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World university ranking systems: an alternative approach using partial least squares path modelling

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University rankings are key drivers in national and institutional strategic planning. The increase in the number of university ranking systems and the diversity of methods and indicators used by these systems necessitate the development of an index that can measure a university's performance in all these systems at once. This article presents the Achievement Index, using real data examples.

Keywords: ARWU; partial least squares path modelling; PLS-PM; QS; THE; university rankings

Introduction

Notwithstanding the considerable research outlining the range of flaws inherent in worldwide university rankings systems (e.g., Billaut, Bouyssou, & Vincke, 2010; Florian, 2007; Ioannidis et al., 2007), improving performance in these ranking systems is a well-documented driver for national and institutional strategic planning (e.g., Hazelkorn, 2007, 2008; O'Connell & Saunders, 2013). Previous publications (e.g., Hou, Morseb, & Chianga, 2012) have provided directions for increasing rank in an individual system. This article offers a method for maximising performance across a number of ranking systems. In addition to reducing the temptation for universities to cherry-pick ranking systems according to their own performance, the method provides a unified ranking of universities, integrating multiple sources and methodologies and therefore arguably more balanced and trustworthy than the rankings of the component systems. The provided model can be used with any number of systems. Here, examples are given with data from three of the most widely cited systems: Academic Ranking of World Universities (ARWU, also known as the Shanghai Rankings), Quacquarelli Symonds (QS) ranking and the Times Higher Education (THE) ranking.

Currently, there are nine major worldwide university ranking systems. Each of these systems uses different criteria, assigning different weightings to each element. As noted by Soh (2013), these are frequently not the weightings actually used in calculating the final rank. Since the presented model is founded on final data only, it is not influenced by discrepancies between stated and actual weightings.

An overview of the ranking systems follows, illustrating the diversity in their measures and methodologies (Table 1).

Although there have been national systems of ranking universities since the 1980s (Marginson, 2009), the first worldwide ranking system was released in 2003 by ARWU (also known as the Shanghai Rankings). ARWU assesses university performance in

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Table 1. Overview of worldwide university ranking systems.

Ranking system	Founding year	Country of origin	Source of citations data
ARWU	2003	China	Thomson Reuters
QS	2004	UK	Scopus
Times Higher Education	2004	UK	Thomson Reuters*
Webometrics	2004	Spain	Scopus
Taiwan	2007	Taiwan	Thomson Reuters
Leiden	2008	Switzerland	Thomson Reuters
SIR	2009	Spain	Scopus
URAP	2010	Turkey	Thomson Reuters
CWUR	2012	Saudi Arabia	Thomson Reuters

Notes: *Times Higher Education (THE) was initially produced in conjunction with QS using Scopus. In 2010, THE and QS parted company and THE rankings moved to using Thomson Reuters.

measures that are publically available: number of Nobel Laureates, Fields Medallists, entries in Thomson Reuters' list of Highly Cited Researchers, papers published in *Nature* or *Science* and articles in journals indexed by Thomson Reuters. In addition to raw scores for each measure, overall performance is normalised according to the number of full-time equivalent academic staff as provided by governmental or similarly impartial and reputable sources (see Table 2). Limitations of the ARWU rankings include the emphasis given to Nobel Prizes and Fields Medals, the heavy weighting towards the natural sciences at the expense of arts and humanities and the lack of assessment of teaching quality.

The Webometrics ranking system grew out of analyses of academic presence on the web by the Cybermetrics Lab at the Spanish National Research Council. Building on work through the 1990s, in 2004, staff at the Cybermetrics Lab were inspired by the ARWU rankings to produce worldwide rankings of their own, using publically available web data. The Webometrics rankings are not limited to universities but consider the broader research community: research centres, hospital and so on. The web presence of each institution is assessed for the volume of web contents and their visibility and impact. In addition, the number of articles in the 10 per cent of most cited papers in each scientific field is also considered. Although the criteria for these rankings differ substantially from all other ranking systems, analysis has found reasonable similarities between their results (Aguillo, Bar-Ilan, Levene & Orteg, 2010).

