Small Advanced
Economies
Initiative

Discussion Paper: Prioritisation of Public Sector Research across the SAEI

Working Paper

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Table of Contents

This paper was prepared by member countries and the coordinating office of the Small Advanced Economies Initiative. Please direct any comments or corrections to Julian Tollestrup in the Office of the New Zealand Prime Minister's Chief Science Advisor: julian.tollestrup@smalladvancedeconomies.org.

About Us

This paper is written by the Secretariat of the Small Advanced Economies Initiative; a group of 6 countries (Denmark, Finland, Ireland, Israel, Singapore and New Zealand) of similar populations who informally collaborate to analyse areas of policy that are influenced by country size.

1. Introduction

It is generally accepted that small countries cannot 'do everything' and therefore must focus within their public STI systems in order to best utilize resources available in terms of both financial and human capital. Aggregation of effort and resource, however, may occur through a variety of ways: it may be de facto as a result of history (e.g. based on competencies present) or advocacy, market driven (by industry or other sectors), as part of a strategic top-down planning exercise, or even through emergent processes that are ad hoc in reaction to externalities.

Prioritisation in publically funded research can refer to consideration of the balance of funding for basic and applied research, and the amount invested in scientific career development. The balance and distribution of public funding between publicly and privately conducted research is also a form of priority setting. Often, however, the term refers to prioritisations of specific areas or topics of research of national significance. We will touch on other areas but focus in greater depth on this latter area where the SAEI countries display a variety of policy settings.

In this discussion paper we distinguish between the terms *prioritisation* and *specialisation* as follows*:*

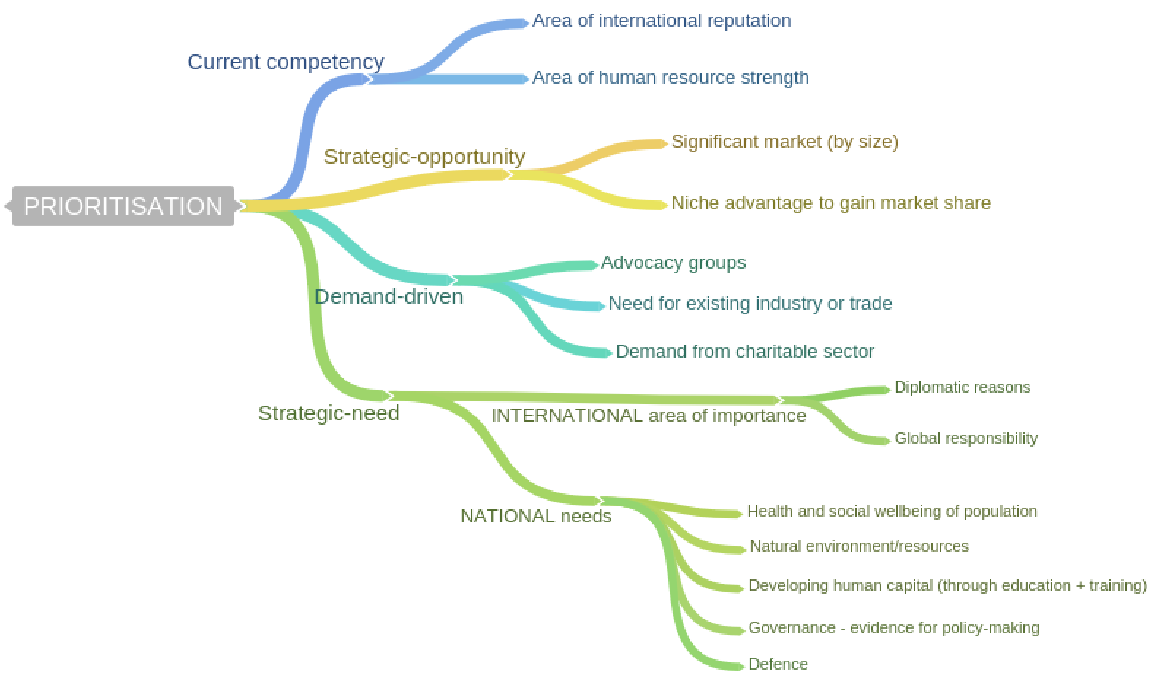
> **Prioritisation**: Concentration of public funding, human resources and/or political attention towards specific topics of research. This concentration of resource may be planned or otherwise, falling on a spectrum from coordinated to ad hoc.
>
> **Specialisation**: An identified strength or comparative advantage for a region or country in this context in the areas of science or technology. This strength may have developed from receiving greater inputs over time, however this is not always the case.

This is slightly different to the OECD's use of the term 'smart specialisation' which in this context could be equated to 'smart prioritisation'.

2. Reasons behind national/regional prioritisation

Figure 1 attempts to highlight and categorise some of the different drivers behind prioritisation of resources within the SAEI. Although not explicitly included in this diagram, it should be noted that in some systems representative interest groups also influence the investment of resources extensively. For the purposes of this discussion we would describe such processes as *prioritised as a result of advocacy*.

Figure 1. **Drivers behind prioritisation across the SAEI**



Source: SAEI

Looking at Figure 1, several important questions are brought to light. Such questions include:

1. **How should funding be balanced** across the different dimensions presented? To what extent should a country fund truly excellent research (here listed as current or emerging competencies) outside of agreed strategic or demand-driven priority areas? To what extent should one fund excellent "blue skies" research?

2. **To what extent are prioritisation efforts carried out formally** or in an *ad hoc* fashion? (A discussion on how countries prioritise can be found in section 4 and examples from across the countries can be found in section 6.)

3. **To what level of granularity** should priority areas be identified at a national level and to what extent should decision-making be devolved to stakeholders within the system? Section 4 discusses 'block' funding to research institutes, for example, as a form of high-level prioritisation.

4. **What funding should remain** for excellent science outside of identified demand-driven and strategic research areas? How should emerging strengths be identified and supported? To what extent should priorities be applied across the whole system or restricted to particular funds?

5. **Timescales of impact:** Within agreed subject areas (particularly those identified as fulfilling a strategic or industry need), how can a balance be struck between supporting research with relatively immediate positive impacts and research focusing on longer term potential? A parallel piece of work on impact assessment in relation to larger research programmes has been released by the SAEI Secretariat[1] and refers to this question.

[1] *Broadening the Scope of Impact, Small Advanced Economies Initiative, March 2015*

Looking at Figure 1 it should also be noted that areas may fall into more than one category. For example, an area of strategic need of a country is often likely to also have market potential and potential economic returns when services or technology can be translated to other countries or organisations facing similar issues. Ideal priority areas are likely to include a variety of the drivers above. In small advanced economies, for example, where resources are limited, many areas that receive priority are likely to include some aspect of national need in order to ensure a return on investment.

Examples from within the 6 nations of prioritised areas based on the drivers listed in Figure 1 include:

- Singapore – Water security has long been a national issue for Singapore. The densely-populated country currently still imports a large fraction of its water supply from Malaysia. This priority area for research was identified in national strategic plans and supported by thematic funding schemes such as the Strategic Research Programmes. For Singapore, development of technology (from reducing waste and leakage, improving recycling of sewage, through to desalination) also offers potential future opportunity to export solutions to other markets facing water security concerns.

- Finland – With a historically strong forestry industry facing declining exports, Finland has invested to turn this capacity towards new exports through supporting a significant research and innovation platform in this space. With natural resource advantages and a solid knowledge-base, Finland has built competency in biofuels and wood-derived products. This research area supports a national economic need to turn around existing companies, builds on Finland's resource strengths and offers a strong market opportunity in the face of EU biofuel regulation.

- New Zealand – Food and nutrition research has been identified as a key focus of many public funding tools, including the National Science Challenges. Such emphasis stems from the central part food exports play in the New Zealand economy. As an area of national but also global importance, investment in this topic may also have diplomatic benefits for the country.

3. Prioritisation for small countries in a global setting

Science, by nature, is an international endeavour with high and increasing levels of international collaboration. It is therefore important to consider the international policy context alongside national issues when assessing how and where to prioritise resources. Discussions within the SAEI have suggested that specific considerations in this domain may include:

- The research focus/priorities of neighbouring economies, frequent collaborators, or trading partners which may directly or indirectly influence domestic research;
- Formal joint initiatives and/or funding programmes with neighbouring countries (e.g. Nordforsk in the Nordic region, Horizon 2020 in Europe, bilateral joint initiatives with China);
- Global issues which receive international political recognition and philanthropic support for research and technology development (such as the Grand Challenges in Global Health).

In addition, small countries may need also to consider:

- Retention of knowledge absorption – What capability do small countries need to retain in non-prioritised areas in order to be able to absorb and apply knowledge from the global base, particularly in areas where there is a lack of national strength?
- How can strengths be generated and retained – How many competencies or specialisations can a small country maintain? How can the country best capitalise on these strengths?

- How can smaller economies participate in meaningful ways in areas of international focus (e.g. grand challenges) and how can they benefit from international collaboration such as Horizon 2020 (see Box 1)?
- How can capacity be developed to support future priorities? How can a small country train, retain or access all the skills required with the increasing trends for multi-disciplinary, mission-oriented research, requiring expertise across a range of conventional disciplines?

An underlying issue in the creation of areas of strength is how a small country can build a critical mass of expertise, which may also have a regional dimension. In this study, however, we focus on national-level priority setting.

Box 1: Europe - Framework Programmes and Horizon2020

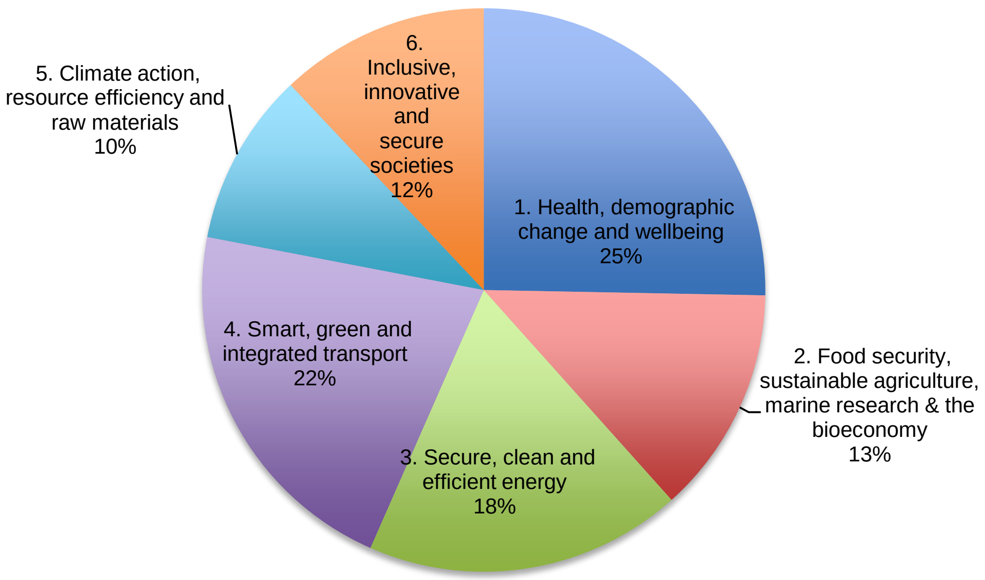
Joint initiatives began in the 1980s in response to challenges from the US. However, since the launch of the European Research Area in 2000 research policy has evolved to be used as a tool. The budgets of the Framework Programmes (FPs) have increased steadily and FP7 (2007-13) was the world's largest research programme (at 54 bn EUR) and the largest budget administered directly by the European Commission. Part of the goal was to reduce fragmentation of research resources across the EU and to promote researcher mobility.

The majority of funds under the FPs support research defined by thematic topics, set traditionally via a top down process. The latest programme, Horizon2020, has the following main themes:

- **Industrial leadership, 23% of the overall budget.** Includes: ICT, nanotechnologies, biotechnologies, space, advanced manufacturing and processing, and advanced materials.
- **Societal challenges, 40% of the overall budget.** Includes: Health and demographic change, sustainable agriculture and bioeconomy, clean energy and transport, climate action and resource efficiency, inclusive/innovative societies, secure societies (see Figure A).
- **Excellent science, 31% of the budget -** A third pillar of the budget is allocated towards supporting the fundamental excellent science base.

As countries in particular look to leverage their investment in research, such priorities may affect national prioritisation areas.

Figure A. **Budget allocation breakdown of societal challenges by theme for Horizon2020**



Source: European Commission

4. How we prioritise

Across the economies in the SAEI, there are a range of policy settings and methods through which resources are ultimately prioritised. Prioritisation may occur intermittently or through regular or continuous processes, examples of which are described below.

1) **Intermittent:** Several of the countries in the group have carried out formal exercises (most notably Ireland, Finland and Denmark) to identify priorities across the system. Such processes vary from the primarily 'bottom-up' processes in Denmark to a more 'top-down' analytical approach taken in Ireland. The degree to which the results are applied across funding schemes, and the extent to which some funding remains outside of the prioritised topics, also varies from nation to nation. Creation of institutes or platforms with specific mandates (e.g. research institutes in specific areas) also represent a form of one-off prioritisation (see below), often with resulting long-term changes to the research landscape in the country concerned.

2) **Regular:** Annual budget allocations and political statements may include some aspects of priority identification, and at a high-level may allocate resources between different themes. Alternatively, councils or committees with strategic oversight of the system may draw up multi-year plans. Singapore, for example, carries such work out on a regular 5-year cycle.

3) **Continuous operational level:** Prioritisation may occur through strategy teams in delivery agencies/funding agencies, or by the individual institutions as a result, for example, of financial incentives (e.g. for universities to produce certain graduates).

Prioritisation via creation of research institutions

The science systems across the countries in the SAEI have different characteristics. Some like New Zealand and Singapore include research institutes with specific mandates alongside universities[2]. Such mandates are often aligned with industry needs or occasionally other national priorities.

Where institutes receive some funding on a non-competitive core basis (whether to support key services, infrastructure maintenance, or general costs), the formation, expansion, or closure of such institutes is also a form of prioritisation. This is not only through funding itself, but also the enhanced visibility, including through political support, which can often result from such processes.

Establishing physical institutions provides some degree of security that areas of strength, strategic importance or industry need will be supported over long timeframes. However, as institutions are often easier to establish than they are to dissolve, they can suffer from a lack of dynamism and 'lock-in' with respect to changing needs and depending on their implementation can lead to silos developing in the research system (including separation of key research actors and a separation from the supply of new talent).

5. Needs and risks in prioritisation processes

Experience from across the group has highlighted several likely requirements of effective prioritisation exercises and a number of risks that can pose a threat to such efforts. These have been identified both in the *framework* (i.e. the principles against which decisions are made) used to undertake prioritisation exercises as

[2] The role of research institutions and universities in the science system has been considered by the SAEI group but is not the topic of this discussion piece.

well as the *processes* through which they're implemented (e.g. selection of panels, curation of inputs). Considering prioritisation exercises overall, it has been agreed they must:

- Identify areas of national strategic need;
- Identify the needs of existing industries and emerging companies;
- Identify existing strengths and comparative advantages that may be leveraged;
- Identify gaps in competency compared to need;
- Reduce fragmentation/duplication of interventions between agents to:
  - mitigate risk for gaps in funding/human resource for areas of national strategic importance,
  - increase efficiency in use of resources;
- Ensure some degree of flexibility is retained in the system (e.g. for areas of emerging competency outside of prioritised areas).

Small countries risk losing researchers whose work they cannot financially support in the near term. For this reason prioritisation exercises also need to consider the opportunity cost of not supporting certain areas and whether this results in acceptable long-term outcomes.

Equally, prioritisation of some areas in the longer term may divert highly skilled individuals away from other areas. Again, consideration of the extent to which this is acceptable/desired and how transition periods can be managed to ensure capabilities are retained is important.

Risks for prioritisation processes and frameworks include:

- **Risk Aversion by committees/policymakers**: self-reinforcing systems supporting existing distribution at expense of new opportunities;
- **Lobbying from specific industries/players:** "he who shouts loudest" effect may support comparative advantage but may also limit new sectors from emerging;
- **Dominance of current context:** issues of near term priority such as employment may dominate the process over longer-term needs, politicians may push for quick results within election cycles;
- **Prioritisation with too much granularity**: too high specificity can reduce flexibility for the future or cause resources to be concentrated in a few narrow sectors which may leave an economy open to volatility;
- **Prioritisation with insufficient granularity:** in which case the prioritisation may only be a superficial exercise with minimal effect.

6. Examples of prioritisation processes from across the SAEI

The following section describes prioritisation processes that have taken place across the SAEI group. While at a high level there appear to be some similarities (for example in some selection criteria), the application of the outputs of such processes has varied. In the Irish case, for example, the prioritisation applies across funding agencies, whilst in Denmark and Finland priority exercises have been implemented through specific programmes or platforms.

Considering the requirements of prioritisation processes highlighted in Section 5, the following text also provides examples of the type of evidence that may be used to facilitate these aims. Particularly for Ireland and Denmark, the following examples highlight the evidence base used to guide and inform their efforts to identify strategic areas of focus.

Box 2: Denmark – RESEARCH2020

In 2006 a broad political agreement was made that the *basis* for political prioritisation of funds for strategic research should be improved. This ultimately resulted in the development of RESEARCH2015 (in 2008), and its successor RESEARCH2020 (in 2012).

For RESEARCH2020, the Danish Agency for Science, Technology and Innovation engaged a wide group of Danish society's most important users and creators of research and research-based knowledge and technology to identify the visions and needs for strategic research for Denmark. The result was a catalogue aimed at reflecting society's demand for research. The aim of the work was to support decisions to invest in research , which may contribute to the development of Danish society as a whole.

Selection Criteria

To be selected, areas in RESEARCH2020 had to meet the following principles:

1. **Have distinctive arguments:** sufficiently convincing to justify discussing a national or global societal challenge or opportunity.
2. **Require research-based knowledge**: to find a solution and/or utilize the potential.
3. **Based on existing research environments**: with the capacity to carry a considerable investment in the area.
4. **Show sufficient breadth:** to allow several research environments to suggest relevant research projects, and offer a national or international horizon.
5. **Significant effect plausible to achieve from investment**: e.g. in relation to growth, welfare, employment, or sustainable development in Denmark in the medium-long term.
6. **Offer future potential:** goes beyond the topical area, to address future challenges and opportunities for Denmark in a global context and provide opportunity to make large and long-term investments.

Process

1. Mapping of research needs on the basis of RESEARCH2015

May 2011 - Ministries, research councils, universities, industry and interest organisations invited to make suggestions for research areas in RESEARCH2020, informed by RESEARCH2015.

2. Identification of themes in dialogue with the stakeholders

- September 2011 – suggestions from stakeholders submitted.
- Sept - Dec 2011 – draft document prepared (based on submissions and analysis).
- Jan/Feb 2012 – oral and written dialogue with stakeholders.

3. Quality assurance and substantiation of draft report

Mar/Apr 2012 – by ministries and Danish Council for Strategic Research and Council for Independent research, including assessing Danish qualifications for being able to accomplish research initiatives.

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Box 2: Denmark – RESEARCH2020 *(continued from previous page)*

Inputs used to inform the RESEARCH2020 process included the following:

- Proposals from stakeholders across the research landscape (on the basis of RESEARCH2015 – see below) - these formed the most important foundation for the process;
- Extensive knowledge of the Danish research landscape via bibliometrics, statistics, analyses by the Danish Agency for Science, Technology and Innovation;
- A Gallup poll of the public perception of issues in science and technology (in 2011);
- Analysis of trends in Denmark and globally (based on a literature review); and
- Information regarding EU strategies (including Horizon2020).

Material from the earlier prioritisation process, RESEARCH2015, was also used to guide the RESEARCH2020 effort, including:

- Horizon-scans, including an OECDHorizon-scan for Denmark identifying societal challenges facing Denmark in a Danish and global context;
- Other contributors' proposals (350+) representing the general public, companies, researchers, universities and organisations;
- A Gallup poll of the public perception of issues in science and technology (in 2007), including questions such as 'who should determine what needs to be researched in Denmark?'.

