competitive environments due to the significant role of government funding decisions and implications on structural change. Specifically, they could lead to some institutions in some jurisdictions to increase their university ranking. Alternatively, it may be possible through industry restructuring to improve a country's overall ranking significantly. However, no known study has directly examined the possible presence and therefore the influence of scale and scope effects in the main global university rankings.

**Question #3: What factors affect economies of scale and scope in higher education?**

Numerous studies have investigated economies of scale and scope in higher education as a means of providing public and private providers of college and university teaching and research and their stakeholders with knowledge of the cost structures that underpin provision in this economically and socially important sector. Regrettably, the chosen institutional, regulatory and market contexts within which existing results have been derived vary so markedly that generalization for informing government policy and industry practice is difficult.

There should be an appropriate way to sort existing findings on the economics of scale and scope in higher education. This thesis firstly identify the potential factors and employs meta-regression analysis (MRA) to examine the impact of moderator variables on cost
economies. MRA is expected to shed greater light on both the general outcomes of a large body of existing work and possible reasons for the differences in these results.

1.4 Thesis structure

This thesis explores economies of scale and scope in higher education. The thesis is structured as follows. To start, as the Australian higher education sector is our main source for responding to the first research question, Chapter 2 provides an overview of its history, financial reforms, and recent structural change.

Chapter 3 conducts a qualitative and a quantitative review of scale and scope economies in higher education to gain some insights about the nature of these cost economies. This chapter also plays an important role in developing our core theory and in finding research gaps in this area. The last section of Chapter 3 is prepared for the response to the final research question of analyzing the factors affecting economies of scale and scope in higher education. This section employs meta-regression analysis to explore factors that potentially affect their presence in the higher education sector with a sample of nearly 50 international studies conducted in Australia, the US, the UK, Italy, China, and others since the early 1980s.

Chapters 3 (section 3.5) to 6 employ a consistent research framework to investigate empirically the economies of scale and scope in higher education. These chapters are either already published or have been prepared for submitting to a referred journal following thesis guideline of Griffith University (2016) and Griffith Business School (GBS, 2016). That is, this thesis has been arranged as a series of papers. Such a format includes one or more papers that have been prepared, submitted, or accepted for publication. Chapters 3 (section 3.5) to 6 have been prepared for fulfilling this requirement. Chapter 4 and 5 have been published as journal papers, Chapter 6 has been published as a book chapter, and Chapter 3 (section 3.5) is
prepared as journal articles submitted for publication.

To be specific, Chapters 4 and 5 are organized to answer the first research question about whether there are new output sources of scale and scope economies. Chapter 4 starts with the investigation of distance education with a sample of 37 Australian public universities over the 10-year period from 2003 to 2012. This chapter contributes to the literature by analyzing the multiple output scale economies of distance education in dual-mode higher education institutions and examining whether traditional higher education institutions should additionally provide distance education to traditional on-campus teaching modes to save costs.

Chapter 5 explores another new output source of cost economies in the form of the internationalization of higher education. This chapter offers a comprehensive analysis of the cost economies underlying higher education provision for international students using a sample of 37 Australian public universities over the period from 2003 to 2012. Such analysis includes whether the unit cost of international students is higher than that of domestic students, how cost economies could be gained by increasing (or even decreasing) the number of international students, and lastly the nature of the cost savings between domestic and international higher education.

In Chapter 6, the focus shifts to investigations of our second research question being the potential impact of economies of scale and scope on ranking results. This chapter employs exogenous information and a quantitative method to investigate the scale economies (as measured by the number of enrollments), and scope economies (as measured by the number of teaching programs) in existing ranking outcomes and quantifies their precise contribution to the rankings.
Chapter 7 summarizes the results from empirical studies above and, most importantly, gives implications and policy recommendations. This chapter also highlights the limitations of the thesis and further indicates future directions for research in this area.
Chapter 2. The Australian university sector

2.1 Introduction

The structure of the Australian university sector continues to be reshaped from the foundation of satisfying the educational needs to recent mergers and alliance between universities owing to the constraint of government budget. Although government funding remains the main income source of public universities, the private contribution proportion from (domestic and international) students and endowments is steadily increasing, which blurs the boundaries between public and private universities (Davis, 2008). Universities are now more market-oriented and form alliances to exert a greater impact on policy making.

The remainder of this chapter is structured as follows. Section 2.2 introduces the development of the Australian university sector. Section 2.3 depicts the recent financial reforms in this sector. These financial reforms have brought a significant effect on Australian university sector’s structural changes, including amalgamations, cooperation, distance education and internationalization, which will be summarized in Section 2.4. In Section 2.5, the conclusion of this chapter will be given.

2.2 Development

The establishment of the University of Sydney in 1850 initiates the history of Australian higher education. The second university, the University of Melbourne is established in 1853. Both universities start with very small enrollments, cohorts of less than 30 students, and remained at a similar scale for many decades (Bentley, Goedegebuure, & Meek, 2014).
Even at the time of Federation in 1901, the combined enrollments of the now four universities (the University of Adelaide and the University of Tasmania are established in 1874 and 1890, respectively) are only 2,652 students, which occupies less than 0.07% of Australian citizens (Solomon, 2007). Since then, the number of higher education institutions and students has been growing. Different types of higher education institutions are built to satisfy multiple educational needs.

Prior to 1988, Australian higher education system was composed of a College of Advanced Education (CAE) sector and a university sector. The former sector dominates most of the student sources and provided varied programs up to Master’s degree level while the latter sector offered only a few programs such as medicine, dentistry, veterinary science and law (DEEWR, 2010). CAEs were formed as vocational and teaching-oriented institutions to satisfy increasing demand for high skill labors (Bentley et al., 2014). However, this type of higher education structure no longer exists in Australia. The structure of Australian higher education is deeply affected by funding system. A series of financial reforms have reshaped not only the relationship between institutions, but also the structure within them.

2.3 Financial reform

Like all other countries, Australia continues to improve its higher education system through a series of financial reforms. The Commonwealth Government changes the rules of funding allocations and sources to guide institutions. Although most Australian universities operate under the State or Territory legislation, their budgets are still constrained by the Commonwealth Government. Since 1951, the Commonwealth Government has gradually increased the ratio of funding under the State Grants Act. After 1974, the Commonwealth Government gains primary financial responsibility for universities in exchange of the
abolition of tuition fees (Access Economics, 2010). Students have not enjoy these free tuition fees for a long time. *The Higher Education Funding Act* of 1988 introduces the Higher Education Contribution Scheme (HECS). Since then, Australian students have no longer enjoyed free fees of their college studies, but have to contribute to the cost of their studies through HECS. For funding purposes, the number of these students is converted into a number of places. We should also notice that these places determine the amount of teaching funding for universities and they are allocated by the Government. This means that universities also have to obey the allocation of student places to receive financial support.

Since 1989, universities have been further authorized to offer fee-paying places to Australian undergraduate students under the condition of matching their enrolment targets for commonwealth funded student and total number of domestic fee-paying students not greater than 35 percent of the total number of places. In 2003, the *Higher Education Support Act* (HESA) is enacted; the limit of the tuition fee for Australian undergraduate students is also removed and the block operating grant system has been replaced by the Commonwealth Grant Scheme (CGS) since 2005. Each university has to make an annual funding agreement with the government, which contains the number of places being funded and the discipline combination. The amount of CGS and the contributions from domestic students is about $7.6 billion Australian dollars in 2010 and constitutes the core elements of funding (base funding). The base funding is generally used to cover the expenses of learning and teaching activities such as staff salary, capital, information and communication technology (ICT), and depreciation costs. Universities have full autonomy to use this funding without detailing the actual expenditures (DEEWR, 2010:16).

However, the Commonwealth contribution rates and maximum student contribution amounts are not enough to cover the operational expenses. Universities have to raise the level of enrollments from full-fee domestic and international undergraduate students
Economies of Scale and Scope in Higher Education

(Access Economics, 2010:10). This has caused huge expansion in scale because of competing for fee-paying students and recruiting international students.

In 2009, the new ambitious goals which could cause Australian universities undergo another major structure change are announced in Transforming Australia’s Higher Education System (DEEWR, 2009) to respond the Bradley review (Bradley, 2008): raising the proportion of 25-34 year olds with undergraduate qualifications to 40% by 2025 and increasing the low socioeconomic status (SES) undergraduate student participation to 20% by 2020. In order to help universities to achieve these goals, the demand driven funding system documented in the Higher Education Support Act Amendment Bill is introduced from 2012 and it removes the cap on the supply of Commonwealth supported places and the allocation of undergraduate student places. The Commonwealth Grant Scheme (CGS) between the Government and each university remains but contains only the number of postgraduate places and medical places, which are referred to as designated courses of study (DIISRTE, n.d.).

Universities now can decide their number of (non-designated) places for undergraduate students in each discipline (except for medicine) and are more autonomous in varying their scale and combination of programs. This reform has caused a rapid expansion of places in enrollments and induced universities to compete for students even before the reform begins to gain access to increased funds. This system has driven a 23.03% increase in the number of Commonwealth supported places (from 469,000 places in 2009 to an estimated 577,000 places in 2013 (DEEWR, 2010)). The dramatic expansion in these supported places has led to Commonwealth Government budget blowouts and forces it to review the whole system (Trounson, 2013).

The efficient operation of the demand driven system hinges on whether universities can bring funding and costs in line and the extent to which discipline funding matches the costs
Chapter 2. The Australian university sector

(DEEWR, 2011). However, the under-funded situations deeply affect the structure within universities such as downgrading the size of administration, decreasing the number of new academic programs, consolidating academic programs and courses (Access Economics, 2010). Because course fees and charges has become the largest single source of non-government revenue, the current cluster funding model with the demand-driven system also lures universities to subsidize less profitable courses with more places in profitable places or decrease the number of less profitable courses (Go8, 2011). The government, therefore, offers A$400 million structural adjustment fund to assist universities to reconstruct the school scale to face the demand driven system (DEEWR, 2012).

2.4 Structural change

Several higher education reforms as well as the resulting funding model discussed above are shaping the form of universities and the relationships between them. Although there are almost no merger activities after 2005, another structural change activity, forming alliances with other institutions having common interests and purposes, starts to grow recently. The other change is other thriving forms of teaching outputs including distance education and international students. These changes will be introduced as follows.

2.4.1 Amalgamations

The Dawkins Reform of 1988 is the most influential recent reform to change the structure of Australian universities. The then Minister for Employment, Education and Training, John Dawkins, saw the redundancies in the universities, such as over-staffed departments and inefficient management (Bessant, 1996). The unification was, therefore, to be used to eliminate the high unit costs resulting from small institutions. The large-scale consolidation
had begun, and the number of universities was slashed down from 70 in 1980s to 41 universities (37 public universities and 4 private universities) today.

Since consolidation could provide wider choice of subjects for students, the interactions among different academics could increase, and most importantly, could make universities more cost and administratively efficient (Bessant, 1988; Lloyd, Morgan, & Williams, 1993). There are 15 new universities resulting from CAEs (nine involves mergers), which increases the number of universities from 19 in 1986 to 34 in 1992 (Harman, 2000; Marginson, 1999). These merger activities also expand the scope of provided service in these new universities. Since then, they have increased their research activities and extended their teaching level to research Masters and Ph.D. programs (Mahony, 1990).

Another three new public universities, Southern Cross University, the University of the Sunshine Coast and the University of Ballarat established in 1994 increase the number to the present 37 (DEEWR, 2010). The most recent proposal about amalgamation among Curtin University of Technology, Murdoch University and Edith Cowan University in 2005 does not work out.

Merger is an almost invertible process, and it makes two or more partners to combine together to create a new one. This process is expected to bring universities economies of scale because they are more capable to provide more courses, learning resources at cheaper price and increase the quality of output (Patterson, 2000). Merger also indirectly causes the popularity of multi-campus operation in Australia. These universities consist of several geographically distinct production units managed together under one administrative organizational unit. Today, there is only one single-campus university, the University of Canberra, in Australia and on average there are 3.4 campuses for every Australian university (Moodie, 2009).
2.4.2 Cooperation

Facing tighter budget constraints and declining government funding, Australian universities seem to pursue a more flexible approach to deal with the under-resourced problem (Bradley, 2008; Worthington & Higgs, 2011). One of the funding reforms could be the motivation to further affect the structure between Australian universities. The relative funding model (RFM) was developed in 1990 to correct the inequalities in funding between the new universities and established universities. Even the present funding model is merely the modified form of the RFM (Go8, 2011). Although unified system give each university equal access to student-based and research funding, it does not mean every university will get uniform development and funding (Wood & Meek, 2002). Universities thus begin to form alliances to gain more influence in reputation and funding.

So far, there are four university alliance groups in Australia. The most famous one would be the alliance of leading eight Australian universities, Group of Eight (Go8, 2017), which focus on the enacting the long-term sustainable research and higher education policy, and developing international alliances. Six research universities form Innovative Research Universities (IRU, 2017) to share resources and make impacts on the policy making. Another five technology universities brought together by The Australian Technology Network of Universities (ATN, 2017). This alliance emphasizes the industry collaboration and real-world research with real-world impact. The last group is Regional Universities Network (RUN, 2017) whose six members play an important role in delivering educational programs across regional Australia and internationally.

Through forming the alliance, it could provide similar cost economies among members and also pose greater precise pressure on the government (Eckel & Hartley, 2008; Tight, 2012). Australian universities, therefore, are taking this measure to actively integrate their resources.
Although alliance and collaboration would not make universities actually become larger, these measures still could result in cost reductions by cooperating and coordinating the assets of the universities. Through alliance or collaboration, universities share their resources just like that they produce outputs together and the cost of joint production could be therefore lower than the cost of institutions without alliance or collaboration. On the other hand, universities with alliance could reduce their unit cost by sharing their resources and joint production. They could enjoy the economies of scope even though they did not expand their scales but increase their volume in terms of different types of product (Jackson, 1998).

2.4.3 Distance education

Except for the face-to-face classroom teaching, the distance education has taken the form of video instruction, satellite broadcast, and internet to help students learn knowledge and skill without the limit of time and location. Note that distance education distinguishes itself from the traditional face-to-face teaching mode in not just the manner of transmission, but also the potential students it targets. Outside traditional class-based face-to-face teaching, distance education has thrived for decades in most countries.

While Australian universities used to be traditional classroom-based providers or so called single-mode institutions, over the last three decades, more and more traditional classroom-based higher education providers have moved to provide distance education for students choosing not to attend on campus (King, 2012). These dual- or mixed-mode institutions provide both on-campus and distance (or off-campus) education to match the needs of flexible learning styles. Presently, all public Australian universities are dual-mode institutions. Relative to internal students who go to school on a regular basis, students taking
distance education in Australia are called *external* students whose learning are through self-paced and structured material delivered by mail or internet.

Since 1980s, distance education in Australia has not only played an important role of alternative mode of delivery but also become a competitive rival to on-campus instruction (Ashenden, 1987). Under previous funding system, universities had to allocate the places for internal and external studies. The relaxation of university places under demand driven funding system makes external studies grow even faster due to the removal of the university places (Kemp & Norton, 2014). In 2010, the annual growth rate of external enrollments (5.11%) is greater than the rate of internal enrollments (4.31%). The number of external completions also rises from 25,360 in 2001 to 34,798 in 2012 and at least one out of ten graduates are through distance education in 2012 (DIISRTE, 2013).

Adopting distance education also means higher fixed costs at least in the short run because a distance education instructor might spend more time designing and producing instruction than does a face-to-face instructor. Some Australian universities thus cooperate with Open Universities Australia (OUA) which are owned and partnered by seven Australian universities (OUA, n.d.). OUA does not develop its own programs along traditional lines but work with universities to deliver a diverse range of courses on line. OUA could help universities achieve scale economies by spreading the costs of the expensive infrastructure and the employees needed for internet delivery among all providers.

### 2.4.4 Internationalization

Internationalization of Australian higher education has been an important goal as stated in many Government reports (Australian Government, 2015a; Australian Vice-Chancellors’ Committee, 2001). It has also been regarded as “…a key enabler of productivity and growth
for virtually every part of an economy” (Australian Government 2015a, p. 8) (Australian Government, 2015a), producing positive effects in the social, cultural, and intellectual life of the exporting country. In the recent Draft National Strategy for International Education, the Australian Government (2015a) further explains what should be included in international education:

> It includes international students studying in Australia and those studying for an Australian qualification overseas, as well as the experiences of Australian students who study abroad. It includes preparing our students to engage globally through language study in all stages of the education cycle from early childhood through to higher education. It includes the two-way movement of researchers, academics and professionals, research collaborations and institutional partnerships. It also encompasses a large range of engagement activities in all areas of education, including promoting international skills exchange, connecting learners through new technologies, internationalising curriculum and engaging with the world through alumni (p. 9).

The quote above clearly show that Australian international education comprises three main activities: (i) international students studying in Australia (i.e., traditional student mobility), (ii) transnational students or international students studying outside Australia, and (iii) Australian students undertaking learning experiences abroad. Through gradually integrating the activities above, Australian universities now have merged international/intercultural dimension into their teaching, research and service.

Another benefit brought from the internationalization is the tremendous revenues, which is the timely relieve of tighter budget constraints and declining government funding. Over the past few decades, the additional revenues available via the export of higher education
(through both relatively higher prices and increased enrollments) have attracted the attention of providers in many developed countries, including the US, the UK, Canada, and Australia. Among these education export competitors, Australia now is among the leading competitive education exporters in the world (Simon Marginson, 2015) and second only to the United States with exports of some US$24.7 billion (OECD, 2014). Australian education services have also represented the country’s largest service export since 2013, with the A$15.7 billion earned in 2014 alone accounting for about 27.5% of the total (ABS, 2015a; DFAT, 2015).

Several reasons might help boost the number of overseas students. The main reason is the removal of the limit on the number of overseas students in 1989 (Norton, 2012). The number of overseas enrollments have grown rapidly ever since then. The number of overseas student enrollments in Australian tertiary education is 157,643 in 2001 but this number doubles in less than ten years. Based on the latest survey from the Government (Australian Government, n.d.-b), in 2015, the number of overseas enrollments is close to 360 thousand in Australia. While the majority of overseas students still study at undergraduate level, the number of overseas students study at postgraduate level grows rapidly. In 2001, the number of overseas postgraduate enrollments is 55,286; however, this number has been almost tripled in 2015.

The other reason contributing to the growth is the removal of the level of tuition fees for international students. Unlike the upper limit on domestic student tuition fees, there is no cap on international student tuition fees. Universities usually charge international students the full cost of meeting most of the fixed costs of operating courses (Access Economics, 2010). In this mechanism, the revenue from international students subsidies every domestic student by about A$1,200 (2009 value) or 10% of total funding (Go8, 2011, 2012). Revenue from international fees helps reduce the stress of declining government funding and this
income has become one of the main financial sources.

2.5 Concluding remarks

The Australian university sector has experienced significant changes in the last 30 years. It used to contain many small and specialized higher education institutions, but it is no longer the case. Through a series of amalgamation activities, Australian university sector today is therefore dominated by comprehensive universities which are large in scale and provide diversified services and courses in scope.

Universities are also given more responsibilities for enrolling more students and raising their financial revenues. Relatively new forms of instruction outputs, distance education and oversea students, have become another important source of students. The number of both types of students grows rapidly, helping add multiple dimensions to institutions’ teaching, research and service. The flourish of recruiting these students also indicates that the student source of Australian universities is not limited by the space and time. Australian universities thus have the capability to further expand their scale and scope.
Chapter 3. The nature of economies of scale and scope in higher education

3.1 Introduction

The theory of economies of scale could be the most fundamental microeconomics theory, and has been extensively applied to many resource-using activities. This theory is originally developed based on the single-output production. Although early researches had recognized the multiple-output structure of higher education, the lack of appropriate estimations for interpreting the multiproduct institutions remained until Baumol et al. (1982) shed the light of multi-product estimation. This estimation additionally makes the discussions of scope economies possible.

Estimating scale and scope economies will provide firms with valuable information about the modifications in scale and scope. Investigation of scale and scope economies involves understanding their theories and the cost structure including the types of outputs and the cost functional form needed in the estimation process (Bailey & Friedlaender, 1982). However, debate continues on the precise nature of the economies of scale and scope found in higher education, not unexpectedly given the implications for optimal size and industry structure and the potential division of higher education providers into research-only, teaching-only and research and teaching institutions for public funding purposes.

This chapter thus provides a detailed review of empirical studies published in the past quarter century, summarizing not only the results drawn from a wide range of national contexts, and their implications for structural, operational and financing reform, but also the methodological challenges likely to arise in future work in this important area.
The remainder of this chapter is structured as follows. Section 3.2 introduces the theory of scale and scope economies. Section 3.3 details the methodology of estimating economies of scale and scope in higher education. The implications from previous studies are given in Section 3.4. The final section, Section 3.5, concludes this chapter with examining the impact of moderator variables on cost economies.

3.2 The theory of economies of scale and scope

Theory of scale economies could date back to Adam Smith (Backus, Kehoe, & Kehoe, 1992; Reynolds, 1983). In his book, *The Wealth of Nations*, economies of scale are used to explain the wealth difference among countries. If economies of scale exist, holding other things constant, average costs are lower at large firms than the costs at small firms resulting from the fixed costs spread over more units of product. This theory has been widely applied to the economic activities, but is limited in single-output production.

In 1975, Baumol (1975) and Panzar & Willig (1975) extend this old concept to the multi-output production and increase the discussion of economies of scope resulting from the cost savings of joint production. Multiproduct estimation introduced in their book (Baumol et al., 1982) even accelerates the spread of these theories. Ever since then, economies of scale and scope have been used to analyze different types of multi-output production industries. In the following sections, this thesis begins our discussions with developments of these economies and their multi-product estimations will also be introduced.
3.2.1 Economies of scale in single-output production

Suppose that, firms only produce one type of product \( y \), the single-product cost function could be written as (Bogetoft & Otto, 2011:244; Coelli, Rao, O'Donnell, & Battese, 2005:21)

\[
C(y, w) = \min_{x \geq 0} \{ w \cdot x | (x, y) \in T \}
\] (3.1)

where \( w \cdot x \) is the inner product (\( \sum_i^m w_i x_i \)) and \( C(y, w) \) is the cost function which gives the least cost of producing a level of single output \( y \) with \( m \) types of inputs whose quantities are a vector of inputs \( x = (x_1, \ldots, x_m) \) given a vector of input prices \( w = (w_1, \ldots, w_m) \), and the underlying nature of the production technology \( (T) \) in charge of the rate of inputs converted into outputs.

Writing costs as a function of the level of output can show that cost will change as the level of output varies. We can test whether technology allows the existence of scale economies. The degree of scale economies in single-product firm could be defined the elasticity of output with respect to cost (Baumol et al., 1982; Helpman, 1984):

\[
S(y, w) = \frac{dy/y}{dC(y, w)/C(y, w)} = \frac{C(y, w)/y}{\partial C(y, w)/\partial y}
\] (3.2)

where \( S(y, w) \) is the ratio of average cost \( (C(y, w)/y) \) to marginal cost \( (\partial C(y, w)/\partial y) \), average cost is the ratio of total cost \( (C(y, w)) \) to the total number of output \( y \) produced, and marginal cost is the cost of producing one more unit, which is derived from taking the first derivative of the cost function with respect to output.

If \( S(y, w) > 1 \), it means that average cost is greater than marginal cost and average cost is declining with the level of output because average cost is pulled down by producing one more unit (Besanko, Dranove, Shanley, & Schaefer, 2009). Economies of scale could be
Economies of Scale and Scope in Higher Education

easily illustrated with a single-product cost function in Figure 3.1. Firms producing the level of output to the left of \( y^m \) are better off by producing additional output. Average cost will remain declining by increasing output (\( y_1 \)) until the level of product reaches the point (\( y^m \)) where average cost equals to marginal cost. On the contrary, when marginal cost exceeds average cost and average cost is increasing with the level of output, there are diseconomies of scale (more than \( y^m \) in Figure 3.1). We can see that the point (\( y^m \)) is the relatively efficient scale for the firm.

![Figure 3.1: Marginal and average cost curves](source)

Source: Adapted from Baumol et al. (1982:19)

### 3.2.2 Economies of scale in multi-output production

Suppose that, firms produce \( n \) types of product whose quantities are contained in the vector \( \mathbf{y} = (y_1, \ldots, y_n) \) with \( m \) types of inputs whose quantities are \( \mathbf{x} = (x_1, \ldots, x_m) \) given a vector of input prices \( \mathbf{w} = (w_1, \ldots, w_m) \), multi-output cost function could be specified as (Baumol et al., 1982 p.52):

\[
C(\mathbf{y}, \mathbf{w}) = \min_{\mathbf{x} \geq 0}\left\{ \mathbf{w} \cdot \mathbf{x} \mid (\mathbf{x}, \mathbf{y}) \in T \right\}
\]

where \( \mathbf{w} \cdot \mathbf{x} \) is the inner product (\( \sum_i w_i x_i \)) and \( C(\mathbf{y}, \mathbf{w}) \) depicts the minimum cost combination of producing \( n \) types of output (\( \mathbf{y} \)) given the input prices (\( \mathbf{w} \)) and the technology set (\( T \)).

Different from single-output production, the calculation of average cost will involve
addition of different types of output in multiproduct scenario. The difficulty of these additions is that they are not measured in common units (Baumol, 1975). One solution to this problem is to treat these additions as a composite commodity or an output bundle and allow the scale of this output bundle to change in a fixed proportion. We therefore can calculate the ray average cost (RAC) as follows (Bailey & Friedlaender, 1982; Baumol, 1977; Willig, 1979).

\[
RAC(y) = \frac{C(ty^0)}{t} \tag{3.4}
\]

where \( y \) is a vector of output and represents a composite commodity (or output bundle), \( y^0 \) is a vector of a composite commodity’s unit (\( \sum y_i^0 = 1 \)), and \( t \) is the number of units in a composite commodity and also the measures of the output bundle’s scale along the ray through \( y = (y_1, \ldots, y_N) \).

A ray average cost curve can be further illustrated with Figure 3.2 assuming that firms produce two types of product (\( y_1 \) and \( y_2 \)). Following the definition of RAC in equation, vector \( y^0 \) is any point between two endpoints ((0, 1) and (1, 0)). Once the quantity of the unit bundle \( y^0 \) has been decided, the ray (OR) is just the \( t \)-fold increase (or decrease) of unit bundle \( y^0 \) (Willig, 1979). Average cost of this composite commodity will be defined on a ray (OR) emanating from the origin and its curve is expected to have a U shape like the single-product average cost curve in Figure 3.1. We have the minimum RAC at the output \( y = y^m \) illustrated in Figure 3.2 and this point represents the efficient scale for a multi-product firm.
With the definition of RAC, ray economies of scale can be defined as the elasticity of output with respect to cost just like the definition of single-output economies of scale (Bailey & Friedlaender, 1982).

\[
SRAY = \frac{dy/y}{dC(y)/C(y)} = \frac{C(y)}{\sum_{i=1}^{n} y_i C_i(y)}
\]

(3.5)

where \( C(y) \) is the total costs for producing that amount of output vector \( y \), \( \frac{C(y)}{\sum_{i=1}^{n} y_i} \) is the ray average cost, and \( C_i(y) = \partial C(y)/\partial y_i \) is the marginal cost of producing the \( i \)-th type of output.

This equation estimates the effect of a simultaneous and proportional increase of all output scale along a ray in output space while holding the composition of each firm’s outputs constant (Bailey & Friedlaender, 1982). It is directly analogous to single-output economies of scale in equation (3.2) because they both measuring the ratio of average costs to marginal costs. They, therefore, share the same results: there exist ray economies (diseconomies) of
scale when SRAY is larger (less) than unity. Cost savings arise when the size of the aggregate output increases but the composition of output still keeps constant.

Once keeping the quantities of other types of products constant, the magnitude of a multi-product firm’s operations may not change proportionally through variation in the output of one product. Product-specific economies of scale (PSCE($y_i$)) come in handy and allow only one type of output to vary at a time while holding all other types of outputs constant. The product-specific expansion in a product set needs further analysis and it will give better information of the organization’s cost structure (Cohn & Cooper, 2004). The first thing we need to know is the incremental cost (IC) of a multiproduct firm producing an additional type of output $i$:

$$IC(y_i) = C(y) - C(y_{N-i})$$  \hspace{1cm} (3.6)

where $y_i$ is the $i$-th type of output, $IC(y_i)$ is the total costs of producing all outputs ($C(y)$) after deducting the cost of $i$-th type of output($C(y_{N-i})$). With this concept, average incremental cost (AIC) could be denoted as follows.

$$AIC(y_i) = \frac{C(y) - C(y_{N-i})}{y_i}$$  \hspace{1cm} (3.7)

It is computed by setting one output at a time to zero. For example, if there are three types of output, a, b, and c, we can estimate AIC of product $y_a$ with the following formula:

$$AIC(y_a) = \frac{C(y_a, y_b, y_c) - C(0, y_b, y_c)}{y_a}$$  \hspace{1cm} (3.8)

The degree of the product-specific economies of scale (PSCE ($y_i$)) could be further defined by:

$$PSCE(y_i) = \frac{AIC(y_i)}{C_i(y)} = \frac{AIC_i}{MC_i}$$  \hspace{1cm} (3.9)

where $AIC_i$ is the average incremental cost of the product $i$, and $MC_i$ is the marginal cost of
the product $i$.

This equation stands for the ratio of the expansion rate in all or certain outputs to the rate of the resulting increase in costs. It also shows the degree of multiproduct firm’s operation could vary by changing the output of one product while holding the quantities of other products constant (Cohn & Cooper, 2004). Economies (diseconomies) of scale would exist when $PSCE(y_i)$ is larger (less) than unity. This equation is actually extended from the concept of a measure of scale economies, which is the ratio of average cost to marginal cost.

### 3.2.3 Economies of scope

Except for deciding how large scale a firm could be, the owner also has to decide the scope of firm’s operation including the extent of vertical or horizontal integration as well as the diversity of products (Rosegger, 1986). The estimates of global economies of scope (GSE) could help make this decision. This estimate could be calculated as the percentage of cost savings from joint production relative to fully integrated costs or as the percentage increase in costs from specialized production:

$$GSE = \frac{\sum_{i=1}^{n} C(y_i) - C(y)}{C(y)}$$

(3.10)

where $\sum_{i=1}^{n} C(y_i)$ is the cost of producing product $i$ in $n$ separated specialized firms, and $C(y)$ is the costs of producing all $n$ products jointly within a firm.

These economies result from the sharing utility of inputs. Therefore, input prices and available technology deeply affect presence of scope economies (Bailey & Friedlaender, 1982). When a firm enjoys the cost savings from the joint production of these varied products, GSE will be greater than zero. When there are economies of scope, it implies the cost of producing different types of products is less than the cost of producing them
Chapter 3. The nature of economies of scale and scope in higher education

separately. On the contrary, when an company does not experience economies of scope, a
multiproduct firm could be tear up into several specialized firms to save costs (Baumol et al.,
1982:73). Therefore, GSE could offer the nature of multiproduct production processes and
the cost synergy that exist among outputs (Chavas & Kim, 2007).

Similar to scale economies, the concept of scope economies can also be applied to
product-specific measures. Product-specific scope economies exist when cost savings arise
from the joint production of a particular type of output with other types of outputs (Clark,
1988). Suppose that there are $n$ types of product, the degree of product-specific scope
economies (PSOE) for $i$-th type of product could be denoted as:

$$
\text{PSOE}(y_i) = \frac{C(y_i) + C(y_{n-i}) - C(y)}{C(y)}
$$

(3.11)

where $C(y_{n-i})$ is the cost of producing all the products except for the product $i$.

Product-specific economies (diseconomies) of scope would exist when $\text{PSOE}(y_i)$ is larger
(less) than zero. The presence of product-specific scope economies imply that the cost of
producing a specific type of product jointly with the other types of products is less than
produce it separately.
3.3 Measuring economies of scale and scope in higher education

Over the last three decades, more than 40 empirical studies published in refereed journals have depicted the cost structure of higher education with the theory of scale and scope economies, whose main findings and estimation methods have been summarized in Table 3.1. Note that if a study has multiple equations for different types of institution (such as Cohn et al. (1989) for private and public institutions), uses different types of teaching outputs (enrollments and completions, see Agasisti (2016), for example) or uses the same dataset but with different econometric models (Izadi et.al., 2002; Johnes, 1996), results will be displayed by the categories above.