The year 2004 also saw the publication of the THE–QS World University Rankings, produced by QS in collaboration with the THE. This collaboration continued until 2010, when QS and THE published separate rankings. The QS rankings introduced survey data, seeking opinions about universities from academics in other institutions and employers of university graduates. Survey data account for 50 per cent with the remainder based on citations per staff, staff student ratio and proportion of international staff and students (see Table 2). QS also provides rankings in 5 faculty areas and 30 subjects. Limitations of the rankings include the heavy weighting assigned to survey data that are neither objective nor publically available.

After splitting with QS in 2010, THE rankings developed a system of 13 indicators (see Table 2) including data on publications and citations, staff and students, research income, degrees awarded and collaborations, as well as survey data (accounting for 33 per cent). Rankings are also provided for six subject areas. Since 2012, THE has also provided a list of the top 100 universities that are less than 50 years old.

Table 2. Measures used for the ARWU, THE and QS latent variables.

Ranking system	Variable name	Category	Weight (per cent)	Details
ARWU	R_ARWU	Rank		
	OS_ARWU	Overall score		
	Al_ARWU	Quality of education	10.00	Alumni of an institution winning Nobel Prizes and Fields Medals
	Aw_ARWU	Quality of faculty	20.00	Staff of an institution winning Nobel Prizes and Fields Medals
	HiCi_ARWU		20.00	Highly cited researchers in 21 broad subject categories
	N&S_ARWU	Research output	20.00	Papers published in *Nature* and *Science*
	PUB_ARWU		20.00	Papers indexed in Science Citation Index-expanded and Social Science Citation Index
	PCP_ARWU	Per capita performance	10.00	Per capita academic performance of an institution
QS	R_QS	Rank		
	OS_QS	Overall score		
	AR_QS	Academic reputation	40.00	Academic reputation from global survey
	C_QS	Citations per faculty	20.00	Citations per faculty
	FSR_QS	Faculty students ratio	20.00	Faculty student ratio
	ER_QS	Employer reputation	10.00	Employer reputation from global survey
	PIF_QS	International faculty	5.00	Proportion of international faculty
	PIS_QS	International students	5.00	Proportion of international students
THE	R_THE	Rank		
	OS_THE	Overall score		
	C_THE	Citations: research influence	30.00	Citations impact (normalised average citations per paper)
	Re_THE	Research: volume, income and reputation	18.00	Reputation survey (research)
			6.00	Research income (scaled)
			6.00	Papers per research and academic staff
	T_THE	Teaching: the learning environment	15.00	Reputation survey (teaching)
			6.00	PhDs awarded per academic
			4.50	Ratio staff to students
			2.25	PhDs/undergraduate degrees awarded
			2.25	Income per academic
	IO_THE	International outlook	2.50	International collaborations
			2.50	Ratio of international to domestic staff
			2.50	Ratio of international to domestic students
	II_THE	Industry income: innovation	2.50	Industry research income (scaled)
	AveR	Average of the three systems' ranks		
	AveOS	Average of the three systems' overall scores		

Four ranking systems based solely on publications performance are Performance Ranking of Scientific Papers for World Universities (Taiwan Rankings, first published 2007), CWTS Leiden rankings (first published 2008), SCImago Institutions Rankings (SIR, first published 2009) and University Ranking by Academic Performance (URAP, first published 2010). These systems returned to the sourcing of only publically available data. The Taiwan rankings provide an aggregated ranking based on eight indicators

including number of articles, number of citations, average citations, h-index and performance in Thomson Reuters' Highly Cited list. Over the years, additional rankings by field and subject have been included, and in 2013, there were rankings for 6 fields and 14 subject areas. The Leiden rankings provide separate rankings for each of eight indicators, concerning either impact or collaborations. These can also be reported according to five fields. Despite having the word 'rankings' in its title, the SIR give a disclaimer notice stating that their list is not a league table, but merely a vehicle for providing data that might assist individual institutions to improve their own research results. The SIR provide ranked lists of universities according to six indicators including volume, quality (measured by both journal rank and highly cited publications), impact and specialisation of publications, as well as international collaborations. The URAP rankings consider journal impact factor and international collaborations in addition to number of publications and citations. The data are also available for six academic disciplines.