RESEARCH2020 was released in July 2012.

Use

Since the completion of RESEARCH2020, elected officials have selected a variety of research themes. The themes have manifested as research programs administered by the then Danish Council for Strategic Research, now Innovation Fund Denmark. Likewise, the catalogue has served as a strategic guide for universities, RTOs and other knowledge institutions.

Preparations towards a successor to the RESEARCH2020 catalogue are currently taking place.

Box 3: Denmark - INNO +

The creation of the INNO+ Catalogue was the result of a political agreement on the allocation of the Research Reserve funding in 2013, in which it was agreed that an innovation policy supplement to the prioritisation platform for strategic investments in research, RESEARCH2020 (see above), was to be drawn up. It has the purpose of providing a knowledge base to help prioritise future societal partnerships on innovation - partnerships in which public and private actors work together to find solutions to societal challenges. The areas identified in the catalogue aim to reflect concrete and significant societal needs, industrial perspectives, and particular Danish prerequisites.

Like RESEARCH2020, the INNO+ Catalogue is the result of a comprehensive iterative consultation process with a large number of stakeholders from industry and interest organisations, ministries, research councils, universities and other higher education institutions, GTS institutes (RTOs), and cluster and innovation network organisations.

Selection criteria

To be eligible, identified areas had to:
1. Build on knowledge-based strongholds and on industrial strongholds.
2. Entail close and binding collaboration between companies, knowledge institutions and public authorities, and include international collaboration to a relevant degree.
3. Show potential for a strategic innovation investment in the field to have a significant effect on growth in Denmark in the short to medium term.
4. Relate to a significant societal challenge or provide arguments for how the field may prove to be a driving force for growth in Denmark.
5. Build upon a demand feature, ensuring that the innovation and technological development projects launched can be translated into practical application on a large scale in a national, and preferably global, market, and thus lead to concrete societal changes and growth in particular.

Knowledge-based innovation and a public sector-initiated innovation effort were potential preconditions for realising the defined goals and tapping the business potentials. A “public innovation effort” was to be understood in a broad sense and encompass the palette of innovation policy instruments in particular, as well as public regulation, public procurement, activities at knowledge and educational institutions, etc.

Process (Lead: DASTI + Danish Ministry of Science, Innovation & Higher Education)

1. Mapping of potential focus areas for strategic investments in innovation:
    - December 2012 - stakeholders invited to come up with proposals in line with focus areas/societal challenges described in RESEARCH2020 (almost 500 submissions).
2. Stakeholder dialogue on selection of the proposed focus areas:
    - Spring 2013 - five workshops based on submissions were held at different places around the country, in which the stakeholders were invited to provide input regarding prioritisation of the proposals.
3. Identification of thematic areas and focus areas:
    - Spring 2013 - first draft prepared on the basis of the selection criteria, proposals, and workshops RESEARCH2020, Horizon 2020 and the recommendations made by the Danish Government’s growth teams were also used in the selection process.
    - May 2013 - catalogue submitted for stakeholder consultation, dialogue meetings held.
4. Finalisation of the INNO+ **Catalogue:**
    - Summer 2013 - based on the consultation responses, dialogue, and in a continued collaboration with key stakeholders, the catalogue was adjusted and finalised.

Use

Since 2014, politicians have selected 7 focus areas from the INNO+ Catalogue, to be translated into action via societal partnerships, in which private-sector enterprises, public-sector research institutions and authorities collaborate on developing new, innovative solutions in response to the specific societal challenges mentioned in the catalogue.

Box 4: Ireland Prioritisation Exercise

Timescales

Sets agenda for 2013-17, with a driver for quick action due to economic crisis (over 50% of actions completed by end Q1 2014). Covered a 5-year time horizon but at least 10 year sustained investment expected, with some real impacts within 5 years.

Scope

National scope, however some non-targeted research expected to continue through competitive calls. Exercise explicitly excluded 'block grant' and funding for company R&D.

Selection criteria

Initial goal was to identify between 10-20 priority areas that take into account alignment with EU/international developments and programmes with the following criteria:

- **Market potential:** Global market size of priority area or market in which Ireland can realistically compete.
- **Country Strength**: Area in which Ireland has/could build strengths in research disciplines relevant to area.
- **Intervention need:** Public R&D is necessary to exploit the area and will complement private R, D & I.
- **Strategic challenge**: Area represents an appropriate approach to a recognised national/global challenge to which Ireland should respond.

Level of granularity set to be sufficiently narrow so as to provide focus but sufficiently broad to avoid 'picking winners' in terms of individual research groups/institutions. Human capital development is recognised as the most important enabler, which links to the National Strategy for Higher Education (published 2011, highlights the objective to support Priority Areas) and National Framework of Doctoral Education.

Stages

1. **Gathered supporting evidence** (see below), for steering group & TWG deliberations.
2. **Thematic working groups (TWG)** met four times across 4 high-level areas and involved funding agencies and 1 representative each from: the universities, institutes of technology, and the enterprise sector. Proposed initial list of areas under the themes.
3. **Stakeholder engagement events –** gathered initial feedback from TWG perspectives and key stakeholders were also invited to formally provide written feedback. TWG then reviewed feedback and provided final recommendations to the Steering Group.
4. **Steering Group -** composed of high-level membership from academia, industry, and public service. Chaired by Jim O'Hara, former general manager of Intel Ireland, who reviewed TWG recommendations and stakeholder feedback and held responsibility for the final recommendations to Government.
5. **Report** of the Research Prioritisation Steering Group published.
6. **Implementation plans -** senior-official cross-agency action group (RPAG) designed implementation plan for each area (10 agencies, and 6 Government departments with responsibility for funding S&I).
7. **Champion** appointed for each priority area (e.g. working group chair for area in RPAG).
8. **Secretariat RPAG monitors progress** and reports quarterly, operational level cooperation between agencies. Framework of metrics and targets developed (adopted July 2013).

The following inputs were also prepared by Forfas to facilitate deliberations throughout the steering group and stakeholder meetings:

- A study on global market opportunities, growth markets & the positioning of the Irish enterprise base – integrated previous sectoral studies and profiled over 70 market areas of relevance to Ireland, with a focus on the R&D agenda and Irish position and capacity. This study also included a consultative process with relevant government agencies and industry representative groups.
- A review of current strengths and areas of emerging critical mass in Irish research – included quantitative and qualitative information and identification of research areas with an emerging critical mass. This exercise captured views of research funding agencies, government departments, HEIs, and other research performers.

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Box 4: Ireland Prioritisation Exercise *(continued from previous page…)*

- A review of drivers, trends and societal issues from a national perspective in a global context – assessed key global issues and trends in areas such as climate change, energy supply, food security, health and ageing etc., identifying 54 drivers across 8 themes. Roundtable discussions were held across all government departments and funding agencies to explore trends and research and technology critical to addressing these challenges.

Implementation

A high percentage of awards and the general themes in 2013 fell within priority areas. Important aspects of the plans included:

- Regular reviews to check continued relevance of areas selected.
- Improving cross-agency co-ordination, including practical operational level collaboration (such as multi-agency awards).
- Merger of some centres (e.g. in manufacturing research) to align with focus/role.
- Gap analysis (e.g. with SFIs funding instruments and change in mandate).
- Ongoing work to build platforms for translation (e.g. developing clinical infrastructure in Ireland alongside medical device expertise, developing knowledge exchange forums between industry/academia/agencies/practitioners).

For further information: *NRPE 1st Progress Report (June 2014), Report of the Research Prioritisation Steering Group (2012)*

Box 5: Finland - FinnSight2015

The Finnish Government system uses foresighting and future planning extensively. For example each sitting Government has the obligation to submit a foresight report covering the Government's view of the future during the next 10-20 years. Each report focuses on a defined set of strategically relevant issues and associated policies. Individual agencies also carry out their own foresighting activities.

One such example was FinnSight 2015 - a one-off foresighting study generated in 2005 centring on S&T and society. It was run by the Academy of Finland and Tekes and was instrumental in helping define the SHOK (Strategic Centres for Science, Technology and Innovation) platforms.

Process:

- Initial ideas for panels were put forward by Tekes and Academy of Finland. Final panel topics were selected on the basis of national significance, level and extent of competence, and potential socio-economic impacts.
- Panels covered 10 topics, involving 120 experts from industry and academia (such as company R&D directors and directors of academic centres/university departments).
- Chairs of each panel were carefully selected and each panel produced a report after c.6 months.
- The summary report highlights Finnish areas of competence under each panel topic.

Benefits:

- Closer collaboration between key funding agencies, Academy of Finland and Tekes.
- Building a multi-disciplinary debate.

Finland – SHOK Platforms

The 6 SHOK platforms were set up in 2007 as a means to support the needs of industry, facilitate economic renewal and provide science-based solutions to industry-driven problems. In reports of the time there was recognition of the need for clusters of competence and that small countries cannot do everything. Benefit was also seen in creating internationally visible programmes and platforms.

The SHOKs are public-private partnership platforms and the research aims to meet the needs of the industry and society within a 5-10 year time horizon. They were selected in areas considered crucial for the future of the Finnish economy and for wider Finnish society. 5 SHOK areas were originally selected by the Science and Technology Policy Council of Finland, with further areas chosen by a steering group led by the MEE and Ministry of Education.

Selection Criteria:

- Highly significant in terms of potential impact on society and economy with significant investments required in R&D.
- Need to achieve sufficient critical mass with regards to personnel and financial resources (annual level of 50-100 M EUR).
- Centres should be constructed around applications central to future of the centre in question, application-driven approach combining cross-cutting research & innovation.
- Core expertise for centres required to come from Finland, with potential for each centre to be among the best in the world.
- Strong commitment required from the main companies, universities, RIs, funders and ministries in question.

Each SHOK is managed by a SHOK company, with shareholders from industry, academia and PROs. Strategic steering/prioritisation of research and funding within the SHOK are agreed by the partners in the SHOK's strategic research agenda. At the national level the SHOK steering group provides governance and the MEE provides national-level guidance. In future the SHOKs are likely to have to compete for status and funding.

Further reading: *"Licence to SHOK?", External evaluation of the Strategic Centres for Science, Technology and Innovation, 2013.*

Box 5: Finland – Academy of Finland: Grand Challenges

The bulk of funding from the Academy of Finland goes on research that is not prescribed in advance and is not thematically defined. Nevertheless, 6 priority areas or 'Grand Challenges' have been defined by the Academy Board to assist in long-term strategy planning as well as in the start-up of new research programmes.

Challenges include: Northern Climate and Environment; Sustainable Energy; Dialogue of Cultures; A Healthy Everyday Life for All; Knowledge and Know-how in the Media Society; and the Ageing Population and Individuals.

References: www.aka.fi/en-GB/frontpage/Evaluation/Foresight, www.2030.fi, FinnSight 2015; Finland as a Knowledge Economy 2.0: Lessons on Policies and Governance (edited by Kimmo Halme, Ilari Lindy, Kalle A. Piirainen, Vesa Salminen, Justine White).

Singapore's National Framework for Research Innovation and Enterprise (RIE)

Box 6: Singapore – RIE Strategies

Singapore has a research, innovation and enterprise (RIE) strategy which covers 5 year periods. The development process for this strategy now occurs over a 2 year period, with the first year dedicated to establishing the needs of the system before the budget issues are addressed the following year. RIE2020 is currently in development, to be released at the end of 2015. This strategy deals with overarching issues and framework conditions. As part of this process, sector-specific development strategies or funding are also included.

Singapore has been planning S&T investments in 5-year plans since 1991. RIE2015 was published in 2011 after a 1-year process. It identified 3 research priorities (biomedical sciences, interactive and digital media and physical sciences and engineering), including identifying more specific areas of comparative advantage and capability within each of these areas.

The RIE planning process is fairly involved:

- Committees cover each vertical area (e.g. biomedical sciences, sustainability, digital economy, engineering and manufacturing) with cross-cutting committees to address overarching issues (e.g. manpower, research commercialisation);
- NRF and the Ministry of Trade and Industry act as the Secretariat for the process, including developing some background material for the Committees;
- The process works across agencies in the Singapore system.

Further reading: Research Innovation & Enterprise (RIE) Plan, 2015

Box 7: New Zealand – National Science Challenges

New Zealand's National Science Challenges (NSCs) are a set of multidisciplinary research programmes. Each Challenge is collaborative in nature, designed to address complex issues facing New Zealand today. Funding is available for up to ten years. The selection of 10 challenges in 2013 (and an 11th Challenge in 2014) represented a form of prioritisation with regards to *strategic* mission-*led* research in New Zealand. However, this process was not designed as a formal prioritisation process across all aspects of the science system. It was recognised that some areas of research important to New Zealand are not best suited to the 'challenge approach'. A unique feature of this process included the level of engagement with the public in the choice of the Challenges.

Each Challenge has the following characteristics:

- Offers a strong, virtual governance structure, with clear leadership and accountabilities across the researchers and institutions involved in the Challenge.
- Provides a broad portfolio of multi-disciplinary research activity with collaboration across a number of research providers.
- Contains a number of inter-related research themes that are integrated and coordinated to provide a plausible pathway to achieving the Challenge.
- Seeks to combine relevant expertise available across the science sector in New Zealand to achieve the Challenge objective.
- Is clearly linked with international research activity to support its achievements.
- Exhibits strong collaboration between researchers and intended end users of the research activity, including, where appropriate, obtaining investment from end users.
- Maps and includes relevant existing research into the scope of the Challenge.

Selection Criteria

1. The Challenge targets a high-level goal that, if achieved, would have a major and enduring public benefit for New Zealand.
2. There is wide public consensus that the Challenge will address a major issue or opportunity of wide public importance for New Zealand.
3. Scientific research is essential to solving the Challenge.
4. New Zealand has the broad scientific capability and capacity to undertake the Challenge successfully.
5. There is sufficient external motivation and linkages for the research results to be successfully implemented to achieve the Challenge objective.

Selection Process

- Submissions were collected from the relevant sectors and also from the general public, including via a television and social marketing campaign (October 2012- January 2013). A total of 233 submissions were received from the science sector, and 138 submissions from the public plus an additional 616 ideas and comments.
- An independent panel of science experts reviewed the submissions, chaired by the Chief Science Advisor to the Prime Minister. The panel's report identified 12 Challenges.
- 10 Challenges were selected by Cabinet and an 11th was deferred until 2014. They were formally announced in May 2013**.**
- The Ministry (MBIE) developed an implementation plan for the NSCs, which began with a series of workshops involving researchers and potential end users to develop high-level descriptions.
- A request for proposals asked for a research and governance (business) plan. Assessment panels that included international science experts reviewed proposals and made recommendations to the Science Board that made final funding decisions. Proposals could be rejected if they did not sufficiently meet assessment criteria.

Managing implementation

A NSC performance framework has been produced to measure how the Challenges are performing with respect to their goals. Challenges will be reviewed by the end of the first funding period (30 June 2019).

7. Current priority areas - examples

The table below highlights examples of areas that have been prioritised across the SAEI. The table is not intended to be exhaustive. Though often used as a form of prioritisation (see page 7), areas of focus established solely through research institutes are not included.

Table 1. **Examples of prioritisation areas across the SAEI (non-exhaustive)**

	Ireland (Prioritisation Exercise)	New Zealand (NSCs + MBIE sectors not otherwise covered)	Finland (Academy =A) (SHOKs)	Denmark (Research2020 and INNO+, 2013-2015)
IT/COMMs	Future networks Data analytics/ Management Digital platforms	-	(SHOK) ICT + services (A) Knowledge in the media society	(R2020) Strategic growth technologies (INNO+) A smart society based on the utilisation of "big data"
ENVIRO	-	4 NSCs: The Deep South NZ's biological heritage Sustainable seas Our land and water 2 MBIE research funds: Biological industries Environmental research	(A) Northern climate + environment	(R2020) Sustainable energy and environment
HEALTH/ WELFARE	Medical devices Diagnostics Therapeutics Connected health + Independent living	3 NSCs: Ageing well A better start Healthier lives MBIE research fund: Health and society	(A) Healthy everyday life (A) Ageing population	(R2020) Health, food and welfare (R2020) Individuals, disease and society (INNO+) Denmark as the preferred country for early clinical testing of new medicine
FOOD	Food for health Sustainable food production	NSC: High value nutrition	-	(R2020) Health, food and welfare (INNO+) Intelligent, sustainable and efficient plant production
ENERGY + NAT. HAZARDS	Marine renewable energy Smart grids/cities	NSC: Resilience to nature 2 MBIE research funds: Hazards & infrastructure Energy & minerals	(A) Sustainable energy (SHOK) Energy & the environment	(R2020) Sustainable Energy and Environment (INNO+) Innovatorium for building renovation of world class standard (INNO+) Blue jobs via green solutions
BUSINESS + MANUFACTURING	Manufacturing competitiveness Processing tech/ novel materials Innovation in services + business processes	NSC: Science for technological innovation MBIE research fund: High-value manufacturing + services	(SHOK) Metal products & mechanical engineering	(R2020) Strategic growth technologies (INNO+) Water-efficient industrial production (INNO+) Advanced materials as a basis for growth and solutions to societal challenges
OTHER	-	NSC: Building better homes, towns and cities	(SHOK) Bio-economy (SHOK) Built environment	(R2020) Transport and infrastructure

8. Methods to determine country strengths

This section briefly describes some of the methods and data used to identify country strengths by the individual SAEI countries and the SAEI Secretariat. Both qualitative and quantitative information provide important insights in this regard and as such a 'mixed-methods' approach is recommended when undertaking such analysis.

Qualitative evidence

Consultation with experts can provide important input regarding perceived strengths and weaknesses (in an international context but also to assist in identifying emerging areas within a nation). This can be highly valuable information but may benefit from supplementation with other lines of evidence (either as part of the consultation, or post-hoc).

Such consultation can occur in a variety of forms, for example:

- Inviting contributors from across the research and innovation system to independently submit evidence;
- Holding workshops which involve a variety of stakeholders simultaneously;
- Appointing independent reviewers (often international) to identify strengths via interviews and site visits.

These processes are important not only in evaluating strengths but also in terms of stakeholder management. Poorly managed processes that are seen as opaque or biased may have adverse consequences on researcher behaviour. Perceptions of such processes can ultimately lead to changes in the research landscape as research groups view their current environment and judge likely future funding opportunities accordingly.

Quantitative and semi-quantitative evidence

A variety of quantitative information can also be used to support qualitative evidence of country strengths. In the context of small economies, however, it is important to consider the level of granularity at which such data is assessed. Discipline-level strengths on an international comparative basis are less likely to appear in small countries due to the size of their relative contribution, despite the fact that much research within the SAEI group is conducted at the cutting-edge internationally.

Work carried out by the SAEI Secretariat has highlighted these issues and reiterated that for small countries in particular, attempts to identify specialist competencies from data alone can prove problematic. To address these challenges in the case of a small system it may be useful look to data to identify top *institutional-level* competencies. Novel evaluation techniques such as co-citation analysis may also be used, which can identify smaller niche, and often-interdisciplinary strengths that tend not to be visible in the traditional high-level divisions of research. Expert consultation here is advised.

In addition to measures of *quality*, contextual evidence of quantity over time is also important (e.g. numbers of publications, FTE researcher hours), in particular to judge whether areas represent an emerging or declining area of expertise and to assess whether they are niche topics or significant fractions of national research effort.

At a high-level, country strengths can be broken down in terms of:

i) **Academic areas of strength/reputation**
As well as measures of volume, potential quantitative evidence as proxies for quality include: bibliometric data such as number of publications in the top 10% worldwide (by citation), international awards, and the number of publication downloads (e.g. downloads by corporations abroad of science produced domestically, which demonstrate some evidence of use).

