Responsible Research and Innovation in Europe: a cross-country comparative analysis

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Abstract
The objective of this paper is to contribute to the emerging attempts to foster empirical, quantitative approaches to Responsible Research and Innovation (RRI) and to provide a low-resolution map of the European RRI landscape, which can serve as a vehicle for international learning. The paper presents indicators of RRI aimed at characterising countries. It examines the empirical structure of the data collected in the 'Monitoring the evolution and benefits of Responsible Research and Innovation' (MoRRI) project, and reports patterns across Europe. Factor analysis is applied to identify 11 empirically anchored dimensions of RRI. Based on indices for these dimensions, cluster analysis reveals four distinct clusters of countries. These results point to diversity regarding the empirically manifest components of RRI as well as diversity in the RRI profiles of the 28 European Union Member States.

Keywords
Responsible Research and Innovation, RRI, indicators, factor analysis, cluster analysis

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1. Introduction

In a recent analysis of semantic shifts through successive EU research funding programmes, Zwart, Landeweerd, and van Rooij (2014) point to the top-down introduction of the label 'Responsible Research and Innovation' (RRI) by policy makers and research funders in contrast to bottom-up conception by the research community itself. They argue that the signifier, i.e. the neologism, sometimes precedes a clear, stable, and shared understanding of what is signified by it. Consequently, in the case of RRI, significant efforts have been devoted to 'catching up' conceptually over the last couple of years. A growing literature attempts to define RRI or map the conceptual landscape within which it is located (e.g. Stilgoe, Owen, & MacNaghten 2013; Rip 2014; von Schomberg 2011; 2013; Burget, Bardone, & Pedaste 2016; Glerup & Horst 2014; Pellé & Reber 2015; Owen, Macnaghten, & Stilgoe 2012; Ribeiro, Smith, & Millar 2016; Lindner, Kuhlmann, & Walhout 2016; de Saille 2015; Arnaldi & Bianchi 2016). Some of these contributions accommodate a theoretical opening up of the notion of RRI, while others, including the European Commission's concept comprising six key areas of RRI (European Union 2012), take an operational approach. While there are aspirations to integrate conceptual streams, e.g. in the framework developed by the RRI Tools project (see www.rri-tools.eu), there has been limited convergence as of yet. The state of play is instead characterised by the co-existence of multiple understandings of what it means to be responsible in research and innovation.

Against this backdrop, our leap into developing and empirically examining indicators of RRI in this paper may seem somewhat premature. In line with Wickson and Carew (2014), however, we contend that there is a need to cut through the – in many ways reasonable – state of interpretative flexibility and become concrete and practical, if researchers, innovators, funders, university managers, and other participants in the ecosystems of research and innovations are to make sense and use of RRI. Ultimately, the transformative potential of RRI, its ability to change research and innovation practices, does indeed depend on practitioners' ability to make sense of it. Indicators offer a platform for inter- and intra-organisational learning and trend detection, which may in turn inspire change in governance arrangements and behaviour.

There is an obvious need for caution in the construction and application of indicators in general and for RRI specifically. Indicators can have constitutive and performative effects (Dahler-Larsen 2014; de Rijcke et al 2016) because they signal what is considered important, and may potentially lead to instrumental practices at odds with the critical, reflexive properties of RRI. It is, therefore, important to employ a responsible approach to evaluative metrics (Wilsdon et al 2015) which recognises that quantitative assessment cannot stand alone, that the quality of data should continuously be scrutinised, that sources and analytical approaches should be transparent, and that the potential systemic effects of indicators should be considered (Hicks et al 2015).

So far, efforts to develop indicators of RRI have been scarce, with the few attempts (Strand et al 2015; Wickson & Carew 2014; Monsonís-Payá, García-Melón, & Lozano 2017; Heras & Ruiz-Mallén 2017) exhibiting a great deal of humility towards the task, emphasising the need for diverse sets of indicators to capture elements of responsibility and the importance of context-sensitivity in the interpretation of results. One significant element in a responsible approach to measuring research and innovation activities is to avoid reporting schemes that invite 'horse races' by condensing information into simple rankings. Instead, analyses of profiles, networks, and similarities and differences between clusters of observations (Grupp & Schubert 2010; Wickson & Carew 2014; Robinson-Garcia, van Leeuwen, & Ràfols 2018; Stahl et al 2017) provide a more fertile context for learning.

The recent project, 'Monitoring the evolution and benefits of Responsible Research and Innovation' (MoRRI) has sought to develop an extensive set of indicators covering the six dimensions of RRI encompassed in the European Commission's RRI scheme, namely 'Gender Equality' (GE), 'Science Literacy and Science Education' (SLSE), 'Public Engagement' (PE), 'Ethics' (E), 'Open Access' (OA), and 'Governance' (GOV) (Peter et al 2018a; see also http://www.technopolis-group.com/morri/). Based on an a series of reviews of literature pertaining to the six key areas, examination of data availability and gaps, and iterative development of new indicators requiring primary data collection, an extensive empirical programme covering all European Union (EU) Member States was carried out by the MoRRI project.

In this paper, we examine the empirical structure of the data collected in MoRRI, with the purpose of understanding the appropriateness of the indicators towards the 'key' dimensions that they were intended to be indicators of. Furthermore, we apply selected indicators in an analysis of the cross-country patterns of RRI in Europe. Through examination of these patterns, we investigate whether different aspects of RRI are related at the country level and how countries cluster in their RRI activities. Our analytical approach avoids cruel rankings, clustering countries based on degrees of similarity of RRI profile instead.

We present indicators of RRI aimed at characterising countries, examine the empirical structure of the data, and report patterns across 28 European countries. The conceptual reach is restricted to the six key areas encompassed in the European Commission's RRI scheme. In part, the emphasis on the six key areas stems from the mandate for the MoRRI project, which was commissioned by the European Commission, but it was also a deliberate choice to focus on a framework that offered some tangible, measurable components of RRI. We readily acknowledge a number of limitations in both conceptual and empirical orientation, and return to some of these through the paper. The objective of the paper is to contribute to the emerging attempts to foster empirical, quantitative approaches to RRI and to provide a low-resolution map of the European RRI landscape, which can serve as a vehicle for international learning.