The most recent worldwide rankings scheme is from the Center for World University Rankings (CWUR) in Saudi Arabia. First published in 2012, CWUR also source only publically available data but include data concerning alumni employment, prestigious awards and patents in addition to publications data. CWUR attempts to include arts and humanities disciplines in its assessment, by considering publications in journals indexed by the European Reference Index for the Humanities. However, this is a minority component within a citations-heavy research quality indicator, so the bias towards the natural sciences persists.

Achievement Index

Developing an index to measure universities' performance in all or some of the ranking systems is important for three main reasons: the diversity of criteria used by the range of ranking systems, the ambition to have a tool that can assess a university's achievement in a number of higher education key performance areas and to enable the universities to run different scenarios to find the key performance areas affecting their achievement.

We used partial least squares path modelling (PLS-PM) method to develop such an index. The PLS-PM method has been designed to confront the situation that there are many, possibly correlated, predictor variables, and relatively few samples.

We introduce a latent variable named 'Achievement' to measure a university's performance in a variety of ranking systems. The available ranking systems are included as other latent variables. We define our model as the better the results in each system, the higher the achievement. In other words, the latent variable (Achievement) is a function of the nine (this can be more or less) latent variables: THE, ARWU, QS, CWUR, Leiden_Ranking, SIR, Taiwan_Ranking, URAP and Webometrics. This model can be expressed in more abstract form as:

$$\text{Achievement} = f(\text{Ranking Systems}) = \alpha\text{ARWU} + \beta\text{THE} + \cdots$$

The graphical display of our model (named the path model) is shown in Figure 1.

The Achievement latent variable is measured by 18 manifest variables: overall scores and overall ranks of the nine ranking systems. The other latent variables are measured by indicators used by their ranking system. Although there are some overlaps between indicators from different ranking systems, the precise calculation of each of these indicators is unique to each ranking system, and therefore, they can be considered to be mutually exclusive.

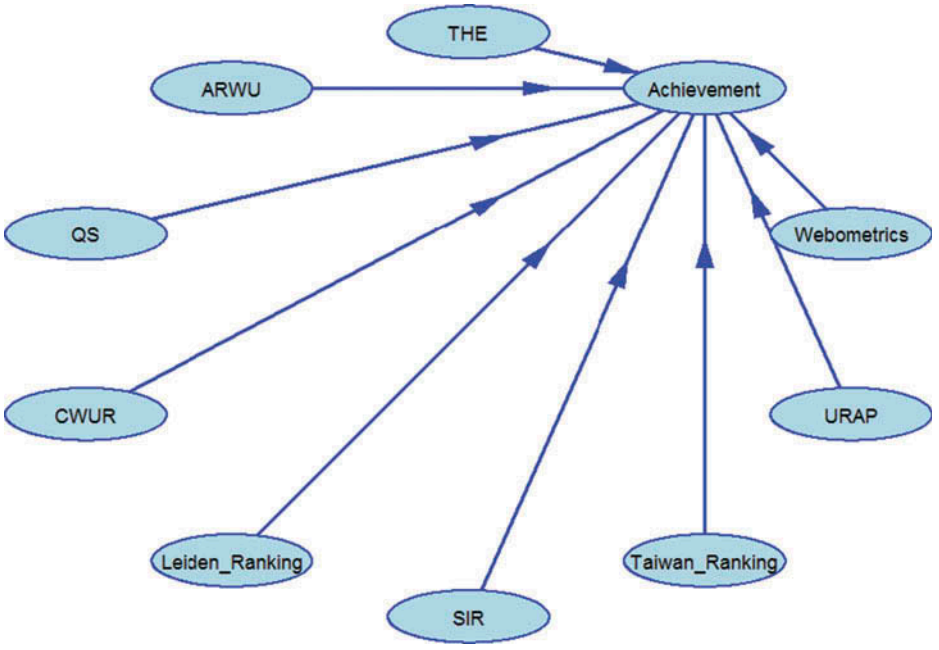

Figure 1. The path model.