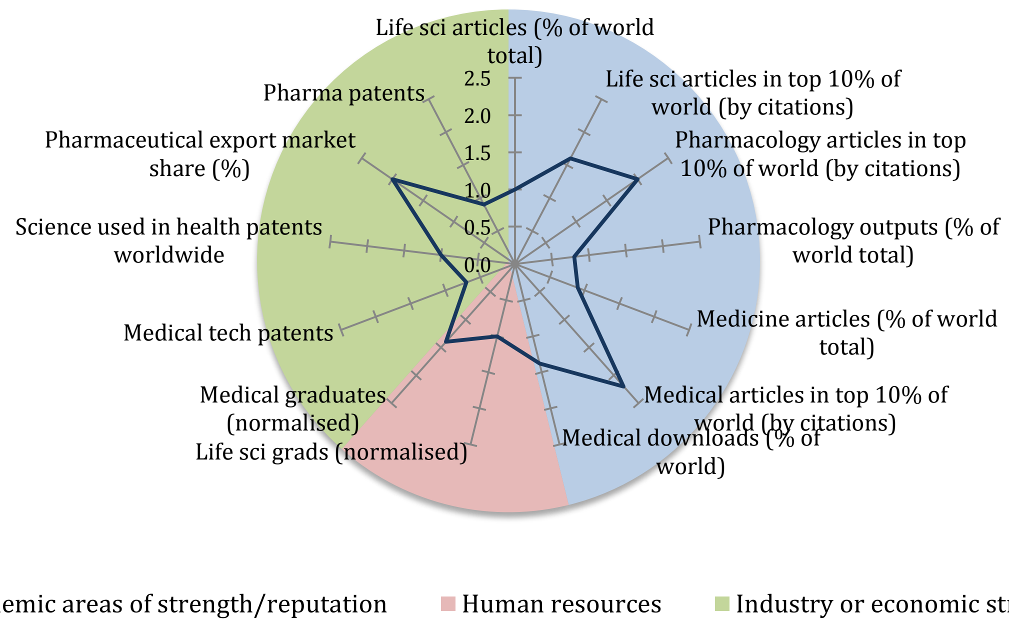
ii) **Human resource capability**
Potential quantitative evidence includes the distribution of PhDs/masters students by subject (compared with international averages), comparative performance of researchers in terms of citations (corrected for career length), and the number of researchers in the private sector.

iii) **Industry or economic strengths relating to research and innovation**
Potential evidence includes data reflecting IP revenue, evidence of patent use (recommended over evidence on *numbers* of patents alone which may reflect other factors[3]), export statistics in research-intensive industries, and data on comparative industry advantage.

For illustrative purposes, Figure 2 highlights a generic example of a comparison of country strengths across these dimensions in life sciences.

While such indicators can serve as useful proxies they also have a number of limitations, which need also be considered. This is particularly the case for bibliometric indicators, where the likes of adverse publishing incentives, the impact of self-citation, and highly skewed distributions can cause high-level metrics to be misleading. For this reason, interpretation of all such metrics should be complemented with expert consultation to place results in context and to verify their accuracy.

Figure 2. **Example of performance in life sciences and related fields (1 = relative to global average)**



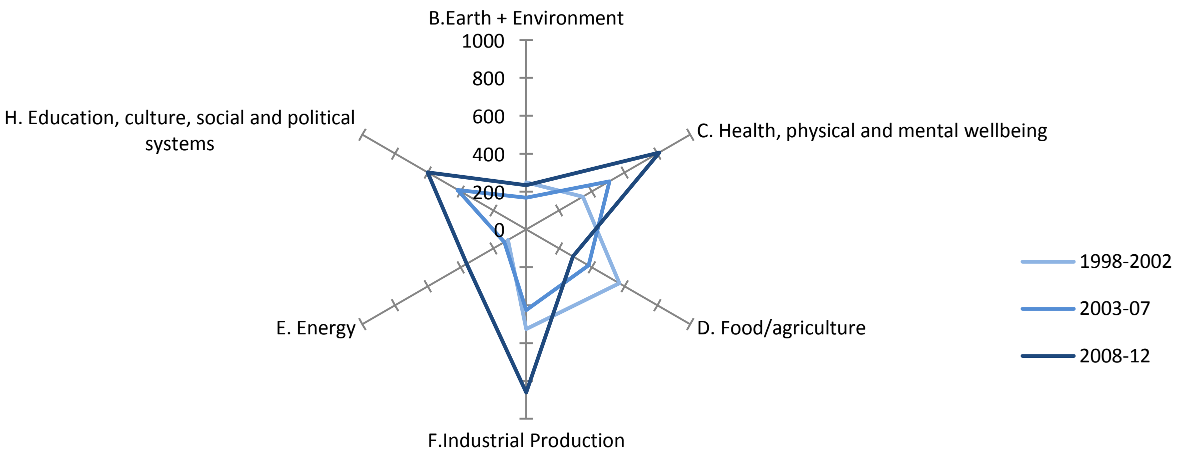
Data: OECD

[3] For example, incentives to produce patents for their own sake which may not always be suitable for this route of IP protection (such as promotions for researchers, defensive patents by companies)

9. Comparing strengths and priorities – evidence of prioritisation effectiveness

One method to examine the effect over time of policies designed to prioritise areas of research, is to take a quantifiable consequence of these policies (such as the relative amount of money spent by area), and look at measures of output for any changes in results. As a first step, Figure 3 shows a generic example of changes in resource spend by topic over time and is useful for looking at the degree of input prioritisation and balance of themes. Such information could then be linked to similarly categorised measures of output to assess for correlations (see Box 8).

Figure 3. **Example of changes in government allocations by mission over time**



Source: SAEI

Where quantifiable evidence is lacking or where other factors have changed significantly, expert opinion may also be used to assess changes in key input parameters. Using an agreed scale to quantify such consultations, information may be displayed and contrasted as shown in table 2 below.

Table 2. **Example of changes in inputs using scores based on expert consultations**

CHANGE IN INPUTS (over time)	Social	Health + life sciences	Maths, Stats + ICT	Physical sciences
Funding	-1	3	2	0
Graduates/Human resource	0	3	5	-5
Infrastructure	0	0	0	0
Policy	0	2	0	-1

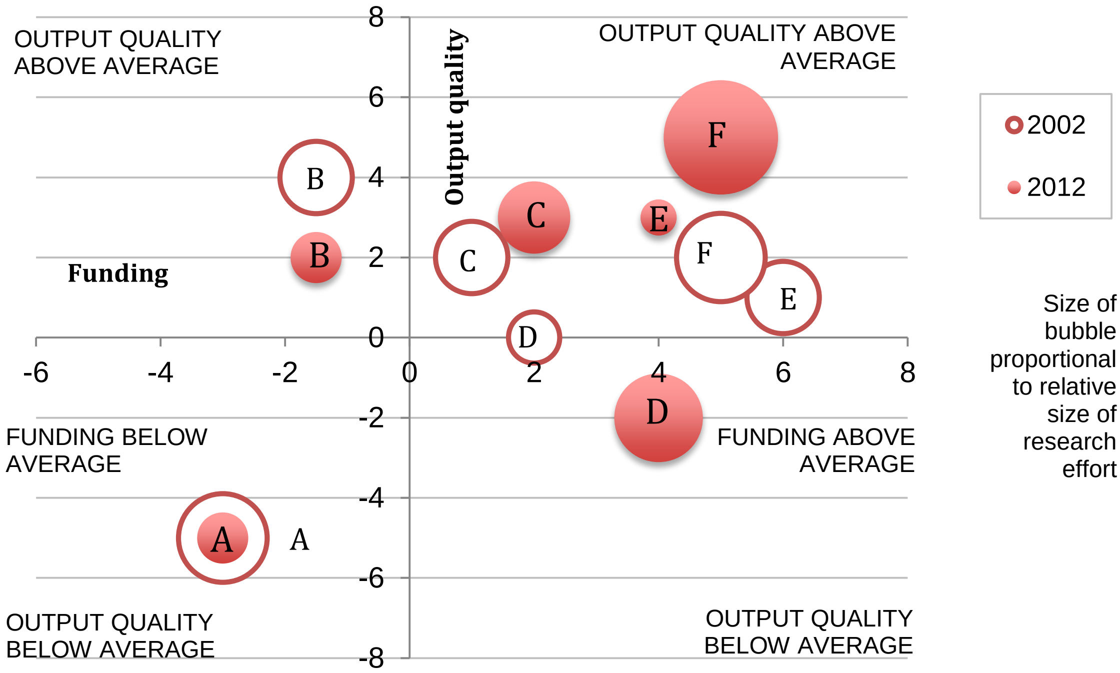
Based on the evidence of change in inputs, it can then be asked whether any evidence of change can be seen as a consequence of these shifts (i.e. has a change in inputs resulted in any improvements in quality or quantity of outputs?). What happens to the overall human capacity in the field? What happens to the best and worst performers in the area as the inputs change (e.g. those producing the top 10% of cited publications[4], and those producing output with no evidence of use - either via citations, downloads or references by 3rd parties)?

[4] Normalised by publication type, discipline etc.

Box 8: System level analysis of input 'impact'

To assess the impact of prioritisation on measures of output, metrics may be assessed using plots such as that in Figure 4. Such a framework enables changes in inputs to be easily assessed against movements in output. To achieve sufficient granularity, analyses of these sort are most insightful when broken down to the discipline level. This requires that proxies are converted into relative terms (e.g. by comparing to a benchmark year or global trends) to eliminate biases caused by differing publication practices or human resource requirements between fields. This is illustrated in Figure 4, where 0 in each case is relative to a measure of global performance in the category (e.g. spending per capita compared to the OECD average). The benefit of such an approach is that it enables comparisons to be made across disciplines and conclusions to be made at a system-wide level. A common challenge with such approaches, however, can be finding common definitions for the disciplinary categorisation of inputs and outputs.

Figure 4. **Example of normalised metrics used to illustrate country prioritisation (size of bubbles proportional to number of researchers)**



A: Relatively low funding (no change), low quality (no change), declining volume of researchers over period
B: Funding below average (no change), declining quality, declining number of researchers
C: Increasing funding, increasing quality, number of researchers static
D: Increasing funding, declining quality, large increase in volume
E: Decreasing funding (from high level), decreasing volume but increasing quality
F: Relatively high funding (no change), high volume of research (no change), increasing reputation

Source: SAEI

10. Final statements

Some degree of concentration of resources in certain sectors is inevitable in small countries. Across the group, different approaches have been taken to assess whether such concentration is managed (e.g. through prioritisation) or whether such specialisation occurs ad hoc.

Given the recent formal prioritisation exercise in Ireland, and recent attempts to identify strategic priorities through bottom-up processes (for example in Denmark and New Zealand), there is a unique opportunity to track trends in performance and see how shifts in approach or focus affect research strengths in the countries in question. This will require application of innovative techniques and case studies to understand the full range of benefits realised by such research for society.

The Small Advanced Economies Initiative has been tracking data, developing techniques and recording the policy processes as presented here, to facilitate such analysis in the future. This work will help us better understand how such policies affect the performance of our science and innovation systems going forward.

Confidential Data Annex

Confidential Data Annex

Following on from the discussion of indicators in the main body of this document, the following section illustrates some of the key metrics that may be used to inform analyses of prioritisation. The charts contained within this annex present data that was collected for the SAEI's own analysis of member countries and cover a range of both conventional and less established measures.

All metrics were selected on the basis of their ability to identify country strengths and to shed light on the efficacy of prioritisation efforts, be it directly or otherwise. For clarity and to assist readers in identifying correlations, indicators have been categorised into separate sections focussed on inputs and outputs.

While some commentary is provided on the interpretation of this data, discussion of the effectiveness of specific prioritisation attempts are not discussed in detail. This is because a wide-ranging analysis of contextual and qualitative factors necessary to draw such conclusions fell outside the scope of this work. Data in this annex has, however, been verified by officials from each of the 6 countries and may be used to assist further work that looks to address such questions.

Where possible, data has been presented for all 6 members of the SAEI, however complete datasets were not available for every member at the time they were collected. Given the nature and sources of this material, this annex has been curated for internal use only.

Section One: Inputs

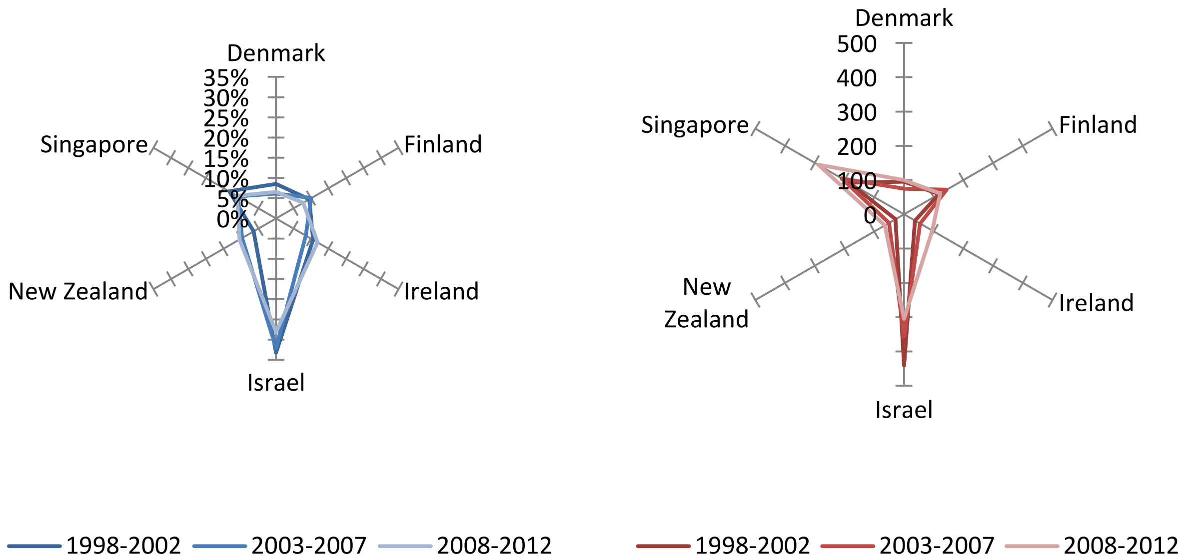
Public funding of private and public R&D

This document focuses largely on public funding of public R&D. However, it is important to recognise from the outset that across the group there are differences in the split between direct funding of public and private research.

As can be seen in Figure 1, five of the countries spent in the region of 10% of their funding on private R&D over the latest period. Israel is the exception in this regard, however, with over 25% of funds distributed in this direction.

Over time there has been a 'move to the middle', with Israel reducing public expenditure on private R&D and New Zealand increasing its spend in this area.

Figure 1. **Division of public R&D funds between the public and private sector (see note below)**



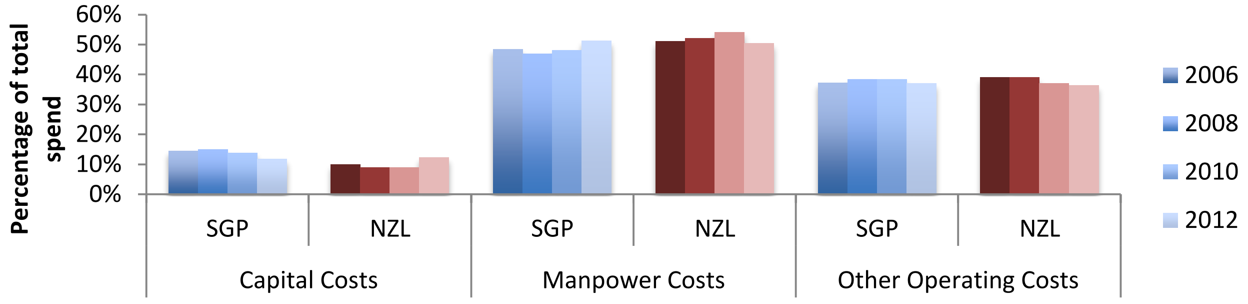
Data: Elsevier Scival

Note: Left - percentage of public funds granted to private R&D expenditure, Right: value of public funds granted directly to private expenditure ($US m, 2005 constant prices, annual average over period)

Public funding of R&D by type

Figure 2 looks at another form of prioritisation, type of expenditure. Although comparable data is limited in this area, the chart below highlights a relative focus on infrastructure in Singapore when compared to New Zealand over the 2006-2010 period.

Figure 2. **Division of funding by type of expenditure – Singapore and New Zealand (2006 – 2012)**



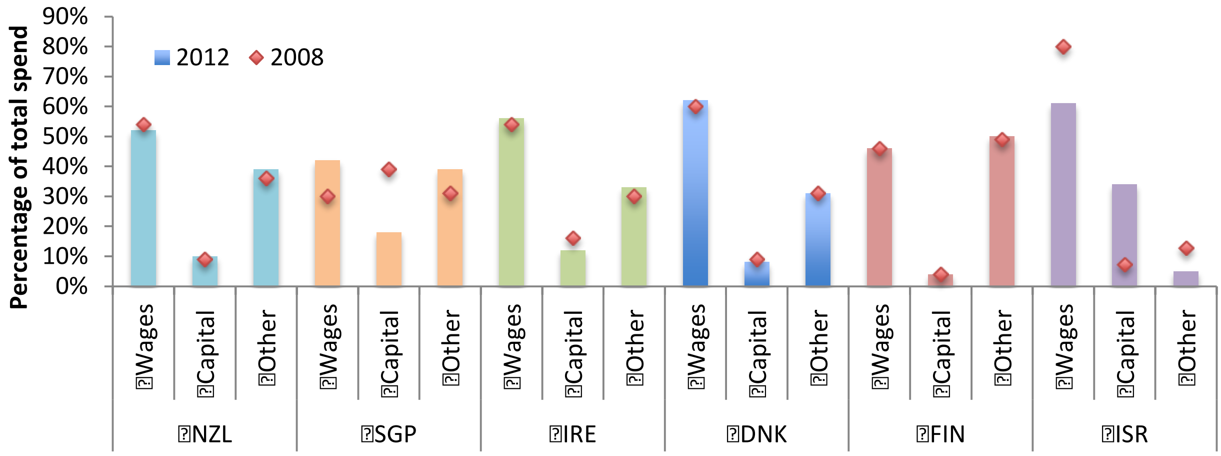
Data: Statistics New Zealand; Singapore Department of Statistics

Private expenditure on R&D by type

Figure 3 again illustrates the division of R&D by type of expenditure, though focuses on private expenditure as opposed to public funding. While not specifically related to the public focus of this compendium, such information may indicate the impact of public expenditure on the allocation of private R&D spending. For instance, a relative shift towards spending on human capital may result from the provision of higher quality infrastructure by government. Alternatively, it may signal greater competition in the market for talent as a result of increased wages in the public R&D sector. Equivalent information on public expenditure would enrich such data.

Although Figure 3 shows most allocations have been relatively steady through time, significant changes can be seen in the allocation of funds between wages and capital in both Israel and Singapore, albeit in different directions.