2. Data, indicators, and imputation procedure

The dataset applied in this study was collected as part of the MoRRI project. It includes: secondary data from Eurostat, She Figures, Eurobarometers, OpenAIRE, and specific cross-European projects such as MORE2, MASIS, EPOCH, and SATORI; primary data collected via surveys of research performing organisations, research funding organisations, and societal stakeholders; bibliographic data and – to a lesser degree – data based on qualitative approaches (for detailed information, see Ravn, Nielsen, & Mejlgaard 2015; Peter et al 2018b).

The data was collected in order to populate 36 substantive indicators, designed to cover the six keys of RRI. In the case of some indicators, such as 'GE2 – share of female researchers' which can be further divided into sectors, 'sub-indicators' were added. Counting these, altogether 43 indicators were established across the six RRI areas (for detailed information including individual data fiches, see Peter et al 2018b). To obtain a cross-sectional dataset covering all 28 European Union (EU) countries, we selected the latest yearly observation available for each indicator. For indicators using primary data collected through the MoRRI empirical programme, the reference year is 2016, while data points from secondary data have varying reference years (see Table 1 below).

The dataset covers all EU-28 countries with some variation in coverage across the different indicators. Table 1 provides an overview of all 43 indicators including data type, source, and reference year. The last column specifies the index (see below) to which the indicator contributes.

[Table 1 here]

The 43 RRI indicators form the gross set of indicators for our analyses. A validation procedure was conducted, which tested four main aspects: the quality of indicators based on survey-questions (removal of indicators based on items with high non-response); the internal consistency of composite measures; the robustness of indicators on the basis of test of ranking effects of small adjustments in indicator specifications; and the degree of within-country variance compared to cross-country variance, in order to gauge discrimination significance (for detailed information about the validation procedure, see Peter et al 2018b). The validation procedure led to the exclusion of PE6, E2, and OA5. Furthermore, a number of indicators were discarded from this particular study presented here for substantive reasons. We choose to use GE2.3 to measure the share of female researchers in the higher education sector, but disregard related indicators of the share of female researchers in all sectors (GE2), the business sector (GE2.1), and the government sector (GE2.2), respectively. The dissimilarity index, GE4, and its division into sectors, GE4.1 and GE4.2, is directly based on the share of female researchers, so we excluded it from this study. We included GE7.1 that captures the gender wage gap in the academic sector, while GE7.2 focusing on wage gap of technicians was omitted to avoid repetition. The procedure resulted in a net set of 34 indicators, which were applied in the analyses. These 34 are marked with light grey background in Table 1.

While the coverage of these indicators across EU countries is comprehensive, for most indicators data was not available for a small number of countries. Around 5 pct. of country observations for the 43 indicators were missing, equal to 60 observations of a total 1204 (28 countries × 43 indicators). For the subset of 34 indicators used in later analyses, the missing information amounted to 35 out of 896 observations, yielding 3.9 pct. missing data. Although they only comprise a small percentage of the total, these missing observations still represent an obstacle to later analysis requiring complete data sets, i.e. full data for all indicators across all observations (Basagaña et al 2013). As we aspire to map the grouping of all EU-28 countries on six RRI dimensions, failing to correct for missing values would exclude up to three countries per indicator, and result in analyses with only 20 countries in total. In order to mitigate this problem, we performed multiple imputation of the missing data to obtain a full sample of 28 countries.

Multiple imputation involves using a predictive model to estimate *m* values for each missing item in a number of variables. This model incorporates all the available information embedded in the existing data along with any prior information (Honaker & King 2010). Several, *m,* data sets are then created with the observed data and missing values filled in with different imputed values from the model.

The imputed value is then obtained by computing the mean of all *m* values (Rubin 1996; King et al 2001). The multiple imputation approach has been considered as a best practice when handling nonresponse in surveys, and has recently been successfully applied to country-level data such as GDP, government spending, etc. (Honaker & King 2010; Lall 2016). Multiple imputation retains the advantages of single imputation via e.g. linear regression because it incorporates information from other variables in the data set, and is based on the assumption that the missing data may depend on these factors, or can be partially predicted by them (Little 1992; Rubin & Schenker 1986). The model is estimated on all separate *m* data sets, and then regression coefficients are combined to a single estimate using Rubin's Rules (See White et al 2011).

Because this type of analysis does not involve estimating a parameter value with associated standard error, no formal method for including cross-imputation variation exists for factor- or cluster analysis (Ahlquist & Breunig 2009). We acknowledge this large limitation of our approach. However, multiple imputation has been successfully used in cluster analysis (Ahlquist & Breunig 2009; 2012; Basagaña et al 2013) when possible variations in cluster assignment across *m* data sets are taken into consideration, and robustness of assignments are checked. Furthermore, the use of a cross-imputation mean appears superior to single-imputation, as it safeguards against possible extreme values being imputed.

3. Analyses and results

We adopt a three-stage approach to examine the structure of the data and the pattern of RRI across European countries. First, we utilise factor analysis of the 34 indicators in our net set of RRI indicators to identify relevant empirical dimensions of responsible research and innovation within each key area. Second, we interpret the factors, select a number of variables of importance according to the factor scores, and construct simple additive indexes of these variables. Third, these altogether 11 indexes are then used to conduct hierarchical cluster analysis to identify groups of countries with similar RRI profiles.

Factor analysis

In order to examine the properties of the indicators, we perform separate principal components analyses (PCA) of all six central RRI keys. The purpose of the factor analysis is first to aid in determining the number of distinct dimensions for each key and second to identify the indicators that are most relevant in capturing these dimensions. Details of the factor analysis can be found in the appendix.

Looking across all factor analyses, there appears to a common trend of bifurcation of factors, with some indicators loading high on one factor and low on the other and vice versa. With the exception of GOV, the analysis suggests that each key area has two underlying dimensions. For the indicators of GOV, one coherent factor emerges. It would thus appear that while our net set of indicators was designed to cover six key areas, in fact 11 dimensions emerge from the empirical examination of the data.