One of the most common applications of PLS-PM is the calculation of indices to quantify some key concept or notion of importance (Sanchez, 2013). In our study, the key concept is the Achievement latent variable. The other latent variables will be estimated using partial least squares method.

Assume $\mathbf{X}$ is a matrix of dimension $n \times p$, where n is the number of observations (number of participating universities in ranking systems) and p is the total number of indicators used by the ranking systems. $\mathbf{X}$ is divided into J (mutually exclusive) blocks (representing ranking systems and achievement): $X_1,\ X_2, \cdots,\ X_J$. Each block X_j has K indicators: $X_{j1},\ X_{j2}, \cdots,\ X_{jk}$. Moreover, each block X_j is assumed to be associated with a latent variable LV_j.

The PLS-PM has two linear models: inner and outer models.

The inner model is the main (path) model that describes the relationship between the latent variables. The mathematical form of our inner model is:

$$LV_j = \beta_0 + \sum_{i \to j} \beta_{ji} LV_i + \text{error}_i$$

such that

$$E\left(LV_j / LV_i\right) = \beta_{0i} + \sum_{i \to j} \beta_{ji} LV_i$$

and

$$\text{cov}\left(LV_j, \text{error}_i\right) = 0$$

The outer model (sometimes called the measurement model) is the part of the model that has to do with the relationships between a latent variable and its block of manifest variables. The mathematical form of our outer model is:

$$X_{jk} = \lambda_{0jk} + \lambda_{jk} LV_j + \text{error}_{jk}$$

such that

$$E\left(X_{jk}/LV_j\right) = \lambda_{0jk} + \lambda_{jk} LV_j$$

The PLS-PM-estimated LV_j are called 'scores', which will be representing the Achievement and the other latent variable indices. Latent variable scores are calculated as weighted sums of their indicators:

$$Y_j = \hat{LV}_j \sum_k w_{jk} X_{jk}$$

The outer weights w_{jk} are estimated iteratively as $\hat{w}_{jk} = (Y_j Y_j)^{-1} Y_j X_{jk}$, while the path (structure) coefficients $\hat{\beta}_{ji}$ are estimated from the multiple regression model $Y_j = \sum_{i \to j} \hat{\beta}_{ji} Y_i$ using least squares method as $\hat{\beta}_{ji} = (\overset{i}{Y} Y_i)^{-1} Y_i Y_j$. The estimates $\hat{\lambda}_{jk} = \text{cor}\left(X_{jk}, Y_j\right)$ are the loadings that are calculated as correlations between a latent variable and its indicators.

Model validation

Since PLS-PM does not depend on any distributional assumptions, significance levels of the parameter estimates (based on normal theory) are not suitable. Instead, re-sampling procedures are used in the following case study to obtain information about the variability of the parameter estimates and hence validate the model. In the case study, we used bootstrapping, a non-parametric approach for estimating the precision of the PLS parameter estimates. Briefly, the bootstrap procedure we used is as follows: 200 samples are created in order to obtain 200 estimates for each parameter in the model. Each sample is obtained by sampling with replacement from the original data-set, with sample size equal to the number of cases ($n = 82$) in the original data-set. The Appendix provides the model validation results.