Figure 3. **Business expenditure on R&D by type of cost (2008 & 2012)**



Data: OECD

Drivers behind resource allocation, by area

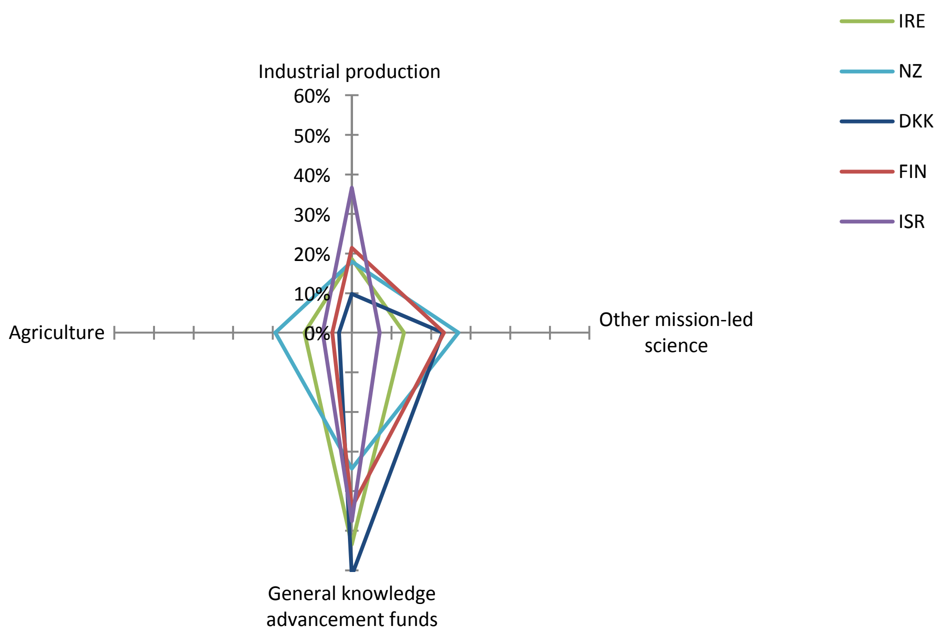
Shifting to look at prioritisation of inputs by *purpose* of research, the charts below use Government budget appropriations/outlays for R&D (GBAORD) as a proxy to understand the split of resource allocation between different objectives. Figure 4 and 5 may be interpreted as follows:

- The 'general knowledge advancement' category gives an indication of how much decisions on where to prioritise expenditure are devolved to parts of the system (such as universities). Figure 4 for example shows the Danish system to have high levels of devolution.
- The 'Industrial production & technology' and 'Agriculture' pillars give an indication of how much government budgets are allocated to areas associated to the needs of local industry. Israel and New Zealand have high levels of allocation in this area.
- The 'mission-led' science category groups together the other areas under GBAORD to give an idea of the extent to which funding is allocated under specific objectives such as health or environment, from a top-down level. New Zealand has the highest level of budget allocation explicitly linked to a particular mission.

While this proxy is not perfect, the overall picture shown below has been verified through consultation with policymakers across the SAEI group.

The benefit of this method is that where data quality is of a sufficient level, it is possible to look back through time to judge how the drivers have been changing (see Figure 5). We recommend alignment on how this data is collected and reported if this proxy is to be used further.

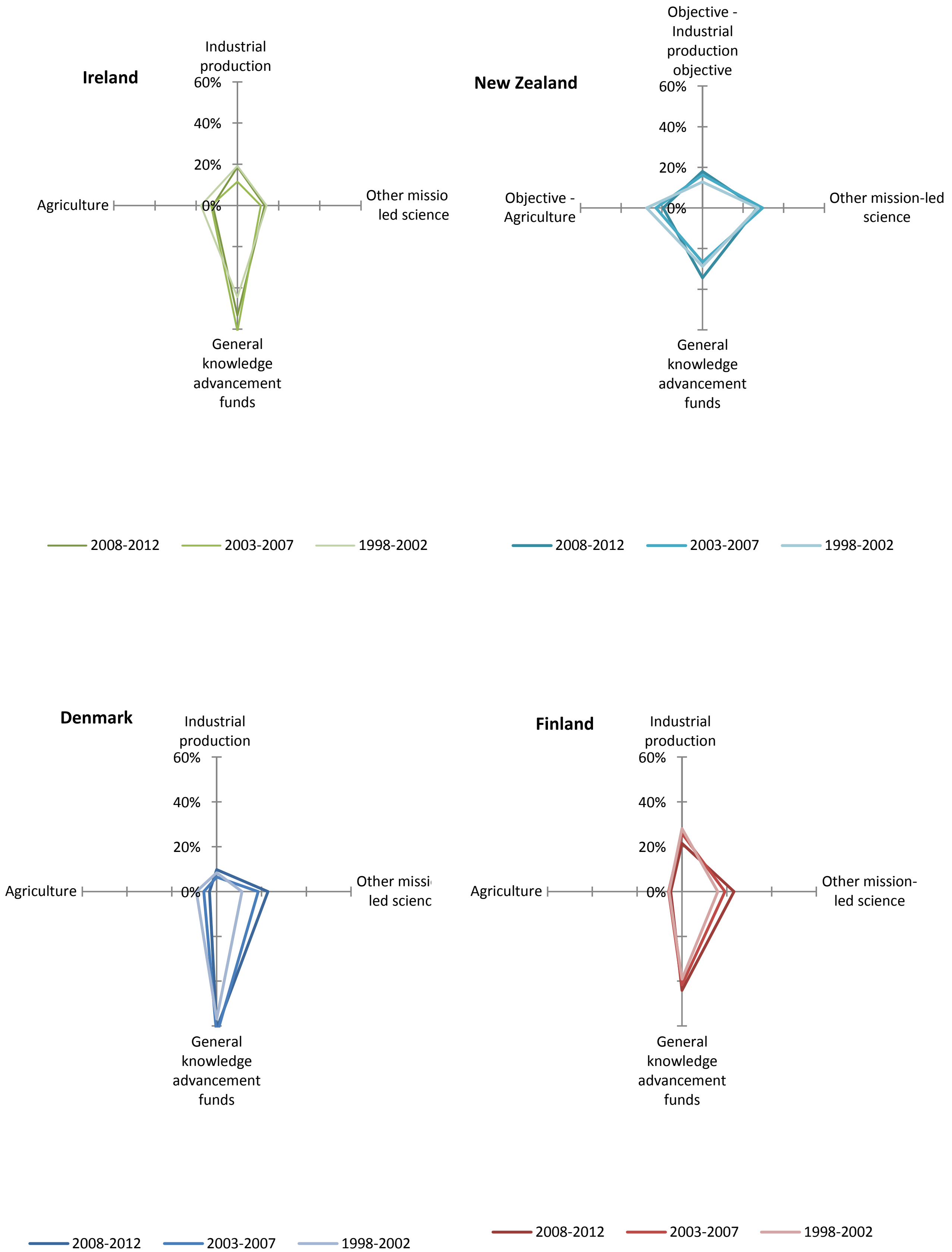
Figure 4. **Allocation of Government R&D funding (GBOARD), 2008-12**



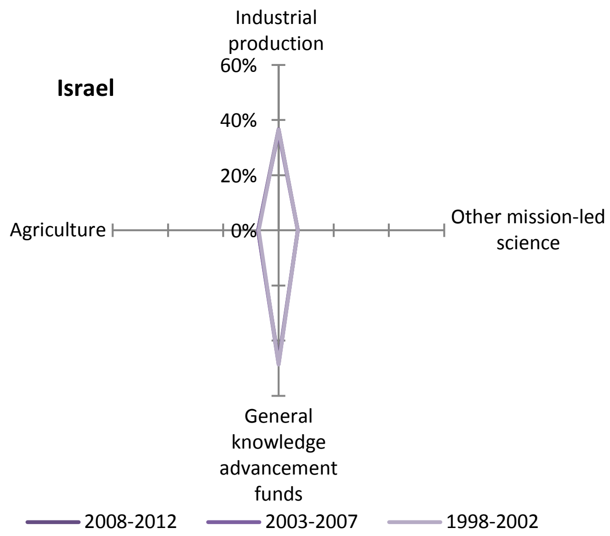
Data: OECD

Inputs

Figure 5. **Allocation of Government R&D funding by objective (GBAORD)**



Inputs



Data: OECD

Note: Percentage of total government allocations or outlays on R&D

An alternative method to identify such information is to assess the drivers behind current priorities using expert opinions. The table below shows such an attempt, using provisional information collected by the SAEI. While less granular, such an approach enables results to be appropriately adjusted for context and to take into account exogenous factors that might otherwise be missed using narrower quantitative proxies.

Table 1. **Prioritisation drivers based on discussions with relevant officials**

	'Current Competency'	'Demand-driven'/business solutions	'Strategic play'	Social/societal challenges
Denmark	++?	++?	++?	+++
Finland	++?	+?	+?	+++?
Ireland	+	++	+++	+++
Israel	+++	++	+?	++?
New Zealand	+	++	++	+++
Singapore	++	+	++?	+++

Source: SAEI

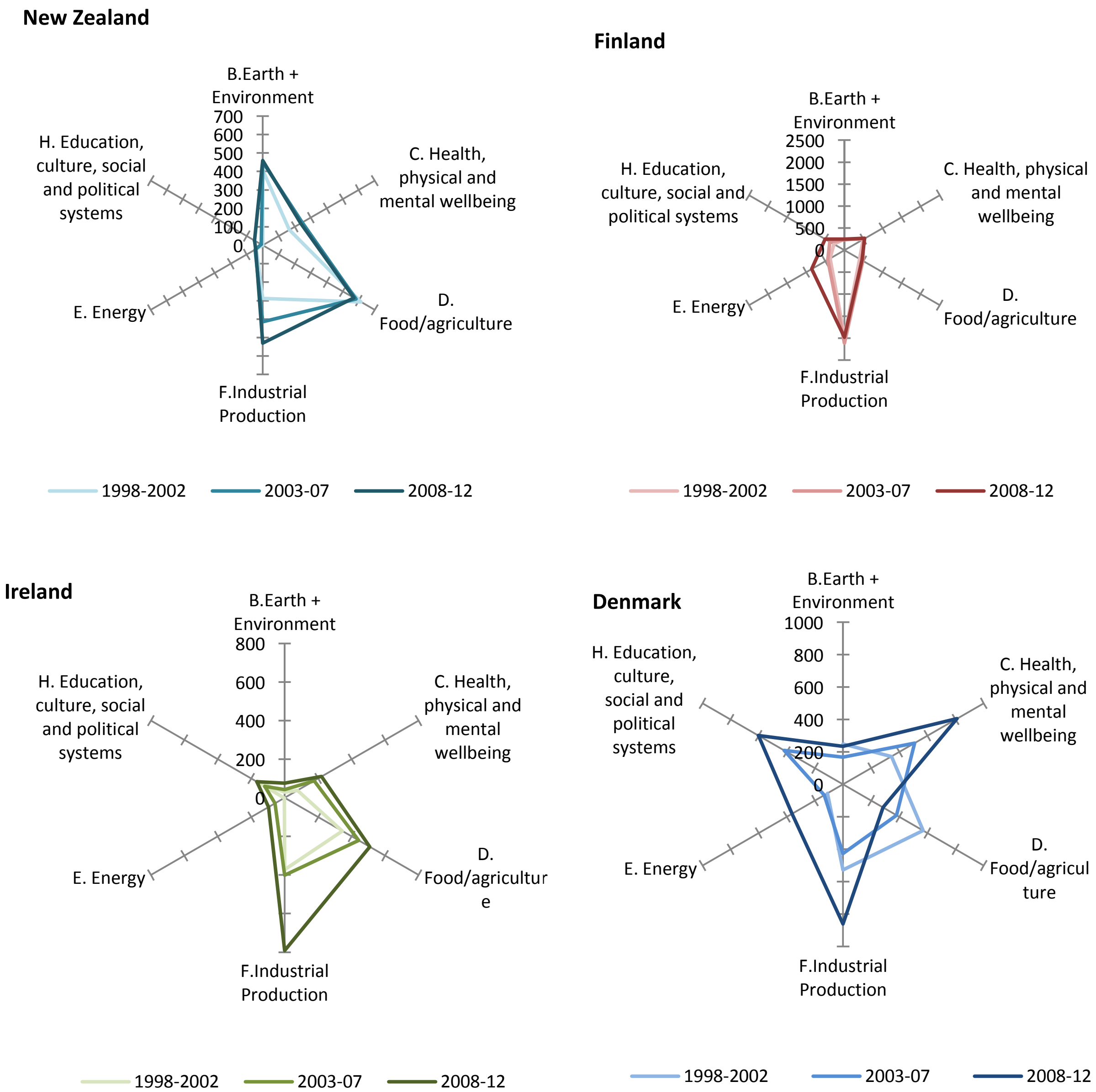
Note: Ratings provisional only and derived from internal SAEI discussions. Further verification required.

Public funding by area

Figure 6 looks in greater depth at budget allocations towards mission-oriented topics and how these allocations have changed through time. Data from only 4 of the countries are presented as data from Israel was not deemed sufficiently reliable (potentially due to the low percentage of mission-oriented allocations as shown in Figure 4) and data from Singapore was unavailable at this time.

Notably, New Zealand and Ireland show general increases in expenditure, though not uniformly across all areas. Denmark displays a different pattern, one of partial reallocation of priorities over the time period studied. Finland shows a relatively static picture other than a substantial increase in allocations on energy R&D.

Figure 6. **Changes in government allocations by mission over time (based on GBAORD data)**



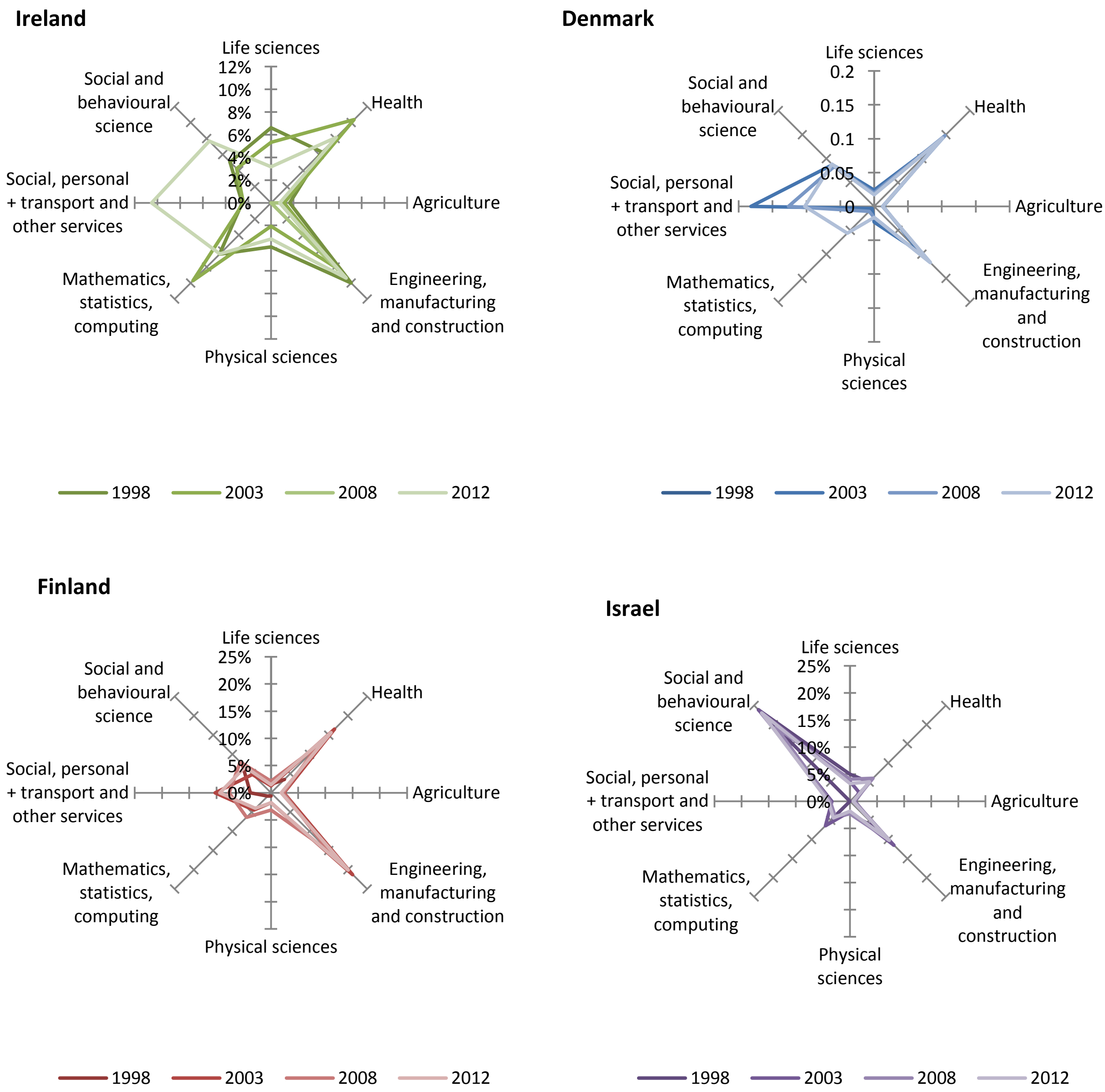
Data: OECD STI Scoreboard
Note: Scales differ across charts

Human resources – Graduates by area

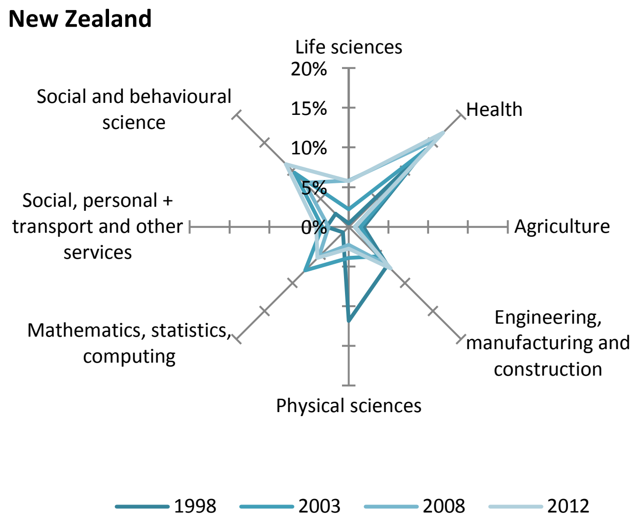
The following section looks at the production of graduates, taking this as the pool of domestic talent from which a country can draw. International migration of researchers by area is another area for potential future investigation, however sufficiently reliable data was not available at the time of this analysis.

Data is considered here in two different ways based on the same underlying OECD dataset. Figure 7 looks through time at the production of graduates by area across the sciences and social sciences. The values shown are percentages of the country's total output of graduates for the year shown. Figure 8 Figure 13 then illustrate this data normalised by population size and compared to growth in recent years.

Figure 7. **Graduate production by area as % of all graduates from the country**



Inputs



Data: Elsevier SciVal

Looking at these charts, several trends can be seen:

- Denmark: Strong but declining output of social services graduates and high output of health and business graduates. Compared to some of the other countries in the group, a more distributed spread across disciplines, with less dominant peaks.

- Finland: High but slightly declining percentage production of engineers (20% of degrees in 2012, compared to 7-12% across the other countries).

- New Zealand: High production of health and life sciences graduates - over 20% of all degrees awarded in 2012. Health degrees dominate overall graduate production with a percentage similar to but slightly higher than Denmark and Finland. The number of life sciences degrees awarded is the highest in the group, conversely engineering and manufacturing graduate production in NZ is low.

- Israel: High production of social and behavioural scientists, representing over 20% of degrees awarded.

- Ireland: High percentage of degrees awarded for mathematics, statistics and computing (6%) compared to other countries (1-3%).