In the remaining of this section, this thesis starts with the description of the higher education market and then explains how previous studies apply theory of scale and scope economies to higher education including the functional forms and types of outputs. A series of equations used for calculating the estimates of scale and scope economies are also given at the end of this section.
### Chapter 3. The nature of economies of scale and scope in higher education

Table 3.1: Summary results of empirical studies on economies of scale and scope in higher education

<table>
<thead>
<tr>
<th>Area and Authors</th>
<th>Samples, periods</th>
<th>Model</th>
<th>Outputs</th>
<th>Measures of scale and scope economies$^a$</th>
<th>SRAY</th>
<th>PSCE$\gamma_1$</th>
<th>GSE</th>
<th>PSEO$\gamma_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Australia</strong></td>
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<tr>
<td>Worthington &amp; Higgs (2011)</td>
<td>36 public institutions, 1998-2006</td>
<td>Regression</td>
<td>Undergraduate completions, Postgraduate completions, PhD completions, Amount of research grants, Weighted number of publications</td>
<td>50-100</td>
<td>Undergraduate completions (50-300)</td>
<td>50-300</td>
<td>Undergraduate completions (50-300), Postgraduate completions (50-300), PhD completions (50-300), Amount of research grants (50-300)</td>
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<td><strong>Bangladesh</strong></td>
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<tr>
<td>Mamun (2012)</td>
<td>18 public institutions, 2002-2007</td>
<td>SFA</td>
<td>Undergraduate FTE enrollments, Postgraduate FTE enrollments, Research expenditure</td>
<td>50-400</td>
<td>Undergraduate FTE enrollments (50, 200-400), Postgraduate FTE enrollments (50-400), Research expenditure (50-400)</td>
<td>50-400</td>
<td>Undergraduate FTE enrollments (50-250), Postgraduate FTE enrollments (50-400), Research expenditure (50-400)</td>
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<td><strong>China</strong></td>
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<tr>
<td>Cheng &amp; Wu (2008)</td>
<td>68 institutions, 2002-2004</td>
<td>Regression</td>
<td>Undergraduate FTE enrollments in sciences, Undergraduate FTE enrollments in arts, Undergraduate FTE enrollments in medicine, Postgraduate FTE enrollments, PhD FTE enrollments, Research expenditure</td>
<td>NA</td>
<td>NA</td>
<td>none*</td>
<td>Undergraduate FTE enrollments in sciences (100)<em>, Undergraduate FTE enrollments in arts (100)</em>, Undergraduate FTE enrollments in medicine (100)<em>, Research expenditure (100)</em></td>
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</tr>
<tr>
<td>Hou et al. (2009)</td>
<td>74 research institutions, 2000/01</td>
<td>Regression</td>
<td>Undergraduate FTE enrollments, Postgraduate FTE enrollments, Research expenditure</td>
<td>50-160</td>
<td>Research expenditure (50-300)</td>
<td>50-350</td>
<td>Undergraduate FTE enrollments (50-350), Postgraduate FTE enrollments (50-350), Research expenditure (50-150)</td>
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</tr>
<tr>
<td>Li &amp; Chen (2012)</td>
<td>75 research institutions, 2008/09</td>
<td>Regression</td>
<td>Undergraduate FTE enrollments, NA Postgraduate FTE enrollments, Distance education enrollments, Research expenditure</td>
<td>NA</td>
<td>NA</td>
<td>100*</td>
<td>Distance education enrollments (50-140), (They only tested this output)</td>
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</table>

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### Economies of Scale and Scope in Higher Education

<table>
<thead>
<tr>
<th>Area and Authors</th>
<th>Samples, periods</th>
<th>Model</th>
<th>Outputs</th>
<th>Measures of scale and scope economies</th>
<th>SRAY</th>
<th>PSCE(y_1)</th>
<th>GSE</th>
<th>PSOE(y_1)</th>
</tr>
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<tbody>
<tr>
<td>Li (2016)</td>
<td>62 institutions, 2008/09</td>
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<td>Undergraduate FTE enrollments, Postgraduate FTE enrollments, International students Research expenditure</td>
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<td>Undergraduate FTE enrollments (50-140), Postgraduate FTE enrollments (50-140), International students (50-140)</td>
<td>50-140</td>
<td>Undergraduate FTE enrollments (50-140), Postgraduate FTE enrollments (50-100), International students (50-140), Research expenditure (50-140)</td>
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<tr>
<td>Johnes &amp; Schwarzenberger (2011)</td>
<td>79 institutions, 2002-2005</td>
<td>SFA</td>
<td>Number of undergraduate and master’s students in science, Number of undergraduate and master’s students in non-science, Number of PhD students, Amount of research grants</td>
<td>none*</td>
<td>Number of undergraduate and master’s students in science(100)<em>, Number of undergraduate and master’s students in non-science(100)</em>, Number of PhD students(100)<em>, Amount of research grants(100)</em></td>
<td>none*</td>
<td>NA</td>
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</tr>
<tr>
<td>Olivares &amp; Wetzel (2014)</td>
<td>154 institutions, 2001-2007</td>
<td>SFA</td>
<td>Number of non-science students, Number of science students, Amount of science research grants, Amount of non-science research grants</td>
<td>NA</td>
<td>NA</td>
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<td>Italy</td>
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<tr>
<td>Agasisti &amp; Dal Bianco (2007)</td>
<td>58 public institutions, 2001-2002</td>
<td>OLS</td>
<td>Number of science students, Number of non-science students, Amount of research grants</td>
<td>none</td>
<td>Number of non-science students (50-200)</td>
<td>none</td>
<td>Amount of research grants (100-200)</td>
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</tr>
<tr>
<td>Agasisti &amp; Johnes (2010)</td>
<td>57 public institutions, 2001-2004</td>
<td>SFA</td>
<td>Number of undergraduate students in science, Number of undergraduate students in non-science, Number of PhD students, Amount of research grants</td>
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<td>Number of undergraduate students in non-science(80-120)</td>
<td>80-120</td>
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</tr>
<tr>
<td>Agasisti (2016)</td>
<td>55 public institutions, 2000-2011</td>
<td>SFA</td>
<td>Number of medical students, Number of science students, Number of social science students, Amount of research grants</td>
<td>none</td>
<td>none</td>
<td>NA</td>
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</tbody>
</table>

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## Chapter 3. The nature of economies of scale and scope in higher education

<table>
<thead>
<tr>
<th>Area and Authors</th>
<th>Samples, periods</th>
<th>Model</th>
<th>Outputs</th>
<th>Measures of scale and scope economies&lt;sup&gt;a&lt;/sup&gt;</th>
<th>GSE</th>
<th>PSOEy&lt;sub&gt;1&lt;/sub&gt;</th>
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</thead>
<tbody>
<tr>
<td>Agasisti (2016)</td>
<td>55 public institutions, 2000-2011</td>
<td>SFA</td>
<td>Number of medical completions, Number of science completions, Number of social science completions, Amount of research grants</td>
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<td>none</td>
<td>NA</td>
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<td><strong>Japan</strong></td>
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<tr>
<td>Hashimoto &amp; Cohn (1997)</td>
<td>94 private institutions, 1990-1991</td>
<td>Regression</td>
<td>Number of undergraduate students, Number of postgraduate students, Amount of research grants</td>
<td>10-300</td>
<td>Number of undergraduate students(10-50), Number of graduate students(10-100), Amount of research grants(50-300)</td>
<td>10-300</td>
</tr>
<tr>
<td>Nemoto &amp; Furumatsu (2014)</td>
<td>218 private institutions, 1999-2000, 2004-2005</td>
<td>SFA</td>
<td>Number of undergraduates, Number of postgraduate students, Amount of research grants</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<td><strong>Philippines</strong></td>
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<td>Rufino (2006)</td>
<td>Public institutions, 2000-2011</td>
<td>Regression</td>
<td>Total enrollments</td>
<td>100-600</td>
<td>NA</td>
<td>NA</td>
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<td>Johnes &amp; Salas-Velasco (2007)</td>
<td>26 institutions, 1998-2004</td>
<td>SFA</td>
<td>Number of undergraduate students in science, Number of undergraduate students in non-science, Number of graduate students, Amount of research grants</td>
<td>100*</td>
<td>Number of undergraduate students in science(100)<em>, Number of undergraduate students in non-science(100)</em>, Number of graduate students(100)<em>, Amount of research grants(100)</em></td>
<td>none*</td>
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<tr>
<td>Fu et al. (2008)</td>
<td>33 institutions, 1999-2001</td>
<td>SFA</td>
<td>Undergraduate FTE enrollments, Postgraduate FTE enrollments</td>
<td>100*</td>
<td>NA</td>
<td>100*</td>
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(continued on the next page)
## Economies of Scale and Scope in Higher Education

<table>
<thead>
<tr>
<th>Area and Authors</th>
<th>Samples, periods</th>
<th>Model*</th>
<th>Outputs</th>
<th>Measures of scale and scope economies*</th>
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<tbody>
<tr>
<td>Fu et al. (2011)</td>
<td>56 institutions, 2000-2003</td>
<td>Regression</td>
<td>Undergraduate FTE enrollments, Postgraduate FTE enrollments</td>
<td>Postgraduate FTE enrollments(100)*</td>
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<td><strong>UK</strong></td>
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<tr>
<td>Glass et al. (1995b)</td>
<td>61 public institutions, 1989/90</td>
<td>Regression</td>
<td>Undergraduate FTE enrollments, Postgraduate FTE enrollments, Number of publications</td>
<td>Undergraduate FTE enrollments(100)<em>, Postgraduate FTE enrollments(100)</em>, Number of publications(100)*</td>
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<tr>
<td>Glass et al. (1995a)</td>
<td>61 public institutions, 1991/92</td>
<td>Regression</td>
<td>Undergraduate FTE enrollments, Postgraduate FTE enrollments, Number of publications</td>
<td>Undergraduate FTE enrollments(100)<em>, Postgraduate FTE enrollments(100)</em></td>
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<td>Johnes (1996)</td>
<td>50 public institutions, 1989/90</td>
<td>Regression</td>
<td>Undergraduate FTE enrollments in science, Undergraduate FTE enrollments in non-science, Postgraduate FTE enrollments in sciences, Postgraduate FTE enrollments in non-science, Amount of research grants in sciences, Amount of research grants in non-science</td>
<td>Postgraduate FTE enrollments in sciences(50-100), Amount of research grants in sciences(50-100)</td>
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<tr>
<td>Johnes (1996)</td>
<td>50 public institutions, 1989/90</td>
<td>SFA</td>
<td>Undergraduate FTE enrollments in science, Undergraduate FTE enrollments in non-science, Postgraduate FTE enrollments in sciences, Postgraduate FTE enrollments in non-science, Amount of research grants in sciences, Amount of research grants in non-science</td>
<td>Postgraduate FTE enrollments in sciences(50-100), Amount of research grants in sciences(50-100)</td>
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<tr>
<td>Johnes (1997)</td>
<td>99 public institutions, 1994/95</td>
<td>Regression</td>
<td>Undergraduate FTE enrollments in science, Undergraduate FTE enrollments in non-science, Postgraduate FTE enrollments, Amount of research grants</td>
<td>Undergraduate FTE enrollments in non-science(100)<em>, Postgraduate FTE enrollments(100)</em>, Amount of research grants(100)*</td>
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## Chapter 3. The nature of economies of scale and scope in higher education

<table>
<thead>
<tr>
<th>Area and Authors</th>
<th>Samples, periods</th>
<th>Model</th>
<th>Outputs</th>
<th>Measures of scale and scope economies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Johnes (1998)</td>
<td>50 public institutions, 1989/90</td>
<td>Regression</td>
<td>Undergraduate FTE enrollments in science, Undergraduate FTE enrollments in non-science, Postgraduate FTE enrollments in sciences, Postgraduate FTE enrollments in non-science, Amount of research grants in sciences, Amount of research grants in non-science</td>
<td>50-100 Postgraduate FTE enrollments in sciences(50-100), Amount of research grants in sciences(50)</td>
</tr>
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<td>Johnes (1998)</td>
<td>50 public institutions, 1989/90</td>
<td>SFA</td>
<td>Undergraduate FTE enrollments in science, Undergraduate FTE enrollments in non-science, Postgraduate FTE enrollments in sciences, Postgraduate FTE enrollments in non-science, Amount of research grants in sciences, Amount of research grants in non-science</td>
<td>50-100 Postgraduate FTE enrollments in sciences(50-100), Amount of research grants in sciences(50)</td>
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<tr>
<td>Izadi et al. (2002)</td>
<td>99 public institutions, 1994/95</td>
<td>Regression</td>
<td>Undergraduate FTE enrollments in science, Undergraduate FTE enrollments in non-science, Postgraduate FTE enrollments, Amount of research grants</td>
<td>100* Undergraduate FTE enrollments in non-science(100)<em>, Postgraduate FTE enrollments(100)</em>, Amount of research grants(100)*</td>
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<td>Izadi et al. (2002)</td>
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<td>SFA</td>
<td>Undergraduate FTE enrollments in science, Undergraduate FTE enrollments in non-science, Postgraduate FTE enrollments, Amount of research grants</td>
<td>100* Undergraduate FTE enrollments in science(100)<em>, Undergraduate FTE enrollments in non-science(100)</em>, Postgraduate FTE enrollments(100)<em>, Amount of research grants(100)</em></td>
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### Economies of Scale and Scope in Higher Education

<table>
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<tr>
<th>Area and Authors</th>
<th>Samples, periods</th>
<th>Model</th>
<th>Outputs</th>
<th>Measures of scale and scope economies&lt;sup&gt;a&lt;/sup&gt;</th>
<th>SRAY</th>
<th>PSCE&lt;sub&gt;y&lt;/sub&gt;</th>
<th>GSE</th>
<th>PSOE&lt;sub&gt;y&lt;/sub&gt;</th>
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<tbody>
<tr>
<td>Lenton (2008)</td>
<td>96 further</td>
<td>Regression</td>
<td>Undergraduate FTE enrollments in science, Undergraduate FTE enrollments in arts, Undergraduate FTE enrollments in vocational, Undergraduate FTE enrollments in high level, Undergraduate FTE enrollments in low level</td>
<td>100-200</td>
<td>Undergraduate FTE enrollments in arts(100-200), Undergraduate FTE enrollments in vocational(100), Undergraduate FTE enrollments in high level(100-200), Undergraduate FTE enrollments in low level(100)</td>
<td>100-200</td>
<td>Undergraduate FTE enrollments in science(100-200), Undergraduate FTE enrollments in arts(100-200), Undergraduate FTE enrollments in vocational(100-200), Undergraduate FTE enrollments in high level(100-200), Undergraduate FTE enrollments in low level(100-200)</td>
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</table>

(continued on the next page)
<table>
<thead>
<tr>
<th>Area and Authors</th>
<th>Samples, periods</th>
<th>Model</th>
<th>Outputs</th>
<th>Measures of scale and scope economies</th>
</tr>
</thead>
<tbody>
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<td>1,195 public institutions, 1981/82</td>
<td>Regression</td>
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<td>SRAY: Undergraduate FTE enrollments(10-100), Postgraduate FTE enrollments(10-600), Amount of research grants(10-150; 500-600)</td>
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</tbody>
</table>

(continued on the next page)
### Economies of Scale and Scope in Higher Education

<table>
<thead>
<tr>
<th>Area and Authors</th>
<th>Samples, periods</th>
<th>Model</th>
<th>Outputs</th>
<th>Measures of scale and scope economies&lt;sup&gt;4&lt;/sup&gt;</th>
<th>SRAY</th>
<th>PSCE&lt;sub&gt;y&lt;sub&gt;1&lt;/sub&gt;&lt;/sub&gt;</th>
<th>GSE</th>
<th>PSOE&lt;sub&gt;y&lt;sub&gt;1&lt;/sub&gt;&lt;/sub&gt;</th>
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</thead>
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(continued on the next page)
### Measures of scale and scope economies

<table>
<thead>
<tr>
<th>Area and Authors</th>
<th>Samples, periods</th>
<th>Model</th>
<th>Outputs</th>
<th>Measures of scale and scope economies</th>
<th>SRAY</th>
<th>PSCEy₁</th>
<th>GSE</th>
<th>PSOEy₁</th>
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## Economies of Scale and Scope in Higher Education

<table>
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<td>Agasisti &amp; Johnes (2015)</td>
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</table>
3.3.1 Assumption of higher education market

Under the assumption of competitive market, the price and quantity of outputs are decided by the market and each firm sells identical produces. The individual firm/organization has limited power to decide those two characteristics of outputs. This is because if one firm tries to operate at the higher or lower level of outputs instead of efficient scale decided by the market, that firm will suffer higher average costs than its competitors.

This competitive market theory, however, might not be suitable for the higher education industry (Cheslock et al., 2016) because institutions produce similar but not identical products and most importantly, and the market entry is usually regulated by the government. We can observe that many higher education institutions provide quite different quantities of outputs in terms of number of enrollments, research grants and studies. This situation makes higher education industry better resemble monopolistic competition market, where each institution can operate at a selected quantity of output.

For being in such monopolistic competition market, institutions could be harder to gain the information about efficient scale and scope from the market. This makes higher education institutions might tend to suffer higher costs and needs guidance to know the optimal scale and scope to avoid the cost diseconomies.

3.3.2 Outputs in higher education

The ideal outputs of instruction could be the amount of knowledge learned or the increments to the stock of human capital (Verry & Davies, 1976), but this is hard to be measured without standardized tests capable of determining knowledge gain across disciplines. Most studies adopt proxies to solve this problem and consider their levels of
instruction ranging from undergraduate teaching to PhD supervision. Three proxies are constantly used: enrollments, credit hours, and completions.

Since students are the learning subjects and the fees they paid have become the main source of higher education funding, enrollments could be an appropriate proxy for instruction output. Some researchers (Sav, 2004, 2010, 2011) regard the number of student credit hours as another proxy. Since each student could take different credit hours for each year, credit hours could more closely relate instructional outputs to the cost. However, this type of data is usually only available for American universities. The indicators above only represent the stock of instructional activities, but not the final output of the instruction (Agasisti & Johnes, 2015). The number of completions (graduates or degrees conferred) standing for the final instructional product in an institution is also considered as another proxy for instruction outputs (Agasisti & Johnes, 2015; Worthington & Higgs, 2011). This indicator could also account for certain quality of instruction since qualified students have to complete the credit hours and achieve the academic standards to gain the degree.

On the other hand, research outputs rely on the integration of human and physical resources to create new knowledge. Just like teaching outputs, an ideal research output is also the net additions to the stock of outputs. Unfortunately, there is no unit of knowledge, so it is hard to be measured directly with physical and value term (Verry & Davies, 1976). This means researchers also need to approximate research outputs by surrogate measures. One proxy for research is the number of publications, including journal articles, books, and conference papers to catch research productivity variances between institutions (de Groot et al., 1991). However, not all research outputs would be published and not all published research, such as review articles and textbooks could be regarded as the addition to the stock of knowledge. This indicator does not consider the quality of research either (Verry & Davies, 1976). We should also note that the time needed to produce a research paper. The number of
publications in certain year does not represent the research outputs in that year as some publications might take more than one year to be published (normally years but depends on the fields). Therefore, if the number of publications is considered as a research output, the cost economies estimates could be questionable since we do not know whether these estimates could represent data year we used.

Another angle is to view the research output as its market values. The amount of research grants (income) is generally awarded by meritorious groups of researchers and has been used a proxy for research output. When this proxy is not available, researchers (Agasisti & Johnes, 2015; Cheng & Wu, 2008; Hou et al., 2009; Koshal & Koshal, 1999) use research expenditure instead. This output is also used as a proxy for the ability of a university generating these funds, and the research performance in the recent past (Cohn et al., 1989; Izadi et al., 2002; Johnes, 1997). Another merit of this proxy is that it could reflect the more contemporaneous quality and quantity of research output compared with the possible time lag of the number of research paper (Agasisti & Johnes, 2015; Worthington & Higgs, 2011).

The final type of output in higher education, public service or third mission activities, could include medical services, museums of various sorts, and business assistance programs (Laband & Lentz, 2003). Similar to research outputs, they are hard to be quantified, but could be approximated by measuring the income from providing these services. Due to data constraint, few studies (Johnes et al., 2008) incorporate this type of outputs into the equation. They proxied outputs of public service by the income obtained from the provision of advice and other services to the public.

3.3.2.1 Accounting for variations in output quality of higher education

Output quality of higher education is an elusive characteristic that is very difficult to define,
yet alone to quantify. It also has multiple dimensions such as quality in instruction, research, and public service. These dimensions could determine the long-run institutional cost structure and the estimates of scale economies (Fu, Huang, & Yang, 2011). When scale economies are present, the average cost would fall with the quantity of output under the assumption of holding quality of output constant. If the assumption is absent, economies of scale could be overestimated and an institution could decrease the average cost by reducing the quality (Koshal & Koshal, 1995).

In the past studies of estimating the extent of scale and scope economies, there are two ways to account for the variation in output quality. The first method is through disaggregating outputs into finer categories. The other method is quality adjustment, which adds some proxies for output quality in the model. These two methods are described as follows.

### 3.3.2.1.1 Cross-classification

This method is to disaggregate outputs into more categories and therefore makes each category more homogeneous. For research outputs, only two studies (Johnes, 1996, 1998) broke outputs (research grant) down into more categories (science and non-science). On the other hand, instruction outputs have more classifications. Most researches divided teaching outputs by the levels of instruction ranging from undergraduate teaching to PhD supervision. Some researches (Agasisti & Johnes, 2015; Izadi, Johnes, Oskrochi, & Crouchley, 2002; Johnes & Johnes, 2009; Johnes & Salas-Velasco, 2007; Lenton, 2008; Thanassoulis, Kortelainen, Johnes, & Johnes, 2011) even disaggregated teaching outputs (only undergraduate teaching) by broad subject areas such as science and non-science.

With the march of information and community technologies, the number of students is also rapidly growing due to the increasing number of distance education in the higher education
industry. The number of enrollments in distance education is suggested by Cohn & Cooper (Cohn & Cooper, 2004) to be regarded as another form of product differentiation, and allow for a broader cross classification. However, so far, there is only one empirical study (Li & Chen, 2012).

3.3.2.1.2 Quality adjustment

This method is to add some proxies for output quality in the model so the quality is accounted when estimating the cost economies. Although there is no consistent indicator for quality, researchers attempted to use proxies such as facilities (Fu et al., 2011), instructional outlay per student (Sav, 2011), student-staff ratio (Cho, Lin, Chen, & Huang, 2011; Fu et al., 2011; Hou, Li, & Min, 2009; Koshal & Koshal, 1999, 2000; Koshal, Koshal, & Gupta, 2001; Lenton, 2008; Li & Chen, 2012), average entry qualifications of students (Johnes et al. 2005), and the proportion of teaching staff to total staff (Lenton, 2008).

Student-staff ratio has been a popular indicator for teaching quality because it implies the contact time between students and teachers, and preparation time for teaching. Since there is no fixed classroom for each student, this indicator is often regarded as an alternative indicator of average class size (Hou et al., 2009). Suppose that the number of students is one type of institutional output, universities with higher student-staff ratio could replace the quality of instruction with quantity of student enrollments (Fu et al., 2011) or force students to tolerate more crowded learning environment such as classrooms and libraries (Fu, Huang, & Tien, 2008).

Some researchers (Koshal & Koshal, 1999, 2000; Lenton, 2008) also doubted that the quality of student intake could affect teaching outputs. For example, average total score of the student intake for each institution such as Scholastic Aptitude Test (SAT) is also
regarded as a signal of quality of an institution because students and their parents are more willing to pay more tuition for institutions with higher average exam scores.

Except for the quality indicators above, researchers (Cheng & Wu, 2008:85) attempted to proxy quality of instruction and research by the quality of input items of human and material resources under the assumption that quality of inputs could directly affect output quality. The quality of human resources mainly refers to the quality of faculties in terms of age, title, and degree. The quality of material resources was measured with the environmental conditions such as size of campus, floor space, and values of instruction and research facilities. Cheng & Wu (2008) incorporated 12 quality variables into their equation, and most of these proxies were time-invariant variables.

In fact, these proxies above are indirect measures and some of them are more likely to be attributed to the quantity of inputs such as the floor space, area of school size and values of assets or equipment. Holding these variables constant could lead to unnecessarily limit the variations that could be explained by the outputs. Student-staff ratio or class size has similar problem and they deny the possibility of increasing the teaching output (such as the number of students) while keeping inputs constant even with the new development of modern technology or instruction technique. Student-staff ratio is usually regarded as a proxy for contact time between lecturer and students, but it does not necessarily mean that students in larger class size will not satisfy the instruction especially when larger class size lectures usually accompany more tutors.

3.3.2.2 Input prices in higher education

Labor and physical capitals are the most important inputs during the production process. Since higher education is a highly labor-intensive industry, the production of teaching,
research and public service mainly relies on academics. The average salaries of academics are usually regarded a necessary indicator of labor price. Non-academic staff also plays an important role in assisting academic staff and maintain the operation of institution. When data is available, average salaries of non-academics would also become another type of labor price (Worthington & Higgs, 2011).

The price of capital could be calculated as capital expenditure per stock of capital or net assets. Capital prices usually are less assessable than labor prices, owing to the lack of information about capital stock (or the net asset). There are only three studies (Glass, Hyndman, & McKillop, 1995a, 1995b, 1996) incorporating the net assets while calculating the price of capital while another study (Worthington & Higgs, 2011) proxied the stock of capital by the number of FTE students.

When all price information above is not available, studies usually include environmental variables that could affect the cost of production. The pioneer multi-output work of Cohn et al. (Cohn, Rhine, & Santos, 1989) found the different cost structure between private and public institutions. Although the followers (de Groot, McMahon, & Volkwein, 1991; Fu et al., 2011) did not separate the estimations, they considered this variable by incorporating it in their cost function. Location is also another popular indicator to account for the environment, especially for samples from Chinese universities (Cheng & Wu, 2008), American universities (Koshal et al., 2001; Sav, 2004) and UK universities (Johnes, Johnes, & Thanassoulis, 2008; Lenton, 2008).

On the other hand, some studies (Johnes & Schwarzenberger, 2011; Lloyd et al., 1993) (Agasisti & Johnes, 2015; Johnes & Johnes, 2009) assumed that input prices were constant across institutions due to the highly regulated contexts. They therefore did not incorporate any prices or environmental variables in their cost function. We should be noticed that most of these studies used samples before year 2003. As the competition among universities
becomes much more intense than ever, this assumption could be weak nowadays.

### 3.3.3 Specifying a functional form

The purpose of specifying a functional form is mainly to associate the production cost with outputs and other variables constructed in stage one. Prior to the paper of Cohn et al. (Cohn et al., 1989), researches in estimating scale economies employ a linear cost function under the single output assumption, i.e., outputs are assumed as homogenous and measured simply by a single output indicator. Those studies have been criticized for violating the multiproduct nature of higher education. Although early researches (Verry & Davies, 1976; Verry & Layard, 1975) had recognized the multiple-output structure of higher education, the lack of appropriate models for interpreting the multiproduct institutions remained until Baumol et al. (1982) shed the light of multiproduct estimation.

Baumol et al. (1982) have suggested three multi-product cost functional forms, constant elasticity of substitution (CES) and hybrid translog (TL) function, and quadratic cost function (QCF). Each cost function makes the measurement of scale and scope economies possible and allows returns to scale to vary. These functional forms also correspond to the ideal conditions of cost functional form: flexible enough to allow scale and scope economies to vary with the levels of output, allow data to decide the existence of scale and scope economics, and permit zero outputs of some services (Lloyd et al., 1993).

However, quadratic cost function dominates the estimation of scale and scope economies in higher education since this cost function permits an output to have zero value without further transformation like other two cost functional forms. The paper of Cohn et al. (Cohn et al., 1989) is the first study to apply multiproduct estimation to higher education. Although several researchers also use other two non-linear function forms including constant
elasticity of substitution (CES) (Izadi et al., 2002; Johnes, 1997) and hybrid translog (TL) function (de Groot et al., 1991; Glass et al., 1995a, 1995b, 1996) to estimate scale economies for higher education, the complication of estimation due to the specification and relatively demanding in terms of data make both functional forms unpopular with researches (Johnes & Johnes, 2009).

Quadratic cost function could be written as follows (for simplicity, price (w) is omitted in the following sections)

\[
C(y) = C(y; \beta) = \beta_0 + \sum_{i=1}^{n} \beta_i y_{ih} + 0.5 \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} y_{ih} y_{jh}
\]

(3.12)

where subscripts \(i\) and \(h\) denote the output and higher education institution respectively, \(C_h\) is the total cost for the \(h\)-th observation of higher education institution, \(y_{ih}\) is the \(i\)-th type of output (out of \(n\) types of output) in the \(h\)-th institution, \(\beta_0\) is the fixed cost, and \(\beta_i\)'s, \(\beta_{ij}\)'s are the scalars of unknown parameters.

One limitation of this function is that the linear homogeneity cannot be easily imposed in cost function compared with other two functions (Farsi, Fetz, & Filippini, 2008). There is only one research (Worthington & Higgs, 2011) considering the linear homogeneity when estimating the degree of scale and scope economies for higher education.

### 3.3.4 Building an appropriate econometric model

The estimation of scale and scope economies will be defined on the parameters (\(\beta\)) estimated from the econometric model. Therefore, it is important to choose an appropriate model for estimating the parameters of the chosen function with the actual observations. Since the cost function will be estimated with the actual observations, the measurement error should be considered in the model. The general model using a quadratic cost function
could be denoted as:

\[ C_h = C(y; \beta) + \varepsilon_h = \beta_0 + \sum_{i=1}^{n} \beta_i y_{ih} + 0.5 \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} y_{ih} y_{jh} + \varepsilon_h \]  

(3.13)

where subscript \( h \) denote the higher education institution, \( C_h \) is the total cost for the \( h \)-th higher education institution, \( \beta_0, \beta_i's, \beta_{ij}'s \) are the scalars, and \( \varepsilon_h \) is the error term.

There are mainly two problems that researchers try to solve at this stage: heterogeneity across universities and non-efficient production. The development of econometric models for estimating scale and scope economies in higher education is centered on solving the problems above through modifying different forms of the error term.

### 3.3.4.1 Models for accounting for heterogeneity across universities

In recent years, more and more researchers challenge the homogeneity of higher education institutions. Heterogeneity across universities comes from the different environments that each institution faces. Regression models assuming two-sided random error are used to deal with this problem. Early studies usually employed cross-sectional data composed of institutions observed in one period or point in time. Regression models are limited with this type of data. Therefore, even though past studies had admitted that the cost structure would vary across institutions, the cross-sectional regression model only permitted them to estimate cost functions for separate groups of institutions (Cohn et al., 1989; Koshal & Koshal, 1999; Sav, 2004, 2010) or incorporated dummies for specific cost-related factors such as location (Sav, 2004) and medical schools (Sav, 2004, 2010) to allow fixed costs to vary.

However, an equation could not incorporate too many environmental variables. When panel data (this type of dataset contains a group of cross-sectional institutions observed over
multiple time periods) is available, panel data regression models could offer more accurate parameters and richer information by simultaneously accounting for heterogeneity and reveal the specific effects (institution effect $\mu_h$ and time effect $\lambda_t$) for each institution. Equation (14) shows the basic model of panel data analysis and it is adapted from equation (13) which is added subscript “$t$” to represent time.

\[
C_{ht} = C(y; \beta) + \varepsilon_{ht} = \beta_0 + \sum_{i=1}^{n} \beta_i y_{ih} + 0.5 \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} y_{ih} y_{jh} + \varepsilon_{ht}
\]

\[
\varepsilon_{ht} = \mu_h + \lambda_t + \nu_{ht}
\]

where subscripts $h$ and $t$ denote the higher education institution and time respectively, $C_{ht}$ is the total cost for the $h$-th higher education institution in the $t$-th time period, $\beta_0$, $\beta_i$'s, $\beta_{ij}$'s are the scalars, and $\varepsilon_{ht}$ is the error term composed of three effects, i.e., institution effect $\mu_h$ accounting for unobservable factors influencing $C_{ht}$ without varying over time, time effect $\lambda_t$ accounting for unobservable factors influencing $C_{ht}$ without varying over institutions, the rest effect $\nu_{ht}$ are other variables affecting $C_{ht}$ while varying both over time and institutions.

This model brings several benefits in estimating scale and scope economies. First of all, it better controls the unobservable variables. Universities operate with different networks with various environmental and organizational characteristics, which could lead to different levels of cost synergies across different services. These characteristics are hard to detect with cross-sectional data. On the contrary, panel data estimates could use institution effect $\mu_h$ and time effect $\lambda_t$ to account for those omitted variables which are fixed over time and institution respectively. These effects could be modelled either as fixed effect or as random effect. Fixed effect model allows arbitrary correlation between independent variables and error terms ($\mu_h$ and $\lambda_t$) while random effect approach rejects this possibility (Cornwell &

Sav (2011:152) compared the results between cross-sectional and panel-data regression models. He used the same variable combination, subjects (some were deleted due to financial data missing), functional form with the study of Sav (2010) but extended his cross-sectional data of year 2007 back to year 2000 and incorporated two proxies for teaching quality. He used the fixed effect model and found institutional effect was significant at the 1% level (but the time effect was not significant). His results suggested that biased estimates were from cross-sectional data analysis. Extensive teaching and research specific economies and economies of scope could exist in American higher education only when using cross-sectional estimates.

These panel data regression models only allow fixed cost (i.e, constant) to vary with institutions, while another model, Random Parametric Model (RPM), additionally permits each institution to face a different cost function in terms of the coefficient. That is, the marginal effect of a change in output variable on cost could be different across institutions. This regression model so far is not performed alone, but is combined with another type of model which will be discussed in the next section.

3.3.4.2 Models for accounting for non-efficient production

Due to the regulation of the Government and characteristics of non-for-profit organizations, the inefficient production could exist in universities. The estimates of scale and scope economies with regression models could be defined on the parameters which do not permit the minimum costs. Cost function derives from regression models is an average cost function because half of the observations will be above the cost function while the rest will be below it. This violates the assumption of cost function since the estimated cost function from regression models does not represent an envelope describing the minimum cost.
Johnes & Johnes, 2009). In other words, the estimates are actually based on the assumption that institutions are less than perfectly efficient.

Researchers therefore take another approach to consider the inefficient production and model it as part of the residual in the model. This model is called Stochastic Frontier Analysis (SFA) developed by the pioneer work of Aigner, Lovell, & Schmidt (1977) and Meeusen & van Den Broeck (1977) for production function. Its dual functional form, the stochastic frontier cost function, can be denoted as

\[
C_h = C(y; \beta) + \epsilon_h = \beta_0 + \sum_{i=1}^{n} \beta_i y_{ih} + 0.5 \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} y_{ih} y_{jh} + \epsilon_h
\]

\[
\epsilon_h = u_h + v_h
\]

Instead of assuming two-sided error term like regression models, SFA further separates inefficient component from the regression residual and divides the residual (\(\epsilon_h\)) in (3.13) into two parts: the first part of component (\(v_h\)) is a two-sided random error with zero mean. The other part (\(u_h\)) accounts for the cost inefficiency and is assumed as one-sided error and non-zero mean. Observation \(h\) will be regarded as an efficient institution when cost inefficiency (\(u_h\)) is 0; otherwise, observations are considered as inefficient institutions.

Since cost inefficiency (\(u_h\)) is always non-negative, it will determine how far the institution \(h\) operates above the cost function \(C(y; \beta)\). Johnes (1996) firstly estimated the parameters for scale economies in higher education with SFA and compared regression results with SFA’s. The coefficients except for the constants (changed from 2.4 million to -35 thousand) and estimates of scale economies were similar due to the normality of residuals in the regression model. However, economies of scope did not exist in the results of SFA.

Another comparison was done by Izadi et al. (2002:66). They used the same dataset and functional form with Johnes (1997) but employed SFA to estimate cost function. Compared
with regression models, they found SFA could provide better and more accurate estimates of cost function based on the likelihood ratio test. They, therefore, argued that the best way to estimate cost function was through stochastic frontier analysis instead of regression models.

From the literature review above, RPM could better control for the heterogeneity across university while SFA could separate the inefficient production from the estimation. These two types of models are used respectively until recently Johnes and Salas-Velasco (2007) combine these two to provide more accurate estimates for calculating scale economies and scope economies. This approach is called random parameter stochastic frontier model and has the advantage of both efficiency evaluation approaches, data envelopment analysis (DEA) and SFA (Agasisti & Johnes, 2010:487). However, they only allowed constants and one of the coefficients (research output) to vary with institutions. The following researches (Agasisti & Johnes, 2015; Johnes & Johnes, 2009) still adopted this model but did not give reasonable explanations to support their decision about allowing which coefficient to be random. Therefore, they are not using the truly random parameter stochastic frontier model. This difficulty still awaits further studies.

### 3.4 Implications of empirical studies

From the preceding discussions, we know that the outputs of instruction, research, and public service are lack of appropriate measures to estimate their quantity. Therefore, most empirical researches proxy these outputs by simple and intermediate output indicators and still focus on the quantifiable instruction and research measures. When all price information are not available, studies usually included environmental variables (such as dummies for location and ownership) that could affect the cost of production.

In practice, studies rarely estimate economies of scale and scope with a specific output
value; instead, they standardize the results with different percentage of output mean values. In other words, scale and scope economies are estimated at the mean values of output variables as well as multiples of the mean values. In addition, they consider 100% of output means as the baseline or current state of the higher education sector. If cost economies exist lower (higher) than 100%, they view it as the sign of decreasing (increasing) the level of outputs to achieve cost economies. Since cost structure and educational system could be different across countries and types of institutions, this thesis separates their discussions based on their types and areas as follows.

### 3.4.1 Implications for different types of institutions

The broadest classification is their ownership. Since public universities are more restrictive than private universities in budgets and government policies, most researches either only studied the former institutions or only investigate the latter. Sav (2004, 2010) even split their US samples into more detailed classification (Carnegie classification), and they estimated the degree of scale and scope economies for each sub-samples. Some researches focused on a relatively homogeneous sample (such as doctorate-granting universities (de Groot et al., 1991), research universities (Hou et al., 2009; Li & Chen, 2012; Foltz, Barham, & Kim, 2007), further education institutions (Lenton, 2008), liberal arts college (Koshal & Koshal, 2000) and bible colleges (Koshal et al., 2001).

These researches have improved our knowledge about cost structures in different types of institution through the estimates of scale and scope economies. Findings showed that private institutions were more capable of enjoying the economies of scale and scope than public institutions at higher percentage of the output means. Cohn et al. (1989) found that ray economies of scale for private intuitions even existed at 600% of the output means while ray economies of scale for public institutions have been exhausted at 100% of the output means. The relatively small private institutions also had the similar patterns. Private
Economies of Scale and Scope in Higher Education

liberal arts (Koshal & Koshal, 2000) and bible colleges (Koshal et al., 2001) had more potentials to expand their mean output in undergraduate enrollments and postgraduate enrollments (bible college has the addition output of research grant) up to 300% of the mean output, and still enjoyed the cost savings from scale and scope economies.

As for further education intuitions, ray and product-specific economies of scale were present for the UK and US institutions at the 100% of output mean level, but expansion beyond that level would only be appropriate for the institutions in the UK (up to 200% of the output mean). Further education intuitions in the UK could even save more cost if they considered joint production among different types of instruction.

3.4.2 Implications for higher education in different countries

We now turn our focus on the results over different areas. Researchers have applied analyses to areas including Australia, Bangladesh, China, German, Japan, Italy, Philippine, Spain, Taiwan, UK, and US. Since results could depend on the type of institutions, the following discussions focus on the public institutions which most studies used. These results as well as their product-specific economies discussed in the previous section are summarized in Table 3.2 and Table 3.3, whose source data is from Table 3.1 We omit the results of product-specific economies for public service since there is no substantial evidence (only one study with a weak proxy).

In general, most studies (except for some cases in Germany (Johnes & Schwarzenberger, 2011), Italy (Agasisti & Johnes, 2010), and Taiwan (Fu et al., 2011) during 2000-2003) found that the ray economies of scale existed at 100% of the mean output, which indicates that institutions in these areas were enjoying the cost savings at the present output mean level. Tremendous cost savings are found especially in developing countries such as Bangladesh (Mamun, 2012) and the Philippines (Rufino, 2006). The cases of ray scale
economies beyond the 100% level could be found in China, UK and US. These countries were encouraged to expand their whole outputs beyond their current output level to achieve further cost economies. Although product-specific economies of scale were still present at the output mean level, they were not present in all types of outputs. Some outputs should be decreased at lower output mean level. For example, a study (Cohn et al., 1989) in US during 1981/82 found the product-specific economies of scale for Bachelor’s instruction only existed at 10-50% of its mean level.
### Table 3.2: Economies of scale for public institutions

<table>
<thead>
<tr>
<th>Area</th>
<th>SRAY</th>
<th>Product-specific economies of scale</th>
<th>Period</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Instruction</td>
<td>Research</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bachelor</td>
<td>Graduate</td>
</tr>
<tr>
<td>Australia</td>
<td>50-100</td>
<td>50-300</td>
<td>none</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>50-400</td>
<td>50, 200-400</td>
<td>50-400</td>
</tr>
<tr>
<td>China</td>
<td>50-160</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>50-140</td>
<td>50-140</td>
<td>none</td>
</tr>
<tr>
<td>Germany</td>
<td>none</td>
<td>100*</td>
<td>100*</td>
</tr>
<tr>
<td>Italy</td>
<td>80</td>
<td>80-120</td>
<td>NA</td>
</tr>
<tr>
<td>Philippines</td>
<td>100-600</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Spain</td>
<td>100*</td>
<td>100*</td>
<td>100*</td>
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<tr>
<td>Taiwan</td>
<td>100*</td>
<td>none*</td>
<td>none*</td>
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<td></td>
<td>none*</td>
<td>none*</td>
<td>100*</td>
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<tr>
<td>UK</td>
<td>50-100</td>
<td>50-100</td>
<td>100*</td>
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<td>100*</td>
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<td></td>
<td>80-120</td>
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<td></td>
<td>none*</td>
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<td>(non-science)</td>
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<tr>
<td>US</td>
<td>10-100</td>
<td>10-50</td>
<td>10-600</td>
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<td>100*</td>
<td>100*</td>
<td>100*</td>
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</tbody>
</table>

**Notes:** (i) * means that studies only report the estimates at 100% of output mean; (ii) NA = Not Available; none means that there is no evidence showing the existence of cost economies; (iii) results of research expenditures are categorized into research grants; (iv) for the same period studies in the same area, we only take the optimistic results among them; (v) source of data is from Table 3.1.

The preceding discussions give the modification implication in scale, while the estimates of scope economies could offer the structural change advices. These estimates are summarized in Table 3.3. There were no economies of scope in Germany, Spain, and Taiwan. Evidence suggested these three higher education systems split their output production to achieve cost savings. In other words, a joint production of instruction and research were more costly than separate production in these countries. Other countries including Australia, China, Italy, UK and US should continue to maintain their joint production form in terms of cost savings. In
these countries, product-specific scope economies were also rising with the increase of all types of output mean level.