Case study (real data example)

In this case study, our model will include the names of the ranking systems: THE, ARWU and QS, as latent variables in addition to the Achievement latent variable. The model can be expressed as:

$$\text{Achievement} = f(\text{Ranking Systems}) = \alpha\text{ARWU} + \beta\text{THE} + \gamma\text{QS}$$

The graphical display of our model (named the path model) is shown in Figure 2. The Achievement latent variable is measured by six manifest variables, overall scores and overall ranks of the three ranking systems, while the other latent variables are measured by indicators used by their ranking system (see Table 2).

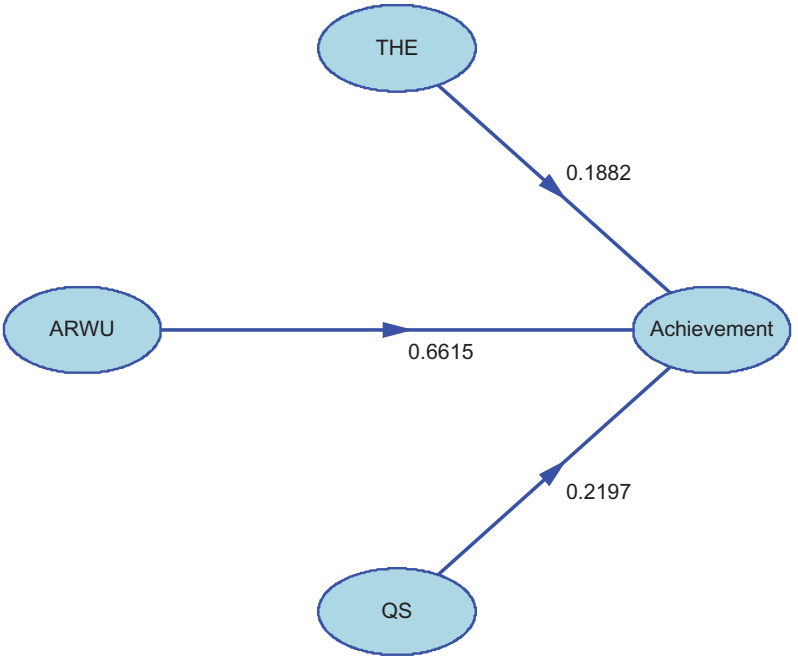

Figure 2. The path model with coefficients.

The data-set used in this case study is the data harvest from the three ranking systems for 2013. The top 100 universities were used from ARWU; then, data for these universities were drawn from THE and QS. After deleting universities that had missing values or for which information was withheld by at least one of the ranking systems, we had only 82 universities ($n = 82$), which were used in the model. Four latent variables ($J = 4$) were used: THE, ARWU, QS and Achievement. The manifest variables ($p = 29$) include the measures of the Achievement variables, which are the overall scores and ranks from the three ranking systems, and the measures for the other latent variables, which are the indicators' values in each system (see Table 2).

Three model outputs are included in this study: the Achievement Index (Table 3) for each university, the path model with coefficients (Figure 2) and the weights affecting each latent variable (Figure 3).

In Table 3, the universities are ranked according to their Achievement Index. Rank in the three systems for each university is also included for comparison.

As can be seen from Table 3, the Achievement Index can be considered as a unique measurement tool that measures the performance of each university in the three different ranking systems. Comparison between these systems is inadequate due to the variety of indicators, methodologies and purposes of each system, which necessitate the use of the Achievement Index. For example, ranking the top 100 universities according to the Achievement Index shows that the University of Sydney is ranked 42, while the University of Queensland is ranked 43. In the QS system, the University of Sydney was ranked 38 and the University of Queensland was ranked 43. In the other two systems, the University of Queensland achieved a higher ranking than the University of Sydney.

Figure 2 shows the relationship between the latent variables. This relationship can be described as follows: a one-unit increase in the THE latent variable will result in about

Table 3. Achievement Index (AI) (rounded to 2 decimal points) and ranking.