Inputs

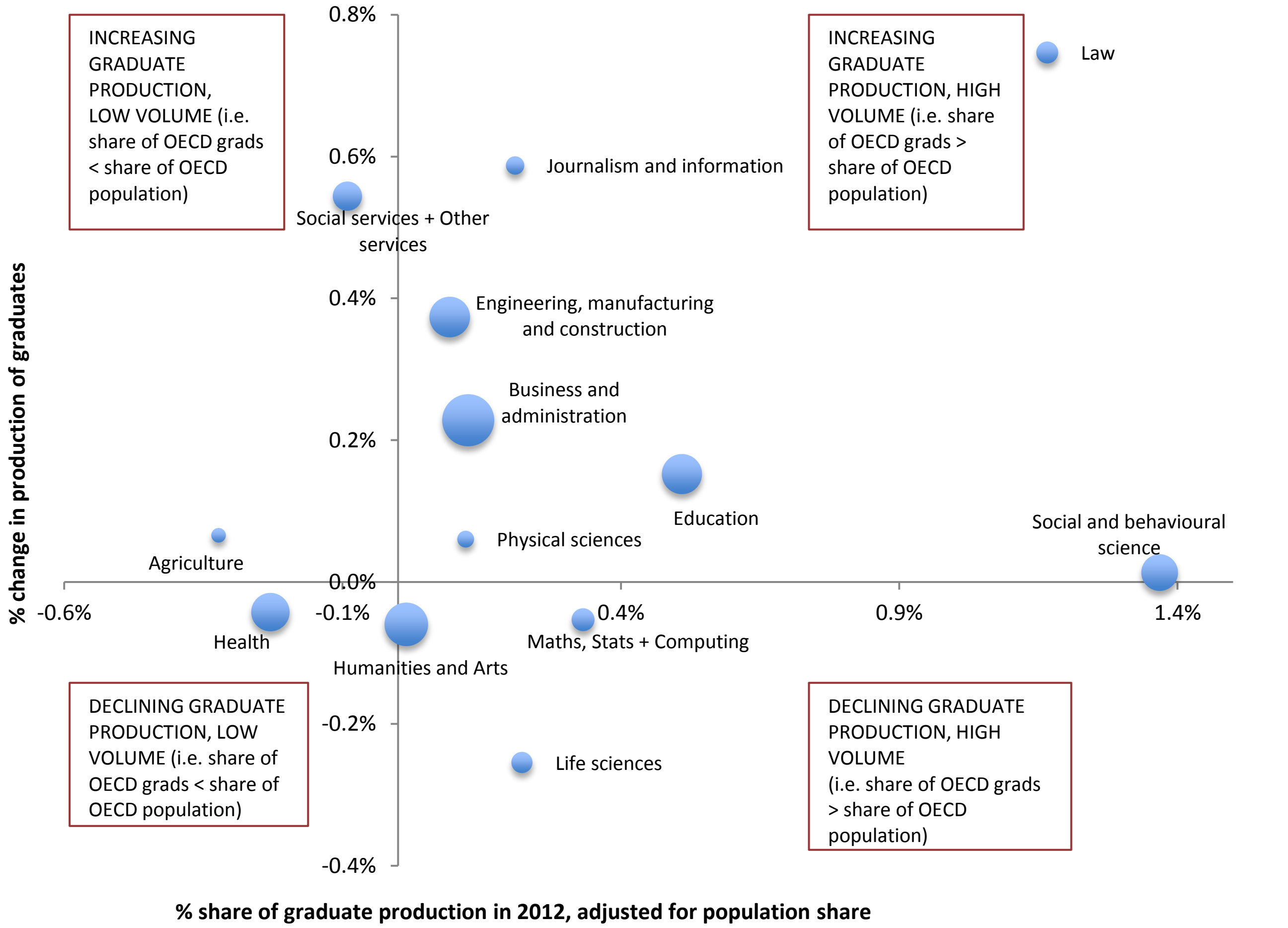
Graduate production compared to other OECD countries

The following figures look at graduate production across all disciplines (including arts and humanities, business, and law). They examine the changes in graduate production through time for each country (as a share of the total output across the OECD), and look at the volume of graduates produced compared to the country's population share in the OECD (i.e. graduate production normalised by population). The axes should be interpreted as follows:

Y–Axis - Change in share of OECD graduates for discipline. For any given country, this is equal to their share of OECD graduate production in 2012, minus their share of OECD graduate production in 1998. Note: 0 on the y-axis represents no change in a country's share of OECD graduates.

X-Axis - Volume of graduates compared to share of OECD population in 2012. For any given country, this is equal to their share of OECD graduates in 2012, minus their share of the OECD population. Note: 0 on the x-axis indicates that a country's share of graduates is equivalent to their share of the OECD population.

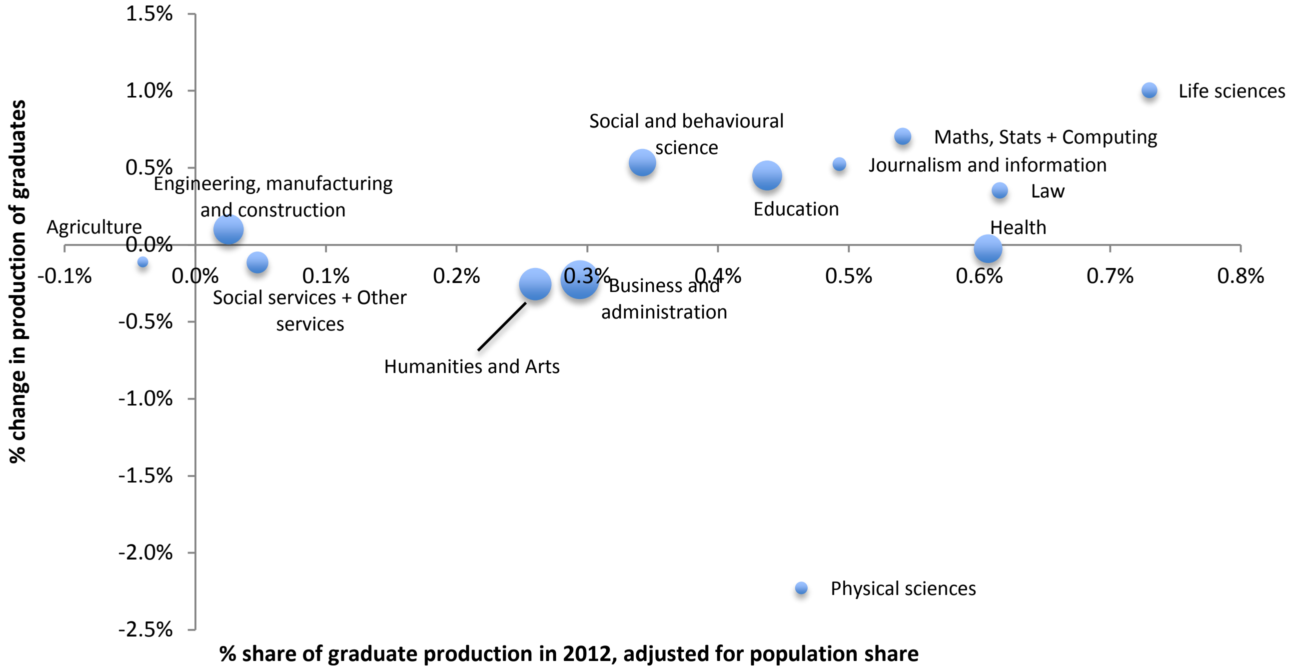
Figure 8. **Israel – changes in graduate production from 1998 to 2012**



Data: OECD
Note: Bubble size represents size of discipline across OECD

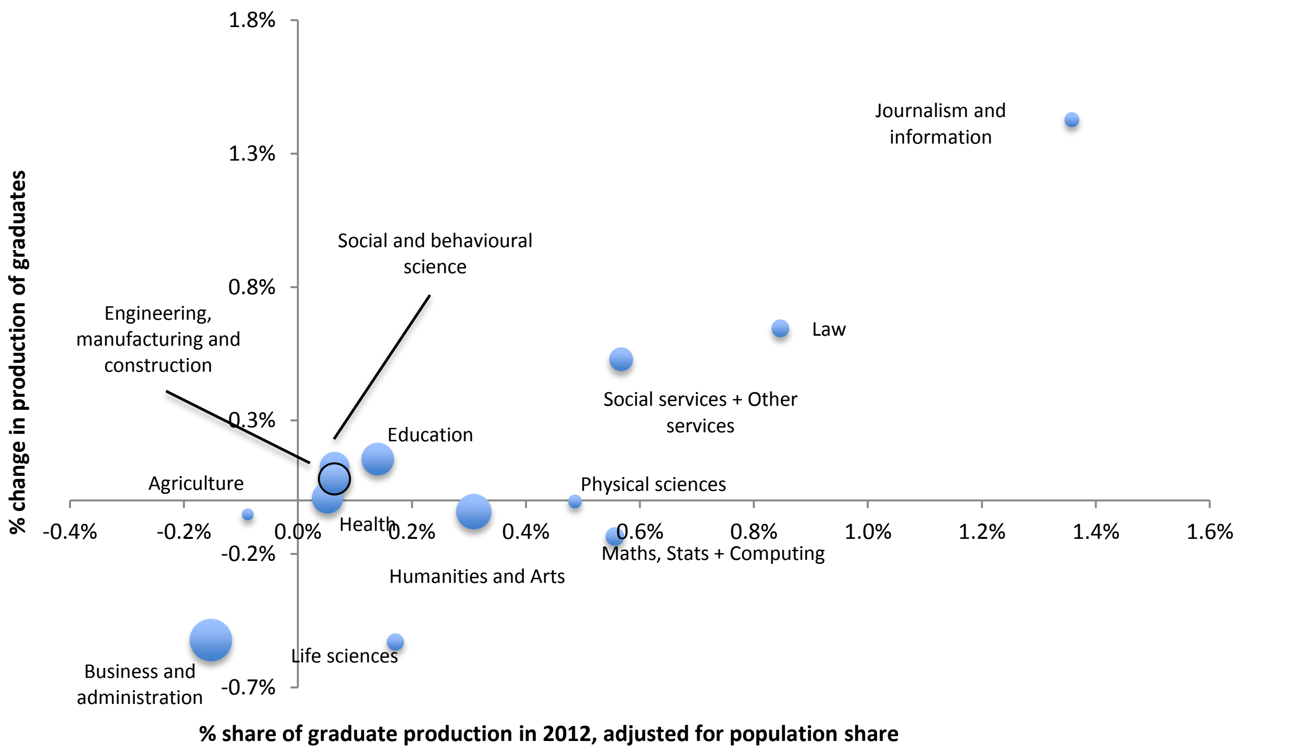
Inputs

Figure 9. **New Zealand – changes in graduate production from 1998 to 2012**



Data: OECD
Note: Bubble size represents size of discipline across OECD

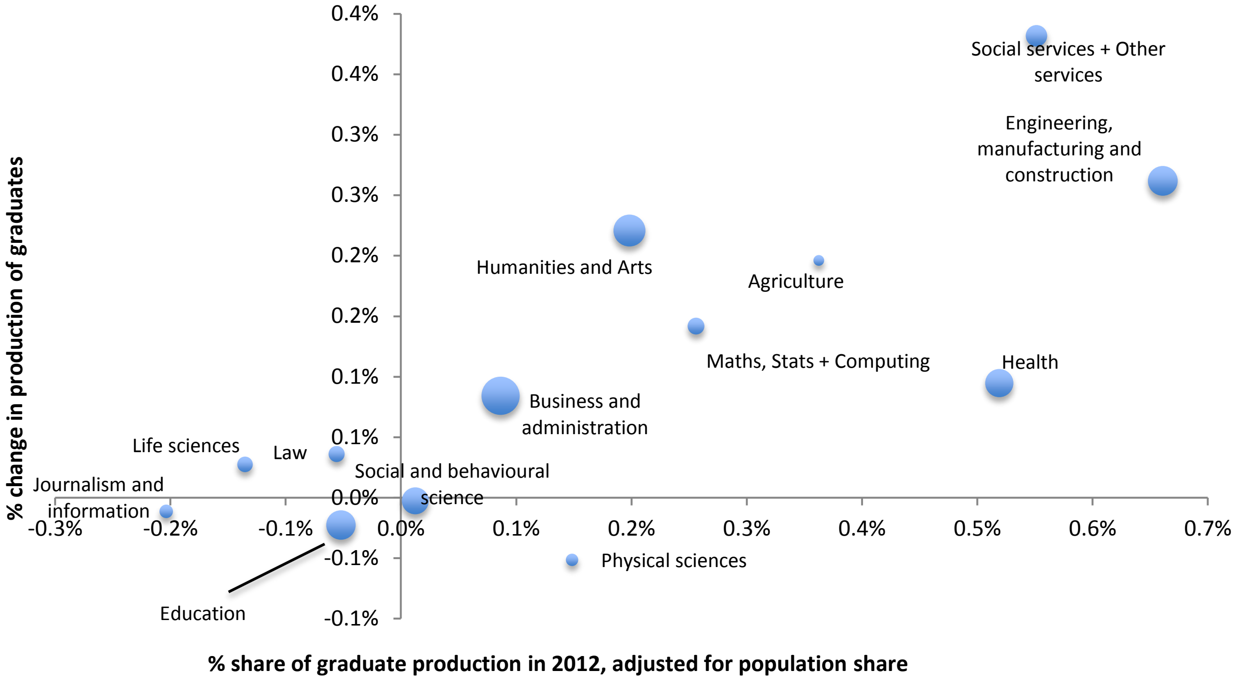
Figure 10. **Ireland – changes in graduate production from 1998 to 2012**



Data: OECD
Note: Bubble size represents size of discipline across OECD

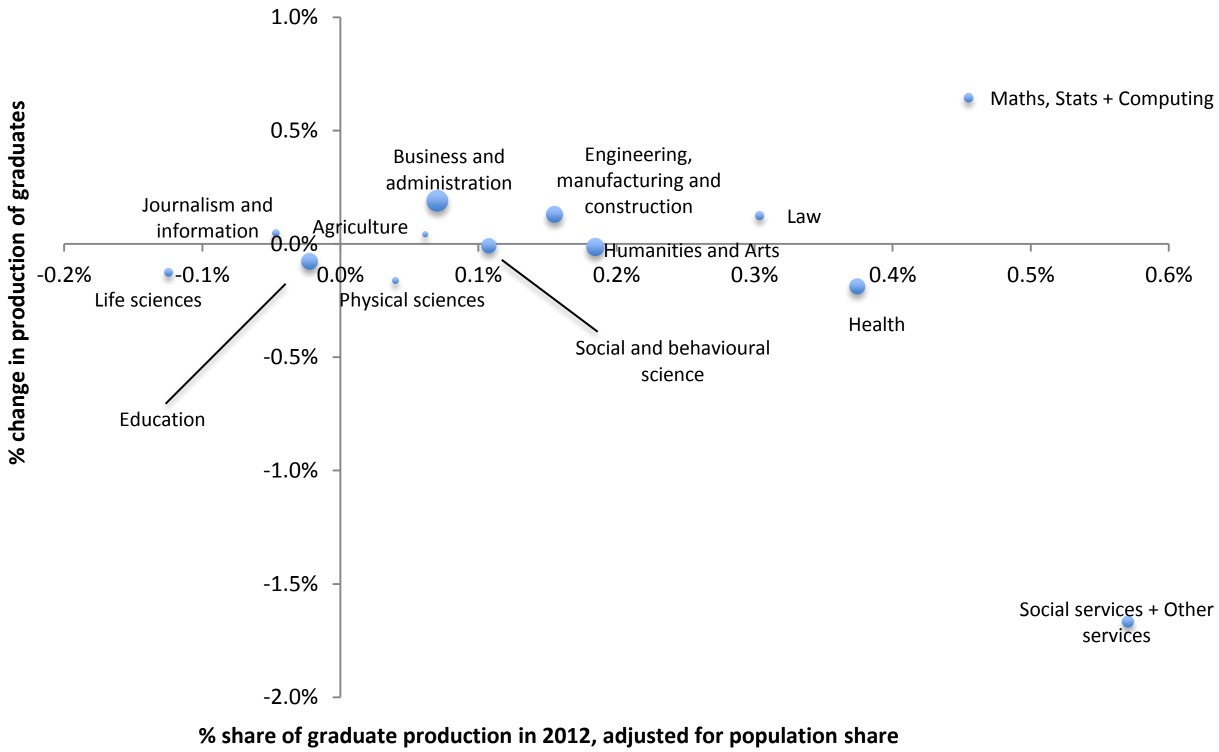
Inputs

Figure 11. **Finland – changes in graduate production from 1998 to 2012**



Data: OECD
Note: Bubble size represents size of discipline across OECD

Figure 12. **Denmark – changes in graduate production from 1998 to 2012**



Data: OECD
Note: Bubble size represents size of discipline across OECD

Other factors - Infrastructure, political support

In addition to graduates and funding, political support and infrastructure (although tightly linked to funding) are also important forms of prioritisation. As such measures can be hard to quantify, the table below attempts to summarise in a structured way some of the key developments in these areas over the past 17 years. Note that the examples presented are intended to capture key events and do not comprise an exhaustive list.

Table 2. **Examples of political support and institutional changes (relevant to R&D prioritisation): 1998-2012**

	1998-2002	2003-2007	2008-2012	New policy
Denmark	2001 – Research Commission reviewed research system, with aim of enhancing efficiency over coming years.	2004 - Danish Council for Strategic Research established, providing funding under themes. 2007 - Merger of universities and RIs.	2008 - Research2015 produced, identifying 21 fields in 6 key areas for focus. Energy technology programme launched. 2009 - Green development and demo fund launched (by Ministry of Food). 2011 - Research2020 produced.	INNO+ produced in 2013. Councils merged into new Innovation Fund.
Finland	First centres of excellence finished (1995-99).	First Strategic Centre for Science, Technology and Innovation (SHOK) launched (Forest industry/bio-economy)	Four additional SHOKs launched – Energy & environ; Metal & eng'; Real estate & construction; Health & wellbeing.	Plans to overhaul state RIs and funding.
Ireland	Technology foresight exercise: invest in biotech and ICT. Overall increase in funding for higher ed. sector.	2006 – Strategy for STI (no specific theme focus).	2012 - National Research Prioritisation Exercise and strategy launch.	Potential for structural changes (as advised in 2011 higher ed. strategy).
Israel			I-CORE program established.	OCS strategic reorganization – shift from subsidy based model to mission-led approach. Focus on scaling up SMEs.

Inputs

NZ	Labour Govt. '99 - 9 CRIs in operation now for over 5 years (established 1992), heavily focused on supporting primary sector in NZ and NZ environment (7 of 9 CRIs).	Labour Govt. PBRF mechanism for distribution of research funding at universities in operation (established in 2002). First centres of research excellence operational (2002/3). Second round 2006/7.	National Govt. 2009 -> 2009 – 6 political priorities identified - targeted funds (in size order): Biological Industries, High-Value Manufacturing and Services, Health and Society, Environment, Hazards and Infrastructure, Energy + Minerals. 2010 – CRIs receive core funding. Primary Growth Partnership established (private, primary sector innovation fund), Centre for Agricultural GHG Research established. 2012 - CRI *Industrial Research Ltd* rolled into new organization – Callaghan Innovation.	NSCs established MBIE reviews contestable funding system. National statement of science investment developed (NSSI) – to be released late 2015.
Singapore	2001 – NSTB restructured to form A*STAR with 2 councils (biomedical + science & eng.) with set priorities.	2003 - Opening of Biopolis (RDI infra. for biomedical research). 2006 – S&T 2010 plan published. NRF & RIEC formed.	2008 – Fusionopolis opened (RDI infrastructure for info-comms + media). 2011 – RIE2015 published with focus on biomedical sciences, Info-comms and media, and electronics.	RIE2020 – focus on value retention, scaling up SMEs, and integrating support mechanisms.

Source: SAEI

Note: Where cells remain blank, further consultation required.

Overview of inputs: Changes from 1998 to 2012

Attempting to summarise information on prioritisation of inputs, the following table provides an overview of the changes in funding, graduate numbers, and political support over the period spanning 1998 to 2012. Changes in funding compare the period 1998-2002 to 2008-2012. Changes in graduate numbers represent changes between the year 1998 and the year 2012. Changes are broken down by quintiles of 20%, both positive and negative, with areas with growth exceeding 100% (+/-) being scored as 5 (+/-). Although no reliable quantitative measures of political support were available at the time this document was finalised, such could be gauged using expert opinions and consultations. It is hoped members may be able to contribute these inputs at a later time.