Indices

Based on the patterns from the factor analyses, we construct 11 indices, which capture two distinct dimensions within each RRI key with the exception of GOV, where only one dimension emerged empirically. The indices are computed by standardising each RRI indicator to vary between 0 and 1, adding together a selection of the most relevant indicators assessed on the basis of factor loadings, and finally standardising the resulting index to run from 0 to 1.[1] For GE, it makes sense from a substantive perspective to build one index around GE1 and GE5, and another for GE2.3 and GE 10.1.

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[1] For an indicator I, the standardisation is computed as $I_s = \frac{I - min\{I\}}{max\{I\} - min\{I\}}$

Table 2 provides an overview of the 11 indices. We also provide a correlation matrix in Table A7 in the appendix.

The first of the 11 dimensions, 'GE action', describes the level of policy action taken by research performing organisations (RPOs) promoting gender equality within a given country. It concerns the general degree of commitment within RPOs to implementing practical mechanisms supporting structural change to reduce inequality. This dimension is supported by two indicators, GE1, which captures the share of RPOs with an explicit gender equality plan, and GE5 measuring the share of research organisations having implemented processes to promote the gender dimension in research content of projects and studies. Examples include concrete rewards and incentives for researchers pursuing gender issues in relation to their research.

[Table 2 here]

The 'GE status' index represents a different dimension of gender equality, concerned with the observed macro level of achieved gender equality in academia within countries. GE2.3 measures the share of female researchers in the higher education sector of a country, while GE10.1 is the share of female authors in scientific publication output from a country.

Also for SLSE, two dimensions materialise. 'RRI training' focuses on the extent to which educational institutions teach issues relating to responsibility in research and innovation. SLSE1 tracks whether societal aspects of science are prevalent in science education for 15- 18 year olds, and is based on extensive desk research of science curricula for high school students or equivalent (depending on countries' educational system). The indicator tracks whether controversial topics such as GMOs or nuclear energy are covered and whether the societal, environmental, and ethical aspects of these technologies are addressed within school curricula of the respective countries. SLSE2 measures the share of higher education institutions in which training of PhD-students include RRI-related aspects, such as the ethical, legal, economic, environmental, and social ramifications of science.

The second SLSE dimension concerns the broader culture of science communication in a country. SLSE3 draws on the qualitative results of the 2010-12 MASIS project assessing the science communication culture of a country as either consolidated, developing, or fragile (Mejlgaard et al 2012). SLSE4 is a composite indicator tracking, firstly, the number of members in the European Citizen Science Association (ECSA) per thousand researchers within the country and, secondly, the number of citizen science publications emanating from a country per thousand researchers. The data stems from annual reports from (ECSA) and from Scopus.

For PE, the two dimensions capture active citizen participation in science on the one hand and the importance of public engagement activities in the funding of research on the other hand. 'Public participation' is based on three indicators. PE1 uses secondary data from the MASIS project to classify countries according to formalisation of public involvement in science and technology policy making and observed level of actual involvement. PE4 measures the share of citizens in each country who have heard of, discussed, or actively sought information about controversial technologies, and builds upon question from the 2010 Eurobarometer Survey 340. This indicator is a composite measure based on three individual items from the Eurobarometer on biotechnology. Finally, PE9 is based on a 'Science in Society Stakeholder' survey administered to civil society organisations engaged in issues around ethics in science, science communication, and technology assessment. The indicator taps into the degree of influence and importance attributed to societal stakeholders in research and innovation decision making within the respective countries.

The second PE dimension concerns the role that public engagement plays in the context of research funding. Based on survey answers from research funding organisations (RFOs), PE7 is a composite measure building on individual items about targeted funding schemes for PE activities, the relative budget size for such activities, and the degree to which citizens are involved in formulating funding strategies. PE8 follows a related track by covering the extent to which PE is a criterion for the appraisal of research applications within the RFOs in the respective countries.

The two empirically based indices of E diverge by either measuring ethical considerations in RPOs or in RFOs. E1.1 gives the share of RPOs with research ethics committees and research integrity offices, while E1.2 extends this indicator by further incorporating information about the independence and authority of ethics committees.

The other ethics dimension concerns ethical aspects in research funding. E3.1 measures the share within a country of funding organisations where ethics assessments / reviews play a role in funding decisions. The indicator is based on a single question from the MoRRI RFO survey, while E3.2 builds on a set of items tapping into the importance attributed to ethics in funding decisions.

Almost equivalent to the pattern from GE, OA indicators seem to support the existence of two dimensions capturing 'status' and 'action', respectively. 'OA status' is concerned with the extent of open access publications emanating from a country. OA1.1 is the total share of open access articles (as pct. of all journal articles) from a country, while OA1.2 is the share of 'Gold' open access articles from a country, i.e. the share of articles published in open access journals. Both indicators build on Web of Science data, with the OA shares computed as the share of a country's total publications registered in Web of Science in a given year.

'OA action' captures the use and uptake of open access scientific literature. OA3 is the share of open access publications used as references in Wikipedia entries, while OA4 is public perceptions of open access, more specifically, the share of people who think publicly funded research should be freely available, using data from Eurobarometer Survey 401. OA6 builds on items from the MoRRI RPOs survey, which address open data and open access policies, use of institutional publication repositories, alongside other organisational schemes to promote OA practices.

Finally, the 'Governance' index includes all three indicators in the set tailored for the GOV key. GOV1 tracks the use of science in policy-making in the different countries based on MASIS-data. GOV2 builds on data from both the RPOs and RFOs surveys and reports the share of organisation having established governance mechanisms related to ethics, public engagement, open access, gender equality, or specific policies on 'RRI'. GOV3 also builds on both surveys and captures the deliberate promotion of RRI by organisations vis-à-vis their own employees or beneficiaries but also partner organisations and networks. Like several of the other indicators in the RRI set, GOV2 and GOV3 again report the aggregated, country level figures, even if the data was collected at lower levels of aggregation, typically the organisational level.