Table 3.3: Economies of scope for public institutions

<table>
<thead>
<tr>
<th>Area</th>
<th>GSE</th>
<th>Product-specific economies of scope</th>
<th>Research</th>
<th>Period</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Instruction</td>
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<tr>
<td></td>
<td></td>
<td>Bachelor</td>
<td>Graduate</td>
<td>Ph.D.</td>
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<td>50-300</td>
<td>50-300</td>
<td>50-300</td>
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<td>50-250</td>
<td>50-400</td>
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<td>50-350</td>
<td>NA</td>
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<td>none*</td>
<td>100*</td>
<td>none*</td>
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<tr>
<td></td>
<td></td>
<td>50-140</td>
<td>50-100</td>
<td>NA</td>
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<tr>
<td></td>
<td></td>
<td>100*</td>
<td>100*(distance education)</td>
<td>NA</td>
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<td>Germany</td>
<td>none*</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Italy</td>
<td>80-120</td>
<td>none</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Spain</td>
<td>none*</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Taiwan</td>
<td>none*</td>
<td>NA</td>
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<td>50-100</td>
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<td>NA</td>
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<td>US</td>
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<td>50-300</td>
<td>50-200</td>
<td>50-300</td>
<td>NA</td>
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<td>100*</td>
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</tr>
</tbody>
</table>

Notes: (i) * means that studies only report the estimates at 100% of output mean; (ii) NA = Not Available; none means that there is no evidence showing the existence of cost economies; (iii) results of research expenditures are categorized into research grants; (iv) for the same period studies in the same area, we only take the optimistic results among them; (v) source of data is from Table 3.1.

Due to the usage of different time-period datasets, researches with datasets in the same country could have different results. The multiple previous researches in UK and US provided us with enough materials to analyze these cases. Researches showed that public institutions in the UK and US had continued to enjoy cost saving in terms of scale and
scope economies from year 1981 to 2003 (extending to 2007 for US). This happens to match the expansion trend during this period in the UNESCO (2005) report we mentioned in the Chapter 1.

So far, we introduce the theory of scale and scope economies, especially focusing on the estimation and the implications for its estimates. Most importantly, the thesis reviews its applications to higher education and depicts the nature of scale and scope economies in higher education. The results show some developed countries such as Australia, Spain, the UK, the US are suggested to maintain present output mean level since the ray economies of scale only existed at 100% of the mean output. On the other hand, results from the developing countries such as Bangladesh (Mamun, 2012) and the Philippines (Rufino, 2006) indicate tremendous cost savings.

However, from the results of this review, we can also find the mixed, even conflicting outcomes from previous studies. From Table 3.2 and Table 3.3, we can observe that results vary with different types and locations of institutions. Many factors could contribute to these mixed results such as the estimation methods. The usage of different time-period datasets also might be the cause. It is thus hard to distinguish the factors affecting estimated scale and scope economies. Thus, in the last (following) section of this chapter, an empirical literature review will be conducted to give more insights into the reasons of mixed results.
3.5 Explaining estimated economies of scale and scope in higher education: A meta-regression analysis

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3.5.1 Introduction

Ever since Baumol, Panzar, & Willig (1982) develop the seminal theory in industrial economics underpinning multiple-output, multiple-input economies of scale and scope, interest in investigating cost structures in a variety of industries has continued to grow. Cohn, Rhine, & Santos (1989) represent the first attempt to apply this theory to higher education and their model has since encouraged others to follow their lead in examining higher education cost structures across a range of contexts and time periods.

These studies contribute to our better understanding of the future of higher education in terms of an appropriate if not optimal size and scope. If there is evidence of economies of scale, it suggests that increasing the operational size of higher education, for both institutions and industries, can yield benefits in the form of lower unit costs. In contrast, evidence of economies of scope would suggest that the joint production of different outputs carries with it cost savings. Therefore, by investigating scale and scope economies, existing studies have imagined the future optimal structure for sustainable delivery using estimates of these critical cost economies. Regrettably, the chosen institutional, regulatory and market contexts within which existing results have been derived vary so markedly that generalization for informing government policy and industry practice is difficult.

We believe we could more appropriately sort existing findings on the economics of scale
and scope in higher education with meta-regression analysis (MRA). MRA is a tool used to examine the impact of moderator variables on study effect size using regression-based techniques. Unlike a mere literature review with its reliance on possibly subjective qualitative discussion [see Cohn & Cooper (2004) for a recent qualitative review of scale and scope economies in higher education], MRA is able to shed greater light on both the general outcomes of a large body of existing work and possible reasons for the differences in these results. We use economies of scale and economies of scope as the effect sizes and investigate the factors that exert a significant impact on these effect sizes, namely, the scale elasticity and cost savings from joint production, both commonly considered as good effect sizes in economics (Stanley & Doucouliagos, 2012).

The purpose of this study is therefore to analyze potential factors affecting economies of scale and scope in higher education through conducting an MRA. The remainder of this paper is structured as follows. Section 3.5.2 discusses the potential factors affecting scale and scope economies. Section 3.5.3 and 3.5.4 outline the method of constructing the meta-regression models and the sampling procedure. Section 3.5.5 details the results of the analysis and most importantly reveals the significant impact factors, from the perspective of both their theoretical and practical importance. The last section provides some brief concluding remarks and some practical suggestions for future research in the area.

### 3.5.2 Literature review

The theory of scale economies dates at least to Adam Smith’s *Wealth of Nations* explanation of them as a source of wealth differences between countries. In brief, if there are economies of scale, all else constant, unit costs are lower in larger firms, resulting from the spreading of fixed costs over additional units of production. Subsequently applied to many economic
activities, but mostly limited to single-output production, Baumol (1975) and Panzar & Willig (1975) extend the idea to multi-output production and added discussion on the economies of scope resulting from the cost savings of joint production. Multi-product estimation, as introduced by Baumol, Panzar, & Willig (1982), further accelerate the spread of these premise of economies of scale and scope to a variety of multi-output production contexts including, as here, higher education.

Cohn et al. (1989) first applied Baumol et al. (1982)’s theory of scale and scope economies to higher education. Using quadratic cost functional (QCF, or flexible fixed cost quadratic) forms, Cohn et al. (1989) estimated scale and scope economies using a sample of 1,195 public and 692 private higher education institutions in the US. As this seminal work directed subsequent inquiry, it is useful to highlight some key features of their analysis. First, while there are other possible functional forms, including constant elasticity of substitution (CES) (Johnes, 1997; Izadi et al., 2002) and hybrid translog (TL) (De Groot et al., 1991; Glass et al. 1995a, 1995b, 1996) functions, quadratic cost functional forms have dominated, even though Baumol et al. (1982) suggested these alternatives. Note that these three functional forms (QCF, CES, and TL) match the ideal conditions of cost functional form: flexible enough to allow scale and scope economies to vary with the levels of output, allow data to decide the existence of scale and scope economics, and permit zero outputs of some services (Lloyd et al., 1993). However, the complication of estimation due to the specification and relatively demanding in terms of data make CES and TL unpopular with researches (Johnes & Johnes, 2009). Given the probably impact of the functional form on the estimated scale and scope economies, this choice remains critical.

Second, Cohn et al. (1989) included both public and private institutions in their analysis. Again, this is an important consideration because the funding of public institutions tends to constrain their enrollments and programs relative to their counterparts. Cohn et al. (1989)
understood this potential impact and therefore split the sample into public and private institutions. They then estimated the cost economies for each type of institution and identified significant differences between them. Several subsequent studies followed this approach, especially in the US, including Chavas (2012), Laband (2003) and Sav (2004). As an alternative, if the public and/or private institution subsamples are relatively small, others, including (Johnes et al., 2008; Johnes & Salas-Velasco, 2007) employ an ownership dummy variable.

Besides these factors, accounting for the managerial efficiency of an institution may also be another important factor affecting scale and scope economies. For example, government regulation and the characters of not-for-profit organizations may invoke inefficient outcomes through the setting of additional social and other organizational objectives. In fact, as the cost economies derived from regression models are from an average cost function, they implicitly assume that at least some institutions are less than perfectly efficient. Johnes (1998) first noted this and suggested the use of a stochastic frontier model or alternative, as did Izadi et al. (2002), Maripani (2007), Johnes and Johnes (2009) and Johnes and Johnes (2016) later.

Another potential factor is the role of teaching outputs in estimation economies of scale and scope in higher education. If we were to consider students as the most important teaching output, the question follows as to how we measure this quantitatively. For instance, at the beginning of the teaching process, each institution counts enrolled students; during the teaching process, students decide when, how many, and what courses they undertake to fulfill set graduation requirements; at the end of the teaching process, students successfully passing all requirements graduate. Each of these teaching (production) processes has its own teaching outputs: at its simplest, enrollments, credits, and completions, and each are evident in the existing literature. Of these, enrollments are the most common choice,
invariably because of data availability. Nevertheless, as each type of output actually
represents a different teaching process, this specification choice can have marked impacts
on the estimated economies of scale and scope. Unfortunately, most past studies did not
provide a reason for the choice of specific teaching output, though Agasisti (2016) recently
specified both enrollments and completions as the teaching outputs and compared the
results.

The potential factors above naturally raise a simple question: how do they affect the
economies of scale and scope in higher education? This question might be answered by
using a sample from a country like previous studies did. It could be easy to include the
factors above but it is impossible to comprehensively contain some important control
variables such as sample size and data source. MRA is built for solving this question by
borrowing the characteristics of previous studies to investigate whether some characteristics
might be the important factors to affect effect size. We will give more details about MRA in
the next section.

3.5.3 Methodology

Following Stanley and Jarrell (1989; 2005), our MRA model for a sample of $S$ studies has
the following form:

$$b_i = \beta + \sum_{k=1}^{K} \alpha_k Z_{ik} + \varepsilon_i \quad for \; i = 1, 2, \ldots, S$$

(3.16)

where $b_i$ is the reported effect size estimate of the $i$-th empirical study, $\beta$ is the true value
of $b_i$, $Z_{ik}$ are the meta-independent (or study-level) variables used for representing the
important characteristics of a study, $\alpha_k$ are the coefficients corresponding to the
Economies of Scale and Scope in Higher Education

meta-independent variables, and \( e_i \) is the meta-regression error term used for accounting for any unexplained disturbance in \( Z_{ik} \).

The purpose of the meta-regression model in (3.16) is to identify the potential factors influencing the effect size, such that statistically significant estimated coefficients for the meta-independent variables indicate that the characteristics of the study have a significant relationship with the results and vice versa. Note that (3.16) could be defined as a fixed-effect model or random effect model depending on the assumption of the reported effect size estimate \( b_i \). If that estimate is assumed a random draw following a standard normal distribution, (3.16) is a fixed-effect model. On the other hand, if \( b_i \) varies randomly around \( \beta + \sum_{k=1}^{K} \alpha_k Z_{ik} \), (3.16) is a random-effect model. These assumptions could be tested with some statistics and we did not find the heteroscedasticity among studies (see section 3.5.5 for details). Therefore, we use a fixed-effect model for (3.16) in this study.

In this study, the effect size, \( b_i \), is the estimates of the cost economies (scale and scope). More specifically, we are interested in factors affecting two cost economies: ray (or overall) scale economies (SRAY) and global (or total) scope economies (GSE). To ensure comparability, we only consider studies whose results are consistent with the multi-output production theory in Baumol et al. (1982). We first introduce the estimate of scale economies for multi-product production:

\[
\text{SRAY}(y) = \frac{C(y)}{\sum_{i=1}^{n} y_i \frac{\partial C}{\partial y_i}} \tag{3.17}
\]

where \( C(y) \) is the total cost of producing all outputs given the different output values \((y_1, \ldots, y_n)\) and other control variables such as output prices, institution characteristics (for simplicity, they are omitted in the equations), such that \( \partial C/\partial y_i \) is the marginal cost of producing product \( y_i \).
Note that this measure calculates the effect of a simultaneous and proportional increase of all output scales along a ray in output space while holding the composition of each institution’s outputs constant. Hence, ray economies of scale. If there are economies of scale, the estimated measure is greater than unity, implying aggregate output increases while the composition of output remains constant.

An estimate of scale economies can help institutions decide how large they should be. In contrast, the estimate of global scope economies is the percentage of cost savings from joint production relative to fully integrated costs (or alternatively, the percentage increase in costs from specialized production):

\[
GSE(y) = \frac{\sum_{i=1}^{n} C(y_i) - C(y)}{C(y)}
\]  

(3.18)

where \(\sum_{i=1}^{n} C(y_i)\) is the cost of producing product \(i\) in \(n\) separated specialized institutions, and \(C(y)\) is the cost of producing all \(n\) products jointly within an institution.

Scope economies typically result from the sharing of inputs across different outputs. Therefore, input prices and the available technology greatly affect their presence (Bailey & Friedlaender, 1982). Using (3.18), if the estimate of \(GSE(y)\) is greater than zero, scope economies are present, implying that the cost of producing different types of products within a single production unit is less than the cost of producing them separately.

From equations (3.17) and (3.18), we can clearly see that both estimates vary with the level of output \(y\). Most previous studies evaluate these estimates at the mean (average) output level for the industry. We follow this approach in our MRA by assuming that the higher education sector in a specific country will have point estimates of scale and scope economies on average. We can also use these estimates to indicate the mere presence of scale and scope economies, by specifying binary dependent variables as follows:
Economies of Scale and Scope in Higher Education

- $D.SRAY$: one for estimates of scale economies evaluated at a mean output level larger than zero, otherwise zero
- $D.GSE$: one for estimates of scope economies evaluated at a mean output level larger than zero, otherwise zero

The meta-independent variables $Z_{ik}$ consist of continuous variables and the dummy variables. Following Stanley et al. (2013) and the literature, we include the following continuous explanatory variables:

- $Year$: start year of the data
- $Sample\ size$: the number of institutions included in the sample

Dummy variables are also included as follows.

- $Public$: one for public institutions, otherwise zero
- $OECD$: one for OECD (2016) member-countries, otherwise zero
- $QCF$: one for QCF functional form, otherwise zero
- $Efficiency$: one for (in)efficiency control, otherwise zero
- $Enrollments$: one for enrollments as teaching outputs, otherwise zero
- $Research$: one for the existence of research outputs, otherwise zero
- $Third\ mission$: one for the existence of third mission activity outputs, otherwise zero
- $Panel$: one for longitudinal study, otherwise zero
- $Journal$: one for refereed journal, otherwise zero

One limitation of our paper is that we cannot offset the potential publication bias (Doucouliagos, 2005) arising from the relatively studies that report standard errors. In fact, in our sample, just two (Fu et al., 2008; Nemoto & Furumatsu, 2014) reported the standard errors of the estimates of scale and scope economies using the delta method. Unfortunately, as all studies use different functional forms and/or independent variables for calculating the cost economies, it is almost impossible to calculate the standard errors retrospectively. This limitation is not uncommon and is shared with most other meta-regression analyses (Bel &
3.5.4 Sampling procedure and study characteristics

The selection of publications is key to conducting a proper meta-analysis. It is especially important to include as many different types of publications as possible to reduce publication bias, with Stanley and Doucouliagos (2012) suggesting that meta-analysis should not only include published works but also incorporate unpublished sources, including thesis, dissertations, working and conference papers and commercial research reports.

We employ two phases in our literature search. The first phase involves the searching of major education, economics, and social science databases, including ERIC, ProQuest Dissertations & Theses Global, Science Direct, JSTOR, Google Scholar, SCOPUS, and EconPapers. As we already know the seminal work in the area (Cohn et al., 1989) dates from 1989, we narrow the literature search to English language articles from 1989 onwards including the keywords ‘higher education’, ‘university’, ‘economies of scale’, and/or ‘economies of scope’.

In the second phase, we remove duplicate studies and those that are not empirical, do not specify multiple outputs, not report estimates evaluated at the sample means, are not specific to higher education, and not conducted at the institutional level. For example, in some higher education studies (Dundar & Lewis, 1995; Gana, 1996; Lewis & Dundar, 1995) data is collected at the departmental or faculty level. For consistency, we include only those studies in our sample reporting estimates evaluated at the mean output level, not the median (Filippini & Lepori, 2007).

Table 3.4 summarizes the 42 publications identified using this process. Note some studies
report more than a single estimate for economies of scale and/or scope given the use of alternative methods, functional form, the use of subsamples, etc. In these cases, we list all estimates, but categorize them as a single study, as indicated by including ‘Yes’ in the column headed Multiple in Table 3.4. Overall, our sample comprises 42 studies with 52 observations for scale economies and 37 observations for scope economies.

The data span using for previous studies is quite wide, spreading more than three decades (from 1981 to 2013). There is also significant variation in the sample size. For instance, Mamun (2012) uses a sample of just 18 institutions while Laband and Lentz (2003) includes some 1,492 institutions.

Most studies reported both estimates of economies of scale and economies of scope. Some studies even report more than one estimate for scale economies of scope economies. However, there are still some publications reporting either one of the estimate. Notice that almost all publications are published in a journal and only two publications (Maripani, 2007; Johnes et al., 2005) is published in other forms (thesis and report).
Table 3.4: Studies included in the meta-regression analysis, by country.

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### Economies of Scale and Scope in Higher Education

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### Chapter 3. The nature of economies of scale and scope in higher education

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<th>Author(s)</th>
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<th>Ownership</th>
<th>Data start year</th>
<th>Country context</th>
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<th>Efficiency control</th>
<th>Teaching output specification</th>
<th>Re-search</th>
<th>Third mission</th>
<th>Panel</th>
<th>Publication type</th>
<th>Type</th>
<th>Multiple estimates</th>
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<tr>
<td>Johnes &amp; Johnes (2016)</td>
<td>103</td>
<td>Public</td>
<td>2013</td>
<td>UK</td>
<td>QCF</td>
<td>Yes</td>
<td>Enrollments</td>
<td>Yes</td>
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<td>No</td>
<td>Journal</td>
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<tr>
<td>Cohn et al. (1989)</td>
<td>1,887</td>
<td>Public and private</td>
<td>1981</td>
<td>US</td>
<td>QCF</td>
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<td>Enrollments</td>
<td>No</td>
<td>No</td>
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<td>Foltz et al. (2007)</td>
<td>96</td>
<td>Public and private</td>
<td>1981</td>
<td>US</td>
<td>QCF</td>
<td>No</td>
<td>Enrollments</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Journal</td>
<td>No</td>
<td>No</td>
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<tr>
<td>de Groot et al. (1991)</td>
<td>147</td>
<td>Public and private</td>
<td>1982</td>
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<td>No</td>
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<td>No</td>
<td>No</td>
<td>No</td>
<td>Journal</td>
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<tr>
<td>Koshal &amp; Koshal (1999)</td>
<td>329</td>
<td>Public and private</td>
<td>1990</td>
<td>US</td>
<td>QCF</td>
<td>No</td>
<td>Enrollments</td>
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<td>No</td>
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<td>Koshal &amp; Koshal (2000)</td>
<td>295</td>
<td>Private</td>
<td>1994</td>
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<td>QCF</td>
<td>No</td>
<td>Enrollments</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Journal</td>
<td>No</td>
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<tr>
<td>Koshal et al. (2001)</td>
<td>184</td>
<td>Private</td>
<td>1994</td>
<td>US</td>
<td>QCF</td>
<td>No</td>
<td>Enrollments</td>
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<td>No</td>
<td>No</td>
<td>Journal</td>
<td>No</td>
<td>No</td>
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<tr>
<td>Laband &amp; Lentz (2003)</td>
<td>2,942</td>
<td>Public and private</td>
<td>1995</td>
<td>US</td>
<td>QCF</td>
<td>No</td>
<td>Enrollments</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Journal</td>
<td>Yes</td>
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</tr>
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<td>Sav (2004)</td>
<td>2,189</td>
<td>Public and private</td>
<td>1995</td>
<td>US</td>
<td>QCF</td>
<td>No</td>
<td>Credit hours</td>
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<td>No</td>
<td>No</td>
<td>Journal</td>
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<td>No</td>
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<td>Sav (2010)</td>
<td>457</td>
<td>Public</td>
<td>2006</td>
<td>US</td>
<td>QCF</td>
<td>No</td>
<td>Credit hours</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Journal</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>Sav (2011)</td>
<td>321</td>
<td>Public</td>
<td>2000</td>
<td>US</td>
<td>QCF</td>
<td>No</td>
<td>Credit hours</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Journal</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Chavas et al. (2012)</td>
<td>92</td>
<td>Public and private</td>
<td>1995</td>
<td>US</td>
<td>Non-parametric</td>
<td>Yes</td>
<td>Completions</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Journal</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

(continued on the next page)
### Economies of Scale and Scope in Higher Education

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>No. of institutions</th>
<th>Ownership</th>
<th>Data start year</th>
<th>Country context</th>
<th>Functional form</th>
<th>Efficiency control</th>
<th>Teaching output specification</th>
<th>Research</th>
<th>Third mission</th>
<th>Panel</th>
<th>Publication type</th>
<th>Multiple estimates</th>
</tr>
</thead>
</table>

Note: * QCF is quadratic cost functional form, TL is hybrid translog function, CES is constant elasticity of substitution function, and nonparametric means the study did not use a specific functional form for estimating scale and scope economies.
Table 3.5 shows the final sample used in our meta-regression analysis. In this paper, there are 52 observations could be used for analyzing factor affecting estimates and presence of economies of scale. The mean for estimate of scale economies (SRAY) is 1.164 but the maximum is up to 4.37. The mean for presence of scale economies (D.SRAY) shows 65.4% of estimates indicating presence of scale economies.

The other statistics also indicate some interesting facts. From Table 3.5, most estimates for scale economies use samples from public institutions (65.4%) and OECD countries (86.5%). As for the methodology adopted by previous studies, 75% of estimates are from using the quadratic cost function with 46.2% of estimates using a panel sample. However, only 36.5% of estimates account for efficiency.

The last two columns of Table 3.5 provide the observations on scope economies used in the meta-regression analysis. There are 37 observations, fewer than for the analysis of scale economies. While the mean estimate for scope economies (GSE) is just 0.013, the presence estimate (D.GSE) suggests another story by indicating that 64.9% of estimates, implying the presence of positive scope economies. The lower mean estimate of scope economies could be the result of a single very low outlier (-8.27) from Cheng & Wu (2008). These results suggest the necessity of considering the presence of cost economies, not just their magnitude, as a dependent variable. That said, the characteristics of the independent variables are quite similar to those found in the extant studies of scale economies.
### Table 3.5: Descriptive statistics of literature on scale economies (n = 52) and scope economies (n = 37)

<table>
<thead>
<tr>
<th></th>
<th>Scale economies</th>
<th></th>
<th>Scope economies</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dependent variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRAY / GSE</td>
<td>1.164</td>
<td>0.575</td>
<td>0.013</td>
<td>1.544</td>
</tr>
<tr>
<td>D.SRAY / D.GSE</td>
<td>0.654</td>
<td>0.480</td>
<td>0.649</td>
<td>0.484</td>
</tr>
<tr>
<td><strong>Independent variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year</td>
<td>1996.923</td>
<td>6.885</td>
<td>1996.351</td>
<td>7.357</td>
</tr>
<tr>
<td>Sample size</td>
<td>232.827</td>
<td>380.211</td>
<td>157.189</td>
<td>251.857</td>
</tr>
<tr>
<td>Public</td>
<td>0.654</td>
<td>0.480</td>
<td>0.622</td>
<td>0.492</td>
</tr>
<tr>
<td>OECD</td>
<td>0.865</td>
<td>0.345</td>
<td>0.838</td>
<td>0.374</td>
</tr>
<tr>
<td>QCF</td>
<td>0.750</td>
<td>0.437</td>
<td>0.703</td>
<td>0.463</td>
</tr>
<tr>
<td>Efficiency</td>
<td>0.365</td>
<td>0.486</td>
<td>0.432</td>
<td>0.502</td>
</tr>
<tr>
<td>Enrollments</td>
<td>0.712</td>
<td>0.457</td>
<td>0.838</td>
<td>0.374</td>
</tr>
<tr>
<td>Research</td>
<td>0.904</td>
<td>0.298</td>
<td>0.946</td>
<td>0.229</td>
</tr>
<tr>
<td>Third mission</td>
<td>0.038</td>
<td>0.194</td>
<td>0.054</td>
<td>0.229</td>
</tr>
<tr>
<td>Panel</td>
<td>0.462</td>
<td>0.503</td>
<td>0.486</td>
<td>0.507</td>
</tr>
<tr>
<td>Journal</td>
<td>0.962</td>
<td>0.194</td>
<td>0.946</td>
<td>0.229</td>
</tr>
</tbody>
</table>

**Notes:**
(i) \( n \) is the number of observations included; (ii) the minimum and maximum SRAY are 0.18 and 4.37 respectively, the minimum and maximum sample size for SRAY studies are 18 and 1,492 respectively; the minimum and maximum GSE are -8.27 and 2.82 respectively, the minimum and the maximum sample size for GSE studies are 18 and 1,195 respectively.

Table 3.6 details the correlations between the variables. The correlation coefficients, including the level of statistical significance, for the scale economy studies are below the diagonal while those for the scope economy studies are above the diagonal. Unsurprisingly, there is a positive correlation (0.451, significant at the .01 level) between the magnitude of the scale economies and its presence. However, the correlations between these two dependent variables and the independent variables differ markedly. For example, the magnitudes of the scale economies significantly only relate to developed country studies (OECD), and whether enrollments serve as a measure of teaching output.

In contrast, the presence of scale economies significantly negatively correlates with three independent variables: the data year, the inclusion of efficiency, and the use of panel data.
suggesting older studies, those omitting efficiency, and cross-sectional and time-series only studies are more likely to conclude the presence of scale economies. The correlation coefficients above the diagonal in Table 3.6 concern the literature on scope economies. However, none of the variable correlations with the magnitude of the scope economies are significant and only enrollments significantly correlate with the presence of scope economies. These results are very similar to those observed with the scale economies.
Economies of Scale and Scope in Higher Education

Table 3.6: Correlation matrix for literature on scale economies (n = 52) and scope economies (n = 37)

<table>
<thead>
<tr>
<th>Variables</th>
<th>SRAY/GSE</th>
<th>D.SRAY/GSE</th>
<th>Year</th>
<th>Sample size</th>
<th>Public</th>
<th>OECD</th>
<th>QCF</th>
<th>Efficiency</th>
<th>Enrollments</th>
<th>Research</th>
<th>Third mission</th>
<th>Panel</th>
<th>Journal</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRAY/GSE</td>
<td>1.000</td>
<td>0.457***</td>
<td>-0.170</td>
<td>0.014</td>
<td>0.236</td>
<td>0.228</td>
<td>-0.193</td>
<td>0.051</td>
<td>-0.054</td>
<td>-0.087</td>
<td>0.029</td>
<td>-0.207</td>
<td>0.008</td>
</tr>
<tr>
<td>D.SRAY/GSE</td>
<td>0.451***</td>
<td>1.000</td>
<td>-0.074</td>
<td>-0.045</td>
<td>0.009</td>
<td>-0.170</td>
<td>0.141</td>
<td>-0.158</td>
<td>-0.170</td>
<td>-0.176</td>
<td>-0.074</td>
<td>-0.190</td>
<td>0.074</td>
</tr>
<tr>
<td>Year</td>
<td>-0.001</td>
<td>-0.263*</td>
<td>1.000</td>
<td>-0.340**</td>
<td>0.207</td>
<td>-0.413**</td>
<td>0.113</td>
<td>0.319</td>
<td>-0.191*</td>
<td>-0.005</td>
<td>0.120</td>
<td>0.303*</td>
<td>-0.021</td>
</tr>
<tr>
<td>Sample size</td>
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<td>-0.022</td>
<td>-0.244*</td>
<td>1.000</td>
<td>-0.168</td>
<td>0.181</td>
<td>0.221</td>
<td>-0.088</td>
<td>-0.063</td>
<td>0.047</td>
<td>-0.035</td>
<td>-0.151</td>
<td>0.082</td>
</tr>
<tr>
<td>Public</td>
<td>0.005</td>
<td>-0.020</td>
<td>0.306**</td>
<td>-0.139</td>
<td>1.000</td>
<td>-0.041</td>
<td>-0.020</td>
<td>-0.106</td>
<td>-0.041</td>
<td>0.306*</td>
<td>0.187</td>
<td>-0.244</td>
<td>0.060</td>
</tr>
<tr>
<td>OECD</td>
<td>-0.295**</td>
<td>-0.050</td>
<td>-0.269*</td>
<td>0.199</td>
<td>0.068</td>
<td>1.000</td>
<td>0.035</td>
<td>0.088</td>
<td>-0.194</td>
<td>0.219</td>
<td>0.105</td>
<td>-0.012</td>
<td>-0.105</td>
</tr>
<tr>
<td>QCF</td>
<td>-0.143</td>
<td>-0.140</td>
<td>0.202</td>
<td>0.227</td>
<td>0.047</td>
<td>0.033</td>
<td>1.000</td>
<td>-0.268</td>
<td>0.035</td>
<td>0.106</td>
<td>0.155</td>
<td>-0.077</td>
<td>0.106</td>
</tr>
<tr>
<td>Efficiency</td>
<td>0.000</td>
<td>-0.371***</td>
<td>0.266*</td>
<td>-0.217</td>
<td>-0.036</td>
<td>0.065</td>
<td>-0.300**</td>
<td>1.000</td>
<td>-0.060</td>
<td>-0.033</td>
<td>0.274</td>
<td>0.569***</td>
<td>-0.274</td>
</tr>
<tr>
<td>Enrollments</td>
<td>0.253*</td>
<td>0.161</td>
<td>-0.325**</td>
<td>-0.077</td>
<td>-0.196</td>
<td>-0.251*</td>
<td>-0.172</td>
<td>0.131</td>
<td>1.000</td>
<td>-0.105</td>
<td>0.105</td>
<td>-0.452***</td>
<td>-0.105</td>
</tr>
<tr>
<td>Research</td>
<td>-0.045</td>
<td>0.037</td>
<td>-0.099</td>
<td>0.144</td>
<td>0.311**</td>
<td>0.636***</td>
<td>-0.038</td>
<td>0.112</td>
<td>-0.208</td>
<td>1.000</td>
<td>0.057</td>
<td>-0.006</td>
<td>-0.057</td>
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<tr>
<td>Third mission</td>
<td>-0.042</td>
<td>-0.065</td>
<td>0.090</td>
<td>-0.059</td>
<td>0.146</td>
<td>0.079</td>
<td>0.115</td>
<td>0.264*</td>
<td>0.127</td>
<td>0.065</td>
<td>1.000</td>
<td>0.246</td>
<td>-0.471***</td>
</tr>
<tr>
<td>Panel</td>
<td>-0.051</td>
<td>-0.299**</td>
<td>0.282**</td>
<td>-0.295**</td>
<td>-0.056</td>
<td>0.026</td>
<td>-0.089</td>
<td>0.579***</td>
<td>-0.262*</td>
<td>0.040</td>
<td>0.216</td>
<td>1.000</td>
<td>-0.246</td>
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<tr>
<td>Journal</td>
<td>0.089</td>
<td>0.065</td>
<td>-0.002</td>
<td>0.086</td>
<td>0.065</td>
<td>-0.079</td>
<td>0.115</td>
<td>-0.264*</td>
<td>-0.127</td>
<td>-0.065</td>
<td>-0.480***</td>
<td>-0.216</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Notes: (i) Correlation coefficients for scale (scope) economies below (above) diagonal; (ii) *, **, and *** denote two-sided significance at the 0.1, 0.05, and 0.01 level, respectively.
The above initial findings indicate some potential correlations between dependent and independent variables. In the following section, we should model all variables with meta-regression analysis.

3.5.5 Meta-regression results

In this section, we regress our meta-independent variables on both estimates of cost economies and the presence of cost economies. The former aims to identify those factors affecting the magnitude of the scale and scope economies while the latter aims to find the factors affecting the likelihood of scale or scope economies.

3.5.5.1 Results for the magnitude of scale and scope economies

For the first meta-regression analysis, we regress the magnitude of the scale and scope economies on the independent variables. Several regression models are potential candidates, especially for analyzing the magnitude of scale economies. Some might consider Tobit regression as the magnitude of the scale economies is usually greater than zero. However, this estimate is usually not equal to zero (i.e. not censored at zero). Of course, theoretically, economies of scale are never zero as the total cost is always positive. Another candidate model is truncated regression. However, given the small number of observations, we do not truncate our data. For additional discussions of modeling censored or truncated dependent variables, see Long (1997) for details. We therefore follow similar MRA studies (Carvalho et al., 2012) and employ ordinary least squares (OLS).

To test the assumption of OLS, we conduct a Breusch–Pagan chi-square test (BP test) for heteroscedasticity. As shown in Table 3.7, the statistics for both dependent variables are
insignificant, indicating the constant variance of error terms is not violated. However, the results for both dependent variables show not all coefficients of independent variables are significant. The insignificant $F$-test and low $R^2$ further confirm these variables do not contribute to explaining the variance of SRAY and GSE.

These results may appear confusing given the independent variables are usual in the literature estimating the magnitude of scale and scope economies. However, with reported estimates closer either one for SRAY or zero for GSE, it might not be surprising about the insignificant results. In fact, Carvalho et al. (2012) also found insignificant results when they applied a meta-regression analysis to scale and scope economies for water utilities.

### Table 3.7: MRA results: dependent variables SRAY and GSE

<table>
<thead>
<tr>
<th>Variables</th>
<th>Magnitude of scale economies</th>
<th>Magnitude of scope economies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficients</td>
<td>$t$-values</td>
</tr>
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<td>Intercept</td>
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<td>-0.319</td>
</tr>
<tr>
<td>Year</td>
<td>0.006</td>
<td>0.343</td>
</tr>
<tr>
<td>Sample size</td>
<td>0.000</td>
<td>0.652</td>
</tr>
<tr>
<td>Public</td>
<td>-0.002</td>
<td>-0.011</td>
</tr>
<tr>
<td>OECD</td>
<td>-0.615*</td>
<td>-1.774</td>
</tr>
<tr>
<td>QCF</td>
<td>-0.204</td>
<td>-0.909</td>
</tr>
<tr>
<td>Efficiency</td>
<td>-0.138</td>
<td>-0.527</td>
</tr>
<tr>
<td>Enrollments</td>
<td>0.342</td>
<td>1.382</td>
</tr>
<tr>
<td>Research</td>
<td>0.478</td>
<td>1.235</td>
</tr>
<tr>
<td>Third mission</td>
<td>0.062</td>
<td>0.118</td>
</tr>
<tr>
<td>Panel</td>
<td>0.123</td>
<td>0.518</td>
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<td>Journal</td>
<td>0.364</td>
<td>0.727</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Number of observations</th>
<th>52</th>
<th>37</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP test</td>
<td>14.515 ($p$-value = 0.206)</td>
<td>12.386 ($p$-value = 0.335)</td>
</tr>
<tr>
<td>$F$-test</td>
<td>0.876 ($p$-value = 0.574)</td>
<td>0.828 ($p$-value = 0.615)</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.193</td>
<td>0.267</td>
</tr>
</tbody>
</table>

*Note: (i) BP test is Breusch–Pagan chi-square statistics; (ii) * denotes two-sided significance at the 0.1 level.*
3.5.5.2 Results for the presence of scale and scope economies

In this section, we will analyze factors explaining the presence of scale (D.SRAY) and scope economies (D.GSE). Notice that D.SRAY and D.GSE are dummy variables whose outcomes are dichotomous or binary (either 1 for cost economies or 0 for cost diseconomies). We follow the suggestion of Bel & Fageda (2009) and use probit regression to conduct a meta-regression analysis for these dependent variables.

The results of factors explaining the presence of scale (D.SRAY) and scope economies (D.GSE) are summarized in Table 3.8. This time, the results are very different from those in Table 3.7. The significant LR test statistic, which has the same function with F-test in Table 3.7 shows at least one of the meta-independent coefficients, is not equal to zero. We can observe that there are some coefficients are significantly different zero in both models; however, the significant factors vary.

For the model with presence of scale economies, QCF and Efficiency have negative impacts on the presence of scale economies. This implies that studies using the quadratic cost function or accounting for efficiency are more likely to conclude the presence of scale diseconomies. This is not surprising as accounting for efficiency usually leads to lower estimates of scale economies. One interesting finding is that the output choice does not affect the presence of scale economies since no significant coefficients are found for Enrolments, Research, and Third mission.

On the other hand, the results of the presence of scope economies point to another direction by showing more factors of affecting its presence. The above factors (functional forms, and whether accounting for efficiency) still have significant effects on the presence of scope economies. In additions, data collected year, the number of institutions (sample size), whether the collected sample is from OECD countries, using enrolments as outputs, and
Economies of Scale and Scope in Higher Education

using a panel data have significant relationships with scope economies. Interestingly, results indicate negative relationship, which further imply that studies did not use the features above (such as using a sample of older or non panel data set or fewer institutions or non-OECD countries) are more likely to conclude the presence of scope economies.

Table 3.8: MRA results: dependent variables D.SRAY and D.GSE

<table>
<thead>
<tr>
<th>Variables</th>
<th>Presence of scale economies (D.SRAY)</th>
<th>Presence of scope economies (D.GSE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficients</td>
<td>z-values</td>
</tr>
<tr>
<td>Intercept</td>
<td>35.687</td>
<td>0.404</td>
</tr>
<tr>
<td>Year</td>
<td>-0.018</td>
<td>-0.398</td>
</tr>
<tr>
<td>Sample size</td>
<td>-0.001</td>
<td>-1.115</td>
</tr>
<tr>
<td>Public</td>
<td>-0.288</td>
<td>-0.532</td>
</tr>
<tr>
<td>OECD</td>
<td>-0.304</td>
<td>-0.321</td>
</tr>
<tr>
<td>QCF</td>
<td>-1.305</td>
<td>-1.755*</td>
</tr>
<tr>
<td>Efficiency</td>
<td>-1.859</td>
<td>-2.477**</td>
</tr>
<tr>
<td>Enrollments</td>
<td>0.701</td>
<td>1.107</td>
</tr>
<tr>
<td>Research</td>
<td>1.330</td>
<td>1.339</td>
</tr>
<tr>
<td>Third mission</td>
<td>1.152</td>
<td>0.958</td>
</tr>
<tr>
<td>Panel</td>
<td>-0.235</td>
<td>-0.414</td>
</tr>
<tr>
<td>Journal</td>
<td>0.616</td>
<td>0.549</td>
</tr>
</tbody>
</table>

Number of observations | 52 | 37
LR test                | 17.721* | 18.774*
McFadden Pseudo R²     | 0.264  | 0.391
AIC                     | 73.362 | 53.199
Log pseudo likelihood   | -24.681 | -14.599

Notes: (i) LR test is the log likelihood ratio chi-square statistic; (ii) *, **, and *** denote two-sided significance at the 0.1, 0.05, and 0.01 level, respectively.