Table 3. **Summary of input changes within SAEI (1998-2012)**

Denmark	Social sciences*	Health & life sciences	Agriculture	Industrial production	ICT, Maths, and Stats	Other physical sciences (inc. energy)
Funding	2	5	-2	3	N/A	3
Graduates	1	2	2	3	5	0
Political Support						

Finland	Social sciences*	Health & life sciences	Agriculture	Industrial production	ICT, Maths, and Stats	Other physical sciences (inc. energy)
Funding	2	0	1	0	N/A	4
Graduates	5	5	-5	-3	5	5
Political Support						

Ireland	Social sciences	Health & life sciences	Agriculture	Industrial production	ICT, Maths, and Stats	Other physical sciences (inc. energy)
Funding	0	5	2	5	N/A	5
Graduates	5	4	0	4	5	3
Political Support						

Israel	Social sciences	Health & life sciences	Agriculture	Industrial production	ICT, Maths, and Stats	Other physical sciences (inc. energy)
Funding	5	2	0	4	N/A	1
Graduates	5	4	2	5	5	4
Political Support						

New Zealand	Social sciences*	Health & life sciences	Agriculture	Industrial production	ICT, Maths, and Stats	Other physical sciences (inc. energy)
Funding	5	2	0	4	N/A	1
Graduates	5	5	-1	5	5	-3
Political Support						

*Change based on 2003-7 to 2008-12

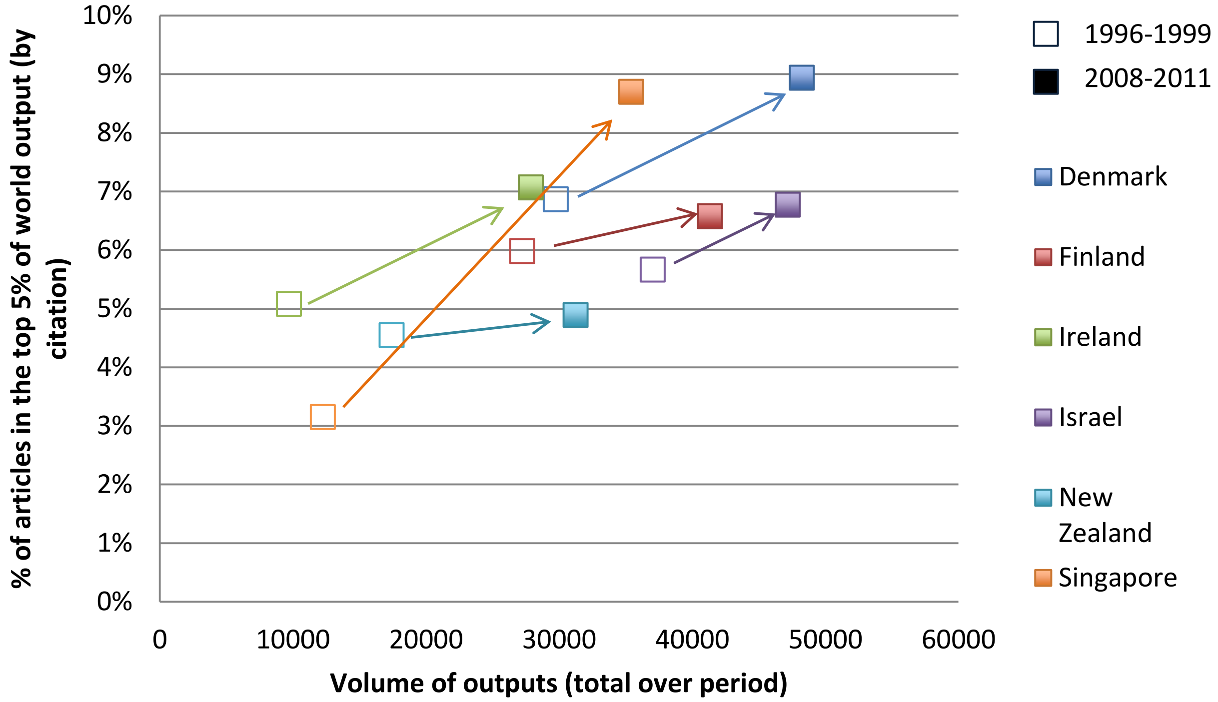
Section Two: Outputs

Moving away from inputs, the following section looks at indicators of output performance that provide evidence of high-level specialisations across the group's 6 nations. As well as looking at metrics of publication volume and quality, research translation and penetration are also touched upon using patents and publication downloads as proxies.

Overall changes in outputs through time

Figure 13 provides a high level view of outputs in the Group's science systems, tracing the growth in both quality and volume of publications through time. While all countries show a comparable increase in volume, growth in the number of star performing publications appears to have been more varied over the stated period of time.

Figure 13. **Volume of output versus 'star – publications ' (1996/99 – 2008/11)**



Data: Elsevier SciVal

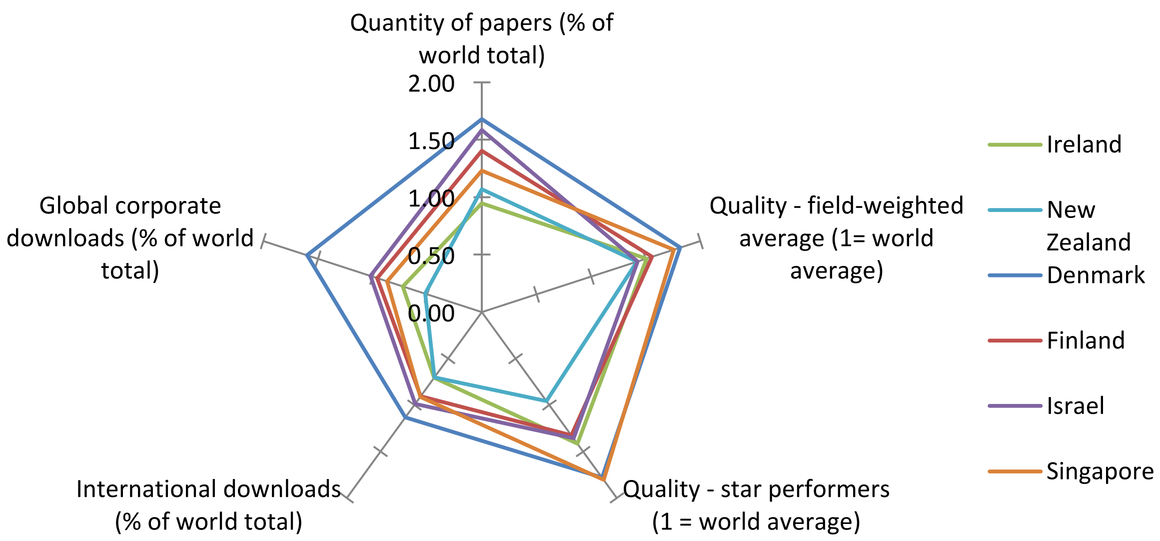
Outputs

Figure 14 to Figure 20 provide an alternative representation of the data presented in Figure 13 with the addition of several more indicators of citation and download performance. Except where stated otherwise, all metrics are normalised such that the world average is equal to 1.

The definitions of the illustrated metrics are as follows:

- **Global corporate downloads**: Downloads by companies of publications produced in the country of interest as a percentage of all corporate downloads globally.
- **International downloads**: Downloads of publications produced in the country of interest as a percentage of total world downloads.
- **Quality – average**: Quality using citations of all publications as a proxy, corrected for discipline and age of publication.
- **Quality – star performers**: Quality using top-cited publications as a proxy where top publications are defined as the percentage of publications in the top 10% globally by number of citations. The metric here has been normalised to 1.

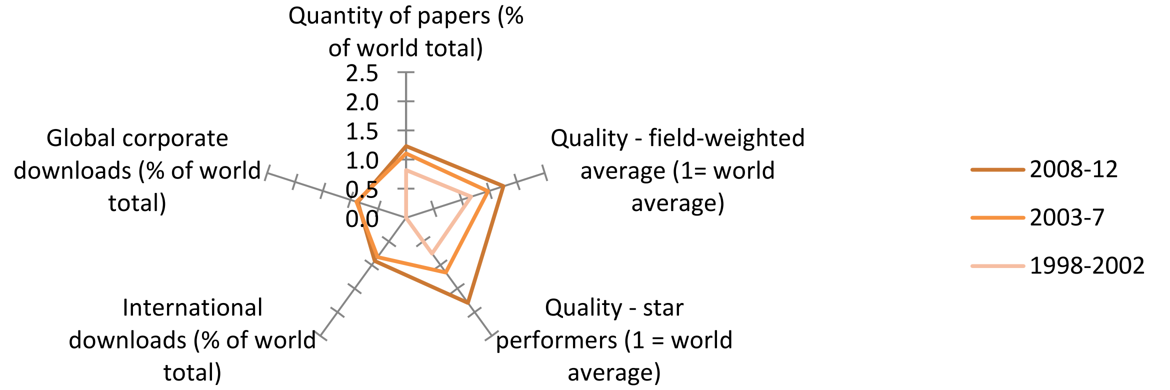
Figure 14. **Research quality and volume indicators – Cross-country comparison (2008-12)**



Data: Elsevier SciVal

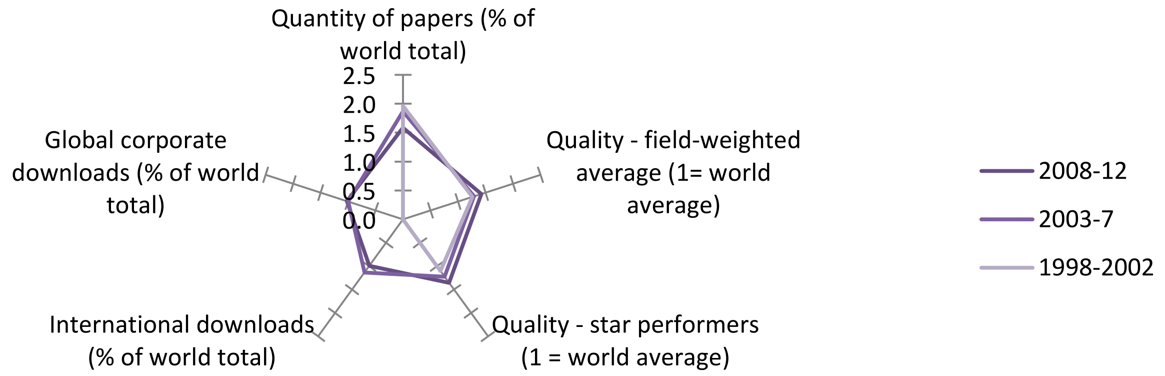
Outputs

Figure 15. **Research quality and volume indicators - Singapore**



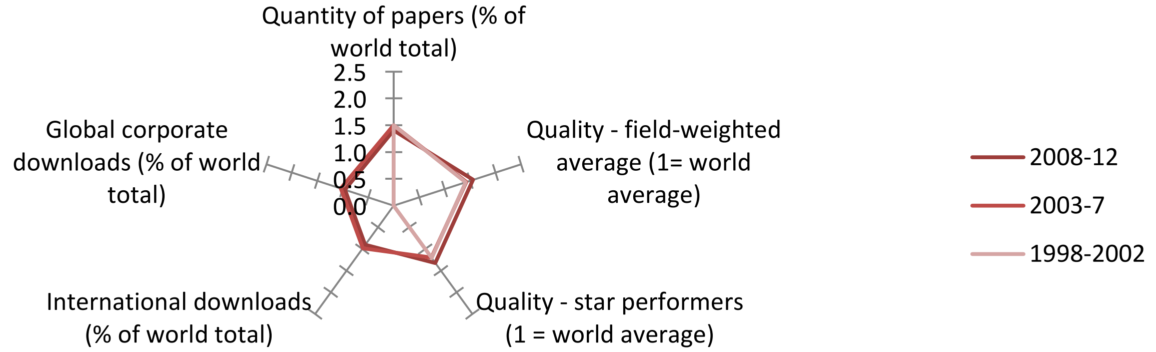
Data: Elsevier SciVal

Figure 16. **Research quality and volume indicators - Israel**



Data Elsevier SciVal

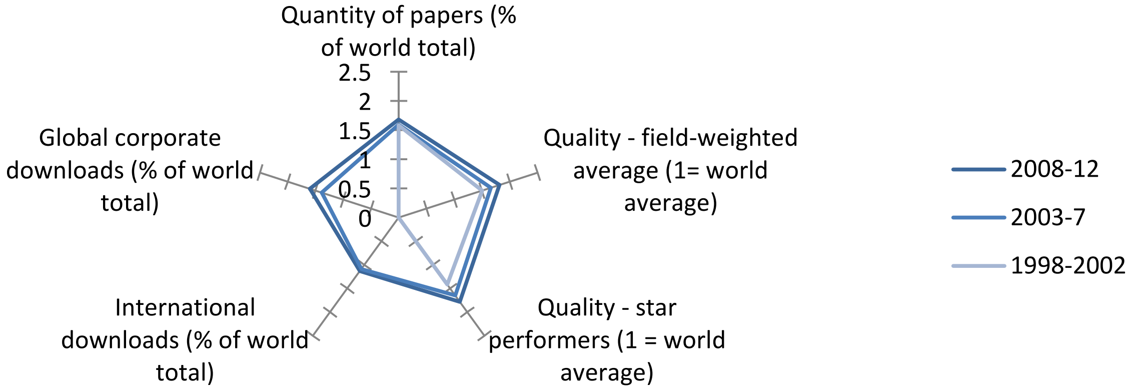
Figure 17. **Research quality and volume indicators - Finland**



Data: Elsevier SciVal

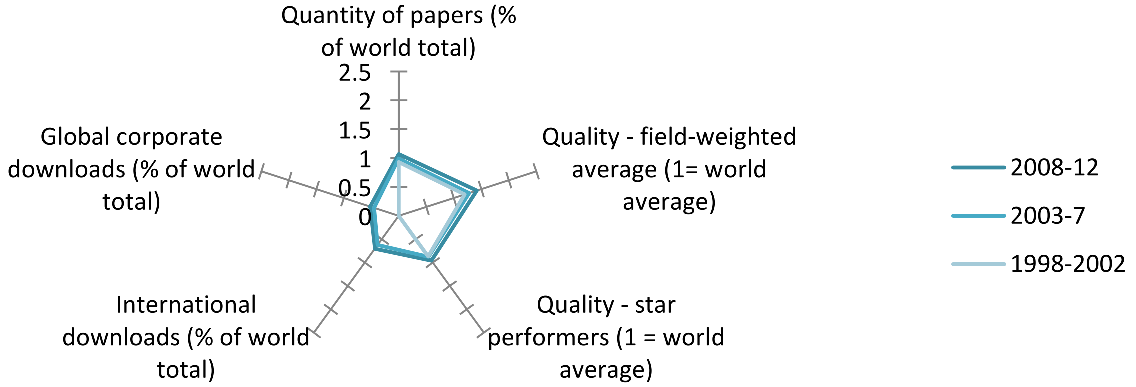
Outputs

Figure 18. **Research quality and volume indicators - Denmark**



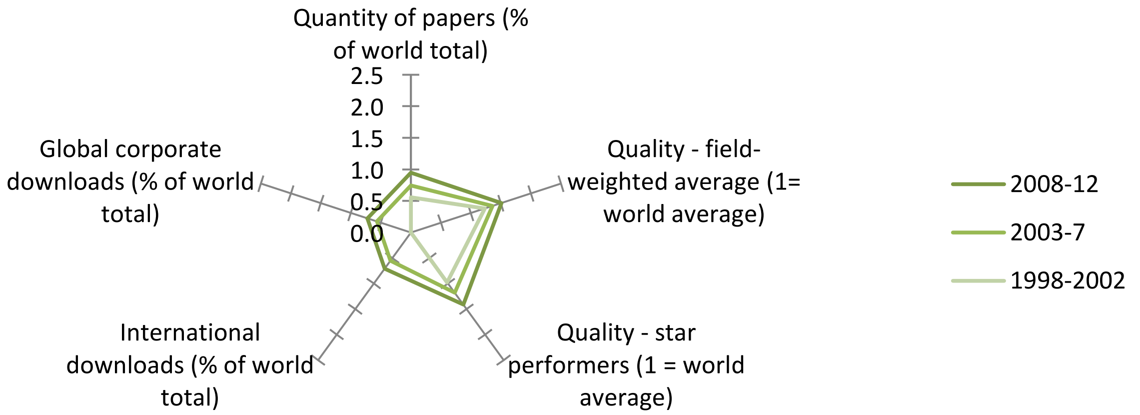
Data: Elsevier SciVal

Figure 19. **Research quality and volume indicators - New Zealand**



Data: Elsevier SciVal

Figure 20. **Research quality and volume indicators - Ireland**

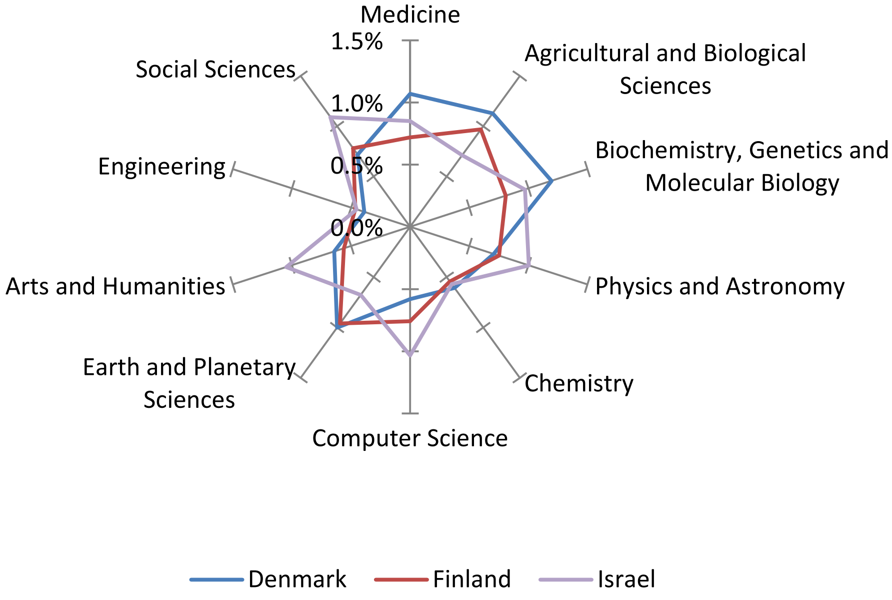


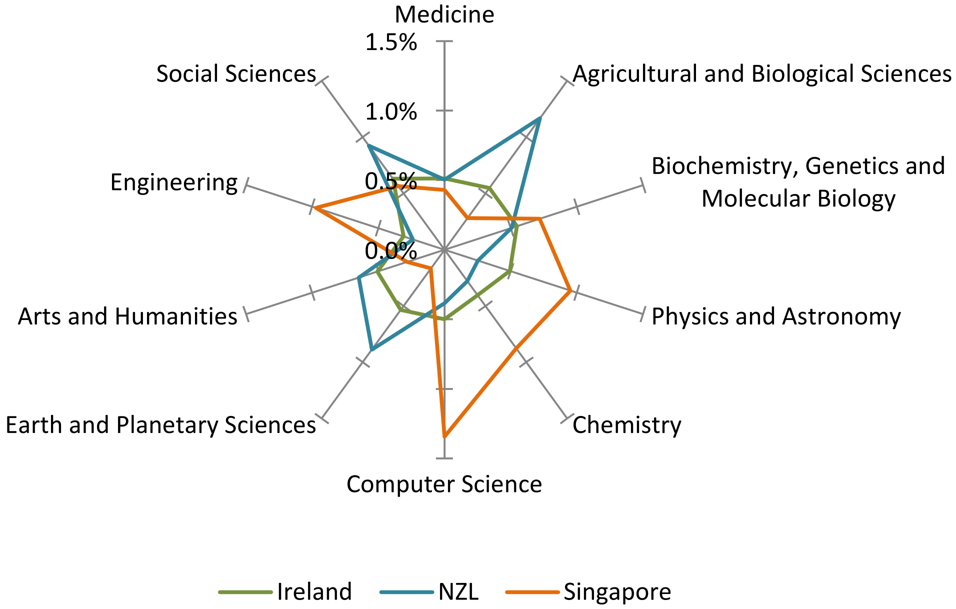
Data: Elsevier SciVal

Bibliometrics by discipline

Figure 21 illustrates the volume of publications produced by each of the SAEI counties, broken down by high level journal category. Although each country can be seen to have a distinct set of foci, some particularly notable areas by their percentage of world volume include computer science in Israel and Singapore, and agricultural and biological sciences in New Zealand and Denmark.