Cluster analysis
To investigate the differences and similarities in approaches to RRI across all 28 EU Member states, we conduct a cluster analysis on all 11 indices described above. In order to group countries, we use a

hierarchical cluster technique, which partitions countries into clusters agglomeratively according to the Euclidean distance between them. A prominent problem with this approach is that the small number of cases may lead outlying countries to exert great influence on the cluster solution. Furthermore, the use of several variables with large differences in scales and variation could lead to some variables dominating the cluster solution. To remedy the latter, we use the standardised version of the 11 RRI indices in order to remove large difference in measurement scales. Secondly, we use a weighted average linkage, hierarchical cluster analysis. Groups of countries are then combined by comparing the Euclidean distance between the weighted averages of two groups instead of e.g. the farthest observations, thus reducing the influence of potential outliers. Figure 1 shows the hierarchical clustering of countries represented in a dendrogram.

[Figure 1 here]

The dendrogram reveals a somewhat heterogeneous set of countries, which do however share some characteristics. To extract a suitable number of clusters, we computed the Duda/Hart-ratio and pseudo T-squared. A comparison of cluster solutions (from 15 to one single cluster) suggests a combination of high ratios and low T-squared for either the four- or six-clusters solution. This is often considered to signal the most distinct cluster solutions. From an interpretability perspective, the four cluster solution seems most appropriate, and we indicate it graphically by color-coding countries in Figure 1. The 'Blue' cluster comprises Austria, Luxembourg, Malta, Czech Republic, Greece, Cyprus, and Hungary. The 'Red' consists of Bulgaria, Poland, Slovenia, Croatia, Lithuania, Estonia, Latvia, and Slovakia. The 'Black' cluster is Spain, Portugal, and Romania. Finally, the 'Green' cluster comprises Belgium, Germany, France, Denmark, Italy, Netherlands, Finland, Sweden, and United Kingdom.

Looking across Europe, then, we observe a somewhat diverse picture of RRI approaches at the level of countries. The cluster means for each of the 11 RRI indices are shown in Figure 2 and Table 3. Figure 2 shows a number of differences and similarities between country clusters. With regard to similarities, the blue (single solid line), red (punctuated line), and black (dotted line) clusters all have similarly high scores for OA status, which indicates that the use of open access for scientific publication relative to all publications is high across these clusters. In the green (double solid line) cluster, the lower open access score does however conceal large within-cluster variations. Countries such as Sweden and Belgium score 1 and 0.9 respectively, while the cluster mean is pulled down by low scores for France, Denmark, and Germany.

[Figure 2 here]

The patterns across clusters are much more diverse when observing the remaining indices. For a number of RRI indices we can detect a sort of inverse relationship between RRI *status* and RRI *actions.* The gender equality dimension exhibits one such interesting pattern. The black and red clusters, comprising most Eastern European countries, score very highly on gender equality status, while the scores for the green and blue clusters, with mainly western- and central European countries, are much lower. The picture is reversed when it comes to gender equality action. A similar pattern also exists for open access. The scores on OA *status* and *action* show a clear difference between clusters. Here, the blue, red, and black clusters are placed in the high end of the spectrum concerning OA status, but the green cluster has the front position when it comes to OA action.

[Table 3 here]

Such a disjunction also materialises for PE. The green cluster has a particularly high score on the index of public participation, while the black cluster consisting of Portugal, Spain, and Romania has the lowest score. However, when it comes to RFOs emphasis on PE in the activities they fund and their assessment criteria, the black cluster has the top position. For ethics, also, this interesting inverse relationship between sub-dimensions is visible. The red and blue cluster are positioned in top concerning the index for saliency of ethical assessment with RFOs, but the green and black clusters have highest levels of commitment to ethical assessment in the context of RPOs.

A slightly different story unfolds for SLSE. The red cluster takes a lead position on the index for RRI training, which covers the extent to which controversial technologies, such as nuclear power, are an integrated part of high school curriculum, and the extent of RRI training in PhD education. When it comes to the index for the broader efforts concerning science communication in the public sphere, the red cluster has the lowest score. The blue cluster, on the other hand, seems to be falling behind both regarding RRI training and broader science communication culture.

Finally, within the area of Governance, we see a clear partition between the countries in the blue and red clusters on the one hand and countries in the black and green clusters on the other hand. The issue of how to create governance arrangements to support RRI thus arises with uneven importance across the four country clusters.

4. Discussion

We have argued that an empirical-analytical, indicator-oriented approach to understanding RRI may provide useful intelligence, which can inform the development of policies and practices promoting responsibility in research and innovation. Three core messages emerge from the analyses presented in this paper.

First, it seems that one of the influential frameworks in the current discussions, i.e. the 'six keys' approach to RRI, might be broken down into a broader set of sub-dimensions. Gender equality, e.g., is not unidimensional, but could be divided into considerations around the intensity of research organisations' efforts to develop strategies and mechanisms promoting equality and gender orientation in research activities on the one hand, and the overall degree of equality at the academic labour market on the other hand. There is an apparent reverse relationship between these sub-dimensions at the national level. Similarly, the empirical structure of indicators of PE, SLSE, OA, and E points to sub-dimensions within these key areas. While this result may contribute to conceptual refinement in relation to the 'six keys' framework, we should reiterate, however, that the 11 RRI dimensions identified in this study do not exhaust the conceptual terrain of this emerging area of scholarship and policy (cf. Burget, Bardone, & Pedaste 2016).

Second, European countries are far from uniform, when it comes to approaches to RRI. Based on the 11 empirical dimensions identified in the MoRRI dataset, it becomes clear that countries vary considerably in their RRI profiles, i.e. the pattern of how priority, effort, and accomplishment is distributed across the 11 areas. A potential single RRI ranking exhibiting the leaders and the laggards would not capture the complexity of the RRI landscape. Countries may be 'high performers' on one dimension but 'low performers' on another, and the dimensions are not easily or logically subsumed under one simple, all-embracing scale. On the contrary, RRI is an umbrella under which an array of topics with subtle interdependencies can be identified. Third, if we draw a European map of RRI, countries can be clustered into groups with limited intra-cluster heterogeneity. In particular, four clusters emerge with distinct patterns across RRI dimensions.