3.5.6 Concluding remarks

In this paper, we investigate the factors affecting economies of scale and scope in higher education. Since Cohn’s et al. (1989) seminal work published in 1989, the number of investigations of scale and scope economies in higher education has grown rapidly. However, the mixed results serve a source of some confusion for industry practitioners,
policy makers and stakeholders. This makes the application of the findings to actual practice and policy exceedingly difficult. This paper is the first attempt to address this problem with a meta-regression analysis proposed by Stanley and Jarrell (1989). This analysis is widely used to investigate the factors affecting the interested effect size. In our analysis, the effect sizes are the magnitude and presence of scale and scope economies.

Although previous studies suggest several factors that potentially affect scale and scope economies, our results suggest that these potential factors do not have significant relationship with the magnitude of scale and scope economies. This finding is consistent with previous work (Carvalho et al., 2012) using MRA to evaluate the degree of scale and scope economies in the water sector. We argue that the degrees of cost (scale and scope) economies might not be a good effect size estimator as these are naturally closer to their thresholds (one for scale economies and zero for scope economies). However, our contribution to the literature is that our investigated factors indeed affect the presence of these cost economies. That is, these factors will affect the probability of passing these thresholds.

Our results suggest that the presence of scale economies tends to be affected by model specification, including functional form and whether departures from managerial efficiency are included. In particular, studies employing a quadratic cost function tend to find the presence of scale diseconomies. This means the choice of functional form is no longer neutral when estimating scale economies. Future studies then need to justify why they choose a particular functional form rather than simply following the precedent.

Allowing for (in)efficiency also has significant and negative relationship with the presence of scale economies. This implies that studies accounting for efficiency are likely to conclude diseconomies of scale. This is not surprising since the costs estimated by such studies usually are less than the costs estimated by a common regression model given the
adjustment of efficiency. As total and marginal costs decline, the output level remains constant, and we expect the magnitude of any scale economies to fall. The interesting part is that this does not affect the magnitude of the scale economies, rather its presence.

The number of significant factors affecting the presence of scope economies is much more than those affecting the presence of scale economies. This suggests that the presence of scope economies is still not free from many model-specification (i.e. functional form choice and efficiency control) related biases. The presence of scope economies is further affected by the data-related factors. Our findings indicate that the data year, sample size, OECD-sourced samples, whether using a panel data are significant factors affecting the presence of scope economies. The negative signs of the estimated coefficients further imply that studies using older, panel data sets, smaller sample sizes or developing country samples are more likely to conclude the presence of scope economies. These findings therefore help us conceptualize the potential ways of realizing scope economies the world over. For example, there should be cost savings from the recent trend toward institutional specialization in developed countries, but from joint production in developing countries, and from a smaller number of institutions rather than a larger number of institutions in a country.

Another factor that significantly affects the presence of scope economies is whether studies use enrollments as teaching outputs. Our results imply that studies using enrollments tend to conclude the presence of scope economies. This suggests that the choice of teaching outputs plays an important role in the estimation and supports Agasisti (2016)’s view of different dimensions in maximizing outputs. However, we should note that such effects do not exist in estimating both the magnitude of the scale and its presence.

As a final point, while collecting the sample, we found most studies did not report the variance or standard deviation for the cost economies. While this does not affect the conduct
of meta-regression analysis, they would be very helpful in diagnosing any potential publication bias with funnel plots. We suggest further studies provide such estimates using the delta method.
Chapter 4. Scale and scope economies of distance education in Australian universities

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4.1 Introduction

Outside traditional class-based face-to-face teaching, distance education (also known as distributed learning, e-learning, or online learning as distinct from hybrid or blended learning involving some physical campus presence other than for assessment) has thrived for decades. Distance education distinguishes itself from traditional modes in not just the manner of transmission, but also the potential students it targets. In the early stages of distance education, these distance programs were mainly broadcast using closed-circuit television and written materials. With the widespread use of computers and the internet, distance education now takes more varied presentation forms, including video instruction and online learning to help students study without the limit of time and location.

These so-called online technologies further enrich learning environments by providing additional multimedia resources and help improve the communication and interaction between instructors and students (Calvert, 2005). Distance education also enables higher education institutions to extend their products to distant markets previously beyond their reach. As a result, governments, as principal funders if not providers of tertiary education in many countries, consider distance education as an effective tool to improve educational access and equity for individuals previously excluded from education after secondary school (Calvert, 2005; Li, Zhou, & Fan, 2014; Rumble, 2004). Yet another common interest shared by educational institutions and governments alike is the potential cost savings
Economies of Scale and Scope in Higher Education

associated with providing distance education over more traditional delivery modes.

One possible source of cost savings is economies of scale, such that average costs per student fall as fixed costs spread over increasing numbers of students. In distance education, these fixed costs mainly consist of the design and delivery of courses in that a distance education instructor usually spends more time designing and producing instruction than does a face-to-face instructor. Once the courses are prepared, the delivery costs of distance education arise from the maintenance of large files and multiple simultaneous users and typically require considerable bandwidth. Together, these factors imply distance education courses and programs have a relatively high share of fixed costs and require sufficient students to achieve economies of scale with delivery. Nonetheless, with the advancement of technology, one advantage of distance education is that it has a much higher theoretical upper limit to enrollment than face-to-face teaching, leading to additional potential scale economies for distance education that in most cases face-to-face teaching simply cannot attain.

The other main economies in distance education arise from economies of scope: cost savings resulting from the joint production of distance education and other education outputs. In the past, a single higher education institution (an open university) sometimes dominated the provision of distance education in a country. There is therefore little allowance for scope economies in this single-output context. However, over the last three decades, more and more traditional classroom-based higher education providers have moved to provide distance education for students choosing not to attend on campus (King, 2012). These dual- or mixed-mode institutions provide both on-campus and distance (or off-campus) education to match the needs of flexible learning styles.

Fortunately, for dual-mode institutions, there are potential scope economies between face-to-face teaching and distance delivery (Morris, 2008) in that the same academic staff
can teach both types of courses through allocating their time and energy, along with the sharing and adaptation of course materials across other courses. Providing distance education also requires more information technology and qualified faculty to support teaching and research activities. These will in turn reduce the costs of producing on-campus teaching and research (Li & Chen, 2012). Therefore, providing distance education could assist dual-mode institutions to achieve scope economies by better spreading the costs of expensive infrastructure and the employees needed for internet delivery over all students across different modes of attendance.

However, the precise nature of the scale and scope economies in distance education is far from resolved (Cohn & Cooper, 2004; Morris, 2008). Most importantly, maintaining a comparable teaching quality with on-campus teaching implies student–staff ratios still drive the variable costs of distance education: the larger the class, the greater the additional lecturer time and the number of tutors required. Therefore, the amount of any cost savings still depends on variable costs, which will vary with the number of students, including additional lecturer time for personalized support and the number of tutors hired. The cost of labor-intensive student support could also impair cost economies gained in other areas (Laurillard, 2007). For example, the higher dropout rates experienced in distance education (Sweet, 1986) are a factor that may serve to erode its cost advantage with increased student turnover through dissatisfaction. Therefore, when the number of students is increasing, the unit cost of distance education graduates could increase because more distance education students drop out. Unfortunately, these factors are difficult to identify as most existing studies of the economies in distance education employ a simple activity-based costing approach (Rumble, 1992, 1997) or rely on limited samples of single-mode institutions (Muta & Sakamoto, 1989; Wagner, 1972, 1977). Of the existing literature, our analysis most relates to Li and Chen’s (2012) seminal exploration of scope economies in distance
education.

However, we further contribute to the literature by investigating the average incremental costs and the multiple output scale economies of distance education in dual-mode higher education institutions. Specifically, we first test whether it is possible to lower unit costs by increasing the number of distance education students. Put differently, what is the nature of the economies of scale in distance education? We then examine whether traditional higher education institutions should additionally provide distance education to traditional on-campus teaching modes to save costs. That is, are there economies of scope between face-to-face teaching and distance education?

The remainder of the paper is structured as follows. Section 4.2 details our method for estimating scale and scope economies. Section 4.3 defines our dataset and the variable specification. Section 4.4 discusses the results. The final section provides our concluding remarks.

4.2 Scale and scope economies in higher education

To estimate the cost economies, we first consider a higher education institution as a multiproduct firm (Cohn & Cooper, 2004). Suppose an institution produces \( n \) types of product whose quantities are contained in the vector \( \mathbf{y} = (y_1, \ldots, y_n) \) with \( m \) types of inputs whose quantities are \( \mathbf{x} = (x_1, \ldots, x_m) \) given a vector of input prices, \( \mathbf{w} = (w_1, \ldots, w_m) \), a multi-output cost function can then be specified as:

\[
C(\mathbf{y}, \mathbf{w}) = \min_{\mathbf{x} \geq 0} \{ \mathbf{w} \cdot \mathbf{x} | (\mathbf{x}, \mathbf{y}) \in T \} \tag{4.1}
\]

Here, the multi-output cost function, \( C(\mathbf{y}, \mathbf{w}) \), describes total cost as a function of the
output quantities \( (y) \) and the input prices \( (w) \). The right-hand side of (4.1) provides that the condition of this cost function should be the minimum total cost combination of producing \( n \) types of output \( (y) \) given the input prices \( (w) \) with the multi-output technology set \( (T) \). \( w \cdot x \) is the inner product \( (\sum_i w_i x_i) \) and is aggregated into observed total cost.

In this analysis, we focus on four types of cost economies using (4.1). These estimates can potentially assist higher education institutions decide their optimal output allocations in terms of the output quantities and mix. The first type of cost economies is the ray economies of scale (SRAY). Using the cost function in (4.1), this is expressed as:

\[
SRAY = \frac{C(y, w)}{\sum_{i=1}^{n} y_i \frac{\partial C}{\partial y_i}} \quad (4.2)
\]

where \( C(y, w) \) is the total cost of producing all the outputs given the different output values \( (y_1, \ldots, y_n) \) and the mean prices, such that \( \partial C/\partial y_i \) is the marginal cost of producing product \( y_i \). This indicator calculates the effect of a simultaneous and proportional increase of all output scales along a ray in output space while holding the composition of each institution’s outputs constant. This calculation involves the addition of different types of output, where these additions are a composite commodity or an output bundle that allow the scale to change in a fixed proportion. If there are ray economies of scale, it means that the ray average cost (RAC) is declining with the level of output because average cost is being pulled down by producing one more unit.

The second type of estimate, product-specific economies of scale (PSCE), allows only a single type of output to vary at a time while holding all other outputs constant. Using the cost function in (4.1) again, we express this as:
Economies of Scale and Scope in Higher Education

\[ \text{PSCEx}_i = \frac{C(y, w) - C(y_{-i})}{\partial C(y, w)/\partial y_i}, \text{ for } i = 1, \ldots, n \]  

(4.3)

where \( C(y_{-i}) \) is the cost of producing all the outputs except the \( i \)-th type of output, and, therefore, \( C(y, w) - C(y_{-i}) \) is the incremental cost due to producing the \( i \)-th type of output. This shows the degree a multi-product institution’s operation could vary by changing the output of one product while holding the quantities of other products constant (Cohn & Cooper, 2004). Economies (diseconomies) of scale exist when this value is greater (less) than unity.

These estimates can help institutions decide how large a scale at which they should operate, while the following two estimates further indicate the scope of operations. Global economies of scope (GSE) are the percentage of cost savings from joint production relative to fully integrated costs or the percentage increase in costs from specialized production:

\[ \text{GSE} = \frac{\sum_{i=1}^{n} C(y_i) - C(y, w)}{C(y, w)} \]  

(4.4)

where \( \sum_{i=1}^{n} C(y_i) \) is the cost of producing product \( i \) in \( n \) separate or specialized institutions, and \( C(y, w) \) is the costs of producing all \( n \) products jointly within an institution.

When an institution enjoys cost savings from the joint production of various products, GSE will be greater than zero. It also implies that the cost of producing different types of products is less than the cost of producing them separately. When an institution does not experience economies of scope, it would be logical for a multi-product institution to be broken up into several specialized institutions to save costs. Similar to scale economies, the concept of scope economies can also apply to product-specific measures.

The final estimate, product-specific scope economies (PSOE), is the percentage of cost savings from the joint production of a particular type of output with other types of outputs:
where $C(y_{n-i})$ is the cost of producing all products except for product $i$. The presence of product-specific scope economies implies that the cost of producing a specific type of product jointly with other types of products is less than that to produce it separately.

Together, these estimations provide higher education institutions and their stakeholders with knowledge of the current cost structure that underpins provision in the higher education sector, i.e. average cost, marginal cost and the extent of scale and scope economies, as well as the potential efficiency gains from operating at an efficient scale. To date, there are analyses of economies of scale and scope in higher education for Australia (Lloyd et al., 1993; Worthington, 2011), China (Cheng & Wu, 2008; Li & Chen, 2012; Longlong, Fengliang, & Weifang, 2009), Germany (Johnes & Schwarzenberger, 2011), Japan (Hashimoto & Cohn, 1997; Nemoto & Furumatsu, 2014), Taiwan (Fu et al., 2011), the UK (Johnes & Johnes, 2009; Johnes et al., 2008), and the US (Agasisti & Johnes, 2015; Sav, 2011). However, most of these studies focus on the estimation of scale and scope economies in conventional (face-to-face) instruction, somewhat neglecting product differentiation in the form of distance education (Cohn & Cooper, 2004).

### 4.3 Data and specification

We employ a balanced panel dataset comprising 37 Australian public universities over the period 2003–2012 from the Department of Industry, Innovation, Science, Research, and Tertiary Education (DIISRTE). Australian universities provide a good example to investigate these potential cost economies because of their generally successful experiences in distance education (Beldarrain, 2006) and their long history of the dual-mode provision
(Rumble, 2004). Unlike internal students attending university on a regular physical basis, students taking distance education in Australia are external students whose learning is through self-paced and structured material delivered by mail or internet. Presently, all public Australian universities are dual-mode institutions. Distance education in Australia has not only played an important role of alternative mode of attendance, but also become a rival to on-campus instruction, with the number of external completions increasing 37 percent from 25,360 in 2001 to 34,798 in 2012, with one in every ten graduates graduating through distance education in 2012 (DIISRTE, 2013).

The dependent variable is total operating expenditure. We include four outputs and three input prices in the cost function. The outputs (y) consist of on-campus completions \(y_1\), distance completions \(y_2\), multi-modal completions \(y_3\), and number of publications \(y_4\). The three factor prices (w) are the prices of academic labor \(w_1\), nonacademic labor \(w_2\), and non-labor inputs \(w_3\). We convert all monetary variables (costs and input prices) to their real values \((2003 = 100)\) using the consumer price index (CPI) from the Australian Bureau of Statistics. We select these variables based on existing studies in the area, but make a number of modifications to fit the primary purpose of our paper.

We select completions over enrollments or credit hours as the teaching outputs mainly because the number of graduates represents the final instructional product in an institution. This indicator also considers a certain quality of instruction, as all students, regardless of their mode of attendance, must complete the same credit hours and achieve the same academic standards to gain a degree. Nonetheless, this indicator does not account for the number of dropout students, who significantly add to university costs. Therefore, we include the attrition rate for each institution using the proportion of students commencing a bachelor’s course in year \((t)\) who neither complete nor return in year \((t+1)\). Lastly, an ideal indicator for the price of capital is capital expenditure divided by net assets. As these data
are not available, we specify the number of full-time equivalent (FTE) students as a proxy following Worthington and Higgs (2011).

Table 4.1 provides the means, standard deviations, minimums, and maximums for the pooled data. As shown, some institutions have no distance education outputs, which implies a quadratic cost function (QCF) for $C(y, w)$ is more appropriate than other multi-product cost functional forms, including the constant elasticity of substitution (CES) and hybrid translog (TL) function. QCF is also a popular functional form for estimating scale and scope economies in higher education, as it also allows zero values for outputs. However, the difficulties of imposing linear homogeneity and concavity in input prices with this function have caused some concern with violating basic cost function assumptions. Some studies (Agasisti & Johnes, 2015; Johnes & Johnes, 2009; Johnes & Schwarzengerber, 2011; Lloyd et al., 1993) bypass these difficulties by assuming constant input prices across higher education institutions, which is generally acceptable given their (usually) highly regulated context. However, the increasing competition among higher education institutions in both factor and product markets has substantially weakened this premise over time.

Table 4.1: Selected variable statistics, 2003–2012

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Mean</th>
<th>Std. dev.</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>c</td>
<td>Total operating expenditure ($000s)</td>
<td>400,671.26</td>
<td>280,775.63</td>
<td>34,355.00</td>
<td>1,327,777.62</td>
</tr>
<tr>
<td>$y_1$</td>
<td>On-campus education completions (n)</td>
<td>5,302.43</td>
<td>3,454.09</td>
<td>15.00</td>
<td>15,848.00</td>
</tr>
<tr>
<td>$y_2$</td>
<td>Distance education completions (n)</td>
<td>755.72</td>
<td>1,022.00</td>
<td>0.00</td>
<td>5,621.00</td>
</tr>
<tr>
<td>$y_3$</td>
<td>Multimodal completions (n)</td>
<td>534.47</td>
<td>730.60</td>
<td>0.00</td>
<td>4,518.00</td>
</tr>
<tr>
<td>$y_4$</td>
<td>Number of publications (n)</td>
<td>1,222.31</td>
<td>1,086.73</td>
<td>60.76</td>
<td>5,118.15</td>
</tr>
<tr>
<td>$w_1$</td>
<td>Price of academic labor ($000s)</td>
<td>76.82</td>
<td>15.67</td>
<td>52.22</td>
<td>131.99</td>
</tr>
<tr>
<td>$w_2$</td>
<td>Price of nonacademic labor ($000s)</td>
<td>56.77</td>
<td>13.07</td>
<td>38.83</td>
<td>121.97</td>
</tr>
<tr>
<td>$w_3$</td>
<td>Price of non-labor ($000s)</td>
<td>8.58</td>
<td>4.18</td>
<td>3.30</td>
<td>28.98</td>
</tr>
<tr>
<td>q</td>
<td>Attrition rate (%)</td>
<td>18.07</td>
<td>6.10</td>
<td>6.21</td>
<td>38.83</td>
</tr>
</tbody>
</table>

To allow for zero outputs as well as imposing the usual cost function assumptions, we
propose a multiplicatively separable cost function in (4.6). This form inherits a quadratic output substructure and makes the impositions easier as the substructure is multiplied by input prices in a Cobb–Douglas functional form. Once we impose linear homogeneity in input prices by summing the price coefficients to one, this functional form further conforms to concavity in input prices.

\[
C(y, w) = \left( \alpha_0 + \sum_{i=1} \alpha_i y_i + 0.5 \sum_{i=1} \alpha_{ii} (y_i)^2 + \sum_{i,j=1; i \neq j} \alpha_{ij} y_i y_j \right) \prod_{i=1} w_i^{\beta_i} \tag{4.6}
\]

One additional advantage over its linear counterparts is that this nonlinear form should provide reliable predictions for the value of output variables outside the observed range of the data. This is extremely advantageous when estimating scope economies as we rarely observe zero output in all output variables. An additional benefit is that we can add cost shifters that account for differing operating environments. In order to maintain the cost function assumption, these cost shifters should be in an exponential form. In this way, the sign of the coefficients will not affect the assumption of increasing factor prices.

For a linear model, researchers may use either fixed or random effects to control for any heterogeneity that can arise in panel data. However, there is no accepted procedure for a nonlinear regression model like in our analysis. Categorical indicators for individual traits could serve this same purpose. In this regard, an interesting feature of Australian universities is that even though they receive public funding primarily from the Commonwealth (federal) government, they operate under state or territory legislation and therefore they are constrained by state laws. Universities also seek alliances and cooperation with each other, such that institutions often share common traits with institutions in the same state and alliance group. Therefore, we include dummy variables for each of eight regions (states and territories) and four alliance groups to control for heterogeneity. The
eight Australian regions specified are New South Wales, Victoria, Queensland, Western Australia, South Australia, the Australian Capital Territory, Tasmania, and the Northern Territory. The four alliance groups comprise the Australian Technology Network, the Group of Eight, the Innovative Research Universities, and the Regional Universities Network. See Garrett-Jones and Turpin (Garrett-Jones & Turpin, 2012) for details.

We use a regression model to link the actual total costs, $c$, with our assumed cost function \( (4.6) \) by involving a multiplicative error which is normal and homoscedastic, that is $\varepsilon \sim N(0, \sigma^2)$.

\[
c = C(y, w) \cdot \exp \left( \sum_{i}^{13} \delta_i Z_i \right) \cdot \exp(\varepsilon) = C(y, w, Z; \beta) \cdot \exp(\varepsilon) \quad (4.7)
\]

Here, $\exp$ denotes the base of the natural logarithm. The coefficient vector is $\beta = [\alpha_0, \alpha_i, \alpha_{ii}, \alpha_{ij}, \beta_i, \delta_i]$. $Z_i$ is the institutional characteristics including attrition rates and two categorical indicators for region and alliance group. With some transformations by taking logarithms of both sides, we make (4.7) linear in the parameters of the input prices.

\[
\ln(c) = \ln(C(y, w, Z; \beta)) + \varepsilon
\]

\[
= \ln \left( \alpha_0 + \sum_{i=1}^{4} \alpha_i y_i + 0.5 \sum_{i=1}^{4} \alpha_{ii} (y_i)^2 + \sum_{i,j=1; i \neq j}^{6} \alpha_{ij} y_i y_j \right)
\]

\[
+ \sum_{i=1}^{3} \beta_i \ln(w_i) + \sum_{i}^{13} \delta_i Z_i + \varepsilon \quad (4.8)
\]

Common least squares can still be used to derive coefficient estimators by minimizing the sum of squares, $\sum (\ln(c) - \ln(C(y, w, Z; \beta)))^2$. This type of question is minimization subject to linear constraints. In our case, the minimization objective function is subject to a linear constraint (the price coefficients sum to one). We can achieve the linear constraint easily by
substituting any one of the three coefficients for input prices back into (4.8). This means we have to impose a functional relationship between the price coefficients, such that $1 = \beta_1 + \beta_2 + \beta_3$. In our case, we choose $\beta_1 = 1 - \beta_2 - \beta_3$ to replace $\beta_1$ in (4.8) to obtain the new equation for input prices, $\ln(w_1) + \beta_2 \ln(w_2/w_1) + \beta_3 \ln(w_3/w_1)$. For estimating $\beta_1$, we could follow the same procedure, but select either $\beta_2$ or $\beta_3$ for the substitutions.

One advantage of this estimation method is that it is easier to impose linear homogeneity in input prices in that we do not have to worry about how the choice of a numeriate price might affect the estimated coefficients, as it is invariant to which one of the three price coefficients we choose to drop. However, as $\ln(C(y,w,Z;\beta))$ is nonlinear in the coefficients, we employ an iterative procedure with initial values for the estimated coefficients to estimate the coefficients. This technique finds application in Izadi et al. (2002) and Johnes (1997) where they estimate a CES cost function for calculating the scale and scope economies of UK universities.

### 4.4 Results

Table 4.2 provides the estimates of the four-output multiplicatively separable cost function. We estimate the model both with and without the dropout rate, but the two models deliver similar results in terms of the magnitudes, signs, and significance of the estimated coefficients. The regional and alliance group dummies, except for Victoria and Queensland, are all significant. However, this affects the significance of cost complementarity between on-campus and distance teaching ($\alpha_{12}$), for which we observe negative values for the coefficient estimates. This cost advantage usually depends on how an institution produces its distance education courses (Rumble, 2004). In practice, the teaching arrangements for these two types of courses in Australia used to be separate, but now all students in either
mode of attendance largely share the same resources (Calvert, 2005). This suggests our finding of significant cost complementarity is convincing.

Unfortunately, as shown in Table 4.2, we find no evidence of cost complementarity between distance education and multimodal teaching even when accounting for dropout rates. This could be due because producing multimodal teaching is more costly as it consumes resources from both on-campus and distance education. In addition, the provision of multimodal teaching is usually an alternative attendance mode for only on-campus students, with distance education students unable to consider it because they usually live away from the university. In some ways, multimodal teaching dilutes the resources of distance education. As the positive value of $\alpha_{23}$ suggests, producing both distance and multimodal together could therefore lead to expending more resources because the university may have to pay more to achieve the same teaching quality.

In contrast, the coefficient for $\alpha_{24}$ is also positive though insignificant, implying that an increase in distance education and research together will not lead to any cost reduction. This contradicts the result in Li and Chen (2012), who find cost complementarity between distance education and research in Chinese research universities. To explain this, we should consider the Australian context, such that teaching-focused universities provide most of the degrees available through distance education. Research-focused universities, like members of the Group of Eight, typically offer only a limited range of education degrees compared with their relatively large number of on-campus degrees. Considering the significant investments required for courses and research outputs, universities choose to devote less to either of the above outputs, because producing both together in equal quantity could lead to higher costs. We believe this is the reason for the lack of cost complementarity.
Table 4.2: Cost function estimates

<table>
<thead>
<tr>
<th>Without dropouts</th>
<th>With dropouts</th>
<th>Without dropouts</th>
<th>With dropouts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coefficient</strong></td>
<td><strong>t-value</strong></td>
<td><strong>Coefficient</strong></td>
<td><strong>t-value</strong></td>
</tr>
<tr>
<td>$\alpha_0$</td>
<td>828.7017</td>
<td>571.8348</td>
<td>0.1585</td>
</tr>
<tr>
<td>$\alpha_1$</td>
<td>1.3197</td>
<td>1.2253</td>
<td>0.1890</td>
</tr>
<tr>
<td>$\alpha_2$</td>
<td>1.6334</td>
<td>1.3094</td>
<td>0.1485</td>
</tr>
<tr>
<td>$\alpha_3$</td>
<td>1.3603</td>
<td>1.1438</td>
<td>$-0.0899$</td>
</tr>
<tr>
<td>$\alpha_4$</td>
<td>3.7356</td>
<td>3.7099</td>
<td>$-0.0743$</td>
</tr>
<tr>
<td>$\alpha_{11}$</td>
<td>$-0.0002$</td>
<td>$-0.0001$</td>
<td>$-0.0179$</td>
</tr>
<tr>
<td>$\alpha_{22}$</td>
<td>$-0.0002$</td>
<td>$-0.0001$</td>
<td>$-0.0054$</td>
</tr>
<tr>
<td>$\alpha_{33}$</td>
<td>$-0.0002$</td>
<td>$-0.0001$</td>
<td>$-0.0763$</td>
</tr>
<tr>
<td>$\alpha_{44}$</td>
<td>$-0.0007$</td>
<td>$-0.0009$</td>
<td>$-0.1463$</td>
</tr>
<tr>
<td>$\alpha_{12}$</td>
<td>$-0.0001$</td>
<td>$-0.0001$</td>
<td>$-0.1961$</td>
</tr>
<tr>
<td>$\alpha_{13}$</td>
<td>$-0.0001$</td>
<td>$-0.0001$</td>
<td>$-0.1417$</td>
</tr>
<tr>
<td>$\alpha_{14}$</td>
<td>$0.0001$</td>
<td>$0.0002$</td>
<td>$-0.3115$</td>
</tr>
<tr>
<td>$\alpha_{23}$</td>
<td>$0.0001$</td>
<td>$0.0001$</td>
<td>$-0.0855$</td>
</tr>
<tr>
<td>$\alpha_{24}$</td>
<td>$0.0002$</td>
<td>$0.0001$</td>
<td>$0.5558$</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>0.2913</td>
<td>0.2443</td>
<td>0.5431</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>0.3445</td>
<td>0.3739</td>
<td>8.4230$^*$</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>0.3641</td>
<td>0.3818</td>
<td>18.6251$^*$</td>
</tr>
</tbody>
</table>

Notes: (i) This table provides pooled estimates for the nonlinear panel regression (4.8) of ln(cost) on ln(independent variables); (ii) All coefficients ($\beta = [\alpha_0, \alpha_i, \alpha_{ij}, \alpha_{ij}, \beta_1, \delta_i]$) are consistent with the notations in (4.8): $\alpha_{i,j} = \{0, 1, 2, 3, 4\}$ are the slope coefficients of the linear terms, $\alpha_{i,j} = \{1, 2, 3, 4\}$ are the slope coefficients of the quadratic terms, $\alpha_{i,j} = \{1, 2\}$ are the slope coefficients of the cross-product terms, $\beta_{i,i} = \{1, 2\}$ are the slope coefficients of the prices, $\delta_{a,i} = \{1, 2\}$ are the slope coefficients of the dummy variables for alliance group, $\delta_{g,i} = \{1, 2\}$ are the slope coefficients of the dummy variables for the region, and $\delta_{d}$ is the slope coefficient of the dropout rate; (iii) RSE is residual standard error; (iv) LLV is log-likelihood value; (v) *, **, and *** denote significance at the 0.05, 0.01 and 0.001 level, respectively.

Given the significant and positive sign of the attrition rate, higher student attrition significantly increases costs as expected. As shown in Table 4.2, the log-likelihood and lower residual standard error indicates that the model including the dropout rate also has better fit, as does a likelihood ratio test ($x_1^2 = 24.63$). Table 4.3 details the annual average incremental costs (AICs) for the three teaching outputs (on-campus, distance, and multimodal completions) and research output (number of publications) at 100% and 200% of existing mean output over the sample period. To compare the effects of dropout rates on
average costs, we calculate all estimates using both the cost functions in Table 4.2. Our findings show that all three average incremental costs for teaching outputs decline with output regardless of student attrition. However, the AICs for external completions decrease faster than for internal completions. External completions are also the least costly, which is consistent with the findings of previous studies (Rumble, 1992; Wagner, 1972, 1977).

Table 4.3: Average incremental cost ($000s) at mean output

<table>
<thead>
<tr>
<th>Output</th>
<th>Mean Without dropouts</th>
<th>Mean With dropouts</th>
<th>% change</th>
<th>Mean Without dropouts</th>
<th>Mean With dropouts</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal completions</td>
<td>35.726</td>
<td>37.5732</td>
<td>5.17%</td>
<td>29.5946</td>
<td>32.8182</td>
<td>10.89%</td>
</tr>
<tr>
<td>External completions</td>
<td>34.0462</td>
<td>24.6609</td>
<td>−27.57%</td>
<td>16.2851</td>
<td>4.0879</td>
<td>−74.90%</td>
</tr>
<tr>
<td>Multimodal completions</td>
<td>39.1089</td>
<td>38.8802</td>
<td>−0.58%</td>
<td>35.0743</td>
<td>38.247</td>
<td>9.05%</td>
</tr>
<tr>
<td>Publications</td>
<td>129.647</td>
<td>146.4628</td>
<td>12.97%</td>
<td>140.812</td>
<td>164.76</td>
<td>17.01%</td>
</tr>
</tbody>
</table>

We further find that multimodal completions are the most costly mode at an average cost of A$38,880, while internal completions are slightly cheaper at around A$37,573. However, including dropouts helps reduce average costs for distance-related teaching outputs. This especially affects the average cost for distance education. At 100% of mean output, we can decrease unit costs by 27.57% once we include the dropout rate. As the number of distance education graduates increases, this effect also increases, such that there is an almost 75% reduction in the average costs of distance education at 200% of mean output. For multimodal education, this effect disappears once the output scale increases to 200% of mean output.

We consider that the results for the models with and without dropouts provide some useful ancillary findings. As shown in Table 4.3, including dropouts in the specification adds marginally to the average cost of internal completions (about A$1,847 per year per completion). This suggests that dropouts actually lower the average cost per internal completion. We suggest this may be because Australian universities typically over-enroll to
ensure maximum government revenue and the loss of potential revenue from under enrollment, and that dropouts enable them to become more inefficient by eliminating the costs associated with these excess students. Possibilities include combining classes, closing courses, streamlining offerings, etc. In contrast, including dropouts significantly increases the average cost of external completions by about A$9,385 per year per completion. This suggests that dropouts are a relatively more significant driver of the average cost of distance learning, especially in that we only analyze costs and ignore the foregone revenue.

The estimates of the scale and scope economies may also vary with output expansion and contraction so we extend the mean output range to 50–200%. Table 4.4 and Table 4.5 summarize these estimates and indicate whether the Australian university sector as a whole is experiencing economies of scale (greater than one) or economies of scope (greater than zero). Surprisingly, even though including student dropouts dramatically affects the estimates of the AICs, the results show strong similarity in the scale economies. As shown in Table 4.4, ray scale economies (SRAY) exist up to 200% of mean output, implying improvements in cost efficiency by expanding all outputs up to at least 200% of current mean output.
Table 4.4: Scale economies at percentage of current mean output

<table>
<thead>
<tr>
<th>Level</th>
<th>Internal completions</th>
<th>External completions</th>
<th>Multimodal completions</th>
<th>Publications</th>
<th>SRAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>1.1190</td>
<td>1.0315</td>
<td>1.0179</td>
<td>1.0616</td>
<td>1.2033</td>
</tr>
<tr>
<td>75%</td>
<td>1.1991</td>
<td>1.0539</td>
<td>1.0278</td>
<td>1.0930</td>
<td>1.2027</td>
</tr>
<tr>
<td>100%</td>
<td>1.3001</td>
<td>1.0835</td>
<td>1.0384</td>
<td>1.1248</td>
<td>1.2286</td>
</tr>
<tr>
<td>125%</td>
<td>1.4317</td>
<td>1.1245</td>
<td>1.0498</td>
<td>1.1571</td>
<td>1.2701</td>
</tr>
<tr>
<td>150%</td>
<td>1.6098</td>
<td>1.1853</td>
<td>1.0621</td>
<td>1.1899</td>
<td>1.3251</td>
</tr>
<tr>
<td>175%</td>
<td>1.8646</td>
<td>1.2844</td>
<td>1.0755</td>
<td>1.2231</td>
<td>1.3945</td>
</tr>
<tr>
<td>200%</td>
<td>2.2592</td>
<td>1.4751</td>
<td>1.0899</td>
<td>1.2568</td>
<td>1.4814</td>
</tr>
</tbody>
</table>

Including dropouts

<table>
<thead>
<tr>
<th>Level</th>
<th>Internal completions</th>
<th>External completions</th>
<th>Multimodal completions</th>
<th>Publications</th>
<th>SRAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>1.1301</td>
<td>1.0229</td>
<td>1.0080</td>
<td>1.0766</td>
<td>1.1609</td>
</tr>
<tr>
<td>75%</td>
<td>1.2165</td>
<td>1.0409</td>
<td>1.0121</td>
<td>1.1152</td>
<td>1.1668</td>
</tr>
<tr>
<td>100%</td>
<td>1.3241</td>
<td>1.0676</td>
<td>1.0163</td>
<td>1.1539</td>
<td>1.1927</td>
</tr>
<tr>
<td>125%</td>
<td>1.4619</td>
<td>1.1112</td>
<td>1.0205</td>
<td>1.1929</td>
<td>1.2306</td>
</tr>
<tr>
<td>150%</td>
<td>1.6446</td>
<td>1.1948</td>
<td>1.0248</td>
<td>1.2320</td>
<td>1.2788</td>
</tr>
<tr>
<td>175%</td>
<td>1.8984</td>
<td>1.4209</td>
<td>1.0292</td>
<td>1.2713</td>
<td>1.3380</td>
</tr>
<tr>
<td>200%</td>
<td>2.2750</td>
<td>4.2451</td>
<td>1.0336</td>
<td>1.3109</td>
<td>1.4100</td>
</tr>
</tbody>
</table>

When not all outputs change proportionally, product-specific economies of scale can reveal whether there are economies of scale when only one type of output varies at a time. The three teaching outputs appear to display product-specific scale economies up to 200% mean output. However, external completions do not have larger potential economies of scale than internal completions until 200% of mean output. This provides some evidence to support Rumble (1987)’s argument that distance education requires a large and sufficient number of students to produce tangible scale economies.

Economies of scope exist if an estimate is greater than zero. Overall, the estimates of the scope economies in Table 4.5 support the joint production of all types of output. Global economies of scope (GSE) exist up to 125% of output mean once we include dropout rates. When not accounting for student attritions, the model produces overestimates: for 100% of
mean output, the estimates indicates that there is a 15.77% reduction in total costs from offering all outputs, which is slightly higher than the 9.33% reduction found in Chinese research universities (Li & Chen, 2012). Once we consider the dropout rate, the cost savings decline to a 7.70% reduction in total costs for the same mean output level.