Figure 21. **Publications by country as a percentage of world output volume (2008-12)**





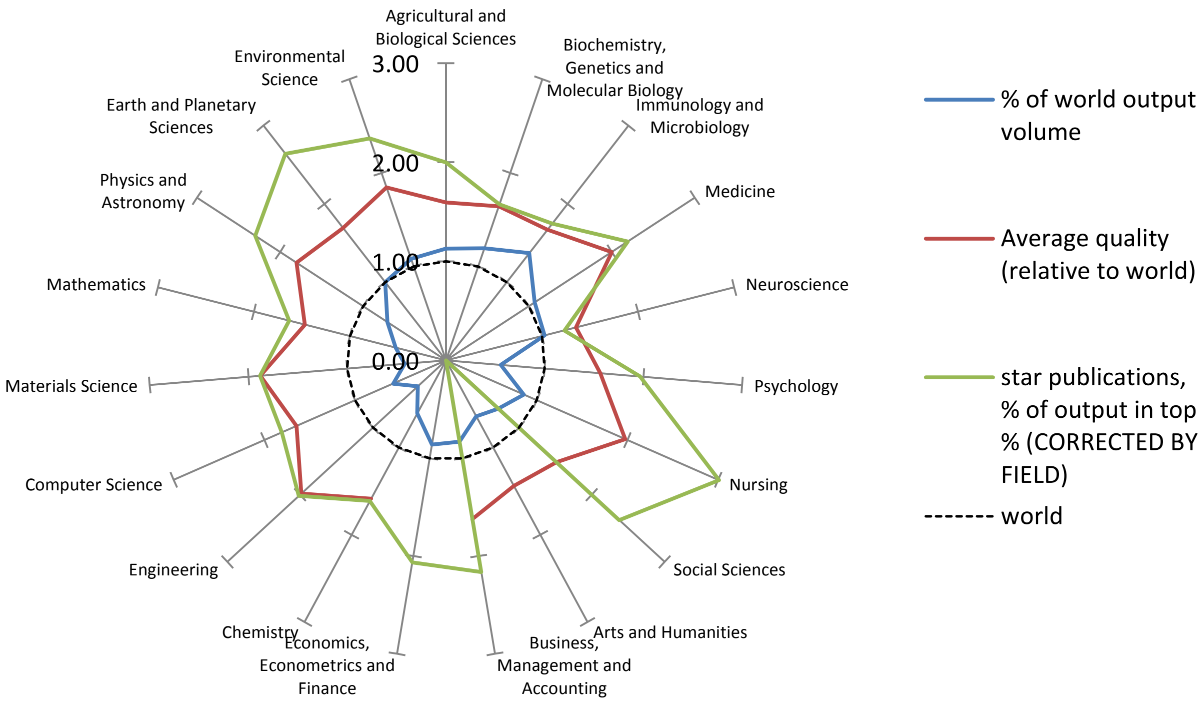
Data: Elsevier SciVal

Outputs

Publication Quantity and Quality Data

Figure 22 to Figure 27 compare publication volume to relative quality and the percentage of 'star' performing papers. While some countries such as Ireland and New Zealand show a close correlation between their areas of strength and focus (possibly due to more deliberate attempts to focus resources in areas of comparative advantage), in other countries the relationship between quality and volume is less apparent.

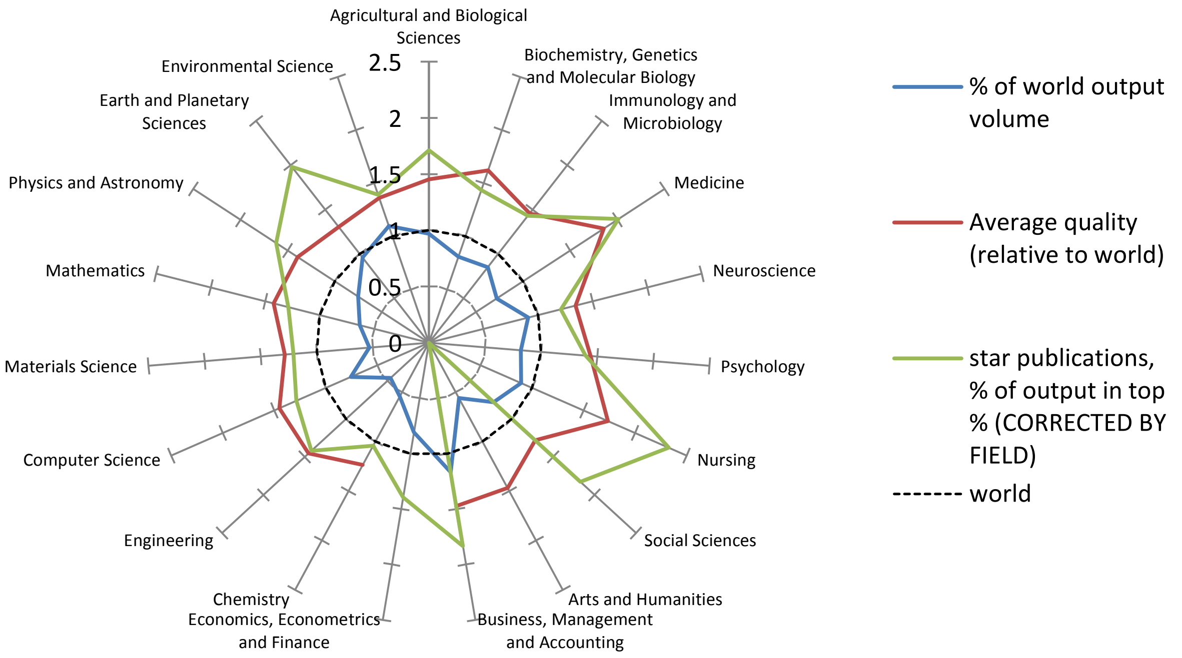
Figure 22. **Publication volume, relative quality, and star performers – Denmark (2008-12)**



Data: Elsevier SciVal

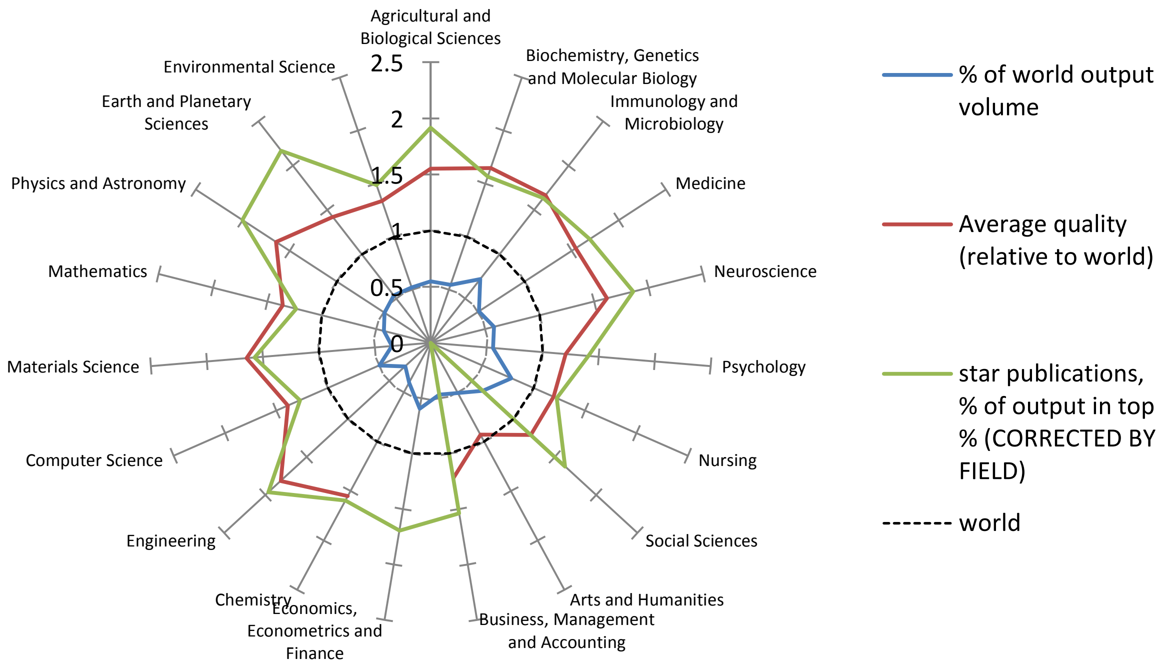
Outputs

Figure 23. **Publication volume, relative quality, and star performers – Finland (2008-12)**



Data: Elsevier SciVal

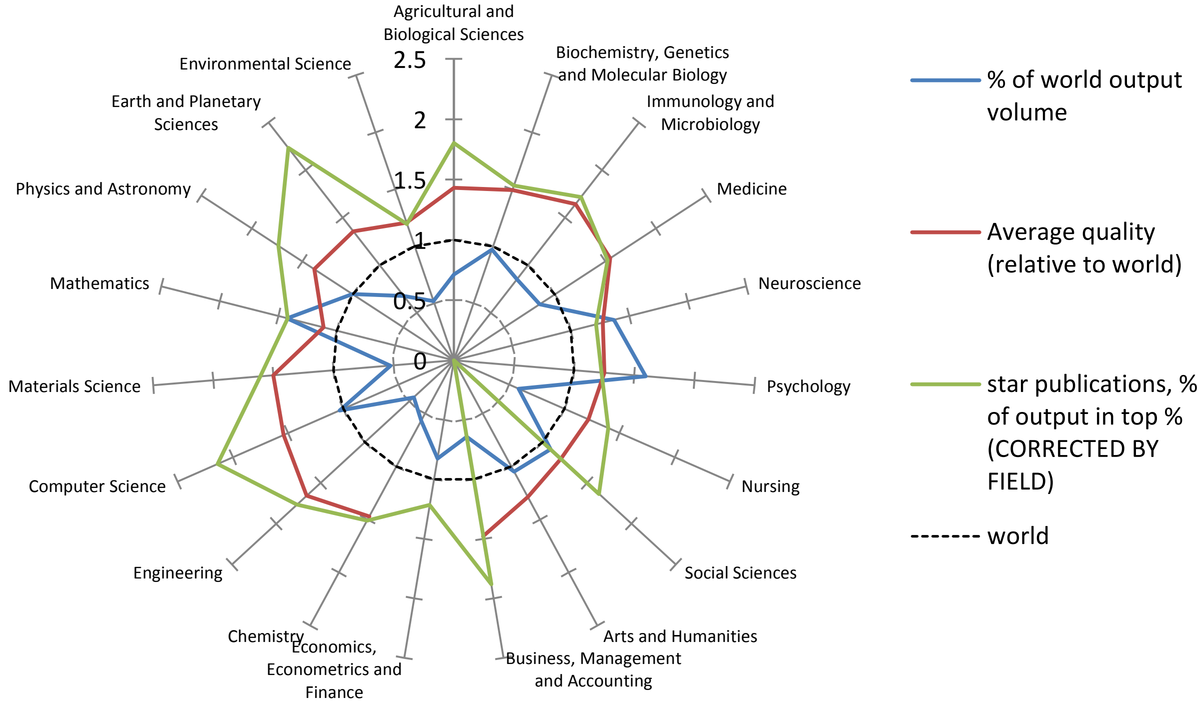
Figure 24. **Publication volume, relative quality, and star performers – Ireland (2008-12)**



Data: Elsevier SciVal

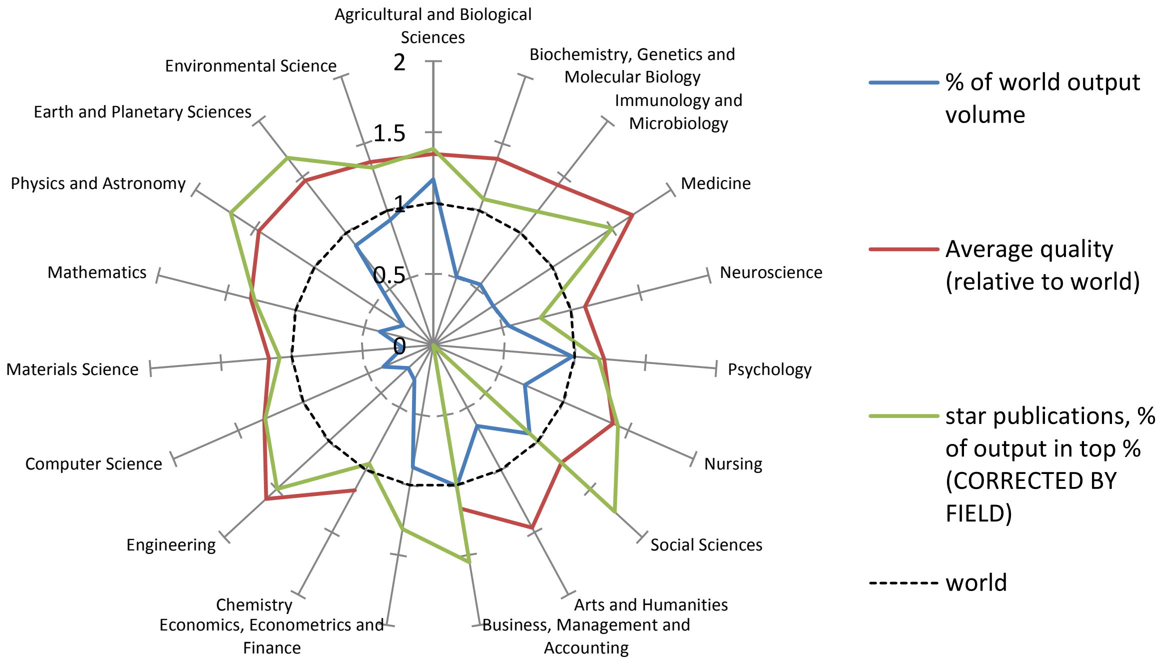
Outputs

Figure 25. **Publication volume, relative quality, and star performers – Israel (2008-12)**



Data: Elsevier SciVal

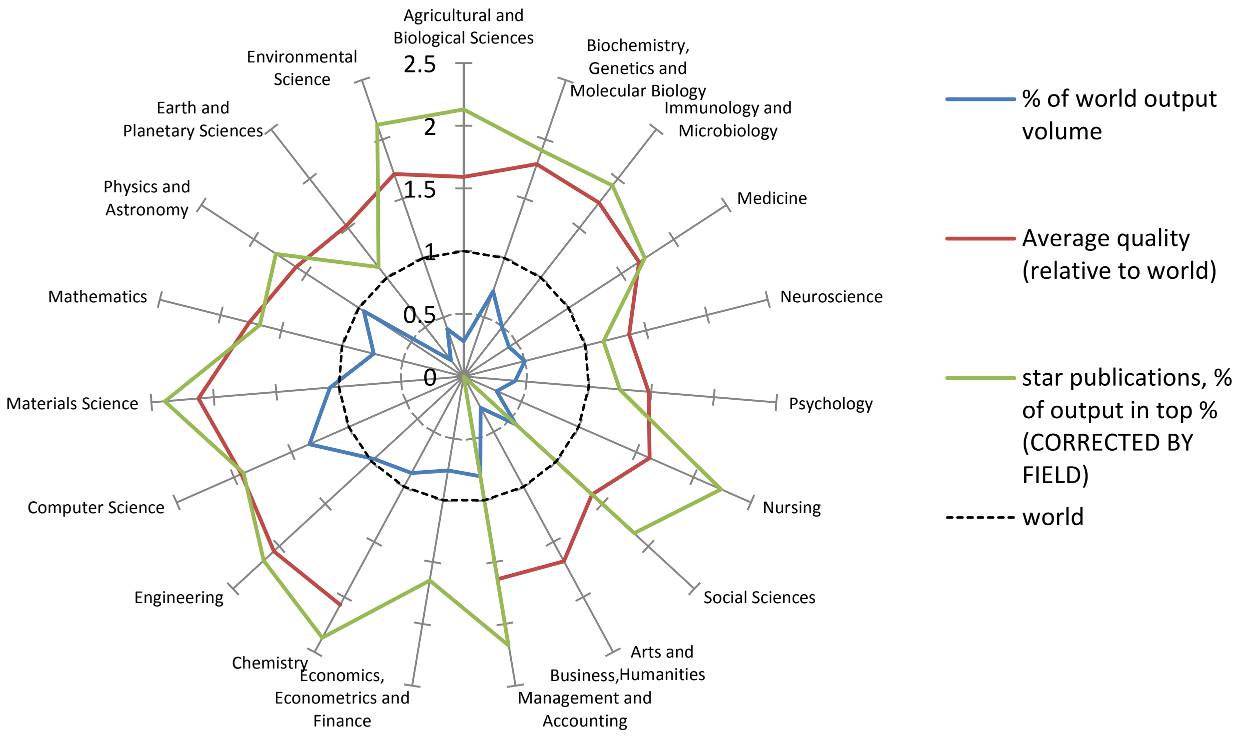
Figure 26. **Publication volume, relative quality, and star performers – New Zealand (2008-12)**



Data: Elsevier SciVal

Outputs

Figure 27. **Publication volume, relative quality, and star performers – Singapore (2008-12)**



Data: Elsevier SciVal

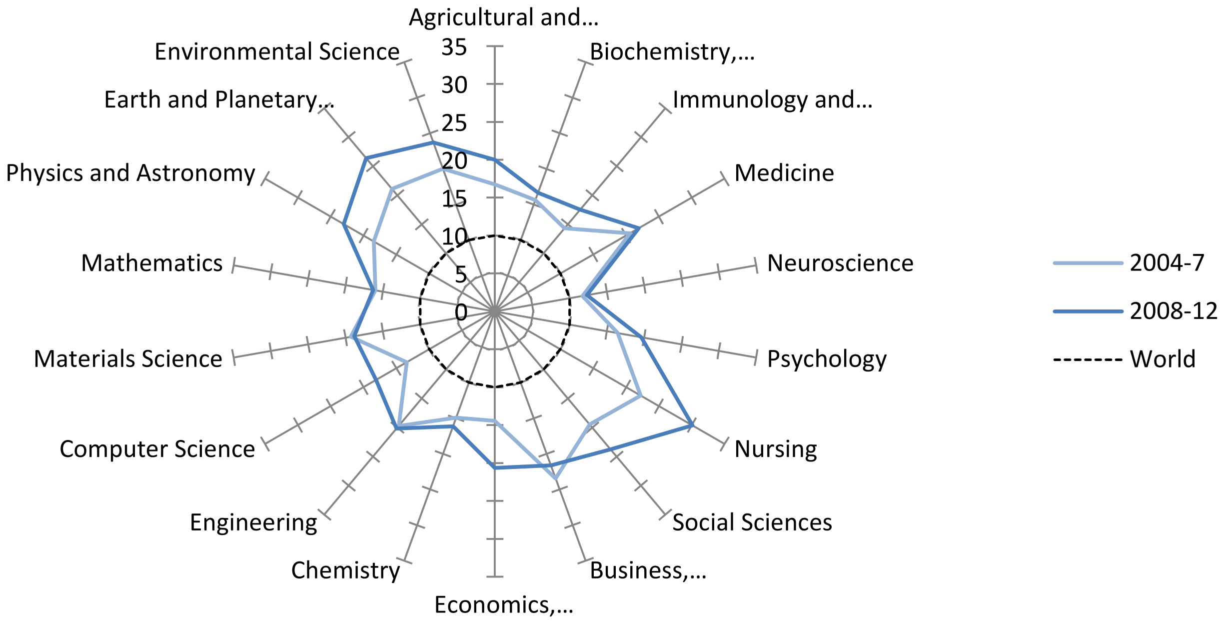
Production of 'Star-publications'

The following charts show the percentage of publications each country has in the top 10% of the world judged by their number of citations. The figures are field adjusted and thus represent the number of publications in the top 10 percent of each discipline only, not the total pool of global publications.