AI rank	Institution	AI	THE rank	ARWU rank	QS rank	AI rank	Institution	AI	THE rank	ARWU rank	QS rank
1	Harvard Uni	4.30	2	1	2	42	Uni of Sydney	−0.35	72	97	38
2	MIT	3.10	5	4	1	43	UQ	−0.35	63	85	43
3	Caltech	2.66	1	6	10	44	UC Davis	−0.37	52	47	85
4	Stanford Uni	2.39	4	2	7	45	TUM	−0.39	87	50	53
5	Uni of Cambridge	2.06	7	5	3	46	Boston Uni	−0.41	50	75	79
6	Uni of Oxford	1.95	2	10	6	47	Uni of Copenhagen	−0.42	150	42	45
7	UC Berkeley	1.65	8	3	25	48	Penn State	−0.44	49	54	107
8	Princeton Uni	1.55	6	7	10	49	Rutgers	−0.46	103	61	52
9	Yale Uni	1.23	11	11	8	50	Utrecht Uni	−0.47	74	52	81
10	Imperial Coll London	1.08	10	24	5	51	Leiden Uni	−0.47	67	74	74
11	UCL	0.94	21	21	4	52	Ohio State Uni	−0.54	59	65	113
12	Upenn	0.84	16	15	13	53	Paris VI	−0.57	96	37	112
13	ETH Zurich	0.81	14	20	12	54	Uni of Pittsburgh	−0.59	78	61	106
14	Johns Hopkins Uni	0.79	15	17	16	55	Uni S California	−0.59	70	47	125
15	Cornell Uni	0.78	19	13	15	56	Uni of Zurich	−0.59	121	60	78
16	Uni of Michigan	0.56	18	23	22	57	Uni of Helsinki	−0.60	100	76	69
17	Uni of Toronto	0.52	20	28	17	58	Uni of Geneva	−0.61	124	69	71
18	Duke Uni	0.46	17	31	23	59	Uppsala Uni	−0.62	111	73	79
19	Uni of Tokyo	0.40	23	21	32	60	UMCP	−0.63	108	38	116
20	Northwestern Uni	0.36	22	30	29	61	Osaka Uni	−0.63	144	85	55
21	UW-Madison	0.28	30	19	37	62	Uni Basel	−0.67	74	83	110
22	Uni of Washington	0.27	25	16	59	63	Uni of Groningen	−0.72	98	92	97
23	UC San Diego	0.16	40	14	63	64	Rice Uni	−0.73	65	92	136
24	Uni of Edinburgh	0.11	39	51	17	65	UC Irvine	−0.73	93	45	149
25	McGill Uni	0.09	35	58	21	66	Uni of Nottingham	−0.73	157	83	75
26	New York Uni	0.07	40	27	44	67	Aarhus Uni	−0.74	138	81	91

(*continued*)

Table 3. (*Continued*).

AI rank	Institution	AI	THE rank	ARWU rank	QS rank	AI rank	Institution	AI	THE rank	ARWU rank	QS rank
27	King's Coll London	0.07	38	67	19	68	Ghent Uni	−0.76	85	85	122
28	Kyoto Uni	0.06	52	26	35	69	UWA	−0.79	168	91	84
29	Uni of Melbourne	−0.00	34	54	31	70	Arizona State Uni	−0.80	146	79	107
30	UBC	−0.01	31	40	49	71	Vanderbilt Uni	−0.83	88	49	181
31	Carnegie Mellon	−0.03	24	52	57	72	Uni Freiburg	−0.84	152	100	102
32	ANU	−0.06	48	66	27	73	McMaster Uni	−0.84	92	92	140
33	Uni of Manchester	−0.07	58	41	33	74	Uni Paris-Sud	−0.84	114	39	189
34	UT Austin	−0.07	27	36	71	75	Uni of Rochester	−0.88	95	90	151
35	Karolinska Inst	−0.16	36	44	60	76	Michigan State Uni	−0.90	83	92	171
36	Normale Sup	−0.17	65	71	28	77	Uni of Arizona	−0.92	103	78	167
37	UNC-Chapel Hill	−0.19	47	43	54	78	Hebrew Uni Jerusalem	−0.92	191	59	141
38	Uni of Bristol	−0.24	79	64	30	79	UT Dallas	−0.93	188	46	153
39	Brown Uni	−0.25	52	67	47	80	Stockholm Uni	−0.94	103	82	170
40	Uni Heidelberg	−0.31	68	54	50	81	Indiana Uni	−0.98	132	85	167
41	UC Santa Barbara	−0.34	33	35	130	82	Uni of Utah	−1.00	143	85	167