These results provoke questions that we have not attempted to answer in this paper: What are the reasons for similarities and differences among countries? How does geographical location, political structure, civic culture, and labour market trajectories affect the RRI profile of individual countries and are there detectable root causes for the clustering results? Which are the implications of different profiles for society and for research and innovation? Which of the dimensions deserve particular attention in specific national contexts? Where are the blind spots in the basket of indicators, and what kind of alternative indicators might better capture essential properties of RRI? What does a desirable RRI profile look like, and how can a change of profile be accomplished? It is our contention that an indicator-based approach to RRI should invite policy reflection rather than policy prescription. The kind of questions raised here deserve inclusive, context-sensitive deliberation, and we believe that indicator-based results serve to stimulate continued conceptual contestation, but, importantly, also concrete discussions about how to promote responsibility in research and innovation.

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Appendix

Factor analysis

In order to ascertain the appropriate number of factors to retain from each analysis, a series of parallel analyses were performed (see Horn 1965, Hayton et al. 2004; Dinno 2009a; 2009b). Parallel analysis involves simulating a data set of random uncorrelated data with the same dimensions as the data set of interest. This involves generating *P* number of variables for a sample size *N*, corresponding to the number of variables and units of analysis as the original data, and performing a factor analysis on this dataset. This exercise is repeated *K* times[2], and the average eigenvalues are calculated. The final step involves comparing these simulated averages to the observed eigenvalues, and retain only those factors whose eigenvalues are greater than the eigenvalues obtained from the random data (Hayton et al 2004: 198). Figure A1 plots the six separately run parallel analyses.

[Figure A1 here]

In Figure A1, the red line plots the eigenvalues from the principal component analysis of the actual data, while the blue line plots the eigenvalues of the simulated dataset of equal magnitude. The black line show the difference in eigenvalues, with solid black dots indicating the number of factors retained. The figure indicates that for the most part, each RRI reflect a single or two factors. For GE, PE, and SLSE, parallel analyses with different simulated datasets suggest between one or two factors. This is also reflected in the small differences between observed and simulated eigenvalues. As a precaution, we focus on two factors for each of these RRI keys. For OA, the difference between the observed and simulated eigenvalues is also small for a third factor. Other simulations suggested only one factor, so we propose to retain two factors. For the remaining keys, E and GOV, respectively two and one factor are consistently predicted.

GE proved to be a special case. A key pattern for GE is that Eastern European countries have a high degree of achieved gender equality according to a number of measures, while Western European countries are most active in promoting gender equality in institutions (Peter et al., 2018b). This translates into factors where indicators of the status of GE load positively while indicators of the promotion of GE load negatively. This is problematic for interpretation in the cluster analysis. For example, a low value for GE could indicate low GE status and low GE promotion, but it could also reflect high values of both, where one offsets the other. To remedy this, we have conducted two separate factor analyses for GE, one for the status of GE and one for actions to promote GE.

Table A1-A6 below presents the factor scores from separate principal component factors analysis with varimax rotation. The analyses were constrained to only two factors for SLSE, PE, E, and OA, while for GOV, the analysis was constrained to one factor.

[Table A1a here]

[2] In this case, the procedure was repeated 30 times the number of variables, such that $K = P \times 30$.

[Table A1b here]

[Table A2 here]

[Table A3 here]

[Table A4 here]

[Table A5 here]

[Table A6 here]

Correlation matrix for indices

Table A7 below finally provides a correlation matrix for the 11 indices derived in the study.

[Table A7 here]

Table 1: Overview of 43 RRI indicators

RRI key	Indicator	Description	Ref. year	Data source	Data type	Index inclusion
Gender equality	GE1	Share of research-performing organisations with gender equality plans	2016	MoRRI RPO survey	Primary	GE action
	GE2	Share of female researchers by sector	2015	Eurostat	Secondary	
	GE2.1	Share of female researchers – all sectors	2015	Eurostat	Secondary	
	GE2.2	Share of female researchers – business enterprise sector	2015	Eurostat	Secondary	
	GE2.3	Share of female researchers – government sector	2015	Eurostat	Secondary	GE status
	GE3	Share of research-funding organisations (RFOs) promoting gender content in research	2016	MoRRI RFO survey	Primary	
	GE4.1	Dissimilarity index: higher education sector	2012	EC She figures	Secondary	
	GE4.2	Dissimilarity index: government sector	2012	EC She figures	Secondary	
	GE5	Share of research-performing organisations (RPOs) with policies to promote gender in research content	2016	MoRRI RPO survey	Primary	GE action
	GE6	Glass ceiling index	2013	EC She figures	Secondary	
	GE7.1	Gender wage gap – academic professions	2014	Eurostat	Secondary	
	GE7.2	Gender wage gap – technicians and associate professionals	2014	Eurostat	Secondary	
	GE8	Share of female heads of research-performing organisations	2016	MoRRI RPO survey	Primary	
	GE9	Share of gender-balanced recruitment committees at research-performing organisations	2016	MoRRI RPO survey	Primary	
	GE10.1	Share of female authors	2016	Web of Science and Scopus	Secondary	GE status
Science Literacy and Education	SLSE1	Importance of societal aspects of science in science curricula for 15 to 18-year-old students	2016	Desk research and interviews	Primary	RRI training
	SLSE2	RRI-related training at higher education institutions	2016	MoRRI RPO survey	Primary	RRI training
	SLSE3	Science communication culture	2012	MASIS project	Secondary	SLSE culture
	SLSE4	Citizen science activities in research-performing organisations	2015-2016	MoRRI RPO survey	Primary	SLSE culture
Public Engagement	PE1	Models of public involvement in science and technology decision-making	2012	MASIS project	Secondary	Public participation
	PE2	Policy-oriented engagement with science	2010	Eurobarometer, 340, 2010	Secondary	
	PE3	Citizen preferences for active participation in science and technology decision-making	2013	Eurobarometer, 401, 2013	Secondary	
	PE4	Active information search about controversial technologies	2010	Eurobarometer, 341, 2010	Secondary	Public participation
	PE5	Public engagement performance mechanisms at the level of research-performing organisations	2016	MoRRI RPO survey	Primary	
	PE6	Dedicated resources for public engagement	2016	MoRRI RPO survey	Primary	
	PE7	Embedment of public engagement activities in the funding structure of key public research-funding agencies	2016	MoRRI RFO survey	Primary	PE in assessment
	PE8	Public engagement elements as evaluative criteria in research proposal evaluations	2016	MoRRI RFO survey	Primary	PE in assessment
	PE9	Research and innovation democratisation index	2016	MoRRI SiS survey	Primary	Public participation
	PE10	National infrastructure for involvement of citizens and societal actors in research and innovation	2016	MoRRI SiS Survey	Primary	
Ethics	E1.1	Ethics at the level of research-performing organisations	2016	MoRRI RPO survey	Primary	Ethics in RPOs
	E1.2	Ethics at the level of research-performing organisations (composite indicator)	2016	MoRRI RPO survey	Primary	Ethics in RPOs