Table 4.5: Scope economies at percentage of current mean output

<table>
<thead>
<tr>
<th>Level</th>
<th>Internal completions</th>
<th>External completions</th>
<th>Multimodal completions</th>
<th>Publications</th>
<th>GSE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excluding dropouts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td>0.1028</td>
<td>0.1276</td>
<td>0.1166</td>
<td>0.0809</td>
<td>0.3289</td>
</tr>
<tr>
<td>75%</td>
<td>0.0624</td>
<td>0.1021</td>
<td>0.0845</td>
<td>0.0272</td>
<td>0.2202</td>
</tr>
<tr>
<td>100%</td>
<td>0.0371</td>
<td>0.0929</td>
<td>0.0681</td>
<td>-0.0122</td>
<td>0.1577</td>
</tr>
<tr>
<td>125%</td>
<td>0.0180</td>
<td>0.0909</td>
<td>0.0586</td>
<td>-0.0464</td>
<td>0.1147</td>
</tr>
<tr>
<td>150%</td>
<td>0.0019</td>
<td>0.0931</td>
<td>0.0526</td>
<td>-0.0787</td>
<td>0.0814</td>
</tr>
<tr>
<td>175%</td>
<td>-0.0129</td>
<td>0.0979</td>
<td>0.0487</td>
<td>-0.1108</td>
<td>0.0535</td>
</tr>
<tr>
<td>200%</td>
<td>-0.0271</td>
<td>0.1048</td>
<td>0.0463</td>
<td>-0.1436</td>
<td>0.0285</td>
</tr>
<tr>
<td>Including dropouts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td>0.0613</td>
<td>0.1031</td>
<td>0.0873</td>
<td>0.0362</td>
<td>0.2312</td>
</tr>
<tr>
<td>75%</td>
<td>0.0203</td>
<td>0.0867</td>
<td>0.0616</td>
<td>-0.0195</td>
<td>0.1361</td>
</tr>
<tr>
<td>100%</td>
<td>-0.0093</td>
<td>0.0833</td>
<td>0.0482</td>
<td>-0.0647</td>
<td>0.0770</td>
</tr>
<tr>
<td>125%</td>
<td>-0.0346</td>
<td>0.0857</td>
<td>0.0401</td>
<td>-0.1066</td>
<td>0.0324</td>
</tr>
<tr>
<td>150%</td>
<td>-0.0583</td>
<td>0.0914</td>
<td>0.0347</td>
<td>-0.1479</td>
<td>-0.0054</td>
</tr>
<tr>
<td>175%</td>
<td>-0.0817</td>
<td>0.0994</td>
<td>0.0308</td>
<td>-0.1901</td>
<td>-0.0399</td>
</tr>
<tr>
<td>200%</td>
<td>-0.1053</td>
<td>0.1093</td>
<td>0.0280</td>
<td>-0.2338</td>
<td>-0.0730</td>
</tr>
</tbody>
</table>

Estimates of the product-specific scope economies provide clues to the possibilities for separate production. Research is an obvious candidate: scope economies exist up to only 75% of mean output even without considering dropouts. However, this result indicates some progress in scope economies in this recent sample as Worthington and Higgs (2011) identified diseconomies of scope for this same output in Australian universities during an earlier period from 1998 to 2006. That is, Australian universities appear to have become better at coordinating the joint production of their several outputs. Scope economies for distance education are even increasing with distance education graduates, representing at
least a 10% reduction in total costs from joint production at 200% of mean output. These findings suggest that significant cost savings result from the new technology and teaching management approaches associated with the delivery of distance education.

4.5 Conclusion

An increasing number of once traditional face-to-face-only teachings institutions now offer distance education courses and programs as a means of reaching potential students. However, we know little about the economies of scale and scope of distance education as one purported benefit of this strategy. This study investigates these economies of distance education in dual-mode institutions using nonlinear regression and a multiplicatively separable cost function for a sample of 37 Australian public universities over the period 2003–2012. Our main findings are as follows.

First, the unit costs for distance education are significantly lower than for conventional teaching modes. However, the economies of scale for on-campus education are generally larger than for distance and multi-modal education unless we include student dropouts and increase the number of students to 200% of its current mean level. Higher degree student attrition in distance education is a contentious issue in the sector (Roberts, 1984; Danaher, Bowser, & Somasundaram, 2008; Greenland & Moore, 2014; Kember, 1989; Willging & Johnson, 2009). Our results suggest that the costs associated with the less than efficient scale of distance education currently offered by Australian universities in general and the additional costs associated with a high level of student attrition remain the main challenges from a cost perspective.

Second, under the condition that all outputs change proportionally, our findings support joint production of all outputs up to 125% of current mean output. Once we assume the
output change is not proportional, the results of product-specific scope economies for the two distance teaching outputs (distance and multimodal) demonstrated that higher education institutions should not deliver distance education separately to traditional on-campus teaching because of the significant cost benefit. As an ancillary finding, the diseconomies of scope for research indicate the costs of producing research output jointly with the other types of products are more than producing it separately. This indicates that the current teaching and research model adopted for all 37 Australian universities results in significant cost inefficiencies, suggesting that at least some specialized institutions focusing on either teaching or research could be more cost efficient for the institutions themselves, the sector, and the Commonwealth government as the principal funder.

Our findings of ray scale and global scope economies suggest a trade-off between scale and scope economies. With the increase in output scale, only scale economies increase, while the scope economies generally decline. However, it does not necessarily mean that all product-specific scope economies will follow the same pattern. Economies of scope for distance education are actually increasing with mean output. This yields an important implication: when allocating places across different modes of attendance or considering further expansion of student numbers, there should be a priority on distance education as a way to achieve significant cost savings.

Finally, a limitation of this paper should be noted: we did not allow for inefficiency in the Australian higher education sector. This lies in the methodology we used for estimating FFCQ-M function. Future studies are encouraged to implement frontier analysis in FFCQ-M function so inefficiency could be considered when estimating cost economies.
Chapter 5. Cost economies in the provision of higher education for international students: Australian evidence

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5.1 Introduction

The global higher education market has been growing exponentially in volume, scope, and complexity over the past two decades, with students, faculty, programs, and even institutions, moving across national and regional borders (Knight, 2013). Student mobility, the traditional internationalization strategy, continues to provide momentum for this global higher education market expansion, with the number of students worldwide pursuing higher education overseas doubling from 2 million in 2000 to 4.2 million in 2012, a rate of growth expected to continue in the foreseeable future (OECD, 2014). Likewise, in Australia, education services have represented the country’s largest service export since 2013, with A$15.7 billion earned in 2014 alone, accounting for about 27.5% of the total (ABS, 2015a; DFAT, 2015). But apart from generating tremendous economic benefits to individual providers, international education, especially in the higher education sector, is well regarded as “…a key enabler of productivity and growth for virtually every part of an economy” ((Australian Government, 2015a), p. 8), producing positive effects in the social, cultural, and intellectual life of the exporting country.

Nonetheless, the financial incentives associated with international education have often led Australian universities to compete aggressively for international students without
considering the associated costs and risks (Australian Government, 2015a). As a result, international education suffers recurrent quality issues such as accusations of degree mills, poor academic performance, and the misconduct of international students, and occasional surface-level negative interactions between international and domestic students (Four Corners, 2015). This counters the expectations of higher education providers and the government, along with other stakeholders, that the education of international students will generate positive benefits for both international and domestic students. Therefore, there is an urgent need for the close examination of the institutional costs of international education, i.e., providing higher education for international students, to inform policy and practice.

Unfortunately, only one recent study (Li, 2016) in this area empirically considers the cost structure of higher education in the provision for international students. Our study further addresses this gap in the literature by particularly focusing on the following three research questions. First, is the unit cost of international students higher than that of domestic students? Second, is it possible to gain cost economies by increasing (or even decreasing) the number of international students and by how much? Lastly, what is the nature of the cost savings between domestic and international higher education?

The responses to these questions will provide useful advice for the future development of international higher education, in both Australia and elsewhere. The response to the first question will directly provide guidance in price setting for international students. The responses to the second and third questions will help us better understand whether there are economies of scale and scope in the provision of international higher education. Our study will thus identify the potential for efficiency improvements to institutions to reflect the true cost of education and subsequently operate at an efficient scale. Such discussions about cost economies will also help institutions construct a more sustainable environment for their operations (Ilieva, Beck, & Waterstone, 2014).
In fact, estimating the scale and scope economies of higher education has been a primary focus of the literature (e.g. Cohn et al. (1989); Johnes and Johnes (2009); Johnes and Schwarzenberger (2011); Li and Chen (2012); Agasisti and Johnes (2015)). Unfortunately, little of this considers the cost economies in international higher education. In considering the potential cost economies, we explore the scale and scope economies of another possible form of instructional output, namely, international higher education in higher education institutions (HEIs). We provide two split methods among domestic and overseas students: undergraduate/postgraduate and science/non-science split. However, based on the model diagnosis analysis, only the results of science/non-science split are shown.

The next section discusses the debate on the costs and potential cost economies of higher education provision for international students. The section following defines our method, including the dataset and model specification. We then discuss our results. The final section presents the conclusion of this paper.

5.2 Cost economies of higher education provision for international students

In most developed countries, including Australia, higher education is highly subsidized, which means that domestic students usually pay less than the full cost of education (currently about 40 percent of costs across all programs). When international higher education first emerged, international students usually enjoyed the same tuition and other fees as domestic students (Knight & de Wit, 1995). However, as the number of international students grew, concerns emerged about whether these students were paying enough to cover the costs of provision. As a result, after the 1980s, there was considerable interest in how to assess tuition charges for international students.
Two pricing rules have been consistently used (Throsby, 1991), namely, average cost and marginal cost pricing. For example, in 1980, the British government decided to remove subsidized fees for overseas students. Instead, overseas students were to pay full-cost fees, as calculated by the average cost of instructional budgets divided by total student enrollments (Blaug, 1981). In contrast, marginal cost pricing employs an econometric model to estimate the marginal costs of incremental enrollments. This type of cost is important because it provides information about whether universities should enroll more overseas students, or instead direct funds toward other investments (Hoenack, Weiler, Goodman, & Pierro, 1986).

However, estimating the cost of international education is difficult because of the entanglement of this type of service with other services provided by HEIs. For example, apart from providing academic courses/programs to international students, the Australian Government (Australian Government, n.d.-a) requires Australian HEIs to offer specialist services to help international students adjust to life and study in Australia. These support services to international students include language and academic support, designated international student advisers, on-arrival reception and orientation programs, childcare, health and counselling, student accommodation, employment services, prayer and worships rooms, banking, shopping and food outlets, and clubs, societies, sport and fitness facilities. Nonetheless, it is obvious that domestic students in Australia will also enjoy some or most of these listed support services offered by the HEIs. That is to say, few of the support services (save designated international advisors) provided by Australian HEIs are reserved exclusively for international students.

One of the biggest debates on the costs of international education relates to the common assumption that international students need substantive language and academic support, which would result in additional costs compared with domestic students who are believed to
be more prepared linguistically and academically, and thus do not require such services. Such an assumption may certainly hold during the early stages of international education development when HEIs need to invest generously to initially establish facilities, organizational structures, operational mechanisms, and human resources to provide their first groups of international students with appropriate linguistic and academic support. However, as the international education system matures in individual HEIs, these will become routine, incurring smaller additional operational costs from the perspective of the HEI.

Another possible factor to affect the costs of teaching international students is completion time. For instance, Hoenack and Davidson (1987) found that the completion time of US international students is significantly lower than that of domestic students. In addition, given the recently increasing numbers of transnational or offshore programs on offer in Australia, as shown in Table 5.1, a considerable number of Australian international (undergraduate) students may study only offshore or attend Australian HEIs for only one or two years, rather than four years as nearly all domestic students do. This means the costs of providing education for these international students can be much less than that for domestic students because the former actually spend less time studying in Australia.

### Table 5.1: Higher education delivery to international students in Australia

<table>
<thead>
<tr>
<th></th>
<th>Student number</th>
<th>% Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2011</td>
<td>2012</td>
</tr>
<tr>
<td>International students in Australia</td>
<td>224,914</td>
<td>215,592</td>
</tr>
<tr>
<td>Students at offshore campuses</td>
<td>80,458</td>
<td>82,468</td>
</tr>
<tr>
<td>Distance education students offshore a</td>
<td>27,205</td>
<td>25,552</td>
</tr>
<tr>
<td>Total</td>
<td>332,577</td>
<td>323,612</td>
</tr>
</tbody>
</table>

Note: *Includes online learning and correspondence students studying award courses.
Source: Australian Government (2014)
All the scenarios discussed make it very difficult (if not impossible) to distinguish the costs of providing higher education for international students from those for domestic students. For example, all enrolled students, regardless of their residency or citizenship, use services provided by a university library. Most previous cost studies estimated the average and marginal costs of all students, and assumed the costs of international education were the same as previous estimates (Chishti, 1984; Heaton & Throsby, 1998; Winkler, 1984a, 1984b). However, this assumption is only appropriate if domestic and overseas students are equally distributed across the same fields and at the same level, which is unreasonable given more than half of overseas student enrollments at Australian HEIs during the last five years have enrolled in science, technology, engineering and mathematics (STEM) courses (Australian Government, 2015b). Table 5.2 provides further details.

### Table 5.2: International student enrollments in Australian higher education: STEM fields by level of study, 2014

<table>
<thead>
<tr>
<th>Broad field of education</th>
<th>Undergraduate</th>
<th>Postgraduate (Research)</th>
<th>Postgraduate (Other)</th>
<th>Total</th>
<th>International student proportion of total students in post-graduate research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering &amp; related technologies</td>
<td>15,050</td>
<td>4,320</td>
<td>7,038</td>
<td>26,408</td>
<td>54.2%</td>
</tr>
<tr>
<td>Information technology</td>
<td>9,045</td>
<td>780</td>
<td>11,387</td>
<td>21,212</td>
<td>51.6%</td>
</tr>
<tr>
<td>Agriculture, environmental &amp; related studies</td>
<td>1,332</td>
<td>617</td>
<td>792</td>
<td>2,741</td>
<td>45.6%</td>
</tr>
<tr>
<td>Natural &amp; physical sciences</td>
<td>7,464</td>
<td>3,926</td>
<td>1,889</td>
<td>13,279</td>
<td>38.1%</td>
</tr>
<tr>
<td>Mathematics related</td>
<td>202</td>
<td>201</td>
<td>205</td>
<td>608</td>
<td>36.2%</td>
</tr>
<tr>
<td>All other broad fields of education</td>
<td>105,954</td>
<td>8,607</td>
<td>70,413</td>
<td>184,974</td>
<td>21.6%</td>
</tr>
<tr>
<td>Total</td>
<td>139,047</td>
<td>18,451</td>
<td>91,724</td>
<td>249,222</td>
<td>31.5%</td>
</tr>
</tbody>
</table>

Source: Australian Government (2015b)
Fortunately, Baumol et al. (1982) developed an econometric technique to overcome these difficulties, by specifying a multi-output cost function. In a multi-output scenario, such as higher education, we cannot directly calculate the average costs for particular outputs. However, we can indirectly estimate them by calculating the average incremental cost. One advantage of this approach is that once we obtain the average and marginal costs, we can calculate the economies of scale of international education by dividing the average cost by the marginal cost. If the estimate is larger than one, this implies the existence of economies of scale for international education. In this case, enrolling more overseas students would benefit the exporting (host) institutions (and by association, the funding country) by creating lower average costs.

International higher education could also generate cost savings from the joint production of international education and other domestic education outputs. Thus, another measure used to determine the cost benefits of international higher education is to estimate its economies of scope. For example, there are potential scope economies between international and domestic education because the same academic staff can teach the same courses to both types of students. In addition, while providing international higher education requires more diversified teaching and administrative staff, and more qualified faculties to support teaching and research activities (Park, 2004), these could subsequently reduce the costs of producing international teaching and research.

5.3 Specification and Methodology

To estimate economies of scale and scope, we need to first specify a cost functional form. In the past thirty years, flexible fixed cost quadratic (FFCQ) function proposed by Mayo (1984) dominates the estimation of scale and scope economies in higher education. This cost
function permits an output to have zero value without further transformation. Mayo (1984, pp 216-217) further divides FFCQ into two kinds of functional form based on input prices entering either additively (FFCQ-A) or multiplicatively (FFCQ-M). The FFCQ-A function is as follows:

\[ C^{FFCQ-A}(y, w; \beta) = F(y; \beta) + A(w; \beta) \]

\[ = \left( \beta_0 + \sum_{i=1}^{n} \beta_{0i} F_i + \sum_{i=1}^{n} \beta_i y_i + 0.5 \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} y_i y_j \right) + \beta_{wl} w_l \]  

(5.1)

where \( F(\cdot) \) is a quadratic form in output vector \( y \) and \( A(\cdot) \) is an linear form in input price vector \( w \), subscripts \( i \) denotes the output, \( y_i \) is the \( i \)-th type of output (out of \( n \) types of output), \( w_l \) is the \( l \)-th input price, \( \beta_0 \) is the fixed cost, \( \beta_{0i} \) is for adjusting fixed cost if some output \( y \) is zero and \( \beta_{wl} \)'s, \( \beta_i \)'s, \( \beta_{ij} \)'s are scalars of unknown parameters.

The FFCQ-M function is \( F(\cdot) \) multiplied by \( M(\cdot) \) then

\[ C^{FFCQ-M}(y, w; \beta) = F(y; \beta) \cdot M(w; \beta) \]

\[ = \left( \beta_0 + \sum_{i=1}^{n} \beta_{0i} F_i + \sum_{i=1}^{n} \beta_i y_i + 0.5 \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} y_i y_j \right) \cdot \prod_{l=1}^{n} w_l^{\beta_{wl}} \]  

(5.2)

where \( M(\cdot) \) is a linearly homogeneous function of input price vector \( w \) and other notations are consistent with equation (5.1).

In the estimation of scale and scope economies in higher education, the FFCQ-A function has been the most popular form since first adopted by Cohn et al. (1989). Of most appeal is its linear nature, which makes it easier to account for the heterogeneity unobserved at the institution level when panel data is available. However, the FFCQ-A function also brings with it several unsolved issues. First, because of a limitation of the linear functional form, it is almost impossible to match all cost function regularity conditions, which could lead to
model misspecification. For example, to impose linear homogeneity, we could omit the
numeraire price by dividing total cost and the other factor prices by this price
(Martínez-Budría, Jara-Díaz, & Ramos-Real, 2003). However, there is no guidance
available to select the numeraire price. Troublingly, the results are not invariant to this
choice (Triebs, Saal, Arocena, & Kumbhakar, 2016). Most studies (Agasisti & Johnes, 2015;
regularity condition by assuming input prices are constant across institutions given their
highly regulated contexts. However, we note that most of these studies have used sample
data before 2003. As the competition among universities is now much more intense, and
most (including in Australia) now operate in more deregulated contexts, this assumption
should now be weaker.

In contrast, the FFCQ-M function is theoretically more appealing than the FFCQ-A because
it easily conforms to all of the cost function regularity conditions, as proven by Greer (2003,
2008, 2010). For example, we impose the symmetry condition with \( \beta_{ij} = \beta_{ji} \), and ensure
linear homogeneity by letting all input-price coefficients sum to one \( \sum_{i=1}^{n} \beta_{wi} = 1 \). Zhang
and Worthington (2016) have also already tested this with Australian higher education data.
For the above reasons, we believe it is necessary to employ the FFCQ-M function to avoid
model misspecification. As this functional form is still novel, we specify the same cost and
control variables as Zhang and Worthington (2016) but provide additional tools for testing
the function. Note that in all other respects, not least purpose and research questions, the
present analysis is very different.

This study employs a balanced panel dataset comprising 37 Australian public universities
from the Department of Industry, Innovation, Science, Research, and Tertiary Education
over the period from 2003 to 2012. The dependent variable is total operating expenditure. In
order to estimate the cost economies of international higher education, we specify the
teaching outputs (students) according to graduate residency status. We refer to these students as international (or overseas) students, in contrast to domestic students, which may include, for example, students who are Australian citizens, New Zealand citizens, or the holders of a permanent residence visa.

However, one problem is how we further disaggregate these students. Two common ways are to classify them based on the field of education (science and non-science) and the level of education (undergraduate and postgraduate). Although it is attractive to use both in our study, there would be too many outputs as we already disaggregate students based on graduate residency status. Therefore, we disaggregate the teaching outputs in both ways and allow the data itself to decide which better fits and matches all model assumptions. This results in five outputs and three input prices in the cost function. We convert all monetary variables (costs and input prices) to their real values (2003 = 100) using the consumer price index from the Australian Bureau of Statistics (ABS, 2015b).

Following previous studies, several control variables (z) are also included. To start, we include the attrition rate (z_q) as a teaching quality-adjusted indicator (Aina, 2013; Zhang & Worthington, 2016). We also include time-invariant dummy variables for each of the eight regions (states and territories) and four alliance groups, which is a common practice used to account for any heterogeneity when using a nonlinear functional form (e.g. (Delgado, Parmeter, Hartarska, & Mersland, 2015; & Worthington, 2016)). The four alliance groups comprise the Australian Technology Network (ATN, z_a1), the Group of Eight (Go8, z_a2), the Innovative Research Universities (IRU, z_a3), and the Regional Universities Network (RUN, z_a4). We specify institutions not belonging to any of these groups (z_a5) as the reference group. The eight Australian regions are New South Wales (NSW, z_r1), Victoria (VIC, z_r2), Queensland (QLD, z_r3), Western Australia (WA, z_r4), South Australia (SA, z_r5), the Australian Capital Territory (ACT, z_r6), Tasmania (TAS, z_r7), and the Northern Territory (NT,
Institutions without a main campus and located in more than one state ($z_{g8}$) are the reference group. Table 5.3 provides the means, standard deviations, minimums, and maximums for each of the variables from 2003 to 2012.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Mean</th>
<th>Std dev.</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific to the model with broad field of education</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( y_1 )</td>
<td>Domestic science completions</td>
<td>1660.81</td>
<td>1099.60</td>
<td>179.00</td>
<td>4954.00</td>
</tr>
<tr>
<td>( y_2 )</td>
<td>Domestic non-science completions</td>
<td>2985.09</td>
<td>1608.41</td>
<td>348.00</td>
<td>7795.00</td>
</tr>
<tr>
<td>( y_3 )</td>
<td>Overseas science completions</td>
<td>668.35</td>
<td>485.54</td>
<td>3.00</td>
<td>2264.00</td>
</tr>
<tr>
<td>( y_4 )</td>
<td>Overseas non-science completions</td>
<td>1499.12</td>
<td>1089.37</td>
<td>23.00</td>
<td>7044.00</td>
</tr>
<tr>
<td>Specific to the model with educational levels</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( y_1 )</td>
<td>Domestic undergraduate completions</td>
<td>2,964.99</td>
<td>1,604.64</td>
<td>414.00</td>
<td>7,709.00</td>
</tr>
<tr>
<td>( y_2 )</td>
<td>Domestic postgraduate completions</td>
<td>1,481.98</td>
<td>932.00</td>
<td>42.00</td>
<td>5,907.00</td>
</tr>
<tr>
<td>( y_3 )</td>
<td>Overseas undergraduate completions</td>
<td>1,105.26</td>
<td>984.52</td>
<td>11.00</td>
<td>7,143.00</td>
</tr>
<tr>
<td>( y_4 )</td>
<td>Overseas postgraduate completions</td>
<td>1,049.37</td>
<td>673.81</td>
<td>10.00</td>
<td>3,276.00</td>
</tr>
<tr>
<td>Shared variables in both models</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( c )</td>
<td>Total operating expenditure (^{a})</td>
<td>400,671.26</td>
<td>280,775.63</td>
<td>34,355.00</td>
<td>1,327,777.62</td>
</tr>
<tr>
<td>( y_5 )</td>
<td>Number of publications</td>
<td>1,222.31</td>
<td>1,086.73</td>
<td>60.76</td>
<td>5,118.15</td>
</tr>
<tr>
<td>( w_1 )</td>
<td>Price of academic labor (^{a})</td>
<td>76.82</td>
<td>15.67</td>
<td>52.22</td>
<td>131.99</td>
</tr>
<tr>
<td>( w_2 )</td>
<td>Price of non-academic labor (^{a})</td>
<td>56.77</td>
<td>13.07</td>
<td>38.83</td>
<td>121.97</td>
</tr>
<tr>
<td>( w_3 )</td>
<td>Price of non-labor (^{b})</td>
<td>8.58</td>
<td>4.18</td>
<td>3.30</td>
<td>28.98</td>
</tr>
<tr>
<td>( z_4 )</td>
<td>Attrition rate (%)</td>
<td>18.07</td>
<td>6.10</td>
<td>6.21</td>
<td>38.83</td>
</tr>
<tr>
<td>( z_{a1} )</td>
<td>ATN institutions</td>
<td>0.14</td>
<td>-</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>( z_{a2} )</td>
<td>Go8 institutions</td>
<td>0.22</td>
<td>-</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>( z_{a3} )</td>
<td>IRU institutions</td>
<td>0.16</td>
<td>-</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>( z_{a4} )</td>
<td>RUN institutions</td>
<td>0.16</td>
<td>-</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>( z_{a5} )</td>
<td>Non-alliance group institutions</td>
<td>0.32</td>
<td>-</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>( z_{a6} )</td>
<td>Institutions located in NSW</td>
<td>0.27</td>
<td>-</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>( z_{a7} )</td>
<td>Institutions located in VIC</td>
<td>0.22</td>
<td>-</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>( z_{a8} )</td>
<td>Institutions located in QLD</td>
<td>0.19</td>
<td>-</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>( z_{a9} )</td>
<td>Institutions located in WA</td>
<td>0.11</td>
<td>-</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>( z_{a10} )</td>
<td>Institutions located in SA</td>
<td>0.08</td>
<td>-</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>( z_{a11} )</td>
<td>Institutions located in ACT</td>
<td>0.05</td>
<td>-</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>( z_{a12} )</td>
<td>Institutions located in TAS</td>
<td>0.03</td>
<td>-</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>( z_{a13} )</td>
<td>Institutions located in NT</td>
<td>0.03</td>
<td>-</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>( z_{a14} )</td>
<td>Institutions located over one state</td>
<td>0.03</td>
<td>-</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Notes: (i) \(^{a}\) In thousands of AUD (2003 = 100); (ii) science includes the following fields of education: natural and physical sciences information technology, engineering and related technologies, architecture and building agriculture environmental and related studies and health; (iii) non-science includes education, management and commerce, society and culture, creative arts, food hospitality and personal services (see ABS (2001) for details)
We use a regression model to link actual total costs, $c$, with our assumed cost function (5.2) by incorporating a multiplicative normal error, $\varepsilon \sim N(0, \sigma^2)$:

$$c = C^{FFCQ-M}(\mathbf{y}, \mathbf{w}; \mathbf{\beta}) \cdot \exp \left( \sum_{m=1}^{13} \beta_{zm}z_m \right) \cdot \exp(\varepsilon)$$

(5.3)

$$= C^{FFCQ-M}(\mathbf{y}, \mathbf{w}, \mathbf{z}; \mathbf{\beta}) \cdot \exp(\varepsilon)$$

Here, $\exp$ denotes the base of the natural logarithm. Note that $\mathbf{z}$ is a vector of institutional characteristics, including attrition rates, and two categorical indicators for the region and alliance group. Those categorical indicators are dummy variables with a value of one for positive amounts of the output $\mathbf{y}$ but zero otherwise. With some transformations by taking logarithms of both sides, we create linearity (5.3) in the parameters of the input prices and control variables:

$$\ln(c) = \ln(C^{FFCQ-M}(\mathbf{y}, \mathbf{w}, \mathbf{z}; \mathbf{\beta})) + \varepsilon$$

(5.4)

$$= \ln \left( \beta_0 + \sum_{i=1}^{5} \beta_i y_i + 0.5 \sum_{i=1}^{5} \beta_{ii} (y_i)^2 + \sum_{i,j=1, i \neq j}^{10} \beta_{ij} y_i y_j \right) + \sum_{i=1}^{3} \beta_{wi} \ln(w_i) + \sum_{m=1}^{13} \beta_{zm}z_m + \varepsilon$$

We use least squares to derive the coefficient estimators by minimizing the sum of squares

$$\Sigma(\ln(c) - \ln(C^{FFCQ-M}(\mathbf{y}, \mathbf{w}, \mathbf{z}; \mathbf{\beta})))^2$$

subject to a linear homogeneity constraint ($\Sigma_{i=1}^{3} \beta_{wi} = 1$). As $\ln(C^{FFCQ-M}(\mathbf{y}, \mathbf{w}, \mathbf{z}; \mathbf{\beta}))$ is nonlinear in the coefficients, we employ an iterative procedure with initial values to estimate the coefficients following Izadi et al. (2002) and Zhang and Worthington (2016).

Note that as we employ a panel dataset, biased findings could result from not clustering.
That is, the institutions are observed repeatedly over time (2003 to 2012 in our analysis) and therefore there is potential dependence in the model residuals. The assumption of independent and identically distributed residuals may then not hold, leading to biased standard errors, for which we correct using a clustering-robust method (Petersen 2009) at the institution level. This corrected covariance-matrix (usually known as the cluster-robust variance matrix) is used for calculating the cluster-robust coefficient standard errors.

To infer the existence of scale and scope economies and the cost differences between domestic and overseas completion, we employ the delta method (Zhang and Worthington 2015) to estimate the standard error of the estimates with the cluster-robust variance matrix. Finally, we construct 95% confidence intervals to conduct significance tests the existence of scale and scope economies. If their intervals do not include one for scale economies or zero for the scope economies, it suggests that these estimates are significantly different from the thresholds (one and zero, respectively) at the 5% significance level. Thus, there is evidence for the existence of scale and scope economies (if their intervals are higher than the threshold) or diseconomies (if their intervals are lower than the threshold). For results with their intervals, including the thresholds, the tests suggest neither cost economies nor diseconomies but indicate that institutions have been cost efficient and that they could not increase efficiency by further changing the quantities of outputs.

5.4 Empirical Results

Table 5.4 details the estimates of the two five-output multiplicatively separable cost functions. Each cost function uses different outputs, as shown in Table 5.3. The appearance of cost complementarity indicates the potential cost savings when producing both types of outputs together. In practice, given all students with either form of residency share much the same resources, we expect cost complementarity between domestic and overseas teaching, at least at the same field of study or level of education ($\beta_{13}$ and $\beta_{24}$). Unfortunately, we
cannot find evidence of cost complementarity in the field of education nor at the level of education. Estimates of $\beta_{13}$ and $\beta_{24}$ in the level of education are negative, but they are not significantly different from zero at the 5% significance level. However, the above finding is not surprising as the multicollinearity resulting from the inclusion of interaction terms could interfere with the significance of cost complementarity (Worthington & Higgs, 2011). Whether there are economies of scope requires further investigation.

For model diagnostics, we provide four indicators, namely, the residual standard error (RSE), the Akaike information criterion (AIC), the Shapiro-Wilk (SW) normality test, and the Runs test (Baty et al., 2015). We use the first two for the model comparisons: the lower the value, the better the model. We use the second two to test the assumption of a nonlinear regression. The SW normality test will test whether the residuals have a normal distribution. The final test statistics show whether the residuals in our models follow the randomness condition. We can see that the model using the level of education data has a better fit than the model using the field of education. Both models do not violate the assumption of residual randomness, as their runs test statistics are not significant. However, the model using the level of education fails to follow the normality of residuals given its significance at the 0.05 level. This indicates that this model could produce biased estimates for the coefficients. On the contrary, albeit with slightly less model fit, the model including field of education easily passes all of the tests. We therefore use this model to calculate the following cost estimates.
By considering the descriptive statistics in Table 5.3 and the cost function estimates in Table 5.4, we calculate the costs, scale and scope economies of higher education provision for international students using the formula in Baumol et al. (1982). The analysis follows common empirical practice—that is, instead of presenting the estimates of costs and economies with specific output values, we standardized the results with different...
percentages of existing mean output (from 25% to 200%), representing the costs for institutions with different sizes (i.e. from one-quarter to double the average size). Therefore, all cost economies estimates are functions of mean output, representing the costs for institutions with different sizes. That is, in the following equations for calculating the cost economies estimates, output $y$ will be replaced with its respective $p \%$ of mean output ($y_{ip}$).

That said, all control variables are set to their respective means.

Table 5.5 presents comparisons of the annual average incremental costs of $i$-th output evaluated at $p \%$ of mean output ($AIC(y_{ip})$). Notice that this is calculated with the difference between total cost and the cost of $i$-th type of output ($IC(y_{ip})$) and then be divided by $i$-th output. With our functional form in equation (5.3), we write the annual average incremental cost as

$$AIC(y_{ip}) = \frac{IC(y_{ip})}{y_{ip}}$$

$$= \left( \beta_1 y_{ip} + 0.5 \beta_2 y_{ip}^2 + \sum_{j=1; j \neq i}^{5} y_{ij} y_{ip} \right) \cdot \prod_{l=1}^{3} w_l^{\beta_wl} \cdot \exp \left( \sum_{m=1}^{13} \beta_{zm} z_m \right) / y_{ip} \quad (5.5)$$

Note that we use $AIC(y_{ip})$ as a proxy for the average costs of international and domestic students. We observe that $AIC(y_{ip})$ for domestic science completions are significantly higher than the costs of their overseas counterparts, at least up to 75% of mean output. However, nothing suggests that there is significant cost difference between domestic and overseas non-science completions. Our findings therefore disagree with those in earlier studies (Blaug, 1981), which asserted that international students could be responsible for institutions incurring higher costs than with their domestic counterparts because some require remedial teaching in English speaking and writing and additional assistance with course and laboratory work. This implies diversity in the costs of providing international higher education, rather than simply higher costs for international students.
### Table 5.5: Point Estimates of average incremental costs of teaching outputs by broad field of education

<table>
<thead>
<tr>
<th>p</th>
<th>AIC(y1p)</th>
<th>AIC(y2p)</th>
<th>AIC(y3p)</th>
<th>AIC(y4p)</th>
<th>AIC(y5p)</th>
<th>AIC(y1p) − AIC(y3p)</th>
<th>AIC(y2p) − AIC(y4p)</th>
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<td>25</td>
<td>88.77</td>
<td>37.20</td>
<td>13.70</td>
<td>36.83</td>
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<td>[8.62 141.52]</td>
<td>[-24.5 25.23]</td>
</tr>
<tr>
<td>50</td>
<td>92.53</td>
<td>36.06</td>
<td>16.85</td>
<td>39.68</td>
<td>116.23</td>
<td>[7.13 144.23]</td>
<td>[-25.8 18.55]</td>
</tr>
<tr>
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<td>20.00</td>
<td>42.54</td>
<td>119.92</td>
<td>[2.87 149.73]</td>
<td>[-29.29 14.05]</td>
</tr>
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<td>100.07</td>
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<td>23.15</td>
<td>45.39</td>
<td>123.61</td>
<td>[7.69 157.50]</td>
<td>[-35.09 11.86]</td>
</tr>
<tr>
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<td>103.83</td>
<td>32.63</td>
<td>26.30</td>
<td>48.24</td>
<td>127.30</td>
<td>[11.95 167.01]</td>
<td>[-42.76 11.54]</td>
</tr>
<tr>
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<td>107.60</td>
<td>31.49</td>
<td>29.46</td>
<td>51.09</td>
<td>130.99</td>
<td>[21.5 177.78]</td>
<td>[-51.65 12.44]</td>
</tr>
<tr>
<td>175</td>
<td>111.36</td>
<td>30.35</td>
<td>32.61</td>
<td>53.95</td>
<td>134.68</td>
<td>[31.97 189.48]</td>
<td>[-61.3 14.1]</td>
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<tr>
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<td>115.13</td>
<td>29.21</td>
<td>35.76</td>
<td>56.80</td>
<td>138.37</td>
<td>[43.1 201.85]</td>
<td>[-71.4 16.22]</td>
</tr>
</tbody>
</table>

Notes: (i) All estimates in A$ thousands (2003 = 100); (ii) output mean is the arithmetic mean over the 10 years (i.e. 370 observations) while input prices are set to their respective means in all of the calculations; (iii) 95% confidence intervals for each difference estimate are given below in square brackets [ ]; and (iv) * denote estimates statistically significant difference from zero at the 0.05 level for a two–tailed t-test.

Marginal cost represents the additional costs of producing one additional output unit. The calculation of the cost is from taking the first derivative of the cost function (equation (5.3)) with respect to output $i$:

$$MC(y_{ip}) = \frac{\partial C^{FFCQ-M}(y_p, w, z; \beta)}{\partial y_{ip}}$$

$$= \left( \beta_i y_{ip} + \beta_{ii} y_{ip}^2 + \sum_{j=1, j \neq i}^{5} \beta_{ij} y_{jp} \right) \cdot \prod_{l=1}^{3} w_i^{\beta_{wl}} \cdot \exp \left( \sum_{m=1}^{13} \beta_{zm} z_m \right)$$

(5.6)

where $y_p$ is a output vector at p % of mean output; that is, $y_p=[y_{1p}, \ldots, y_{5p}]$.

As shown in Table 5.6, the findings suggest that these depend on both the field of education and the percentage of mean output. For example, at 100% of mean output, we can see that...
producing one additional overseas science completion is much cheaper than producing one additional domestic science completion (A$20,090 vs. A$68,950). Interestingly, this difference is decreasing with the increase in mean output. However, we do not obtain similar results for non-science completions, as there is no significant difference between domestic and international students at any indexed percentage of mean output. The marginal cost differences between domestic and overseas science completions are also in line with the average incremental cost results, but the significance remains up to 150% of mean output.

It may be of some surprise that the AIC and MC for overseas science completions are much lower. To obtain some insight, we return to Table 5.3. Note that overseas science completions only occupy a relatively small portion of full completions with 688 annual graduates as against 1,661 annual domestic graduates. One institution even has only three graduates each year. Another possible reason is the short completion time we discussed earlier. This effect ought to have more influence on more expensive courses like the science field subjects in our study. Our model may reflect these difference in the lower AIC and MC for overseas science completions. However, from our results, these cost advantages only apply to smallish institutions (those less than 75% of mean output for AIC and 125% of mean output for MC).
To observe the effect of size expansion and contraction on the estimates of scale and scope economies, Table 5.7 and Table 5.8 summarize these estimates and indicate whether the Australian university sector as a whole is experiencing economies of scale (significantly greater than one) or economies of scope (significantly greater than zero).