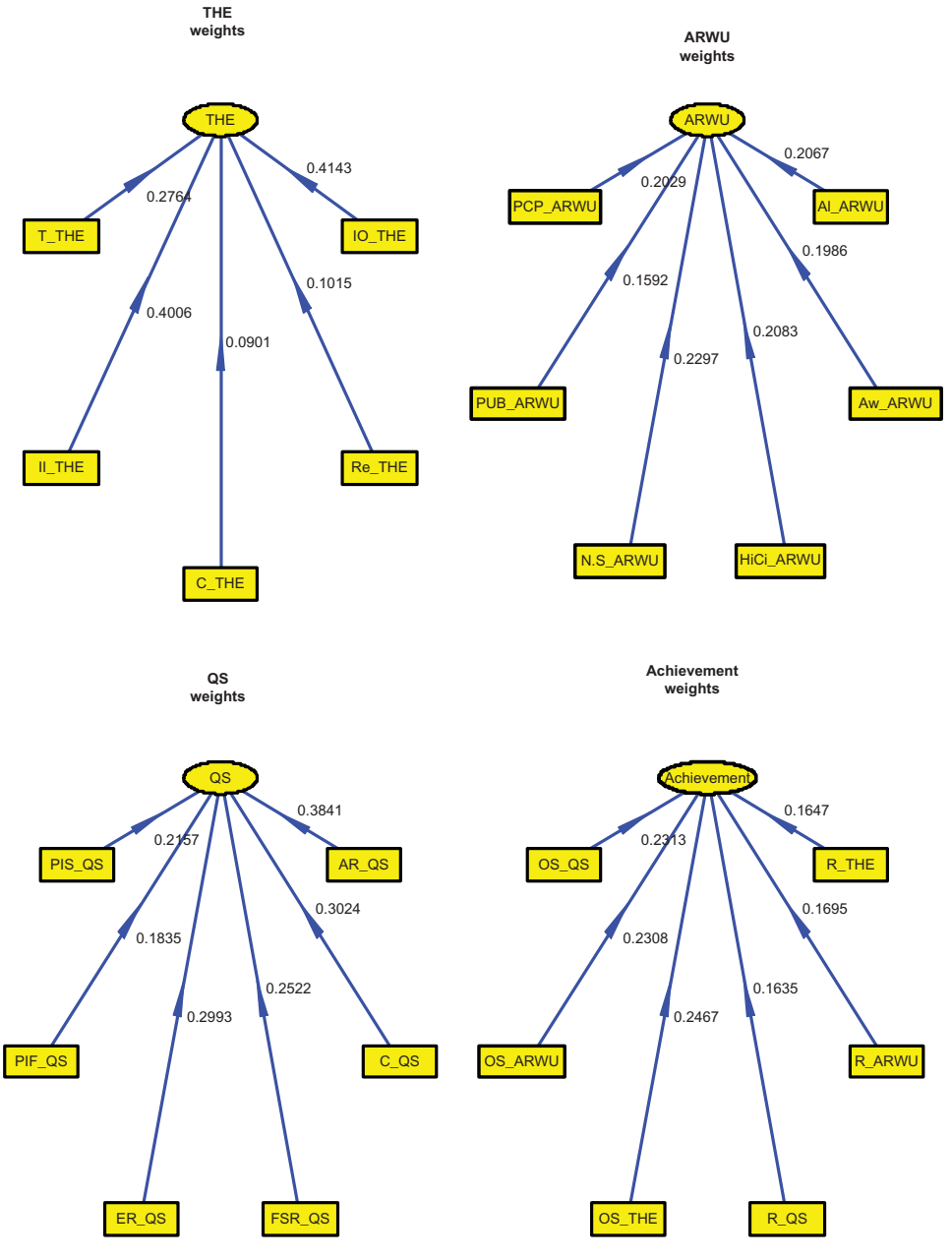

Figure 3. Weights affecting each latent variable.

19 per cent increase in the Achievement latent variable, a one-unit increase in the ARWU latent variable will cause about 66 per cent increase in the Achievement latent variable, while a one-unit increase in QS will result in about 22 per cent increase in Achievement.

Figure 3 shows the relationship between the latent variables and their measurements (manifest variables). This relationship can be described in the same way as we did in Figure 2.

Conclusions

In this study, we developed an index to measure a university's achievement in multiple ranking systems at once. This tool will assist universities in strategic planning by overcoming the problems caused by the multiplicity of world university ranking systems and the diversity of methods and indicators used by these systems, allowing them to make evidence-based decisions about ways in which to improve rankings performance.

In addition to the contribution of the manifest variables to the latent variables and the correlation between the latent variables shown in the figures included in this study, multiple scenarios can be executed to explore the impact of variable changes for a specific university in any ranking system using the Achievement Index.

Sources for ranking methodologies

ARWU: http://www.shanghairanking.com