	E2	National ethics committees' index	2012	EPOCH	Secondary	
	E3.1	Research-funding organisations' index	2016	MoRRI RPO survey	Primary	Ethics in RFOs
	E3.2	Research-funding organisations' index (composite indicator)	2016	MoRRI RPO survey	Primary	Ethics in RFOs
Open Access	OA1.1	Share of open access publications	2016	Web of Science and Scopus	Secondary	OA status
	OA1.2	Citation scores for OA publications	2016	DOAJ, PMC, ROAD, CrossRef, OpenAIRE	Secondary	OA status
	OA3	Social media outreach/take-up of open access literature	2012-2015	CWTS	Pimary	OA action
	OA4	Public perception of open access	2013	Eurobarometer, 401, 2013	Secondary	OA action
	OA5	Funder mandates	2011	EC Commission Recommendations on Access and Preservation of Scientific Information in the Digital Age	Secondary	
	OA6	Research-performing organisations' support structures for researchers as regards incentives and barriers for data sharing	2016	MoRRI RPO survey	Primary	OA action
Governance	GOV1	Use of science in policymaking	2012	MASIS project	Secondary	Governance
	GOV2	RRI-related governance mechanisms within research-funding and performing organisations	2016	MoRRI RPO survey	Primary	Governance
	GOV3	RRI-related governance mechanisms within research-funding and performing organisations – composite index	2016	MoRRI RPO survey	Primary	Governance

Note: The majority of primary data collection has been performed within the framework of the MoRRI surveys fielded to Research Performing Organisations (RPOs), Research Funding Organisations (RFOs), and Science-in-Society (SiS) actors. For the selection of secondary data, we have relied on statistical information from Eurostat, the European Commission's (EC) She Figures, and various waves of the Eurobarometer surveys from 2010 and 2013. We have also utilised information from the FP7-funded projects "Ethics in Public Policy Making: The Case of Human Enhancement" (EPOCH) and "Monitoring policy and research activities on Science in Society in Europe" (MASIS), the Web of Science and Scopus databases along with lists of open access journals from the Directory of Open Access Journals (DOAJ), PubMed Central, the Directory of Open Access Scholarly Resources (ROAD), CrossRef, and the OpenAIRE project. Finally, the European Commission's "Commission Recommendations on Access and Preservation of Scientific Information in the Digital Age" has been used to assess funder mandates for open acesss.

Table 2: RRI indices

Indices; labelled	*Indicators*	*Mean*	*Standard deviation*
GE action	GE1, GE5	0.4407	0.2890
GE status	GE2.3, GE10.1	0.4476	0.3338
RRI training	SLSE1, SLSE2	0.5334	0.2723
SLSE culture	SLSE3, SLSE4	0.6429	0.3293
Public participation	PE1, PE4, PE9	0.4944	0.2865
PE in assessment	PE7, PE8	0.3194	0.2437
Ethics in RPOs	E1.1, E1.2	0.3543	0.2223
Ethics in RFOs	E3.1, E3.2	0.5279	0.3502
OA status	OA1.1, OA1.2	0.6244	0.2611
OA action	OA3, OA4, OA6	0.4201	0.2443
Governance	GOV1, GOV2, GOV3	0.5739	0.3285

Table 3: Mean cluster scores on 11 RRI indices

Cluster	*GE action*	*GE status*	*SLSE training*	*SLSE culture*	*PE participation*	*PE in assessment*	*Ethics in RPOs*	*Ethics at funders*	*OA status*	*OA activities*	*Governance*
Blue	0.45	0.18	0.31	0.44	0.27	0.20	0.27	0.56	0.72	0.40	0.43
Red	0.17	0.79	0.70	0.38	0.51	0.20	0.28	0.72	0.65	0.45	0.30
Black	0.35	0.79	0.54	0.83	0.22	0.65	0.38	0.14	0.75	0.23	0.82
Green	0.70	0.27	0.58	1.00	0.77	0.42	0.49	0.46	0.47	0.47	0.86
Total	0.44	0.45	0.53	0.64	0.49	0.32	0.35	0.53	0.62	0.42	0.57

Note: Scores are within-cluster means of the 11 constructed RRI indices, while 'Total' denotes the across-cluster means.