Economies of scale indicate the situation in which average costs per student (as measured by completions) fall as fixed costs spread over increasing numbers of students, calculated by dividing the AIC by the MC. When all outputs change proportionally, we can estimate ray economies of scale (SRAY) as the proxy scale for the economies:

\[
SRAY(y_p) = \frac{\sum_{i=1}^{5} y_{ip} \cdot MC(y_{ip})}{MC(y_{ip})} - MC(y_{ip})
\]
As shown in Table 5.7, SRAY exist up to 200% of mean output. This implies that we could achieve improvements in cost efficiency by expanding all outputs up to at least 200% of the current mean output. This finding is consistent with Zhang and Worthington (2016) using the same period of data, but slightly different from Worthington and Higgs (2011) using older data from 1998 to 2006, which indicated scale economies up to only 100% of mean output. This again confirms that the Australian university sector is currently experiencing economies of scale.

When not all outputs change proportionally, product-specific scale economies can reveal whether there are scale economies in which only one type of output varies at a time. These estimates (PSCE($y_{ip}$)) are calculated by divided AIC($y_{ip}$) in Table 5.5 by MC($y_{ip}$) in Table 5.6 at their corresponding $p$% of mean output. For example, the estimate of product-specific scale economies at 25% of mean output for domestic science completions is 1.10 (i.e. 88.77 is divided by 80.99). We observe consistent results regarding economies of scale. When considering completions as teaching outputs, there are economies of scale for overseas non-science completions up to 200% of output mean level. Another interesting finding is that the estimates of scale economies for the other three teaching outputs are not significant. This suggests that the current number of completions for these three outputs have achieved their cost efficient level and that universities could not increase efficiency further by increasing completions across these outputs.
Table 5.7: Point estimates of scale economies at percentages of current mean output

<table>
<thead>
<tr>
<th>p</th>
<th>$PSCE(y_{1p})$</th>
<th>$PSCE(y_{2p})$</th>
<th>$PSCE(y_{3p})$</th>
<th>$PSCE(y_{4p})$</th>
<th>$PSCE(y_{5p})$</th>
<th>$SRAY(y_p)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>1.10</td>
<td>1.09</td>
<td>1.06</td>
<td>1.10*</td>
<td>1.02</td>
<td>1.13*</td>
</tr>
<tr>
<td></td>
<td>[0.97  1.22]</td>
<td>[0.97  1.22]</td>
<td>[0.78  1.34]</td>
<td>[1.02  1.18]</td>
<td>[0.99  1.05]</td>
<td>[1.05  1.20]</td>
</tr>
<tr>
<td>50</td>
<td>1.20</td>
<td>1.22</td>
<td>1.10</td>
<td>1.21*</td>
<td>1.04</td>
<td>1.10*</td>
</tr>
<tr>
<td></td>
<td>[0.94  1.47]</td>
<td>[0.90  1.51]</td>
<td>[0.58  1.62]</td>
<td>[1.06  1.35]</td>
<td>[0.99  1.09]</td>
<td>[1.06  1.14]</td>
</tr>
<tr>
<td>75</td>
<td>1.32</td>
<td>1.38</td>
<td>1.13</td>
<td>1.31*</td>
<td>1.06</td>
<td>1.10*</td>
</tr>
<tr>
<td></td>
<td>[0.91  1.73]</td>
<td>[0.76  1.88]</td>
<td>[0.42  1.84]</td>
<td>[1.13  1.50]</td>
<td>[0.98  1.14]</td>
<td>[1.07  1.14]</td>
</tr>
<tr>
<td>100</td>
<td>1.45</td>
<td>1.62</td>
<td>1.15</td>
<td>1.43*</td>
<td>1.08</td>
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</tr>
<tr>
<td></td>
<td>[0.88  2.03]</td>
<td>[0.49  2.42]</td>
<td>[0.27  2.03]</td>
<td>[1.20  1.65]</td>
<td>[0.98  1.18]</td>
<td>[1.07  1.17]</td>
</tr>
<tr>
<td>125</td>
<td>1.60</td>
<td>1.98</td>
<td>1.17</td>
<td>1.54*</td>
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</tr>
<tr>
<td></td>
<td>[0.83  2.37]</td>
<td>[-0.12  3.32]</td>
<td>[0.15  2.19]</td>
<td>[1.29  1.79]</td>
<td>[0.97  1.22]</td>
<td>[1.07  1.22]</td>
</tr>
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<td>150</td>
<td>1.77</td>
<td>2.59</td>
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<td>1.66*</td>
<td>1.12</td>
<td>1.17*</td>
</tr>
<tr>
<td></td>
<td>[0.77  2.76]</td>
<td>[-1.68  5.21]</td>
<td>[0.05  2.32]</td>
<td>[1.37  1.95]</td>
<td>[0.97  1.26]</td>
<td>[1.08  1.27]</td>
</tr>
<tr>
<td>175</td>
<td>1.96</td>
<td>3.90</td>
<td>1.20</td>
<td>1.78*</td>
<td>1.13</td>
<td>1.20*</td>
</tr>
<tr>
<td></td>
<td>[0.66  3.25]</td>
<td>[-7.17  11.09]</td>
<td>[-0.05  2.44]</td>
<td>[1.43  2.13]</td>
<td>[0.96  1.30]</td>
<td>[1.08  1.33]</td>
</tr>
<tr>
<td>200</td>
<td>2.18</td>
<td>8.53</td>
<td>1.21</td>
<td>1.91*</td>
<td>1.15</td>
<td>1.24*</td>
</tr>
<tr>
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<td>[-50.74  55.09]</td>
<td>[-0.13  2.54]</td>
<td>[1.45  2.37]</td>
<td>[0.96  1.34]</td>
<td>[1.08  1.40]</td>
</tr>
</tbody>
</table>

Notes: (i) Output mean is the arithmetic mean over the 10 years (i.e. 370 observations) while other shared variables are set to their respective means in all of the calculations; (ii) 95% confidence intervals for each difference estimate are given below in square brackets [ ]; and (iii) * denotes estimates statistically significant difference from one at the 0.05 level for a two–tailed $t$-test.

Investigating economies of scope provides further insights into possible strategy for future structural change. We calculate the estimate of global scope economies (GSE) as the percentage of cost savings from joint production relative to fully integrated costs or as the percentage increase in costs from specialized production:

$$GSE(y_p) = \frac{\sum_{i=1}^{5} \left( C^{FFCQ-M}(y_{ip}, y_{jp} = 0, w, z; \beta) - C^{FFCQ-M}(y_{ip}, w, z; \beta) \right)}{C^{FFCQ-M}(y_{ip}, w, z; \beta)} \text{ for } j = 1 \ldots 5 \text{ but } j \neq i. \quad (5.8)$$

Overall, estimates of GSE in Table 5.8 support the joint production of all types of output, but at only 25% of mean output. The value of 0.34 indicated at least a 34% reduction in total costs from joint production at 25% of mean output. The negative estimates appear once the mean output exceeds 50%. This finding is slightly different from Zhang and
Worthington (2016) and Worthington and Higgs (2011) as GSE is evident at least up to 125%. However, as both these analyses did not provide any significance test, we favor the more conservative level suggested here.

Similar to scale economies, the concept of scope economies can also apply to product-specific measures. The degree of product-specific scope economies (PSOE) for $i$-th type of product at $p\%$ of output mean could be denoted as:

$$\text{PSOE}(y_{ip}) = \frac{C^{FFPQ-M}(y_{ip}, y_{jp} = 0, w, z; \beta) + C^{FFPQ-M}(y_{ip} = 0, y_{jp}, w, z; \beta) - C^{FFPQ-M}(y_{p} w, z; \beta)}{C^{FFPQ-M}(y_{p}, w, z; \beta)}$$

(5.9)

for $j = 1 \ldots 5$ but $j \neq i$

Product-specific economies (diseconomies) of scope exist when $\text{PSOE}(y_{ip})$ is significantly larger (less) than zero. The presence of product-specific scope economies implies that the cost of producing a specific type of product jointly with the other types of products is less than that to produce it separately. Similar to the GSE results, the product-specific scope economies exist at only 25% of the mean output except for domestic science. As the remaining estimates are not significant, it reflects that these quantities of outputs are cost efficient.
Table 5.8: Point estimates of scope economies at percentages of current mean output

<table>
<thead>
<tr>
<th>p</th>
<th>PSOE(y_{1p})</th>
<th>PSOE(y_{2p})</th>
<th>PSOE(y_{3p})</th>
<th>PSOE(y_{4p})</th>
<th>PSOE(y_{5p})</th>
<th>GSE(y_p)</th>
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<td>0.08*</td>
<td>0.08*</td>
<td>0.34*</td>
</tr>
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<td>[0.09  0.58]</td>
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<td>0.01</td>
<td>0.02</td>
<td>0.11</td>
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<td>-0.01</td>
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</tr>
<tr>
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</tr>
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<td>-0.15</td>
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<td>[-0.40  0.13]</td>
<td>[-0.96  0.15]</td>
</tr>
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</table>

Notes: (i) Output mean is the arithmetic mean over the 10 years (i.e. 370 observations) while other shared variables are set to their respective means in all of the calculations; (ii) 95% confidence intervals for each difference estimate are given below in square brackets [ ]; (iii) * denotes estimates statistically significant difference from zero at the 0.05 level for a two–tailed t-test.

5.5 Concluding Remarks

The significant and growing revenue streams made possible by international higher education have dominated the decisions of universities in providing this form of education. However, few studies have investigated its cost structure, let alone the possible benefits that may arise associated with these costs from economies of scale and scope that could also benefit domestic student services. Therefore, this study offers a comprehensive review of the costs and economies of providing higher education for overseas students using a sample of 37 Australian public universities over the period from 2003 to 2012. Most importantly, instead of inferring significance purely based on the estimates, as in most previous studies, we test all results using a two-sided t-test. Our main conclusions as follows correspond to
the research questions initially proposed. We draw the conclusion from our estimation results and this should be especially useful for future study.

First, the unit and marginal costs for overseas students are not necessarily higher than are those for their domestic counterparts. In fact, our findings show that the costs of overseas students are lower or not significantly different to domestic students in that the costs mainly depend on the field of education and the quantity of output. In the non-science field of education, despite the observed differences, there is no significant difference in unit or marginal costs between domestic and overseas completions. On the other hand, in the science field of education, the marginal costs of overseas students are significantly lower than the costs of domestic students up to 125% of mean output. As discussed, this could be because of the typically shorter degree completion time of international students. From our findings, this effect has a stronger influence on lowering the costs of overseas science completions. The above findings provide a solid cost-side rationale for directing resources to international students other than the potentially higher revenues.

Second, our findings suggest two possible strategies for HEIs to achieve cost economies by adjusting their number of teaching outputs. For HEIs that wish to change only one output level at a time, we suggest an increase in the output of overseas non-science completions up to 200% of current mean output because there are only product-specific scale economies with this output. Note that our findings indicate that the other three types of outputs have already achieved their optimal number of completions and so Australian HEIs could seek to maintain their current number of domestic science and non-science and overseas science completions.

On the other hand, if HEIs wish to make all their outputs change together, the presence of economies of scale for Australian higher education suggests that they could increase all output levels proportionally up to 200% of the mean output. This implies that existing larger
institutions have benefitted substantially from these cost advantages, while smaller Australian HEIs should seek to expand all their entire outputs proportionally in order to achieve the proven cost savings. In contrast, the cost saving (of between 8–9%) between domestic and international teaching is only found in very small institutions (less than 25% of mean output). Fortunately, there is no evidence of diseconomies of scope between these two outputs and therefore our results indicate that universities should maintain their current joint production of domestic and international students.

In contrast to most previous studies that did not provide tests of significance for their estimates of cost economies, our study clearly highlights the importance of these tests. From Table 5.7 and Table 5.8, we can clearly observe that the wider confidence intervals (or larger standard errors) for these estimates increase with the percentage of mean output, implying less precision. This is not surprising as there are fewer large-size observations, leading to larger standard deviations for the estimates. In addition, we can see that estimates closer to the critical point are usually not significantly different from that point. These findings suggest that previous studies should not assert the presence of scale and scope (dis)economies simply because their estimates are (lower) higher than some critical point. In other words, for future studies, it is necessary to provide significance tests whenever inferring the existence of scale and scope economies.

Finally, despite best efforts, this paper is not free from limitations. The first limitation is due to the methodology. As this paper does not apply stochastic frontier analysis to our function, the assumption behind this is that all institutions (universities in Australian higher education sector in our case) from the sample operate efficiently. Note that this assumption could be tested by frontier analysis. Future studies are encouraged to implement frontier analysis in FFCQ-M function so inefficiency could be accounted for when estimating cost economies. The data limitation also prevents us from further investigation of lower average cost of
overseas science students. Notice that our science/non-science split is based on the broad field classification, whose classification cannot indicate which subject that a student studied. To conduct the investigation, a data set using more detailed classification or a qualitative investigation through interviews or a focus group might be useful, which awaits future studies.
Chapter 6. The impact of scale and scope on global university rankings: What we know and what we need to learn

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6.1 Introduction

Raising the world ranking of higher education institutions is increasingly one of the most important issues facing domestic industry stakeholders, especially governments (Dearden et al., 2014; Marope et al., 2013). Attention especially focuses on how to increase those tangible easily measured outputs that characterize the primary global university rankings, including the Quacquarelli Symonds (QS) World University Rankings, the Shanghai Jiao Tong Academic Ranking of World Universities (ARWU), the US News Best Global Universities Ranking (USN), and the Times Higher Education World University Rankings (THE). Typically, these rankings all include allowance for the number of publications and citations along with intangible measures such as academic and reviewer reputation.

In this chapter, we define scale as the number of student enrollments and scope as the number of research or teaching programs in a higher education institution. This enables us to understand how university scores and how their rankings may benefit from its inherent advantages in scale and scope, leading to cost advantages resulting from economies of scale and scope. Economies of scale exist when larger universities are better able to spread the fixed costs of inputs associated with teaching and research outcomes, including intangibles such as goodwill and reputation, across larger and more recognizable levels of output. By
Implication, larger universities will necessarily perform better if there are significant scale economies in global university production. Similarly, some universities may benefit from scope economies in that a benefit arises between the different dimensions of performance making up the generic ranking, say, between teaching and research, or between reputation as broadly defined and teaching or research outcomes. Carried to the extreme, rankings devoid of consideration of scale and scope may of little operational benefit to universities and others seeking to improve relative performance and therefore rank.

If economies of scale and scope exist in higher education rankings, the cost advantage (lower unit costs from scale economies or lower total costs from scope economies) could make it easier for larger universities easier to attain a higher rank given their lower production costs compared with their small-sized counterparts. Therefore, in practice, scale and scope effects plague rankings of all types and these have the potential to both seriously distort ranking outcomes and any best-practice policy and industry behavior conditional on these rankings (Li, Shankar, & Tang, 2011; Safón, 2013).

These effects are especially increasingly critical for universities operating in globally competitive environments because of the significant role of government funding decisions and verdicts on structural change. Specifically, they could lead to some institutions in some jurisdictions to increase their university ranking. Alternatively, it may be possible through industry restructuring to improve a country's overall ranking significantly. However, no known study has directly examined the possible presence and therefore the influence of scale and scope effects in the main global university rankings. As the first analysis to address the possible correlation between the above effects and global rankings, we select the ARWU and QS ranking scores as our data source mainly because they represent research and reputation-oriented ranking systems, respectively (Hazelkorn, 2014).

This chapter uses the theory of scale and scope economies to investigate empirically the
possible links between scale and scope effects on global rankings. To achieve this goal, we first review economies of scale and scope in the academic production process, which will provide us valuable insights and methodology for our further empirical investigations. We then employ exogenous information and a quantitative method to investigate the scale and scope effects in existing ranking outcomes and quantify the precise contribution each makes to the rankings as a whole and by an institution. Finally, we discuss the connection between these scale and scope effects and the rankings, and formulate both useful guidance for refining the various metrics and assess the impact on global, national, regional, and institutional decision-making.

6.2 Background

In this section, we lay the foundation for investigating scale and scope effects on global rankings. This involves understanding the theory and the cost structure. As scale and scope effects are originated from the theory of scale and scope economies, the brief introduction to the theory is as follows.

The theory of scale economies dates to Adam Smith. In *The Wealth of Nations*, Smith used economies of scale to explain wealth differences between countries. If economies of scale exist, holding other things constant, average costs are lower in large firms, resulting from spreading fixed costs over more units of production. This theory has been widely applied to economic activities, but is limited in single-output production. In 1975, Baumol (1975) and Panzar & Willig (1975) extend this concept to multi-output production and increased discussion of the economies of scope resulting from the cost savings of joint production. Multi-product estimation, as introduced by Baumol, Panzar, & Willig (1982), further accelerated the spread of these theories. Since then, analysis of economies of scale and
Economies of Scale and Scope in Higher Education

Scope has covered different types of multi-output production industries, typically using the following cost function.

Suppose universities produce \( n \) types of product whose quantities are contained in the vector \( y = (y_1, \ldots, y_n) \) with \( m \) types of inputs whose quantities are \( x = (x_1, \ldots, x_m) \) given a vector of input prices \( w = (w_1, \ldots, w_m) \), the multi-output cost function could be specified as (Baumol et al., 1982 p. 52):

\[
C(y, w) = \min_{x \geq 0} \left\{ w \cdot x \mid (x, y) \in T \right\}
\]

(6.1)

where \( w \cdot x \) is the inner product \( (\sum_i w_i x_i) \) and \( C(y, w) \) depicts the minimum cost combination of producing \( n \) types of output \( y \) given the input prices \( w \) and the technology set \( T \).

Unlike single-output production, the calculation of average cost involves the addition of various types of output in the multiproduct scenario. The difficulty of these additions is that measurement is usually not in common units (Baumol, 1975). One solution to this problem is to treat these additions as “a composite commodity” or “an output bundle” and allow the scale of this output bundle to change in some fixed proportion. We can calculate the ray average cost (RAC) as follows (Bailey & Friedlaender, 1982; Willig, 1979).

\[
\text{RAC}(y) = \frac{C(ty^0)}{t}
\]

(6.2)

where \( y \) is a vector of output and represents a composite commodity (or output bundle), \( y^0 \) is a vector of a composite commodity’s unit \( (\sum_i y_i^0 = 1) \), and \( t \) is the number of units in a composite commodity and also the measures of the output bundle’s scale along the ray through \( y = (y_1, \ldots, y_n) \). Note that there is no price and therefore \( w \) is omitted in this and the following equations.

We can illustrate the ray average cost curve with Figure 5.1 assuming that firms produce
two types of product ($y_1$ and $y_2$). Following the definition of RAC in the equation, vector $y^0$ is any point between two endpoints ((0, 1) and (1, 0)). Once the quantity of the unit bundle $y^0$ has been decided, the ray (OR) is merely the $t$-fold increase (or decrease) of unit bundle $y^0$ (Willig, 1979). The average cost of this composite commodity will be defined on a ray (OR) emanating from the origin and is expected to have a U-shaped cost curve. We have the minimum RAC at output $y = y^m$ as illustrated in Figure 5.1 and this point represents the efficient scale for a multi-product firm.

![Figure 6.1: The illustration of ray average cost](image)

**Source:** Baumol et al., 1982

With the definition of RAC, we define ray economies of scale as the elasticity of output with respect to cost (Bailey & Friedlaender, 1982).

$$SRAY = \frac{dy}{dy/C(y)/C(y)} = \frac{C(y)}{\sum_{i=1}^{n} y_i C_i(y)} \quad (6.3)$$

where $C(y)$ is the total cost of producing that amount of output vector (y), $\frac{C(y)}{\sum_{i=1}^{n} y_i}$ is the ray average cost, and $C_i(y) = \frac{\partial C(y)}{\partial y_i}$ is the marginal cost of producing the $i$-th type of
output.

This equation estimates the effect of the simultaneous and proportional increase of all output scales along a ray in output space while holding the composition of each firm’s outputs constant (Bailey & Friedlaender, 1982). Ray economies (diseconomies) of scale then exist when SRAY is greater (less) than unity. Cost savings arise when the size of the aggregate output increases, but the composition of output remains constant.

Other than deciding how large a firm should be, the owner also has to decide the scope of the firm’s operation, including the extent of vertical or horizontal integration as well as the diversity of products. The estimates of economies of scope (GSE) could help make this decision. We calculate this estimate either as the percentage of cost savings from joint production relative to fully integrated costs or as the percentage increase in costs from specialized production:

\[
\text{GSE} = \frac{\sum_{i=1}^{n} C(y_i) - C(y)}{C(y)}
\]  

(6.4)

where \(\sum_{i=1}^{n} C(y_i)\) is the cost of producing product \(i\) in \(n\) separate specialized firms, and \(C(y)\) is the costs of producing all \(n\) products jointly within a firm.

These economies result from the sharing of inputs. Therefore, input prices and available technology majorly affect the presence of scope economies (Bailey & Friedlaender, 1982). When a firm enjoys cost savings from the joint production of varied products, the GSE will be greater than zero. These economies of scope imply that the cost of producing different types of products is less than the cost of producing them separately. In contrast, when a firm does not experience economies of scope, a hitherto multi-product firm could be broken into several specialized firms to save costs (Baumol et al., 1982). Therefore, GSE offers information on both the nature of the multi-product production process and the cost synergies that exist between outputs (Chavas & Kim, 2007).
6.3 Main focus of the chapter

With the background of the theory of scale and scope economies, in this section, we will further discuss the relationship between university rankings and cost economies. This will be achieved by briefly reviewing two major ranking systems (ARWU and QS) and introducing our methods of measuring the possible links between them.

6.3.1 Brief review of ARWU and QS rankings

The Institute of Higher Education in Shanghai Jiao Tong University, China first published the ARWU ranking list in 2003, with 500 leading universities ranked based on the weighted sum of scores of six different indicators (see Table 6.1). The best scoring institution receives a score of 100, with all other institutions obtaining a normalized score between 0 and 100. However, only the first 100 universities receive ranking scores, with the remaining 400 universities ranked by group.

Table 6.1: ARWU and QS ranking indicators

<table>
<thead>
<tr>
<th>Category</th>
<th>ARWU</th>
<th>QS</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research</td>
<td>Highly-cited researchers in 21 broad subject categories</td>
<td>Citations per faculty</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>Papers published in Nature and Science</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Papers indexed in SCI-expanded and SSCI</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Per capita academic performance of an institution</td>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Reputation</td>
<td>Alumni of an institution winning Nobel prizes and Fields medals</td>
<td>Employer reputation</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>Staff of an institution winning Nobel prizes and Fields medals</td>
<td></td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Academic reputation</td>
<td>40%</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>International faculty ratio</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>International student ratio</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Student-to-faculty ratio</td>
<td>20%</td>
</tr>
</tbody>
</table>

Source: ARWU (2014) and QS (2014)
Because of the lack of internationally comparable data and the stated intention to avoid subjective measures, the selection of the indicators is most to represent academic performance (Liu & Cheng, 2005). For example, the primary focus is on the number of ‘excellent’ scholars and research outputs such as papers published in *Nature* and *Science* and those indexed in the *Science Citation Index* and *Social Science Citation Index*, accounting for some 60% of the weighting. Given the ranking is mainly determined by the number of research outputs, larger universities will generally rank higher on the ARWU (Billaut, Bouyssou, & Vincke, 2010; Li et al., 2011; Rauhvargers, 2011; Zitt & Filliatreau, 2006). Although per capita academic performance of an institution is also included in one of the indicators, its mere 10% weighting seems insufficient to overbalance the scale effect.

Other world ranking systems, including the Times Higher Education World University Rankings, the QS World University Rankings, and Webometrics Ranking of World Universities, of course, have different focuses. In this chapter, we nominate the QS World University Rankings as the point of comparison with the ARWU. In contrast to focusing on research outputs like ARWU, QS primarily uses reputation to signify the performance of an institution (Dobrota, Bulajic,Bornmann, & Jeremic, 2016). Reputation (academic and employer) accounts for up to 50% of the final ranking result, while only 20% reflects publication outputs (citations per faculty) (QS, 2014). The data is from surveying peer reviews.

However, despite the QS focusing more on university reputation, it may still favor institutions with larger scale and scope (Brooks, 2005). This is because participants in the QS surveys may favor those institutions where relatively more students have studied, and large institutions have a higher likelihood to be rated highly by their alumni.

From the above brief review, we understand that both ranking systems mainly rely on size dependent indicators, which are calculated by counting the absolute number such as the
number of papers in ARWU or easily affected by the number of an institution’s alumni such as reputation in QS. On the other hand, size-independent indicators use the concept of proportion. This means that this type of indicators will consider the number that produces the outputs, but not focus on the absolute number of output only. You can find examples like per capita academic performance of an institution in ARWU or citations per faculty in QS. Unfortunately, fewer weights are assigned to size-independent indicators in both systems and we can expect scale and scope effects on both rankings.

### 6.3.2 How we measure the scale and scope effects on ARWU and QS rankings

Of the two rankings we select in this analysis, QS is largely reputation-oriented and ARWU is primarily research-oriented (AWRU) (Shin, Toutkoushian, & Teichler, 2011). We hypothesize both are at least a partial function of the scale and scope economies in universities. Because they are more indicative of relative performance, we employ the scores instead of the final ranking (Li et al., 2011).

For most ranking systems, scores exist for only the first 100 institutions. We therefore only include the top-100 universities in each ranking system as our data set. We draw the proxies for the scale and scope effects (number of enrollments and teaching programs) directly from the university’s profile on the ARWU webpage. If the number of enrollments is missing from the ARWU webpages, we replace the missing values with data from government or university websites. In 2014, 62 universities appear in both the ARWU’s and QS’s top-100 list. Unfortunately, the number of programs is often missing from the ARWU’s website and this information may not be readily available on university websites.

Accordingly, our final dataset comprises 85 universities for ARWU and 63 universities for
Economies of Scale and Scope in Higher Education

QS as shown in Table 6.2. In general, on the ARWU list, there are many more public than private universities, though private universities generally have higher scores, with the average private university scores being 10.39 points higher than for a public university. However, public universities are generally larger than private universities in terms of number of enrollments (our measure of scale) and programs (our measure of scope). The largest public university is the University of Toronto with 85,900 enrollments while the University of Edinburgh provides most diversified teaching programs, with some 830 programs.

Table 6.2: Summary statistics for top-100 universities in 2014 ARWU and QS.

<table>
<thead>
<tr>
<th>Variables</th>
<th>No.</th>
<th>Mean</th>
<th>Std dev.</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ARWU</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Score</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full sample</td>
<td>85</td>
<td>36.19</td>
<td>13.62</td>
<td>24.00</td>
<td>100.00</td>
</tr>
<tr>
<td>Public</td>
<td>63</td>
<td>33.50</td>
<td>9.57</td>
<td>24.10</td>
<td>70.10</td>
</tr>
<tr>
<td>Private</td>
<td>22</td>
<td>43.89</td>
<td>19.68</td>
<td>24.00</td>
<td>100.00</td>
</tr>
<tr>
<td>Enrollments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full sample</td>
<td>85</td>
<td>30010.11</td>
<td>16149.56</td>
<td>2327.00</td>
<td>85900.00</td>
</tr>
<tr>
<td>Public</td>
<td>63</td>
<td>32806.84</td>
<td>16176.57</td>
<td>2374.00</td>
<td>85900.00</td>
</tr>
<tr>
<td>Private</td>
<td>22</td>
<td>22001.27</td>
<td>13416.00</td>
<td>2327.00</td>
<td>52125.00</td>
</tr>
<tr>
<td>No. of Programs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full sample</td>
<td>85</td>
<td>230.08</td>
<td>164.22</td>
<td>9.00</td>
<td>830.00</td>
</tr>
<tr>
<td>Public</td>
<td>63</td>
<td>249.32</td>
<td>183.49</td>
<td>9.00</td>
<td>830.00</td>
</tr>
<tr>
<td>Private</td>
<td>22</td>
<td>175.00</td>
<td>64.66</td>
<td>60.00</td>
<td>285.00</td>
</tr>
<tr>
<td><strong>QS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Score</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full sample</td>
<td>63</td>
<td>83.94</td>
<td>8.95</td>
<td>70.80</td>
<td>100.00</td>
</tr>
<tr>
<td>Public</td>
<td>46</td>
<td>82.31</td>
<td>8.06</td>
<td>71.60</td>
<td>99.40</td>
</tr>
<tr>
<td>Private</td>
<td>17</td>
<td>88.36</td>
<td>9.97</td>
<td>70.80</td>
<td>100.00</td>
</tr>
<tr>
<td>Enrollments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full sample</td>
<td>63</td>
<td>28810.38</td>
<td>14820.84</td>
<td>2327.00</td>
<td>85900.00</td>
</tr>
<tr>
<td>Public</td>
<td>46</td>
<td>31051.57</td>
<td>14800.92</td>
<td>2700.00</td>
<td>85900.00</td>
</tr>
<tr>
<td>Private</td>
<td>17</td>
<td>22746.00</td>
<td>13473.28</td>
<td>2327.00</td>
<td>52125.00</td>
</tr>
<tr>
<td>No. of Programs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full sample</td>
<td>63</td>
<td>238.79</td>
<td>169.95</td>
<td>13.00</td>
<td>830.00</td>
</tr>
<tr>
<td>Public</td>
<td>46</td>
<td>264.15</td>
<td>189.33</td>
<td>13.00</td>
<td>830.00</td>
</tr>
<tr>
<td>Private</td>
<td>17</td>
<td>170.18</td>
<td>65.19</td>
<td>60.00</td>
<td>270.00</td>
</tr>
</tbody>
</table>

As explained earlier, the scale and scope proxies are from the ARWU website and there are only 62 universities in both the ARWU and the QS. However, Table 6.2 displays similar characteristics for all variables. Private universities dominate the QS list by scoring higher on average and securing the top position (MIT). We can also observe that the numbers of
enrollments and teaching programs in private institutions are lower than in public institutions.

We approximate the relationship between university ranking, scale and scope effect with a quadratic function ($QF$):

$$R_h = QF + \varepsilon_h = \sum_{i=1}^{2} \beta_i y_{ih} + 0.5 \sum_{i=1}^{2} \sum_{j=1}^{2} \beta_{ij} y_{ih} y_{jh} + \varepsilon_h$$  \hspace{1cm} (6.5)

where subscript $h$ denotes the higher education institution, $R_h$ is the university ranking score for the $h$-th higher education institution, $\beta_i$'s, $\beta_{ij}$'s are coefficients to be estimated, and $\varepsilon_h$ is the error term distributed as a normal distribution with zero mean and variance.

Note that there is no intercept in (6.5) as this has no economic meaning when scale and scope (here, the numbers of enrollments and programs, respectively) are zero.

Our quadratic function also represents the effects of scale and scope on scores for the $h$-th institution. We obtain adjusted scores (without scale and scope effects) with the following:

$$\varepsilon_h = R_h - \left( \sum_{i=1}^{2} \beta_i y_{ih} + 0.5 \sum_{i=1}^{2} \sum_{j=1}^{2} \beta_{ij} y_{ih} y_{jh} \right)$$  \hspace{1cm} (6.6)

Note that because the error term has a normal distribution with zero mean, the ranking scores for some institutions after removing the scale and scope effects could be negative.

Given the increasing paucity of public resources available for higher education and merger activity enforced by government, we expect that scale and scope effects should affect public institutions more than their private counterparts. We should also note that public institutions typically rely more on government funding than private institutions. To address this institutional division, we fit equations separately for public and private institutions, a feature very common in the literature on scale and scope economies in higher education (Sav,
6.4 Solutions and recommendations

In this section, we provide the empirical results for answering our research question and offer the recommendations.

6.4.1 Scale and scope effects on ARWU scores

Table 6.3 provides the regression results for the ARWU scores using ordinary least squares applied to the full sample and public and private institutions separately. For the entire sample, our scale and scope model can explain 80.52% of the variance in ARWU scores. Overall, the coefficients for enrollments and programs are both significant and suggest positive scale and scope effects on ARWU scores. That is, the larger the enrollments and the number of programs for a university, the higher its ARWU score. These positive effects, however, ultimately decrease with the increase in enrollments and programs, as the estimated coefficient for the squared terms for both variables is negative (although insignificant). For private institutions, there are no significant scale and scope effects on the scores. We therefore consider that the positive impact identified in the full sample mainly arises through the inclusion of public institutions.
Table 6.3: Regression results for ARWU scores

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Full sample</th>
<th>Public institutions</th>
<th>Private institutions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>Std dev.</td>
<td>Coefficient</td>
</tr>
<tr>
<td>Enrollments (000s)</td>
<td>1.07802**</td>
<td>0.32</td>
<td>1.13714***</td>
</tr>
<tr>
<td>Programs</td>
<td>0.14280**</td>
<td>0.04</td>
<td>0.08464*</td>
</tr>
<tr>
<td>Enrollments^2 (000s)</td>
<td>-0.01008</td>
<td>0.01</td>
<td>-0.00972</td>
</tr>
<tr>
<td>Programs^2</td>
<td>-0.00016</td>
<td>0.00</td>
<td>-0.00004</td>
</tr>
<tr>
<td>Enrollments×Programs</td>
<td>-0.00241*</td>
<td>0.00</td>
<td>-0.00194*</td>
</tr>
<tr>
<td>R^2</td>
<td>0.80520</td>
<td></td>
<td>0.86850</td>
</tr>
<tr>
<td>Adjusted R^2</td>
<td>0.79310</td>
<td></td>
<td>0.85720</td>
</tr>
<tr>
<td>N</td>
<td>85</td>
<td></td>
<td>63</td>
</tr>
</tbody>
</table>

Note: *, **, and *** denote two-sided significance at the 0.05, 0.01, and 0.001 level, respectively; the above models are also tested by adding a country dummy (one for US institutions, otherwise zero), and this additional dummy variable does not affect the significance and signs of other variables.

6.4.2 Scale and scope effects on QS scores

In our analysis, QS scores largely function as a proxy for institutional reputation. We use a regression model to investigate whether this includes scale and scope effects. As shown in Table 5.4, there are positive though decreasing scale and scope effects for the full sample and public institutions. However, unlike the results for the ARWU scores, there is a negative but insignificant scale effect in private institutions. We also identify a positive scope effect, further suggesting that private institutions can potentially increase their scoring in the QS ranking by expanding their range of teaching programs.
Table 6.4: Regression results for QS scores

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Full sample</th>
<th>Public institutions</th>
<th>Private institutions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>Std dev.</td>
<td>Coefficient</td>
</tr>
<tr>
<td>Enrollments (000s)</td>
<td>2.88735***</td>
<td>0.54</td>
<td>3.08446***</td>
</tr>
<tr>
<td>Programs</td>
<td>0.24360***</td>
<td>0.07</td>
<td>0.16006*</td>
</tr>
<tr>
<td>Enrollments^2 (000s)</td>
<td>-0.02957</td>
<td>0.02</td>
<td>-0.02985</td>
</tr>
<tr>
<td>Programs^2</td>
<td>-0.00017</td>
<td>0.00</td>
<td>0.00000</td>
</tr>
<tr>
<td>Enrollments×Programs</td>
<td>-0.00516**</td>
<td>0.00</td>
<td>-0.00466**</td>
</tr>
<tr>
<td>R^2</td>
<td>0.9115</td>
<td>0.9329</td>
<td>0.9820</td>
</tr>
<tr>
<td>Adjusted R^2</td>
<td>0.9039</td>
<td>0.9247</td>
<td>0.9745</td>
</tr>
<tr>
<td>N</td>
<td>63</td>
<td>46</td>
<td>17</td>
</tr>
</tbody>
</table>

Note: *, **, and *** denote two-sided significance at the 0.05, 0.01, and 0.001 level, respectively; the above models are also tested by adding a country dummy (one for US institutions, otherwise zero) and this additional dummy variable does not affect the significance and signs of other variables.

6.4.3 Scale and scope-adjusted institutional scores and ranks

In this section, we use equations (6.5) and (6.6) to recalculate the scores for individual institutions after removing the effects of scale and scope. To explain how we remove scale and scope effects, we can use MIT’s score in QS as an example. Notice that MIT has 11.798 enrollments (000s) and 168 programs and gained a score of 100 in QS. To remove its scale and scope effects, we need to subtract its score by the scale and scope effects. Following equation (6.6) and using coefficients estimated with equations (6.5) and shown in Table 6.4, MIT’s ranking score after removing scale and scope effects is -10.48809:

\[ R_h = \sum_{i=1}^{2} \beta_i y_{ih} + 0.5 \sum_{i=1}^{2} \sum_{j=1}^{2} \beta_{ij} y_{ih} y_{jh} = 100 - (-2.81797 \times 11.798 + 1.56733 \times 168 + 0.5 \times (-0.00945 \times 11.798 + (-0.01016) \times 168^2) + 0.01234 \times 11.798 \times 168) \]

Calculations for other top 100 institutions are similar, which is to replace the above scores, enrollments and programs with that institution’s. We summarize the results with Figure 6.2 and Figure 6.3 where triangles denote the original score and hollow dots represent the scores after removing the scale and scope effects for both sets of ranking scores. Therefore,
the distances between the triangles and hollow dots identify the scale and scope effects for a particular institution.

We first generate the dot plots for private institutions and the ARWU and QS scores and ranking in Figure 6.2. As shown in the left-hand side plot, Harvard University retains the best position in the ARWU ranking. Stanford University, however, is no longer second, replaced by Caltech. We can particularly see that three universities (Purdue, Northwestern, and Caltech) do not benefit as much as much from the positive effects of scale and scope economies as many other universities, and therefore their relative positions in the ranking improve substantially when we hold the scale and scope effects constant.

The right-hand side plot in Figure 6.2 provides the results for the QS rankings. Unlike the results for ARWU, the distance between the original scores and the scores without scale and scope effects are much wider for the same institutions in the QS ranking, implying scale and scope effects majorly boost the relative performance of institutions in the QS ranking. As an extreme example, MIT falls from first to almost last position once we remove the scale and scope effects. These results then reinforce our previous findings in Table 6.3 and Table 6.4: scale and scope effects majorly affect the scores of private institutions in the QS ranking.
We examine the scale and scope effects on ranking scores for public institutions, as shown in Figure 6.3. For the AWRU rankings, Berkley falls to third position while the University of Cambridge falls even further to eighth on the QS ranking. The above findings for public institutions again emphasize the impact of scale and scope effects, indicating that institutions with larger enrollments and programs will generally score higher on the QS ranking.