CWUR: http://cwur.org
Leiden: http://www.leidenranking.com
QS: http://www.topuniversities.com/qs-world-university-rankings
SIR: http://www.scimagoir.com
Taiwan: http://nturanking.lis.ntu.edu.tw
THE: http://www.timeshighereducation.co.uk/world-university-rankings
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Appendix

Table A1. Model validation results.

	Weighting			95% Confidence interval	
Indicator	Original	Mean boot	Std. error	perc.025	perc.975
IO_THE	0.41	0.41	0.02	0.38	0.44
Re_THE	0.10	0.11	0.03	0.03	0.16
C_THE	0.09	0.09	0.05	−0.01	0.18
II_THE	0.40	0.40	0.02	0.37	0.43
T_THE	0.28	0.27	0.01	0.24	0.30
AI_ARWU	0.21	0.21	0.01	0.19	0.24
Aw_ARWU	0.20	0.20	0.01	0.18	0.23
HiCi_ARWU	0.21	0.21	0.01	0.19	0.24
N.S_ARWU	0.23	0.23	0.02	0.20	0.28
PUB_ARWU	0.16	0.16	0.02	0.12	0.19
PCP_ARWU	0.20	0.20	0.01	0.18	0.24
AR_QS	0.38	0.38	0.04	0.32	0.48
C_QS	0.30	0.30	0.03	0.25	0.36
FSR_QS	0.25	0.24	0.03	0.19	0.31
ER_QS	0.30	0.30	0.03	0.25	0.36
PIF_QS	0.18	0.18	0.03	0.09	0.24
PIS_QS	0.22	0.21	0.03	0.16	0.25
R_THE	0.16	0.17	0.02	0.14	0.20
R_ARWU	0.17	0.17	0.01	0.15	0.20
R_QS	0.16	0.17	0.02	0.14	0.19
OS_THE	0.25	0.24	0.01	0.22	0.26
OS_ARWU	0.23	0.22	0.01	0.20	0.24
OS_QS	0.23	0.22	0.01	0.20	0.24
Path					
THE→Achievement	0.18	0.19	0.06	0.08	0.32
ARWU→Achievement	0.66	0.66	0.06	0.54	0.76
QS→Achievement	0.22	0.22	0.03	0.17	0.27
Achievement	0.97	0.97	0.01	0.95	0.98