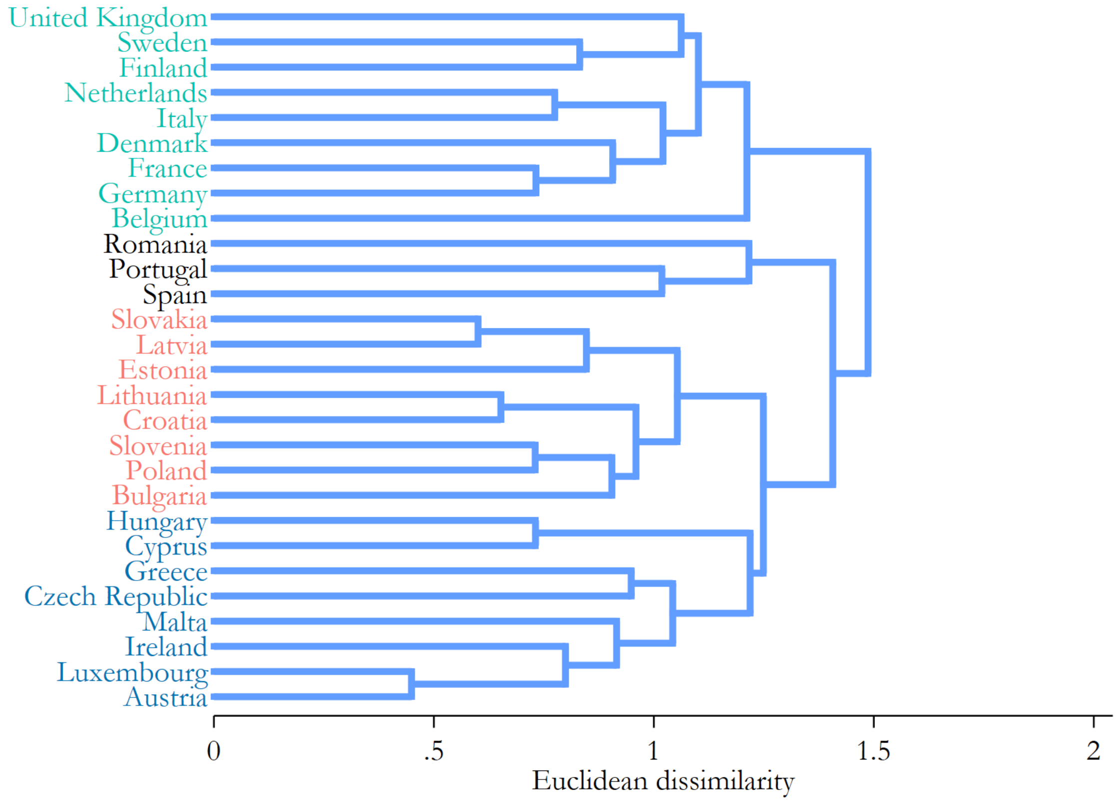

Figure 1: Dendrogram of cluster solutions

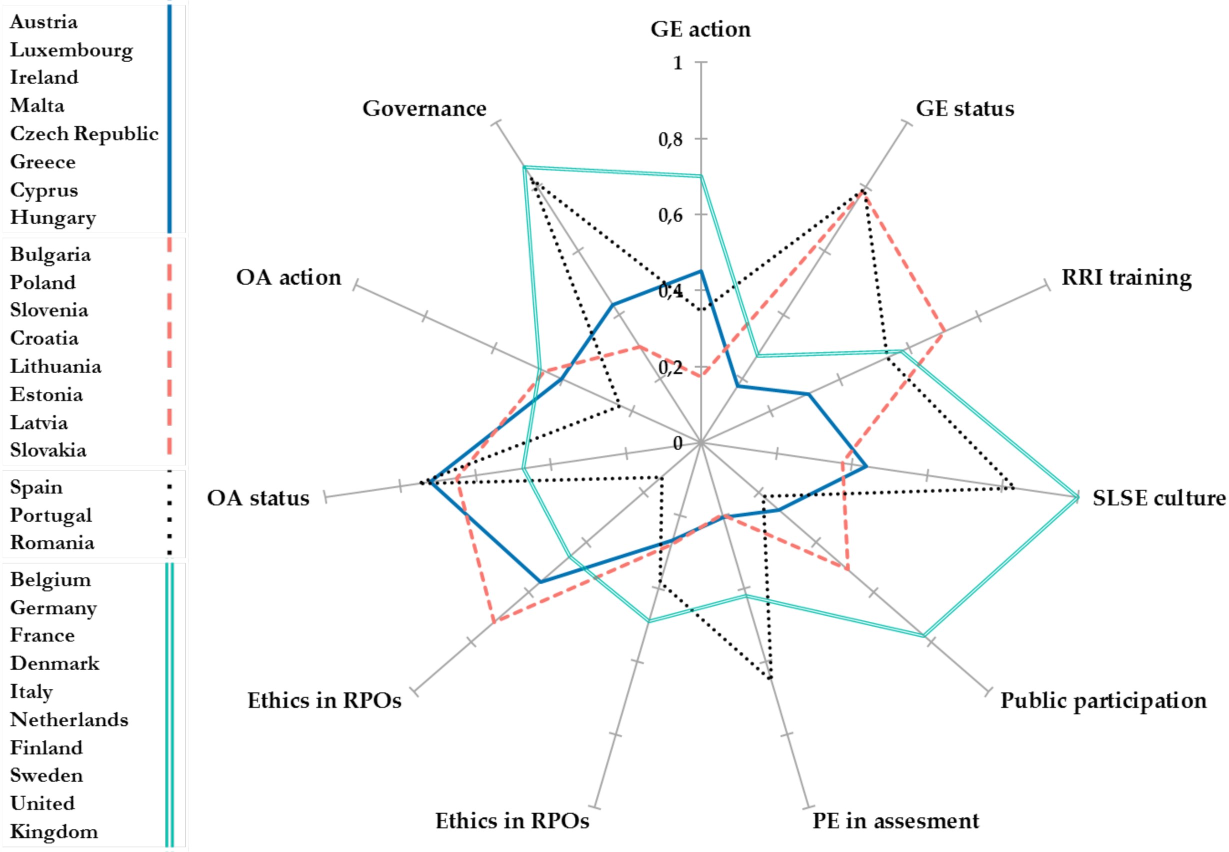

Figure 2: Within cluster means across indices

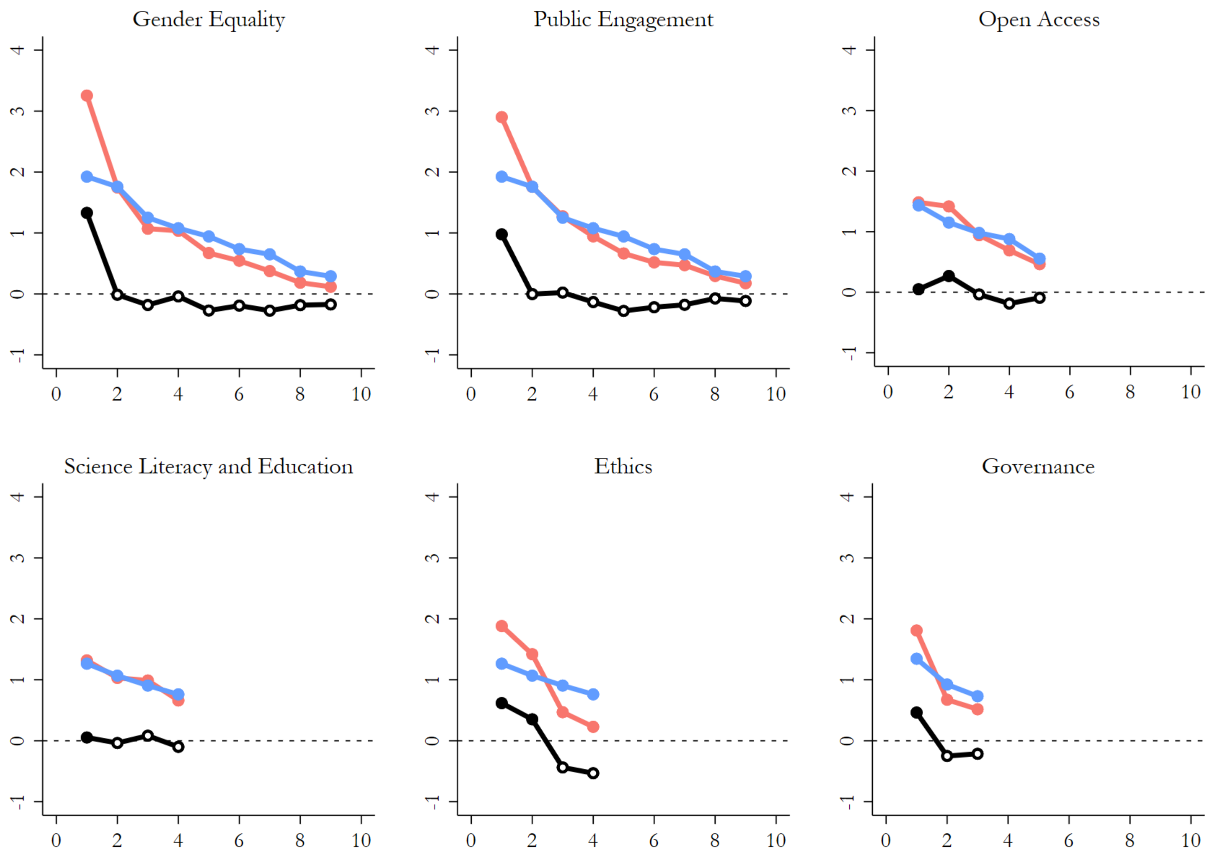

Figure A1: Horn's parallel analysis for four principal component factors

Table A1a: Factor analysis of Gender Equality indicators (1)

	Factor 1
GE1	**0.9489**
GE3	0.1531
GE5	**0.9314**
Variance	0.5971

Note: Principal components factors with varimax rotation. N = 28

Table A1b: Factor analysis of Gender Equality indicators (2)

	Factor 1
GE2.3	**0.8643**
GE6	-0.0394
GE7.1	**0.3064**
GE8	**0.3176**
GE9	0.2927
GE10.1	**0.8592**
Variance	0.8714

Note: Principal components factors with varimax rotation. N = 28

Table A2: Factor analysis of Science Literacy and Education indicators

	Factor 1	Factor 2
SLSE1	-0.0105	**-0.3339**
SLSE2	-0.0866	**0.8625**
SLSE3	**0.6314**	0.5280
SLSE4	**0.8895**	-0.1353
Variance	0.2994	0.2881

Note: Principal components factors with varimax rotation. N = 28

Table A3: Factor analysis of Public Engagement indicators

	Factor 1	Factor 2
PE1	**0.7443**	0.2529
PE2	**0.4970**	0.4337
PE3	**0.5241**	0.2072
PE4	**0.7760**	-0.1606
PE5	0.0556	**0.5662**
PE7	0.1918	**0.8575**
PE8	-0.2138	**0.7700**
PE9	**0.7714**	0.0161
PE10	**0.5741**	0.0248
Variance	0.2987	0.2189

Note: Principal components factors with varimax rotation. N = 28

Table A4: Factor analysis of Ethics indicators

	Factor 1	Factor 2
E1.1	-0.1723	**0.8533**
E1.2	0.0563	**0.8812**