We should also remind readers that there are some limitations when removing scale and scope effects. From Table 6.3 and Table 6.4, we can see that scale and scope effects explain at least 80% of variance in ARWU scores and 90% in QS scores. However, due to the data limitation, we did not include other indicators such as research and reputation. It is possible that the above indicators are included in these scale and scope effects, which also corresponds to the assumption we made in the introduction section: scale and scope effects plague ranking scores.
Future research directions

To date, to the best of our knowledge, no study has investigated the relationship between scale and scope effects and global rankings. This study fills this gap in the literature by using proxies for these effects (enrollments and programs) and for institutional performance...
Economies of Scale and Scope in Higher Education

(ARWU and QS ranking scores) fitted with our quadratic regression model. Our empirical results could be the foundations for the further studies. First, we found that the ranking scores of Top 100 public institutions are affected by institutional scale and scope. The reliance of public funding could be the factor but we still do not know the mechanism behind this. Another future research direction could be to investigate alternative ranking indicators that are free from scale and scope effects. Studies can especially focus on developing size-independent indicators.

6.6 Conclusion

In the global education market, the research performance and reputation of an institution almost guarantee student enrollments and better availability of funding. For some time, the ARWU and QS rankings have been some of the most cited benchmarks for institutions to pursue above-average international performance. However, the doubts and debate about these ranking results are never stopped ever since the first global ranking report is published. It is possible that one ranking system claims to measure certain traits of higher education institutions but instead it actually measures something else. Our results provide the evidence that the ranking outcomes are deeply affected by the scale and scope effects. QS and ARWU are suggested to balance the size-dependent and size-independent indicators instead of favoring one of them. If balancing these two types of indicators is hard to achieve in the short run, the ranking system should warn their users by explicitly explaining which indictors are possibly affected by the scale and scope of an institution. A good example could be found in Leiden Ranking (2015).

This chapter also shed a light on the role of scale and scope in the QS and ARWU ranking results. Our results show that institutions with higher enrollments and more programs tend to have higher ARWU and QS ranking scores. We find evidence of significant coefficients for enrollments and programs in the full sample, implying the existence of scale and scope
effects on both ARWU and QS ranking scores. However, once we split the sample into public and private institutions, these effects are especially notably for public institutions. This is not surprising in that larger public institutions, since enrolling more students will gain more government funding.

These scale and scope effects, however, are not obvious in private institutions though. The evidence shows that private universities will not gain as many in terms of ARWU scores as public institutions from increasing their enrollments and programs. This could be because private institutions often do not rely on tuition fees as much as public institutions. For example, in 2013 tuition fees at Harvard University only represented 10% of its total revenue, but as much as 30% of total revenue at Berkeley (U.S. Department of Education, n.d.). In other words, private universities are better able to diversify their funding sources, and while this can reduce risk, mean that these institutions will not so actively seek opportunities for increasing their scale and scope.

The most important outcome of this work is that we believe a significant component of the superior performance of many universities in global rankings flows not from superior performance per se, rather from the innate, often inherited benefits of their superiors scale and scope. These benefits enable them not only to produce teaching, research and other outputs more cheaply than smaller universities, but also means they benefit qualitatively from reputation, given their greater visibility and the larger number of their alumni targeted for survey. Accordingly, over the longer term, universities should include efforts at increasing their scale and scope as part of their strategies to increase their relative performance in global university rankings.
Chapter 7. Conclusion

7.1 Summary

The preceding thesis is summarized as follows. Chapter 1 Introduction outlined the motivation and structure of this thesis. Most importantly, it addressed the research gaps in previous studies regarding cost economies and thus raised three research questions. The data and methodology were also summarized for responding to the thesis questions.

Chapter 2 The Australian university sector offered more details of our sample including the selected country’s higher education development history, financial reforms and recent structural changes. Most importantly, Chapter 2 explained why Australia is an ideal candidate for exploring the new sources of cost economies.

Chapter 3 The nature of economies of scale and scope in higher education established the core theory in the thesis. This chapter depicted the nature of economies of scale and scope in higher education by reviewing published journal articles. This chapter also served the purpose of pointing out research gaps in this area, which included the need for updating research data, missing discussion of key outputs (distance education and internationalization of higher education), and mixed results from previous studies.

In the last section of Chapter 3 Explaining estimated economies of scale and scope in higher education: A meta-regression analysis could be considered as an empirical summary of cost economies in higher education. Different from simply literature reviewing previous relevant studies, this thesis employed meta-regression analysis to explore not only the overall level of scale and scope economies across studies, but also those factors that potentially affect their presence in the higher education sector. Findings suggested that functional form, and
Economies of Scale and Scope in Higher Education

allowances for managerial efficiency had a significant impact on the estimated scale economies. In contrast, for scope economies, the key factors appeared to be when the age of the analysis, the diversity of the sample, and the national level of economic development in the chosen context.

In addition to the last section of Chapter 3, other empirical investigations were conducted in Chapters 4 to 6. Chapter 4 and Chapter 5 used a balanced panel data, including 37 Australian public universities over the period 2003-12. The purposes of these two chapters were to investigate whether distance education and internationalization of higher education could be the new sources of scale and scope economies. In Chapter 4 Scale and scope economies of distance education in Australian universities, the findings suggested strong overall scale and scope economies and product-specific scale economies for distance education. Further, the economies of scope for distance education were increasing with mean output, suggesting an increasing cost benefit of producing distance education in conjunction with traditional class-based face-to-face teaching.

Chapter 5 Cost economies in the provision of higher education for international students: Australian evidence analyzed the cost economies in the internationalization of higher education. The findings implied that it was more appealing to enroll additional overseas students due to their lower average and marginal costs and the significant economies of scale prevailing in higher education. Further, while the evidence of economies of scope for overseas students was found only in smaller institutions, there was no evidence of diseconomies of scope, implying the current number of overseas students and their joint production with domestic students at least did not lead to higher costs.

Chapter 6 The impact of scale and scope on global university rankings: What we know and what we need to learn inspected the potential relationship between global rankings, scale and scope effects, considering that scale and scope were increasingly critical for universities
operating in globally competitive higher education teaching, research and training markets. That is, it investigated the relationships between scale (as measured by the number of enrollments) and scope (as measured by the number of teaching programs), research performance, and institutional reputation (as measured by the ARWU and QS ranking scores). The results showed that larger and more diverse institutions tended to have higher scores. However, when separated into public and private universities, the scale and scope effects were not so obvious between private universities and the ARWU ranking scores. Nevertheless, this thesis does identify a significant scope effect in the QS rankings for private institutions, implying that expanding research, teaching, and training programs may benefit these scores.

7.2 Contribution

This thesis has significantly contributed to the existing literature in three main ways. First, this thesis develops a better functional form (FFCQ-M) for estimating scale and scope economies in higher education. The main advantage over its counterpart (FFCQ-A) lies in easily conforming to all of the cost function regularity conditions. That is, this functional form helps avoid the model misspecification. Accompanied with this functional form, this thesis also provides several indicators to examine the model diagnostics, as detailed in Chapter 5 with its computer code in the Appendix.

Second, instead using common output classifications, this thesis further explores new sources of cost economies by using distance education and overseas completions as outputs. For the past few decades, the improving communications and evolving technology have continued to reshape the way of teaching and help deliver courses to students living away from institutions. These communication technologies also help attract more overseas
students. Distance education and internationalization have therefore thrived and widely exist in higher education. While the characteristics of their higher fixed costs, and lower variable costs make them the ideal candidates to help achieve at least economies of scale. Chapters 4 and 5 have provided sound and empirical evidence for the potential of these two outputs to help institutions achieve cost economies. For institutions wanting to increase their number of students, there should be a priority on distance education or overseas students as a means of achieving significant cost savings.

Finally, the systematic and empirical review results of this thesis also help point out the direction of future structural change. To our best knowledge, this thesis is the first study to review empirically previous researches using meta-regression analysis. Based on the results of previous studies and this thesis, some structure changes might benefit certain countries to achieve cost economies. In general, for some developed countries such as Australia, Spain, the UK, and the US where the ray economies of scale are at 100% of the mean output, these results indicate the cost savings at the present output mean level in these areas. However, in the developing countries such as Bangladesh (Mamun, 2012) and the Philippines (Rufino, 2006), tremendous cost savings are found. Institutions in these countries are encouraged to further expand their scale to achieve lower unit costs.

Another direction of structural change is through modifying the types of outputs. From previous studies, our review shows that there are no economies of scope in Germany, Spain, and Taiwan. Evidence suggests these three higher education systems split their output production to achieve cost savings. In other words, a joint production of instruction and research could be more costly than separate production in these countries. Other countries including Australia, China, Italy, the UK and the US should continue to maintain their joint production form in terms of cost savings.
7.3 Limitations

Despite best efforts, this thesis is not free from limitations. However, these limitations also point out further research directions. The first limitation comes from the data. One of the purposes in this thesis is to explore new sources of cost economies in higher education. Unfortunately, a sample from multiple countries is usually uncollectable considering different financial and educational systems. Limited by the data, this thesis examines our theory with a sample from a single country (Australia) where is famous for successful distance education and internationalization. However, this data limitation is somewhat offset in that results from other countries are supplemented by qualitative and quantitative review (Chapters 3).

Second, several methodology limitations are worth mentions. When conducting meta-regression analysis, we cannot offset the potential publication bias due to the missing standard errors. There is no consensus about the proxy for cost economies standard errors, either. Unfortunately, as all studies used different functional forms and/or independent variables for calculating the cost economies, it is almost impossible to calculate the standard errors retrospectively. Since the method of calculating their standard errors have been developed (Zhang & Worthington, 2015), we suggest further studies provide such estimates.

Another limitation is that this thesis did not allow for inefficiency in the Australian higher education sector. This lies in the methodology we used for estimating FFCQ-M function. As this thesis does not apply stochastic frontier analysis to this function, the assumption behind this is that all institutions from the sample operate efficiently. Note that this assumption could be tested by frontier analysis. However, there is still no appropriate way to implement this analysis in FFCQ-M function since this function has a very nonlinear form.

Finally, this thesis emphasizes the limitation when applying the results of scale and scope
economies, especially regarding the assumptions behind previous studies and this thesis. We should notice that the quality of outputs is assumed constant since the quality of outputs are controlled or implicitly adjusted through model specifications (see Chapter 3 for details). Although this thesis suggests that the theory of scale and scope economies could be used for guidance for cost savings, it does not imply institutions can ignore the quality of outputs and blindly follow the results of cost economies. There could be a trade-off between quantity and quality. This trade-off especially happens when a small institution expands its quantity of the outputs without increasing its facilities or staff accordingly. Imagine that when a small institution over enroll too many students without increasing the teaching staff such as tutors and lecturers, the quality of teaching could therefore be lower, leading to more students failing the courses. Therefore, how to increase the quantity of outputs without the decline of its quality still depends on the policies of institutions.

7.4 Future research directions

Following the research limitations and discussions in previous chapters, this thesis points out several future research directions. First, this thesis has found that previous studies use educational levels (undergraduate and postgraduate) or broad fields of subject (science and non-science subjects) as their major instruction outputs while neglecting other types of outputs for bringing new sources of scale and scope economies. A sample of public Australian universities is used as an example to investigate other types of outputs including distance education and internationalization. Results show potential cost savings in both types of outputs aligned with few previous studies with a sample from China (Li, 2016; Li & Chen, 2012). However, whether these cost economies persist in other countries or over time still awaits further studies to testify.
Second, from the MRA findings in Chapter 7, two findings help point out future directions. The first one is the results suggest that these potential factors do not have a significant relationship with the magnitude of scale and scope economies. This finding is consistent with previous work (Carvalho et al., 2012) using MRA to evaluate the degree of scale and scope economies in the water sector, indicating the degrees of cost (scale and scope) economies might not be a good effect size estimator. The ideal effect size for MRA might be the presence of cost economies. The other future direction about future studies is that our findings indicate the presence of scale economies tends to be affected by some model-specification related factors, including functional form, whether departures from managerial efficiency are included, and specifying enrollments as teaching outputs. This means the choice of functional form, estimation methods, and outputs is no longer neutral when estimating scale economies. Future studies need to justify why they choose a particular model specification rather than simply following previous studies.

Finally, there is an urgent need for the guidance about expanding the levels and increasing the number of types of outputs without sacrificing their quality. This type of study might depend on qualitative methods such as case study and unstructured interviewing. However, the first confronting problem is how to identify the successful institutions. Recent merger activities, which increase output levels and types, may be an ideal start. For example, Goedegebuure (2012) has found that European countries such as German, Finnish and French encourage their universities to merge in the face of global competition. Further studies are suggested to investigate these merger activities, especially focusing on whether the quality of outputs is maintained or even improved.
Appendix

The following computer code is developed for conducting the empirical analysis of this thesis (Chapters 3 to 6). The code can be performed on the open-source software R (R Core Team, 2016). The relevant R packages (Beaujean, 2012; Elzhov, Mullen, Spiess, & Bolker, 2015; Fox & Weisberg, 2016; Harrell, 2016; Peterson & Carl, 2014; Revelle, 2016) are also used during developing the code for this thesis. All results produced from the code have been rechecked and retested on 13 February 2017.

Appendix 1. Computer code for Chapter 3 (section 3.5)

###########################################################################
## This R script is prepared for the paper:
## Zhang, L. -C. & Worthington, A. C. (2016). Explaining estimated economies
## of scale and scope in higher education: A meta-regression analysis, Griffith
## Business School Discussion Papers in Economics and Business Statistics
## (forthcoming).
## Code developer: Liang-Cheng Zhang
###########################################################################

# Install packages --------------------------------------------------------
install.packages("BaylorEdPsych")
install.packages("PerformanceAnalytics")
install.packages("psych")

# Descriptive statistics --------------------------------------------------
library("psych")
MD = read.csv("Meta.Data.csv", header = T)
describe(MD)

#Deleting data for missing value in economies of scale
MD.Scale = MD[complete.cases(MD[,c(2:3,6:16)]),]
write.table(describe(MD.Scale), file = "summary.Scale.csv", row.names = T,
append = T, sep = ",", col.names = NA)
Economies of Scale and Scope in Higher Education

```
MD.Scope = MD[complete.cases(MD[,c(4:5,6:16)]),]
write.table(describe(MD.Scope), file = "summary.Scope.csv", row.names = T, append = T, sep = "", col.names = NA)

# Correlation matrix -----------------------------------------------
library(Hmisc)
Scale.Corr = rcorr(as.matrix(MD.Scale[,c(2:3,6:16)]), type = "pearson")
Scope.Corr = rcorr(as.matrix(MD.Scope[,c(4:5,6:16)]), type = "pearson")

# Meta-Regression -----------------------------------------------
library(lmtest)
MD = read.csv("Meta.Data.csv", header = T)
# OLS results, not good but should also display, all coefficients are not significant, main reference: Colegrave, A. D., & Giles, M. J. (2008)
## Scale economies
### All independent variables
OLS.ALL = SRAY ~ Year + Sample_size + Public + OECD + QCF + Efficiency + Enrolments + Research + Third_mission + Panel + Journal
# OLS.ALL = SRAY ~ Year + Sample_size + Public + OECD + QCF + Efficiency + Enrolments + Panel + Journal + Multiple
Meta.OLS.ALL <- lm(OLS.ALL, data = MD)
summary(Meta.OLS.ALL)
bptest(OLS.ALL, data = MD) # Breusch-Pagan chi-square
write.table(summary(Meta.OLS.ALL)$coefficients, file = "OLSsummary.Scale.csv", row.names = T, append = T, sep = "", col.names = NA)

## Scope economies
### Independent variables (significant in correlation matrix)
OLS.GSE.Sig = GSE ~ OECD
Meta.OLS.GSE.Sig <- lm(OLS.GSE.Sig, data = MD) # independent variables selected from significant correlations with SRAY
summary(Meta.OLS.GSE.Sig)
bptest(OLS.GSE.Sig, data = MD) # Breusch-Pagan chi-square
```
### All independent variables

$$\text{OLS.GSE.ALL} = \text{GSE} \sim \text{Year} + \text{Sample_size} + \text{Public} + \text{OECD} + \text{QCF} + \text{Efficiency} + \text{Enrolments} + \text{Research} + \text{Third_mission} + \text{Panel} + \text{Journal}$$

$$\#\text{OLS.GSE.ALL} = \text{GSE} \sim \text{Year} + \text{Sample_size} + \text{Public} + \text{OECD} + \text{QCF} + \text{Efficiency} + \text{Enrolments} + \text{Panel} + \text{Journal} + \text{Multiple}$$

$$\text{Meta.OLS.GSE.ALL} \leftarrow \text{lm}(\text{OLS.GSE.ALL, data = MD})$$

```r
summary(Meta.OLS.GSE.ALL)
```

```r
bptest(OLS.GSE.ALL, data = MD)  # Breusch-Pagan chi-square
```

```r
write.table(summary(Meta.OLS.GSE.ALL)$coefficients, file = "OLSsummary.Scope.csv", row.names = T, append = T, sep = ",", col.names = NA)
```

# Probit regression

### Scale economies

$$\text{Probit.SRAY.ALL} = \text{D.SRAY} \sim \text{Year} + \text{Sample_size} + \text{Public} + \text{OECD} + \text{QCF} + \text{Efficiency} + \text{Enrolments} + \text{Research} + \text{Third_mission} + \text{Panel} + \text{Journal}$$

$$\#\text{Probit.SRAY.ALL} = \text{D.SRAY} \sim \text{Year} + \text{Sample_size} + \text{Public} + \text{OECD} + \text{QCF} + \text{Efficiency} + \text{Enrolments} + \text{Panel} + \text{Journal} + \text{Multiple}$$

$$\text{SRAY.probit} \leftarrow \text{glm}(\text{Probit.SRAY.ALL, data = MD, family = binomial(link = "probit")})$$

```r
summary(SRAY.probit)
```

```r
PseudoR2(SRAY.probit)  # choose McFadden following STATA outputs (see the interpretations via http://www.ats.ucla.edu/stat/stata/output/Stata_Probit.htm)
```

```r
lrtest(SRAY.probit)
```

```r
logLik(SRAY.probit)
```

```r
write.table(summary(SRAY.probit)$coefficients, file = "Probitsummary.Scale.csv", row.names = T, append = T, sep = ",", col.names = NA)
```

### Scope economies

$$\text{Probit.GSE.ALL} = \text{D.GSE} \sim \text{Year} + \text{Sample_size} + \text{Public} + \text{OECD} + \text{QCF} + \text{Efficiency} + \text{Enrolments} + \text{Research} + \text{Third_mission} + \text{Panel} + \text{Journal}$$

$$\#\text{Probit.GSE.ALL} = \text{D.GSE} \sim \text{Year} + \text{Sample_size} + \text{Public} + \text{OECD} + \text{QCF} + \text{Efficiency} + \text{Enrolments} + \text{Panel} + \text{Journal} + \text{Multiple}$$

$$\text{GSE.probit} \leftarrow \text{glm}(\text{Probit.GSE.ALL, data = MD, family = binomial(link = "probit")})$$

```r
summary(GSE.probit)
```

```r
PseudoR2(GSE.probit)  # choose McFadden following STATA outputs (see the interpretations via http://www.ats.ucla.edu/stat/stata/output/Stata_Probit.htm)
```

```r
lrtest(GSE.probit)
```
logLik(GSE.probit)
write.table(summary(GSE.probit)$coefficients, file =
"Probitsummary.Scope.csv", row.names = T, append = T, sep = ",", col.names = NA)

#End of the code-----------------------------------------------------------
Appendix 2. Computer code for Chapter 4

```r
# The following R code is prepared for the paper:
# Zhang, L. -C. & Worthington, A.C. Scale and scope economies of distance education in Australian universities, Studies in Higher Education. DOI: 10.1080/03075079.2015.1126817
# Code developer: Liang-Cheng Zhang

#Variables----------------------------------------------------------------
#y1=On-campus education completions (n)
#y2=Distance-education completions (n)
#y3=Multi-modal completions (n)
#y4=Number of publications (n)
#w1=Price of academic labor ($000s)
#w2=Price of academic labor ($000s)
#w3=Price of non-labor ($000s)
#q=Attrition rate (%)

#import data---------------------------------------------------------------
#You should replace uni0312_AM6.csv with your data file
unidat=read.csv("uni0312_AM6.csv", header=T)

#Modified quadratic cost function
args(nls)
#add attrition rate, no q ,allianze (z),state(g), wi is the numeriate price.
#Coefficient notations follow equation
NLSlhwlzugl<-nls(log(c)~log(b0+b1*y1+b2*y2+b3*y3+b4*y4+b11*(0.5*y1^2)+b22*(0.5*y2^2)+b33*(0.5*y3^2)+b44*(0.5*y4^2)+b12*(y1*y2)+b13*(y1*y3)+b14*(y1*y4)+b23*(y2*y3)+b24*(y2*y4)+b34*(y3*y4))+log(w1)+bp2*log(w2/w1)+bp3*log(w3/w1)+bd1*z1+bd2*z2+bd3*z3+bd4*z4+bgl1*g1+bgl2*g2+bgl3*g3+bgl4*g4+bgl5*g5+bgl6*g6+bgl7*g7+bgl8*g8,stats=list(b0=999,b1=0,b2=0,b3=0,b4=0,b11=0,b22=0,b33=0,b44=0,b12=0,b13=0,b14=0,b23=0,b24=0,b34=0,bp3=0,bp2=0,bd1=0,bd2=0,bd3=0,bd4=0,bgl1=0,bgl2=0,bgl3=0,bgl4=0,bgl5=0,bgl6=0,bgl7=0,bgl8=0),data=unidat,trace=TRUE)
summary(NLSlhwlzugl)
#add attrition rate, q ,allianze (z),state(g)
```

171
Economies of Scale and Scope in Higher Education

NLS1hw1qzg1 <- nls(log(c) ~ log(b0 + b1*y1 + b2*y2 + b3*y3 + b4*y4 + b11*(0.5*y1^2) + b22*(0.5*y2^2) + b33*(0.5*y3^2) + b44*(0.5*y4^2) + b12*(y1*y2) + b13*(y1*y3) + b14*(y1*y4) + b23*(y2*y3) + b24*(y2*y4) + b34*(y3*y4)) + log(w1) + bp2*log(w2/w1) + bp3*log(w3/w1) + bd1*z1 + bd2*z2 + bd3*z3 + bd4*z4 + bg1*g1 + bg2*g2 + bg3*g3 + bg4*g4 + bg5*g5 + bg6*g6 + bg7*g7 + bg8*g8 + bg9*q + start=list(b0=999, b1=0, b2=0, b3=0, b4=0, b11=0, b12=0, b13=0, b14=0, b23=0, b24=0, b34=0, bp2=0, bp3=0, bp4=0, bp5=0, bp6=0, bp7=0, bp8=0, bp9=0), data=unidat, trace=TRUE)

summary(NLS1hw1qzg1)

#compare estimates and t values between two models-------------------------
NLSvsNLSq <- cbind(NLSco=round(coef(NLS1hw1zg1), digits=5), NLSt=round(summary(NLS1hw1zg1)$coef[, "t value"], digits=5), NLSqco=round(coef(NLS1hw1qzg1), digits=5), NLSqt=round(coef(summary(NLS1hw1qzg1))[, "t value"], digits=5))
write.table(NLSvsNLSq, file = "NLSvsNLSq.csv", row.names = T, append=T, sep = "", col.names = NA)

#code for calculating scale and scope economies for mean level of output---
#I use a model with attrition rates as an example.
model<-NLS1hw1qzg1

#the following code is used to extract the coefficients from the estimated model
b0<- coef(model)["b0"]
b1<- coef(model)["b1"]
b2<- coef(model)["b2"]
b3<- coef(model)["b3"]
b4<- coef(model)["b4"]
b11<- coef(model)["b11"]
b22<- coef(model)["b22"]
b33<- coef(model)["b33"]
b44<- coef(model)["b44"]
b12<- coef(model)["b12"]
b13<- coef(model)["b13"]
b14<- coef(model)["b14"]
b23<- coef(model)["b23"]
b24<- coef(model)["b24"]
b34<- coef(model)["b34"]
#bp1<- coef(model)["bp1"]
bp2<- coef(model)["bp2"]
bp3<- coef(model)["bp3"]
bp1<- 1- bp2- bp3
bq<- coef(model)["bq"]
bd1<- coef(model)["bd1"]
bd2<- coef(model)["bd2"]
bd3<- coef(model)["bd3"]
bd4<- coef(model)["bd4"]
bg1<- coef(model)["bg1"]
bg2<- coef(model)["bg2"]
bg3<- coef(model)["bg3"]
bg4<- coef(model)["bg4"]
bg5<- coef(model)["bg5"]
bg6<- coef(model)["bg6"]
bg7<- coef(model)["bg7"]
bg8<- coef(model)["bg8"]

#the followings codes are loops for calculating estimates from 50% to 300% levels
#at means
p<-0.25
repeat {
  p<-p+0.25
  if(p > 3) break;
  #percentage of output mean. For example, if p is 1, it means 100% of output mean
  my1<- mean(unidat$y1)*p
  my2<- mean(unidat$y2)*p
  my3<- mean(unidat$y3)*p
  my4<- mean(unidat$y4)*p
  mw1<- mean(unidat$w1)
  mw2<- mean(unidat$w2)
  mw3<- mean(unidat$w3)
  mq<- mean(unidat$q)
  mz1<- mean(unidat$z1)
  mz2<- mean(unidat$z2)
  mz3<- mean(unidat$z3)
  mz4<- mean(unidat$z4)
  mg1<- mean(unidat$g1)
  mg2<- mean(unidat$g2)
  mg3<- mean(unidat$g3)
mg4<-mean(unidat$g4)
mg5<-mean(unidat$g5)
mg6<-mean(unidat$g6)
mg7<-mean(unidat$g7)
mg8<-mean(unidat$g8)

#The followings codes are used to calculate different types of costs with the
#numbers calculated above
#Total costs
Tcost<-((b0+b1*my1+b2*my2+b3*my3+b4*my4+0.5*b11*my1^2+0.5*b22*my2^2+0.5*b33
*my3^2+0.5*b44*my4^2+b12*my1*my2+b13*my1*my3+b14*my1*my4+b23*my2*my3+b24*my
2*my4+b34*my3*my4)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz
3+bd4*mz4*bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8))

#marginal costs for producing y1
mcy1<-(b1+b11*my1+b12*my2+b13*my3+b14*my4)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4*bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8)

#marginal costs for producing y2
mcy2<-(b2+b22*my2+b12*my1+b23*my3+b24*my4)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4*bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8)

#marginal costs for producing y3
mcy3<-(b3+b33*my3+b13*my1+b23*my2+b34*my4)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4*bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8)

#marginal costs for producing y4
mcy4<-(b4+b44*my4+b14*my1+b24*my2+b34*my3)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4*bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8)

#incremental costs for y1
ICY1<-(b1*my1+0.5*b11*my1^2+b12*my1*my2+b13*my1*my3+b14*my1*my4)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4*bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8)
# Incremental costs for y2

\[ IC_{y2} = (b_{2}\cdot m_{y2} + 0.5\cdot b_{22}\cdot m_{y2}^2 + b_{12}\cdot m_{y1}\cdot m_{y2} + b_{23}\cdot m_{y2}\cdot m_{y3} + b_{24}\cdot m_{y2}\cdot m_{y4})\cdot m_{w1}\cdot b_{p1}\cdot m_{w2}\cdot b_{p2}\cdot m_{w3}\cdot b_{p3}\cdot \exp(b_{q}\cdot m_{q} + b_{d1}\cdot m_{z1} + b_{d2}\cdot m_{z2} + b_{d3}\cdot m_{z3} + b_{d4}\cdot m_{z4} + b_{g1}\cdot m_{g1} + b_{g2}\cdot m_{g2} + b_{g3}\cdot m_{g3} + b_{g4}\cdot m_{g4} + b_{g5}\cdot m_{g5} + b_{g6}\cdot m_{g6} + b_{g7}\cdot m_{g7} + b_{g8}\cdot m_{g8}) \]

# Incremental costs for y3

\[ IC_{y3} = (b_{3}\cdot m_{y3} + 0.5\cdot b_{33}\cdot m_{y3}^2 + b_{13}\cdot m_{y1}\cdot m_{y3} + b_{23}\cdot m_{y2}\cdot m_{y3} + b_{34}\cdot m_{y3}\cdot m_{y4})\cdot m_{w1}\cdot b_{p1}\cdot m_{w2}\cdot b_{p2}\cdot m_{w3}\cdot b_{p3}\cdot \exp(b_{q}\cdot m_{q} + b_{d1}\cdot m_{z1} + b_{d2}\cdot m_{z2} + b_{d3}\cdot m_{z3} + b_{d4}\cdot m_{z4} + b_{g1}\cdot m_{g1} + b_{g2}\cdot m_{g2} + b_{g3}\cdot m_{g3} + b_{g4}\cdot m_{g4} + b_{g5}\cdot m_{g5} + b_{g6}\cdot m_{g6} + b_{g7}\cdot m_{g7} + b_{g8}\cdot m_{g8}) \]

# Incremental costs for y4

\[ IC_{y4} = (b_{4}\cdot m_{y4} + 0.5\cdot b_{44}\cdot m_{y4}^2 + b_{14}\cdot m_{y1}\cdot m_{y4} + b_{24}\cdot m_{y2}\cdot m_{y4} + b_{34}\cdot m_{y3}\cdot m_{y4})\cdot m_{w1}\cdot b_{p1}\cdot m_{w2}\cdot b_{p2}\cdot m_{w3}\cdot b_{p3}\cdot \exp(b_{q}\cdot m_{q} + b_{d1}\cdot m_{z1} + b_{d2}\cdot m_{z2} + b_{d3}\cdot m_{z3} + b_{d4}\cdot m_{z4} + b_{g1}\cdot m_{g1} + b_{g2}\cdot m_{g2} + b_{g3}\cdot m_{g3} + b_{g4}\cdot m_{g4} + b_{g5}\cdot m_{g5} + b_{g6}\cdot m_{g6} + b_{g7}\cdot m_{g7} + b_{g8}\cdot m_{g8}) \]

# Costs of producing output y1

\[ C_{y1} = (b_{0} + b_{1}\cdot m_{y1} + 0.5\cdot b_{11}\cdot m_{y1}^2)\cdot m_{w1}\cdot b_{p1}\cdot m_{w2}\cdot b_{p2}\cdot m_{w3}\cdot b_{p3}\cdot \exp(b_{q}\cdot m_{q} + b_{d1}\cdot m_{z1} + b_{d2}\cdot m_{z2} + b_{d3}\cdot m_{z3} + b_{d4}\cdot m_{z4} + b_{g1}\cdot m_{g1} + b_{g2}\cdot m_{g2} + b_{g3}\cdot m_{g3} + b_{g4}\cdot m_{g4} + b_{g5}\cdot m_{g5} + b_{g6}\cdot m_{g6} + b_{g7}\cdot m_{g7} + b_{g8}\cdot m_{g8}) \]

# Costs of producing output y2

\[ C_{y2} = (b_{0} + b_{2}\cdot m_{y2} + 0.5\cdot b_{22}\cdot m_{y2}^2)\cdot m_{w1}\cdot b_{p1}\cdot m_{w2}\cdot b_{p2}\cdot m_{w3}\cdot b_{p3}\cdot \exp(b_{q}\cdot m_{q} + b_{d1}\cdot m_{z1} + b_{d2}\cdot m_{z2} + b_{d3}\cdot m_{z3} + b_{d4}\cdot m_{z4} + b_{g1}\cdot m_{g1} + b_{g2}\cdot m_{g2} + b_{g3}\cdot m_{g3} + b_{g4}\cdot m_{g4} + b_{g5}\cdot m_{g5} + b_{g6}\cdot m_{g6} + b_{g7}\cdot m_{g7} + b_{g8}\cdot m_{g8}) \]

# Costs of producing output y3

\[ C_{y3} = (b_{0} + b_{3}\cdot m_{y3} + 0.5\cdot b_{33}\cdot m_{y3}^2)\cdot m_{w1}\cdot b_{p1}\cdot m_{w2}\cdot b_{p2}\cdot m_{w3}\cdot b_{p3}\cdot \exp(b_{q}\cdot m_{q} + b_{d1}\cdot m_{z1} + b_{d2}\cdot m_{z2} + b_{d3}\cdot m_{z3} + b_{d4}\cdot m_{z4} + b_{g1}\cdot m_{g1} + b_{g2}\cdot m_{g2} + b_{g3}\cdot m_{g3} + b_{g4}\cdot m_{g4} + b_{g5}\cdot m_{g5} + b_{g6}\cdot m_{g6} + b_{g7}\cdot m_{g7} + b_{g8}\cdot m_{g8}) \]

# Costs of producing output y4

\[ C_{y4} = (b_{0} + b_{4}\cdot m_{y4} + 0.5\cdot b_{44}\cdot m_{y4}^2)\cdot m_{w1}\cdot b_{p1}\cdot m_{w2}\cdot b_{p2}\cdot m_{w3}\cdot b_{p3}\cdot \exp(b_{q}\cdot m_{q} + b_{d1}\cdot m_{z1} + b_{d2}\cdot m_{z2} + b_{d3}\cdot m_{z3} + b_{d4}\cdot m_{z4} + b_{g1}\cdot m_{g1} + b_{g2}\cdot m_{g2} + b_{g3}\cdot m_{g3} + b_{g4}\cdot m_{g4} + b_{g5}\cdot m_{g5} + b_{g6}\cdot m_{g6} + b_{g7}\cdot m_{g7} + b_{g8}\cdot m_{g8}) \]

# Costs of producing all the products except for the product y1

\[ C_{y1} = (b_{0} + b_{2}\cdot m_{y2} + b_{3}\cdot m_{y3} + b_{4}\cdot m_{y4} + 0.5\cdot b_{22}\cdot m_{y2}^2 + 0.5\cdot b_{33}\cdot m_{y3}^2 + 0.5\cdot b_{44}\cdot m_{y4}^2 + \ldots) \]
Economies of Scale and Scope in Higher Education

b23*my2*my3+b24*my4+b34*my3*my4)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4+bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8))

# costs of producing all the products except for the product y2
Cy_2<-(b0+b1*my1+b3*my3+b4*my4+0.5*b11*my1^2+b33*my3^2+0.5*b44*my4^2+b13*my1*my3+b2*my2*b4*my2+0.5*b11*my1^2+b33*my3^2+0.5*b44*my4^2)

# costs of producing all the products except for the product y3
Cy_3<-(b0+b1*my1+b2*my2+b3*my3+b4*my4+0.5*b11*my1^2+b22*my2^2+b33*my3^2+b44*my4^2+b12*my1*my2+b14*my1*my4+b24*my2*my4)

# costs of producing all the products except for the product y4
Cy_4<-(b0+b1*my1+b2*my2+b3*my3+b4*my4+0.5*b11*my1^2+b22*my2^2+b33*my3^2+b44*my4^2)

# the following codes are used to calculate the degree of scale and scope economies with the estimated parameters and sample data
SRAY<-Tcost/(my1*mcy1+my2*mcy2+my3*mcy3+my4*mcy4) # Ray Scale Economies
Sy1<-ICy1/(my1*mcy1) # product-specific scale economies for y1
Sy2<-ICy2/(my2*mcy2) # product-specific scale economies for y2
Sy3<-ICy3/(my3*mcy3) # product-specific scale economies for y3
Sy4<-ICy4/(my4*mcy4) # product-specific scale economies for y4
GSE<-(Cy1+Cy2+Cy3+Cy4-Tcost)/Tcost # Global Scope Economies
PSEy1<-(Cy1+Cy_1-Tcost)/Tcost # product-specific scope economies for y1
PSEy2<-(Cy2+Cy_2-Tcost)/Tcost # product-specific scope economies for y2
PSEy3<-(Cy3+Cy_3-Tcost)/Tcost # product-specific scope economies for y3
PSEy4<-(Cy4+Cy_4-Tcost)/Tcost # product-specific scope economies for y4
measures<-cbind(Sy1, Sy2, Sy3, GSE, PSEy1, PSEy2, PSEy3, PSEy4, mcy1, mcy2, mcy3, mcy4, ICy1/my1, ICy2/my2, ICy3/my3, ICy4/my4, Tcost)
write.table(measures, file = "estimates of scale and scope economies.csv", row.names = p, append=T, sep = " ", col.names = NA)
} #End of the code---------------------------------------------------------------
Appendix 3. Computer code for Chapter 5

##########################################################################
## The following R code is prepared for the paper:
## provision of higher education for international students: Australian
## Code developer: Liang-Cheng Zhang
## The following code uses the model with Broad Field of Education outputs as
## an example
##########################################################################

# Variables ---------------------------------------------------------------
#y1= Domestic science completions
#y2= Domestic non-science completions
#y3= Overseas science completions
#y4= Overseas non-science completions
#y5= Number of publications
#w1=Price of academic labor ($000s)
#w2=Price of academic labor ($000s)
#w3=Price of non-labor ($000s)
#q=Attrition rate (%)

# Install packages --------------------------------------------------------
install.packages("psych")
install.packages("minpack.lm")
install.packages("car")

#import data
You should replace uni0312_CO5_fieldEdu.csv with your data file
unidat = read.csv("uni0312_CO5_fieldEdu.csv", header = T)
K <- 36 #number of variables (including intercepts)(bw1 does not could since
#it is 1-bw2-bw3)

library("psych")
describe(unidat)
write.table(describe(unidat), file = "summary.csv", row.names = T, append =
T,sep = ",", col.names = NA)
library(minpack.lm)

O5.NLSlhw1qzg1 <- nlsLM(log(c) ~ log(b0 + b1*y1 + b2*y2 + b3*y3 + b4*y4 + b5*y5 + b11*(0.5*y1^2) + b22*(0.5*y2^2) + b33*(0.5*y3^2) + b44*(0.5*y4^2) + b55*(0.5*y5^2) + b12*(y1*y2) + b13*(y1*y3) + b14*(y1*y4) + b15*(y1*y5) + b23*(y2*y3) + b24*(y2*y4) + b25*(y2*y5) + b34*(y3*y4) + b35*(y3*y5) + b45*(y4*y5)) + log(w1) + bp2*log(w2/w1) + bp3*log(w3/w1) + bp4*log(w4/w1) + bp5*log(w5/w1) + bp6*log(w6/w1) + bp7*log(w7/w1) + bp8*log(w8/w1), start=list(b0=600, b1=0, b2=0, b3=0, b4=0, b5=0, b11=0, b22=0, b33=0, b44=0, b55=0, b12=0, b13=0, b14=0, b15=0, b23=0, b24=0, b25=0, b34=0, b35=0, b45=0, bp2=0, bp3=0, bp4=0, bp5=0, bp6=0, bp7=0, bp8=0), data=unidat, trace=TRUE)

summary(O5.NLSlhw1qzg1)

# Calculating clustering sd ---------------------------------------------

## One way

model = O5.NLSlhw1qzg1
cluster = unidat$unicode

M <- length(unique(cluster))
dfcw <- model$df / (model$df - (M - 1))

clx <- function(fm, dfcw, cluster){
  library(sandwich)
  library(lmtest)
  M <- length(unique(cluster))
  N <- length(cluster)
  dfc <- (M/(M - 1)) * ((N - 1)/(N - K)) # K (regressors which should depends on model) should be fm$rank. it is done since there is no rank argument in NLS
  u <- apply(estfun(fm), 2, function(x) tapply(x, cluster, sum))
  vcovCL <- dfc*sandwich(fm, meat = crossprod(u)/N)*dfcw
  coeftest(fm, vcovCL)
}

Model.test <- clx(model, 1, unidat$unicode) # dfcw=1 Set this argument to 1 when such a degree of freedom correction is not necessary. follows p5 of http://www.ne.su.se/polopoly_fs/1.216115.1426234213!/menu/standard/file/clustering1.pdf

# Export estimates and t values

model <- model
NLS <- cbind(NLSco = round(coef(model), digits = 4),
            NLSt = round(Model.test[,3] # for extracting clustering t test,
                      digits = 4))
write.table(NLS, file = "NLS.csv", row.names = T, append = T, sep = ", ", col.names = NA)

# Function for extracting vcovCL ------------------------------------------
## One Way
clx.vcov <- function(fm, dfcw, cluster){
  library(sandwich)
  library(lmtest)
  M <- length(unique(cluster))
  N <- length(cluster)
  dfc <- (M/(M - 1))*((N - 1)/(N - K))
  u <- apply(estfun(fm),2,
             function(x) tapply(x, cluster, sum))
  vcovCL <- dfc*sandwich(fm, meat = crossprod(u)/N)*dfcw
}
vcovCL <- clx.vcov(model, 1, unidat$unicode)

# Model diagnostics -----------------------------------------------------
Model<-O5.NLSlhw1qzg1
## residual normality test -----------------------------------------------
shapiro.test(residuals(Model))
## Runs Test for autocorrelation ----------------------------------------
library(nlstools)
test.nlsResiduals(nlsResiduals(Model)) #(Baty et al., 2015:12)

# code for calculating scale and scope economies for mean level of outputs
library(car)
model <- O5.NLSlhw1qzg1
vcovCL <- vcovCL
O <- nrow(unidat) # number of observations
# the following codes are used to extract the coefficients from the estimated model
# bp1 <- coef(model)["bp1"]
bp2 <- coef(model)["bp2"]
bp3 <- coef(model)["bp3"]
bp1 <- 1 – bp2 – bp3 #the above code is prepared for bp1 since deltamethod cannot
#extract it from the model.