E3.1	**0.9315**	-0.1098
E3.2	**0.9408**	0.0127
Variance	0.4464	0.3792

Note: Principal components factors with varimax rotation. N = 28

Table A5: Factor analysis of Open Access indicators

	Factor 1	Factor 2
OA1.1	**0.8568**	-0.0241
OA1.2	**0.8340**	0.0142
OA3	0.1501	**0.4401**
OA4	0.0229	**0.7563**
OA6	-0.0503	**0.8251**
Variance	0.2911	0.2894

Note: Principal components factors with varimax rotation. N = 28

Table A6: Factor analysis of Governance indicators

	Factor 1
GOV1	**0.8098**
GOV2	**0.7947**
GOV3	**0.7225**
Variance	0.6031

Note: Principal components factors with varimax rotation. N = 28

Table A7: Correlation matrix for RRI indices

	GE action	GE status	RRI training	SLSE culture	Public participation	PE in assessment	Ethics in RPOs	Ethics in RFOs	OA status	OA action	Governance
GE action	1.0000										
GE status	-0.6446	1.0000									
RRI training	-0.0836	0.2521	1.0000								
SLSE culture	0.5826	-0.2685	0.0551	1.0000							
Public participation	0.2963	-0.0818	0.2217	0.3930	1.0000						
PE in assessment	0.2283	0.0653	0.0797	0.6177	0.0701	1.0000					
Ethics in RPOs	0.3122	-0.1183	0.1724	0.3342	0.0659	0.0709	1.0000				
Ethics in RFOs	-0.2062	0.0360	-0.0247	-0.3515	-0.0052	-0.1805	-0.1655	1.0000			
OA status	-0.2386	0.2177	-0.1568	-0.4164	-0.3349	-0.1949	-0.1408	0.2121	1.0000		
OA action	-0.0118	-0.0303	0.1920	0.0462	0.2863	0.0319	0.0689	-0.2251	0.0353	1.0000	
Governance	0.5272	-0.2102	-0.0890	0.6836	0.2911	0.5864	0.1565	-0.1200	-0.2703	-0.1583	1.000