#The followings codes are loops for calculating estimates from 50% to 300% levels
#at means
#percentage of output mean. For example, if p is 1, it means 100% of output mean
p <- 0
repeat {
p <- p + 0.25
if (p > 2) break;
my1 <- mean(unidat$y1)*p
my2 <- mean(unidat$y2)*p
my3 <- mean(unidat$y3)*p
my4 <- mean(unidat$y4)*p
my5 <- mean(unidat$y5)*p
mw1 <- mean(unidat$w1)
mw2 <- mean(unidat$w2)
mw3 <- mean(unidat$w3)
mq <- mean(unidat$q)
mz1 <- mean(unidat$z1)
mz2 <- mean(unidat$z2)
mz3 <- mean(unidat$z3)
mz4 <- mean(unidat$z4)
mq1 <- mean(unidat$g1)
mq2 <- mean(unidat$g2)
mq3 <- mean(unidat$g3)
mq4 <- mean(unidat$g4)
mq5 <- mean(unidat$g5)
mq6 <- mean(unidat$g6)
mq7 <- mean(unidat$g7)
mq8 <- mean(unidat$g8)

#the followings codes are used to calculate different types of costs with the
#numbers calculated above

#Total costs
Tcost<-"((b0+b1*my1+b2*my2+b3*my3+b4*my4+b5*my5+0.5*b11*my1^2+0.5*b22*my2^2
+0.5*b33*my3^2+0.5*b44*my4^2+0.5*b55*my5^2+b12*my1*my2+b13*my1*my3+b14*my1*
my4+b15*my1*my5+b23*my2*my3+b24*my2*my4+b25*my2*my5+b34*my3*my4+b35*my3*my5
+b45*my4*my5+b56*my5^2+b67*my6^2+b78*my7^2+b89*my8^2)"
Economies of Scale and Scope in Higher Education

+m45*my4*my5)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4+bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8))"

#marginal costs for producing y1
mcy1<"(b1+b11*my1+b12*my2+b13*my3+b14*my4+b15*my5)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4+bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8)"

#marginal costs for producing y2
mcy2<"(b2+b22*my2+b12*my1+b23*my3+b24*my4+b25*my5)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4+bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8)"

#marginal costs for producing y3
mcy3<"(b3+b33*my3+b13*my1+b23*my2+b34*my4+b35*my5)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4+bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8)"

#marginal costs for producing y4
mcy4<"(b4+b44*my4+b14*my1+b24*my2+b34*my3+b45*my5)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4+bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8)"

#marginal costs for producing y5
mcy5<"(b5+b55*my5+b15*my1+b25*my2+b35*my3+b45*my4)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4+bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8)"

# incremental costs for y1
ICy1<"(b1*my1+0.5*b11*my1^2+b12*my1*my2+b13*my1*my3+b14*my1*my4+b15*my1*my5)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4+bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8)"

#incremental costs for y2
ICy2<"(b2*my2+0.5*b22*my2^2+b12*my1*my2+b23*my2*my3+b24*my2*my4+b25*my2*my5)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4+bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8)"
#incremental costs for y3
\[
IC_y3 := (b_3 \times m_3 + 0.5 \times b_{33} \times m_3^2 + b_{13} \times m_1 \times m_3 + b_{23} \times m_2 \times m_3 + b_{34} \times m_3 \times m_4 + b_{35} \times m_3 \times m_5) \times m_{w1}^{b_{p1}} \times m_{w2}^{b_{p2}} \times m_{w3}^{b_{p3}} \times \exp(b_{q} \times m_{q} + b_{d1} \times m_{z1} + b_{d2} \times m_{z2} + b_{d3} \times m_{z3} + b_{d4} \times m_{z4} + b_{g1} \times m_{g1} + b_{g2} \times m_{g2} + b_{g3} \times m_{g3} + b_{g4} \times m_{g4} + b_{g5} \times m_{g5} + b_{g6} \times m_{g6} + b_{g7} \times m_{g7} + b_{g8} \times m_{g8})
\]

#incremental costs for y4
\[
IC_y4 := (b_4 \times m_4 + 0.5 \times b_{44} \times m_4^2 + b_{14} \times m_1 \times m_4 + b_{24} \times m_2 \times m_4 + b_{34} \times m_3 \times m_4 + b_{45} \times m_4 \times m_5) \times m_{w1}^{b_{p1}} \times m_{w2}^{b_{p2}} \times m_{w3}^{b_{p3}} \times \exp(b_{q} \times m_{q} + b_{d1} \times m_{z1} + b_{d2} \times m_{z2} + b_{d3} \times m_{z3} + b_{d4} \times m_{z4} + b_{g1} \times m_{g1} + b_{g2} \times m_{g2} + b_{g3} \times m_{g3} + b_{g4} \times m_{g4} + b_{g5} \times m_{g5} + b_{g6} \times m_{g6} + b_{g7} \times m_{g7} + b_{g8} \times m_{g8})
\]

#incremental costs for y5
\[
IC_y5 := (b_5 \times m_5 + 0.5 \times b_{55} \times m_5^2 + b_{15} \times m_1 \times m_5 + b_{25} \times m_2 \times m_5 + b_{35} \times m_3 \times m_5 + b_{45} \times m_4 \times m_5) \times m_{w1}^{b_{p1}} \times m_{w2}^{b_{p2}} \times m_{w3}^{b_{p3}} \times \exp(b_{q} \times m_{q} + b_{d1} \times m_{z1} + b_{d2} \times m_{z2} + b_{d3} \times m_{z3} + b_{d4} \times m_{z4} + b_{g1} \times m_{g1} + b_{g2} \times m_{g2} + b_{g3} \times m_{g3} + b_{g4} \times m_{g4} + b_{g5} \times m_{g5} + b_{g6} \times m_{g6} + b_{g7} \times m_{g7} + b_{g8} \times m_{g8})
\]

#costs of producing output y1
\[
Cy_1 := (b_0 + b_1 \times m_1 + 0.5 \times b_{11} \times m_1^2) \times m_{w1}^{b_{p1}} \times m_{w2}^{b_{p2}} \times m_{w3}^{b_{p3}} \times \exp(b_{q} \times m_{q} + b_{d1} \times m_{z1} + b_{d2} \times m_{z2} + b_{d3} \times m_{z3} + b_{d4} \times m_{z4} + b_{g1} \times m_{g1} + b_{g2} \times m_{g2} + b_{g3} \times m_{g3} + b_{g4} \times m_{g4} + b_{g5} \times m_{g5} + b_{g6} \times m_{g6} + b_{g7} \times m_{g7} + b_{g8} \times m_{g8})
\]

#costs of producing output y2
\[
Cy_2 := (b_0 + b_2 \times m_2 + 0.5 \times b_{22} \times m_2^2) \times m_{w1}^{b_{p1}} \times m_{w2}^{b_{p2}} \times m_{w3}^{b_{p3}} \times \exp(b_{q} \times m_{q} + b_{d1} \times m_{z1} + b_{d2} \times m_{z2} + b_{d3} \times m_{z3} + b_{d4} \times m_{z4} + b_{g1} \times m_{g1} + b_{g2} \times m_{g2} + b_{g3} \times m_{g3} + b_{g4} \times m_{g4} + b_{g5} \times m_{g5} + b_{g6} \times m_{g6} + b_{g7} \times m_{g7} + b_{g8} \times m_{g8})
\]

#costs of producing output y3
\[
Cy_3 := (b_0 + b_3 \times m_3 + 0.5 \times b_{33} \times m_3^2) \times m_{w1}^{b_{p1}} \times m_{w2}^{b_{p2}} \times m_{w3}^{b_{p3}} \times \exp(b_{q} \times m_{q} + b_{d1} \times m_{z1} + b_{d2} \times m_{z2} + b_{d3} \times m_{z3} + b_{d4} \times m_{z4} + b_{g1} \times m_{g1} + b_{g2} \times m_{g2} + b_{g3} \times m_{g3} + b_{g4} \times m_{g4} + b_{g5} \times m_{g5} + b_{g6} \times m_{g6} + b_{g7} \times m_{g7} + b_{g8} \times m_{g8})
\]

#costs of producing output y4
\[
Cy_4 := (b_0 + b_4 \times m_4 + 0.5 \times b_{44} \times m_4^2) \times m_{w1}^{b_{p1}} \times m_{w2}^{b_{p2}} \times m_{w3}^{b_{p3}} \times \exp(b_{q} \times m_{q} + b_{d1} \times m_{z1} + b_{d2} \times m_{z2} + b_{d3} \times m_{z3} + b_{d4} \times m_{z4} + b_{g1} \times m_{g1} + b_{g2} \times m_{g2} + b_{g3} \times m_{g3} + b_{g4} \times m_{g4} + b_{g5} \times m_{g5} + b_{g6} \times m_{g6} + b_{g7} \times m_{g7} + b_{g8} \times m_{g8})
\]

#costs of producing output y5
\[
Cy_5 := (b_0 + b_5 \times m_5 + 0.5 \times b_{55} \times m_5^2) \times m_{w1}^{b_{p1}} \times m_{w2}^{b_{p2}} \times m_{w3}^{b_{p3}} \times \exp(b_{q} \times m_{q} + b_{d1} \times m_{z1} + b_{d2} \times m_{z2} + b_{d3} \times m_{z3} + b_{d4} \times m_{z4} + b_{g1} \times m_{g1} + b_{g2} \times m_{g2} + b_{g3} \times m_{g3} + b_{g4} \times m_{g4} + b_{g5} \times m_{g5} + b_{g6} \times m_{g6} + b_{g7} \times m_{g7} + b_{g8} \times m_{g8})
\]
Economies of Scale and Scope in Higher Education

d2*mz2+bd3*mz3+bd4*mz4+bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8"

#costs of producing all the products except for the product y1
Cy_1<="((b0+b2*my2+b3*my3+b4*my4+b5*my5+0.5*b22*my2^2+0.5*b33*my3^2+0.5*b44*my4^2+0.5*b55*my5^2+my2*my3+my2*my4+my2*my5+b24*my2*my4+b25*my2*my5+b34*my3*my4+b35*my3*my5+b45*my4*my5)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4+bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8))"

#costs of producing all the products except for the product y2
Cy_2<="((b0+b1*my1+b3*my3+b4*my4+b5*my5+0.5*b11*my1^2+0.5*b33*my3^2+0.5*b44*my4^2+0.5*b55*my5^2+my1*my3+my1*my4+my1*my5+b13*my1*my3+b14*my1*my4+b15*my1*my5+b24*my2*my4+b25*my2*my5+b34*my3*my4+b35*my3*my5+b45*my4*my5)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4+bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8))"

#costs of producing all the products except for the product y3
Cy_3<="((b0+b1*my1+b2*my2+b4*my4+b5*my5+0.5*b11*my1^2+0.5*b22*my2^2+0.5*b44*my4^2+0.5*b55*my5^2+my1*my2+my1*my4+my1*my5+b12*my1*my2+b13*my1*my3+b14*my1*my4+b15*my1*my5+b24*my2*my4+b25*my2*my5+b34*my3*my4+b35*my3*my5+b45*my4*my5)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4+bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8))"

#costs of producing all the products except for the product y4
Cy_4<="((b0+b1*my1+b2*my2+b3*my3+b4*my4+b5*my5+0.5*b11*my1^2+0.5*b22*my2^2+0.5*b33*my3^2+0.5*b44*my4^2+0.5*b55*my5^2+my1*my2+my1*my3+my1*my4+my1*my5+b12*my1*my2+b13*my1*my3+b14*my1*my4+b15*my1*my5+b23*my2*my3+b24*my2*my4+b25*my2*my5+b34*my3*my4+b35*my3*my5+b45*my4*my5)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4+bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8))"

#costs of producing all the products except for the product y5
Cy_5<="((b0+b1*my1+b2*my2+b3*my3+b4*my4+b5*my5+0.5*b11*my1^2+0.5*b22*my2^2+0.5*b33*my3^2+0.5*b44*my4^2+0.5*b55*my5^2+my1*my2+my1*my3+my1*my4+my1*my5+b13*my1*my3+b14*my1*my4+b15*my1*my5+b23*my2*my3+b24*my2*my4+b25*my2*my5+b34*my3*my4+b35*my3*my5+b45*my4*my5)*mw1^bp1*mw2^bp2*mw3^bp3*exp(bq*mq+bd1*mz1+bd2*mz2+bd3*mz3+bd4*mz4+bg1*mg1+bg2*mg2+bg3*mg3+bg4*mg4+bg5*mg5+bg6*mg6+bg7*mg7+bg8*mg8))"
# the following codes are used to calculate the degree of scale and scope economies
# with the estimated parameters and sample data

```r
parameterNames = list(paste("b", 0:67, sep = ""), paste("bp", 1:3, sep = ""), "bq", paste("bd", 1:4, sep = ""), paste("bg", 1:8, sep = ""))

# MC for y1
MCy1 <- deltaMethod(coef(model), mcy1, parameterNames = parameterNames, vcov. = vcovCL)

# MC for y2
MCy2 <- deltaMethod(coef(model), mcy2, parameterNames = parameterNames, vcov. = vcovCL)

# MC for y3
MCy3 <- deltaMethod(coef(model), mcy3, parameterNames = parameterNames, vcov. = vcovCL)

# MC for y4
MCy4 <- deltaMethod(coef(model), mcy4, parameterNames = parameterNames, vcov. = vcovCL)

# MC for y5
MCy5 <- deltaMethod(coef(model), mcy5, parameterNames = parameterNames, vcov. = vcovCL)

# Difference test between MCy1 and MCy3
D.MCy1_3 <- deltaMethod(coef(model), paste(mcy1, "-", mcy3, sep = ""), parameterNames = parameterNames, vcov. = vcovCL)
D.MCy1_3Lo <- D.MCy1_3$Estimate - qt(0.975, df = O - K) * D.MCy1_3$SE
D.MCy1_3Hi <- D.MCy1_3$Estimate + qt(0.975, df = O - K) * D.MCy1_3$SE

# Difference test between MCy2 and MCy4
D.MCy2_4 <- deltaMethod(coef(model), paste(mcy2, "-", mcy4, sep = ""), parameterNames = parameterNames, vcov. = vcovCL)
D.MCy2_4Lo <- D.MCy2_4$Estimate - qt(0.975, df = O - K) * D.MCy2_4$SE
D.MCy2_4Hi <- D.MCy2_4$Estimate + qt(0.975, df = O - K) * D.MCy2_4$SE

# AIC for y1
```

References
Economies of Scale and Scope in Higher Education

AICy1 <- deltaMethod(coef(model), paste(ICy1,"/",my1, sep = ""), parameterNames = parameterNames, vcov. = vcovCL)

#AIC for y2
AICy2 <- deltaMethod(coef(model), paste(ICy2,"/",my2, sep = ""), parameterNames = parameterNames, vcov. = vcovCL)

#AIC for y3
AICy3 <- deltaMethod(coef(model), paste(ICy3,"/",my3, sep = ""), parameterNames = parameterNames, vcov. = vcovCL)

#AIC for y4
AICy4 <- deltaMethod(coef(model), paste(ICy4,"/",my4, sep = ""), parameterNames = parameterNames, vcov. = vcovCL)

#AIC for y5
AICy5 <- deltaMethod(coef(model), paste(ICy5,"/",my5, sep = ""), parameterNames = parameterNames, vcov. = vcovCL)

#Difference test between AICy1 and AICy3
D.AICy1_3 <- deltaMethod(coef(model), paste("(" , ICy1,"/",my1,"" )" , "-" , "(" , ICy3,"/",my3,"" )" , sep="" ), parameterNames= parameterNames, vcov. = vcovCL)
D.AICy1_3Lo <- D.AICy1_3$Estimate - qt(0.975,df = O - K)*D.AICy1_3$SE
D.AICy1_3Hi <- D.AICy1_3$Estimate + qt(0.975,df = O - K)*D.AICy1_3$SE

#Difference test between AICy2 and AICy4
D.AICy2_4 <- deltaMethod(coef(model), paste("(" , ICy2,"/",my2,"" )" , "-" , "(" , ICy4,"/",my4,"" )" , sep="" ), parameterNames= parameterNames, vcov. = vcovCL)
D.AICy2_4Lo <- D.AICy2_4$Estimate - qt(0.975,df = O - K)*D.AICy2_4$SE
D.AICy2_4Hi <- D.AICy2_4$Estimate + qt(0.975,df = O - K)*D.AICy2_4$SE

#Ray Scale Economies
SRAY <- deltaMethod(coef(model),
paste(Tcost,"/" , "my1","+" , mcy1,"+" , my2,"+" , mcy2,"+" , my3,"+" , mcy3,"+" , my4,"+" , mcy4,"+" , my5,"+" , mcy5,"" ), sep="" ), parameterNames= parameterNames, vcov. = vcovCL)
SRAYLo <- SRAY$Estimate-qt(0.975,df=O-K)*SRAY$SE
SRAYHi <- SRAY$Estimate+qt(0.975,df=O-K)*SRAY$SE
# product-specific scale economies for y1
Sy1 <- deltaMethod(coef(model), paste(ICy1,"/\(m_1,m_2,\ldots,m_5\)\), sep=""),
parameterNames= parameterNames, vcov. = vcovCL)
Sy1Lo <- Sy1$Estimate-qt(0.975,df=O-K)*Sy1$SE
Sy1Hi <- Sy1$Estimate+qt(0.975,df=O-K)*Sy1$SE

# product-specific scale economies for y2
Sy2<-deltaMethod(coef(model), paste(ICy2,"/\(m_1,m_2,\ldots,m_5\)\), sep=""),
parameterNames= parameterNames, vcov. = vcovCL)
Sy2Lo<-Sy1$Estimate-qt(0.975,df=O-K)*Sy2$SE
Sy2Hi<-Sy1$Estimate+qt(0.975,df=O-K)*Sy2$SE

# product-specific scale economies for y3
Sy3<-deltaMethod(coef(model), paste(ICy3,"/\(m_1,m_2,\ldots,m_5\)\), sep=""),
parameterNames= parameterNames, vcov. = vcovCL)
Sy3Lo<-Sy3$Estimate-qt(0.975,df=O-K)*Sy3$SE
Sy3Hi<-Sy3$Estimate+qt(0.975,df=O-K)*Sy3$SE

# product-specific scale economies for y4
Sy4<-deltaMethod(coef(model), paste(ICy4,"/\(m_1,m_2,\ldots,m_5\)\), sep=""),
parameterNames= parameterNames, vcov. = vcovCL)
Sy4Lo<-Sy4$Estimate-qt(0.975,df=O-K)*Sy4$SE
Sy4Hi<-Sy4$Estimate+qt(0.975,df=O-K)*Sy4$SE

# product-specific scale economies for y5
Sy5<-deltaMethod(coef(model), paste(ICy5,"/\(m_1,m_2,\ldots,m_5\)\), sep=""),
parameterNames= parameterNames, vcov. = vcovCL)
Sy5Lo<-Sy5$Estimate-qt(0.975,df=O-K)*Sy5$SE
Sy5Hi<-Sy5$Estimate+qt(0.975,df=O-K)*Sy5$SE

# Global Scope Economies
GSE<-deltaMethod(coef(model),
paste("\((\(m_1,m_2,\ldots,m_5\)-Tcost)/\), Tcost, \), sep=""), parameterNames= parameterNames, vcov. = vcovCL)
GSELo<-GSE$Estimate-qt(0.975,df=O-K)*GSE$SE
GSEHi<-GSE$Estimate+qt(0.975,df=O-K)*GSE$SE
# product-specific scope economies for \( y_1 \)
\[
PSEy1 <- \text{deltaMethod(coef(model), paste("(", Cy1,"+", Cy_1, ",-", Tcost, ")/", Tcost, sep=""), parameterNames= parameterNames, vcov. = vcovCL)} \\
PSEy1Lo <- PSEy1$Estimate - qt(0.975, df=O-K) * PSEy1$SE \\
PSEy1Hi <- PSEy1$Estimate + qt(0.975, df=O-K) * PSEy1$SE
\]

# product-specific scope economies for \( y_2 \)
\[
PSEy2 <- \text{deltaMethod(coef(model), paste("(", Cy2,"+", Cy_2, ",-", Tcost, ")/", Tcost, sep=""), parameterNames= parameterNames, vcov. = vcovCL)} \\
PSEy2Lo <- PSEy2$Estimate - qt(0.975, df=O-K) * PSEy2$SE \\
PSEy2Hi <- PSEy2$Estimate + qt(0.975, df=O-K) * PSEy2$SE
\]

# product-specific scope economies for \( y_3 \)
\[
PSEy3 <- \text{deltaMethod(coef(model), paste("(", Cy3,"+", Cy_3, ",-", Tcost, ")/", Tcost, sep=""), parameterNames= parameterNames, vcov. = vcovCL)} \\
PSEy3Lo <- PSEy3$Estimate - qt(0.975, df=O-K) * PSEy3$SE \\
PSEy3Hi <- PSEy3$Estimate + qt(0.975, df=O-K) * PSEy3$SE
\]

# product-specific scope economies for \( y_4 \)
\[
PSEy4 <- \text{deltaMethod(coef(model), paste("(", Cy4,"+", Cy_4, ",-", Tcost, ")/", Tcost, sep=""), parameterNames= parameterNames, vcov. = vcovCL)} \\
PSEy4Lo <- PSEy4$Estimate - qt(0.975, df=O-K) * PSEy4$SE \\
PSEy4Hi <- PSEy4$Estimate + qt(0.975, df=O-K) * PSEy4$SE
\]

# product-specific scope economies for \( y_5 \)
\[
PSEy5 <- \text{deltaMethod(coef(model), paste("(", Cy5,"+", Cy_5, ",-", Tcost, ")/", Tcost, sep=""), parameterNames= parameterNames, vcov. = vcovCL)} \\
PSEy5Lo <- PSEy5$Estimate - qt(0.975, df=O-K) * PSEy5$SE \\
PSEy5Hi <- PSEy5$Estimate + qt(0.975, df=O-K) * PSEy5$SE
\]

measures <- cbind(Sy1$Estimate, Sy2$Estimate, Sy3$Estimate, Sy4$Estimate, Sy5$Estimate, 
SRAY$Estimate, PSEy1$Estimate, PSEy2$Estimate, PSEy3$Estimate, PSEy4$Estimate, 
PSEy5$Estimate, PSEy6$Estimate, GSE$Estimate, MCy1$Estimate, MCy2$Estimate, 
MCy3$Estimate, MCy4$Estimate, MCy5$Estimate, D.MCy1_3$Estimate, 
D.MCy2_4$Estimate, AICy1$Estimate, AICy2$Estimate, AICy3$Estimate, 
AICy4$Estimate, AICy5$Estimate, D.AICy1_3$Estimate, D.AICy2_4$Estimate)
colnames(measures) <- c("Sy1", "Sy2", "Sy3", "Sy4", "Sy5", "SRAY")
"PSEy1", "PSEy2", "PSEy3", "PSEy4", "PSEy5", "GSE",
"MCy1", "MCy2", "MCy3", "MCy4", "MCy5", "D.MCy1_3", "D.MCy2_4",
"AICy1", "AICy2", "AICy3", "AICy4", "AICy5", "D.AICy1_3", "D.AICy2_4")
SE <- cbind(Sy1$SE, Sy2$SE, Sy3$SE, Sy4$SE, Sy5$SE, SRAY$SE,
PSEy1$SE, PSEy2$SE, PSEy3$SE, PSEy4$SE, PSEy5$SE, GSE$SE,
MCy1$SE, MCy2$SE, MCy3$SE, MCy4$SE, MCy5$SE, D.MCy1_3$SE, D.MCy2_4$SE,
AICy1$SE, AICy2$SE, AICy3$SE, AICy4$SE, AICy5$SE, D.AICy1_3$SE, D.AICy2_4$SE)
colnames(SE) <- c("Sy1", "Sy2", "Sy3", "Sy4", "Sy5", "SRAY",
"PSEy1", "PSEy2", "PSEy3", "PSEy4", "PSEy5", "GSE",
"MCy1", "MCy2", "MCy3", "MCy4", "MCy5", "D.MCy1_3", "D.MCy2_4",
"AICy1", "AICy2", "AICy3", "AICy4", "AICy5", "D.AICy1_3", "D.AICy2_4")
write.table(measures, file = "estimates of scale and scope economies.csv",
row.names = p, append = T, sep = " ", col.names = NA)
write.table(SE, file = "estimates SE of scale and scope economies.csv", row.names = p, append = T, sep = ", ", col.names = NA)

#Combining all results
measures <- cbind(p, Sy1$Estimate, Sy1Lo, Sy1Hi, Sy2$Estimate, Sy2Lo, Sy2Hi,
Sy3$Estimate, Sy3Lo, Sy3Hi, Sy4$Estimate, Sy4Lo, Sy4Hi, Sy5$Estimate, Sy5Lo,
Sy5Hi, D.MCy1_3$Estimate, D.MCy1_3Lo, D.MCy1_3Hi, D.MCy2_4$Estimate,
D.MCy2_4Lo, D.MCy2_4Hi, D.AICy1_3$Estimate, D.AICy1_3Lo, D.AICy1_3Hi,
D.AICy1_3Hi, D.AICy2_4$Estimate, D.AICy2_4Lo, D.AICy2_4Hi,
SRAY$Estimate, SRAYLo, SRAYHi, PSEy1$Estimate, PSEy1Lo,
PSEy1Hi, PSEy2$Estimate, PSEy2Lo, PSEy2Hi, PSEy3$Estimate, PSEy3Lo,
PSEy3Hi, PSEy4$Estimate, PSEy4Lo, PSEy4Hi, PSEy5$Estimate, PSEy5Lo, PSEy5Hi,
GSE$Estimate, GSELo, GSEHi)
write.table(measures, file = "point estimates of scale and scope economies and thier intervals.csv", row.names = F, append = T, sep = ", ", col.names = F)

#End of the code-----------------------------------------------------------
Appendix 4. Computer code for Chapter 6

#######The following R code is prepared for the paper:
#Zhang, L. -C. & Worthington, A. C. (2016). The impact of scale and scope on
global university rankings: What we know and what we need to learn. In K. Downing
#& F. A. Ganotice (Eds.), World university rankings and the future of higher
#Code developer: Liang-Cheng Zhang

# Install packages --------------------------------------------------------
install.packages("Hmisc")
install.packages("psych")

# Import Data -------------------------------------------------------------
ARWU = read.csv("ARWUTop100data.csv", header=T)
QS = read.csv("QSTop100data.csv", header=T)

# summary statistics for ARWU and QS --------------------------------------
library("psych")
write.table(describe(ARWU), file ="ARWU.csv", row.names = T, append=T,sep = ",
",col.names = NA)
write.table(describeBy(ARWU,ARWU$private,mat=T), file ="ARWUPri.csv",
row.names = T, append=T,sep = ",",col.names = NA)
write.table(describe(QS), file ="QS.csv", row.names = T, append=T,sep = ",
",col.names = NA)
write.table(describeBy(QS,QS$private,mat=T), file ="QSPri.csv", row.names = T,
append=T,sep = ",",col.names = NA)

# Modelling --------------------------------------------------------------
#Exclude intercept and add square term and interaction term(Quadratic form)
##Model for ARWU
ARWU$y1<-ARWU$enrollments/1000 #data for scale effect
ARWU$y2<-ARWU$Nprograms #data for scope effect
SJTQF<-lm(SJT$s~1+y1+y2+I(0.5*y1^2)+I(0.5*y2^2)+I(y1*y2), data=ARWU)
SJTQFsd<-summary(SJTQF)$coefficients[, 2]#extract std. dev.
summary(SJTQF)
SJTpubQF <- lm(SJTs ~ 1 + y1 + y2 + I(0.5*y1^2) + I(0.5*y2^2) + I(y1*y2),
data = subset (ARWU, private == 0))
SJTpubQFsd <- summary(SJTpubQF)$coefficients[, 2] # extract std. dev.
summary(SJTpubQF)
SJTpriQF <- lm(SJTs ~ 1 + y1 + y2 + I(0.5*y1^2) + I(0.5*y2^2) + I(y1*y2),
data = subset (ARWU, private == 1))
SJTpriQFsd <- summary(SJTpriQF)$coefficients[, 2] # extract std. dev.
summary(SJTpriQF)
SJT <- cbind(SJTQF = round(coef(SJTQF), digits = 5), SJTQFsd = round(SJTQFsd, digits = 5), SJTpubQF = round(coef(SJTpubQF), digits = 5), SJTpubQFsd = round(SJTpubQFsd, digits = 5), SJTpriQF = round(coef(SJTpriQF), digits = 5), SJTpriQFsd = round(SJTpriQFsd, digits = 5))
write.table(SJT, file = "SJT.csv", row.names = T, append = T, sep = " ", col.names = NA)

## Model for QS
QS$y1 <- QS$enrollments / 1000 # data for scale effect
QS$y2 <- QS$Nprograms # data for scope effect
QSQF <- lm(QSs ~ 1 + y1 + y2 + I(0.5*y1^2) + I(0.5*y2^2) + I(y1*y2), data = QS)
summary(QSQF)
QSQFsd <- summary(QSQF)$coefficients[, 2] # extract std. dev.
QSpubQF <- lm(QSs ~ 1 + y1 + y2 + I(0.5*y1^2) + I(0.5*y2^2) + I(y1*y2),
data = subset (QS, private == 0))
summary(QSpubQF)
QSpubQFsd <- summary(QSpubQF)$coefficients[, 2] # extract std. dev.
QSpriQF <- lm(QSs ~ 1 + y1 + y2 + I(0.5*y1^2) + I(0.5*y2^2) + I(y1*y2),
data = subset (QS, private == 1))
summary(QSpriQF)
QSpriQFsd <- summary(QSpriQF)$coefficients[, 2] # extract std. dev.
QSbind <- cbind(QSQF = round(coef(QSQF), digits = 5), QSQFsd = round(QSQFsd, digits = 5), QSpubQF = round(coef(QSpubQF), digits = 5), QSpubQFsd = round(QSpubQFsd, digits = 5), QSpriQF = round(coef(QSpriQF), digits = 5), QSpriQFsd = round(QSpriQFsd, digits = 5))
write.table(QSbind, file = "QS.csv", row.names = T, append = T, sep = ",", col.names = NA)
# Dotplots for comparing effects and without effects ----------------------

library(Hmisc)

# Dotplots for Private institutions

tiff(file="privateS.tiff", compression = "lzw", width=3200, height=2000, res=300) # for publisher requirement

N.ARWUpri<- ARWU[ which (ARWU$private=='1'),]
N.ARWUpri$SJTsRes<- resid(SJTpriQF)
N.QSpri<- QS[ which(QS$private=='1'),]
N.QSpri$QSsRes<- resid(QSpriQF)

layout(matrix(c(1,2,3,3), ncol=2, byrow=TRUE), heights=c(4, 1))

par(mar=c(2, 2,2,2),oma=c(1,2,1,1))
dotchart2(N.ARWUpri$SJTs, col="red", dotsize = 1.5,label=N.ARWUpri$Uni,pch=17,color="red",xlim=c(-30,100),main="ARWU ranking",sort=FALSE)
dotchart2(N.ARWUpri$SJTsRes,col="blue",dotsize = 1.5, pch=16, add=T)
dotchart2(N.QSpri$QSs, col="red",dotsize = 1.5,label=N.QSpri$Uni,pch=17,xlim=c(-30,100),main="QS ranking")
dotchart2(N.QSpri$QSsRes,col="blue",dotsize = 1.5, pch=16, add=T)
par(mai=c(0,0,0,0))

plot.new()

legend("top", legend = c("Scores without scale and scope effects", "Original scores"), pch=c(16,17), bty="n", col=c("blue","red"), horiz = T)
dev.off()

# Dotplots for Public institutions

tiff(file="publicS.tif", compression = "lzw", width=4500, height=6000, res=300)

N.ARWUpub<- ARWU[ which (ARWU$private=='0'),]
N.ARWUpub$SJTsRes<- resid(SJTpubQF)
N.QSpub<- QS[ which(QS$private=='0'),]
N.QSpub$QSsRes<- resid(QSpubQF)

layout(matrix(c(1,2,3,3), ncol=2, byrow=TRUE), heights=c(4, 1))

par(mar=c(2, 2,2,2),oma=c(1,2,1,1))
dotchart2(N.ARWUpub$SJTs, col="red", dotsize = 1.5, pch=17,xlim=c(-30,100),main="ARWU ranking",cex.labels = 1.2)
dotchart2(N.ARWUpub$SJTsRes, col="blue",dotsize = 1.5, pch=16, add=T)
dotchart2(N.QSpub$QSs, col="red",dotsize = 1.5, label=N.QSpub$Uni,pch=17,xlim=c(-30,100),main="QS ranking",cex.labels = 1.2)
dotchart2(N.QSpub$QSsRes,col="blue",dotsize = 1.5, pch=16, add=T)

plot.new()

legend("top", legend = c("Scores without scale and scope effects", "Original scores"), pch=c(16,17), bty="n", col=c("blue","red"), horiz = T)
dev.off()
R code:

dotchart2(N.QSpub$QSsRes, col="blue", dotsize = 1.5, pch=16, add=T)
par(mai=c(0,0,0,0))
plot.new()
legend("top", cex=1.5, legend = c("Scores without scale and scope effects", "Original scores"), pch=c(16,17), bty="n", col=c("blue","red"), horiz = T)
dev.off()

#Select some schools for rechecking
#Use QS ranking as an example
100-(coef(QSpriQF)[1]*11.798+coef(QSpriQF)[2]*168+0.5*(coef(QSpriQF)[3]*11.798^2+coef(QSpriQF)[4]*168^2)+coef(QSpriQF)[5]*11.798*168) #MIT
99.3-(coef(QSpriQF)[1]*35.535+coef(QSpriQF)[2]*179+0.5*(coef(QSpriQF)[3]*35.535^2+coef(QSpriQF)[4]*179^2)+coef(QSpriQF)[5]*35.535*179) #Harvard

#End of the code-----------------------------------------------
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202
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