While quality by this metric appears to have been relatively constant across the group in recent years, Singapore, Ireland, and Denmark in particular have shown consistent improvements across most areas.

Outputs

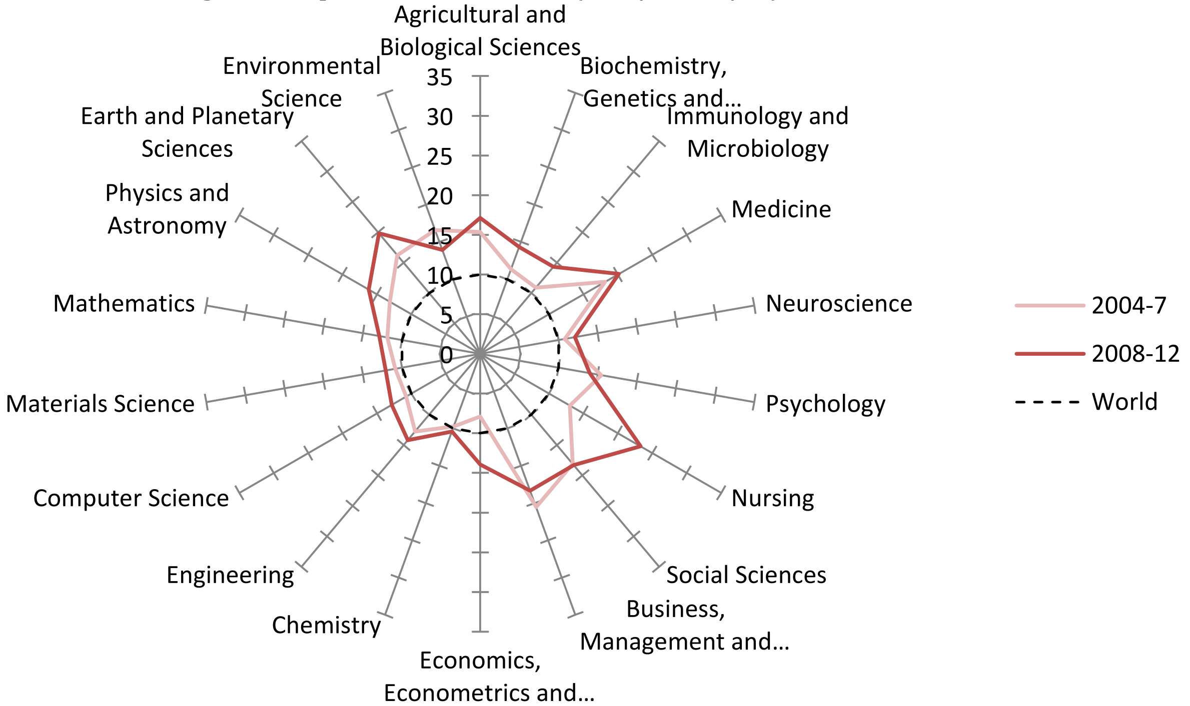
Figure 28. **Percentage of 'star' publications over time (2004/7-2008/12) - Denmark**



Data: Elsevier SciVal

Note: 'Star' publications defined as those in the top 10% of all publications globally by number of citations

Figure 29. **Percentage of 'star' publications over time (2004/7-2008/12) - Finland**

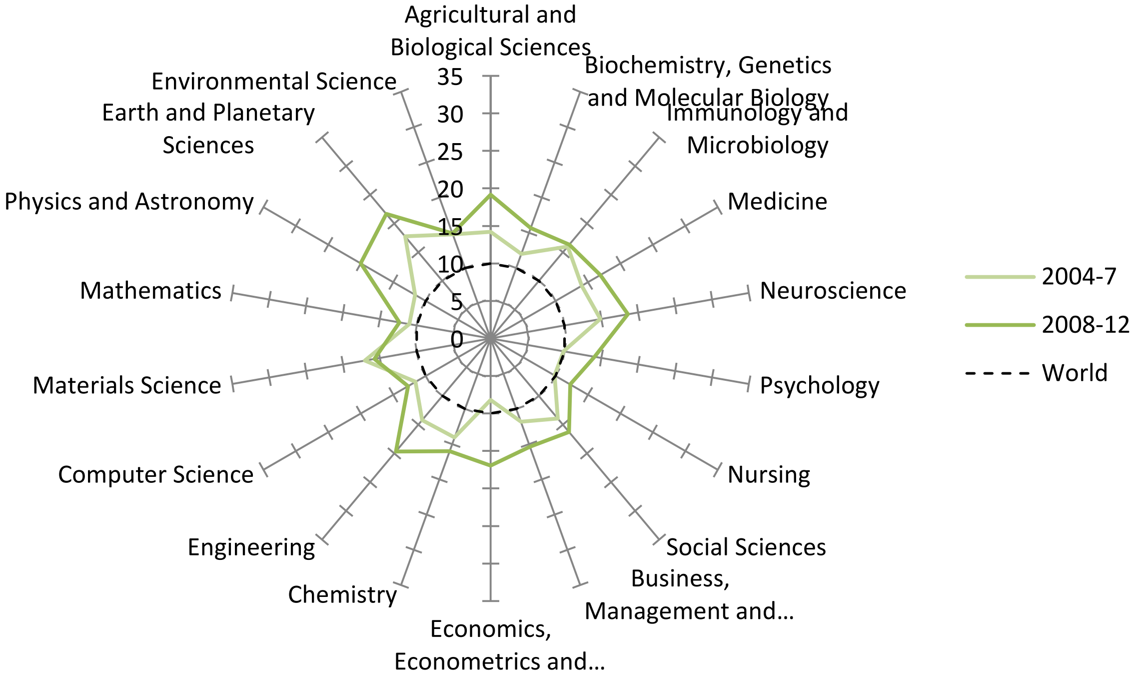


Data: Elsevier SciVal

Note: 'Star' publications defined as those in the top 10% of all publications globally by number of citations

Outputs

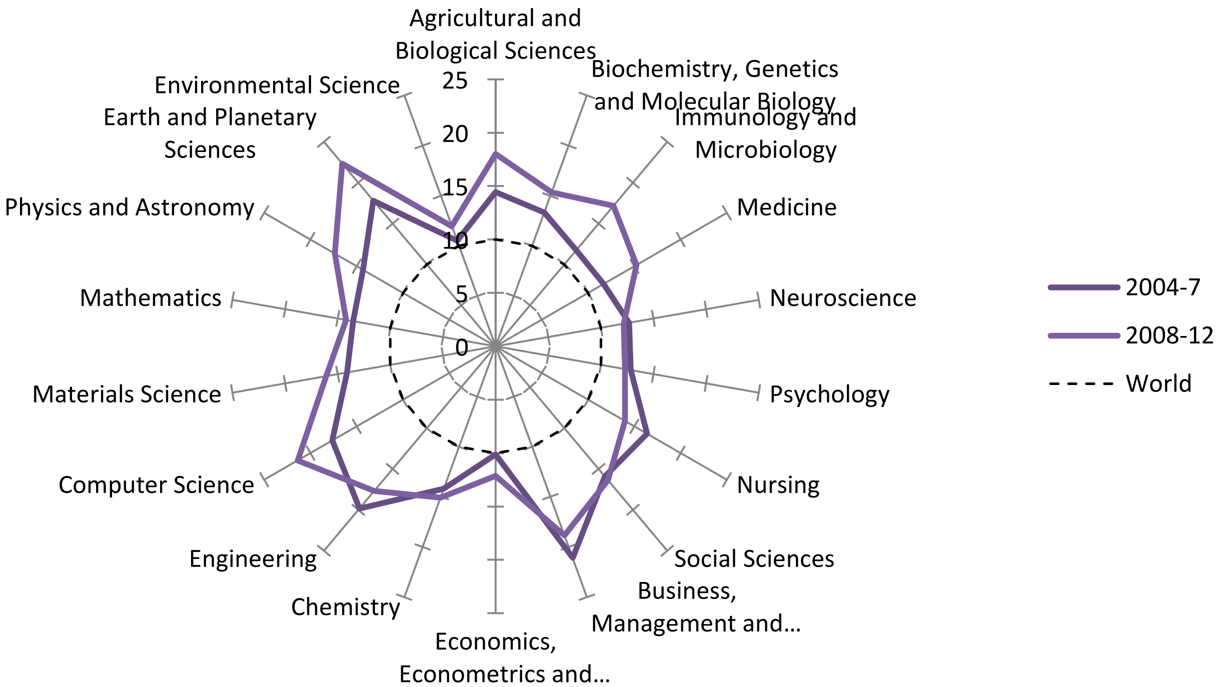
Figure 30. **Percentage of 'star' publications over time (2004/7-2008/12) - Ireland**



Data: Elsevier SciVal

Note: 'Star' publications defined as those in the top 10% of all publications globally by number of citations

Figure 31. **Percentage of 'star' publications over time (2004/7-2008/12) - Israel**

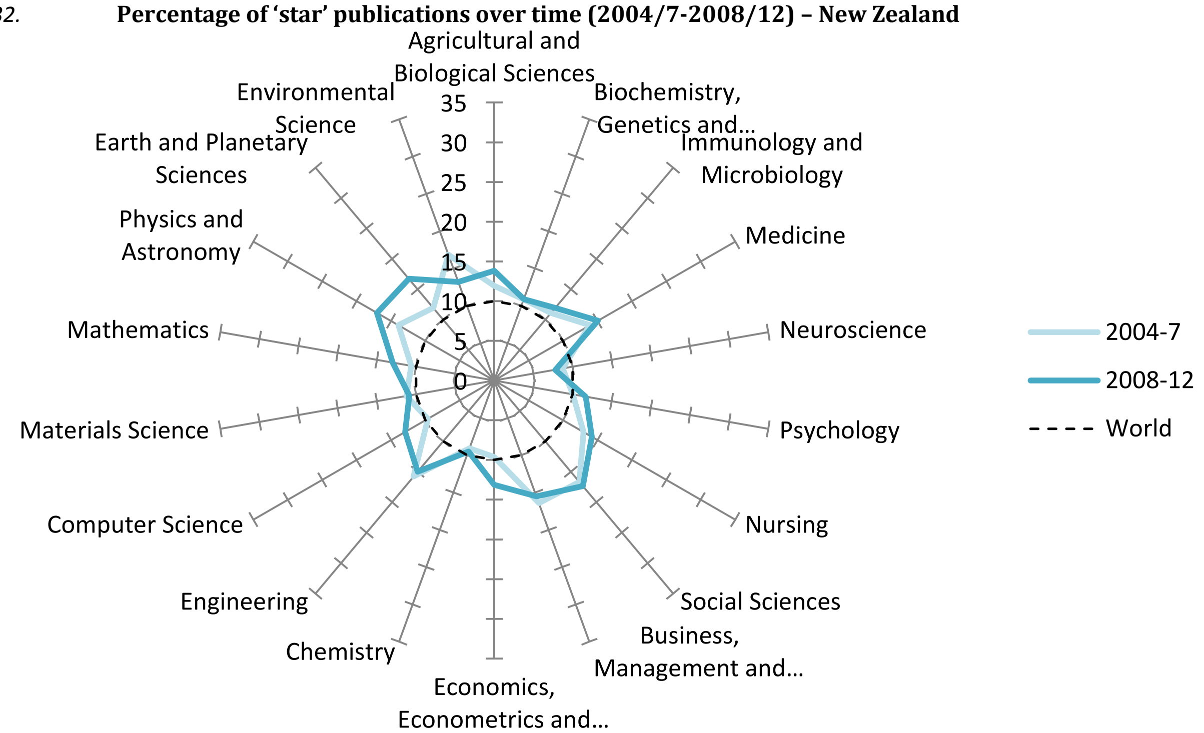


Data: Elsevier SciVal

Note: 'Star' publications defined as those in the top 10% of all publications globally by number of citations

Outputs

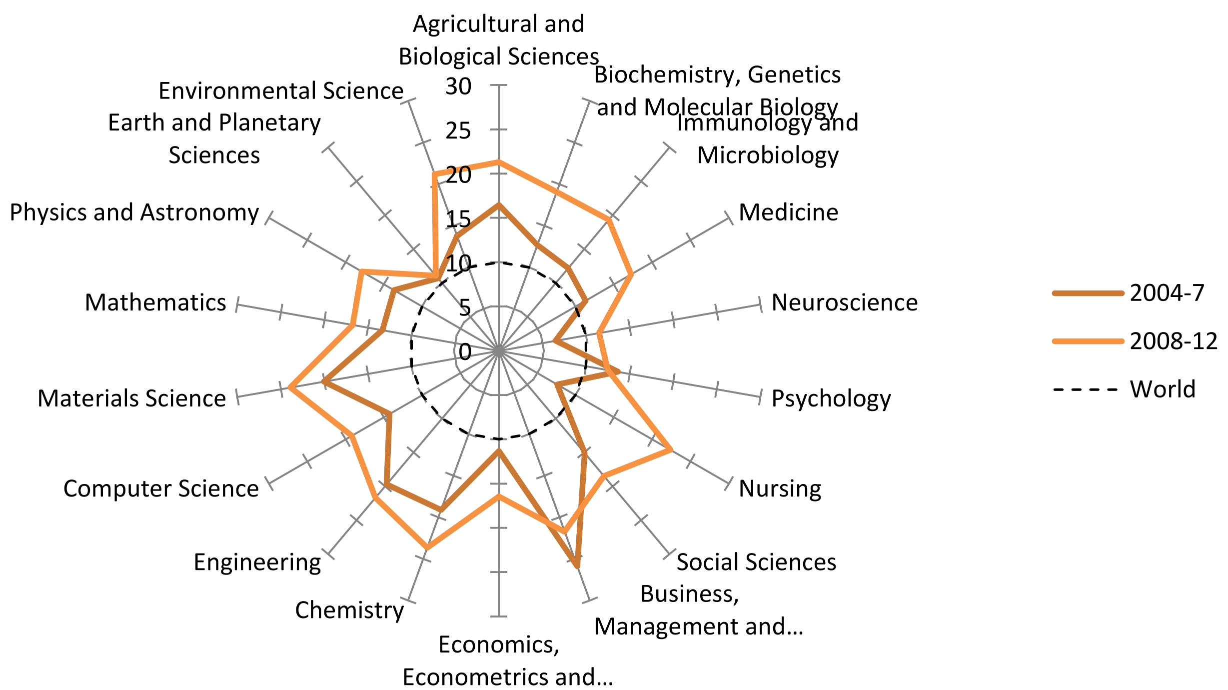
Figure 32. **Percentage of 'star' publications over time (2004/7-2008/12) – New Zealand**



Data: Elsevier SciVal

Note: 'Star' publications defined as those in the top 10% of all publications globally by number of citations

Figure 33. **Percentage of 'star' publications over time (2004/7-2008/12) - Singapore**



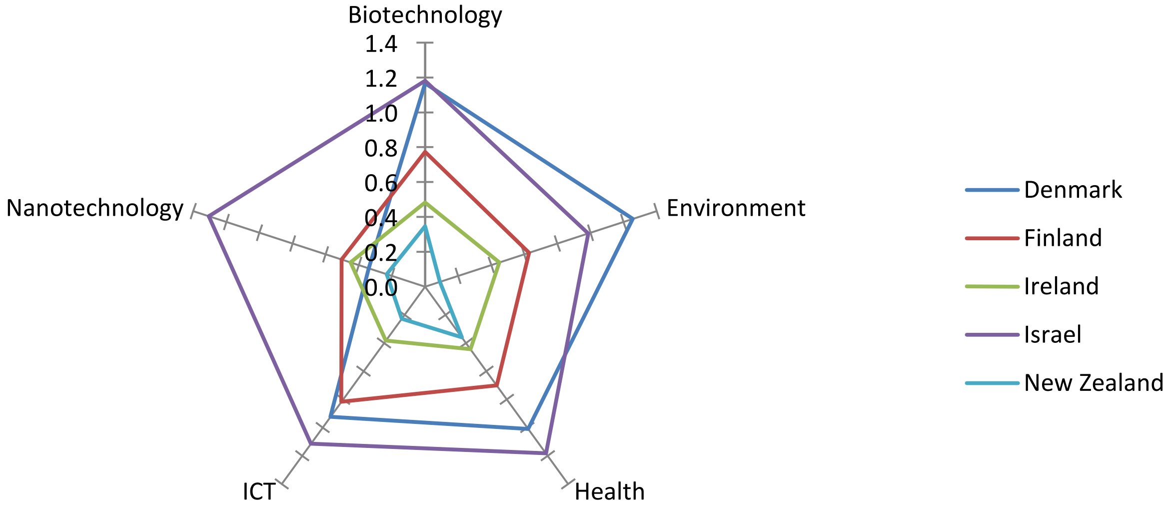
Data: Elsevier SciVal

Note: 'Star' publications defined as those in the top 10% of all publications globally by number of citations

Outputs in Patents

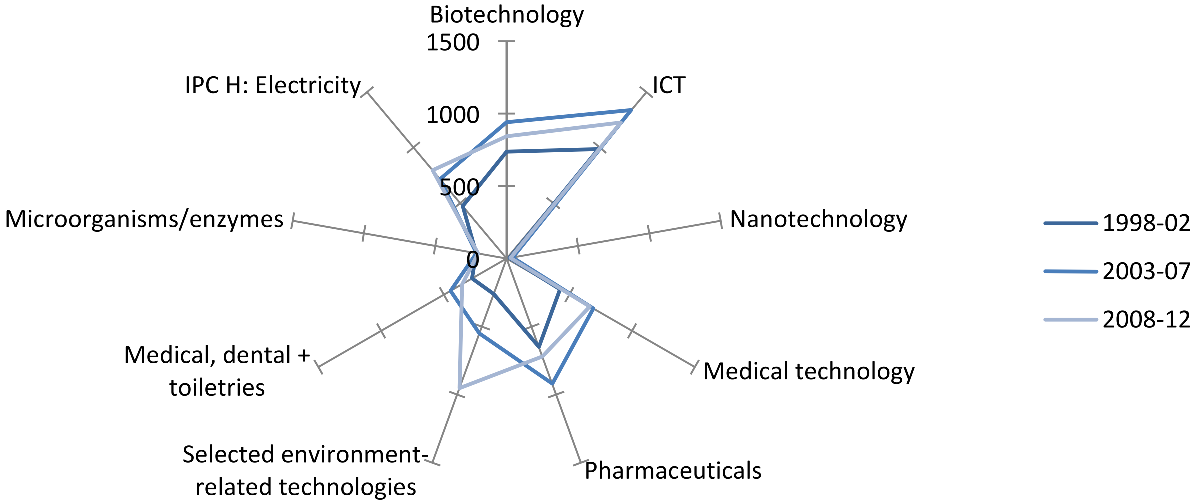
Figure 34Figure 40 show the volume of patent applications by country, through time. While there is significant variability between countries and technology fields – likely driven in part by different patenting cultures and practices – all countries show significant increases in the number of patents being filed in the ICT area.

Figure 34. **Sources of scientific literature cited in patents (as a % of all scientific documents cited in technology area) (2001-11)**



Data: OECD STI Scoreboard 2013

Figure 35. **Patent applications by field and through time – Denmark**

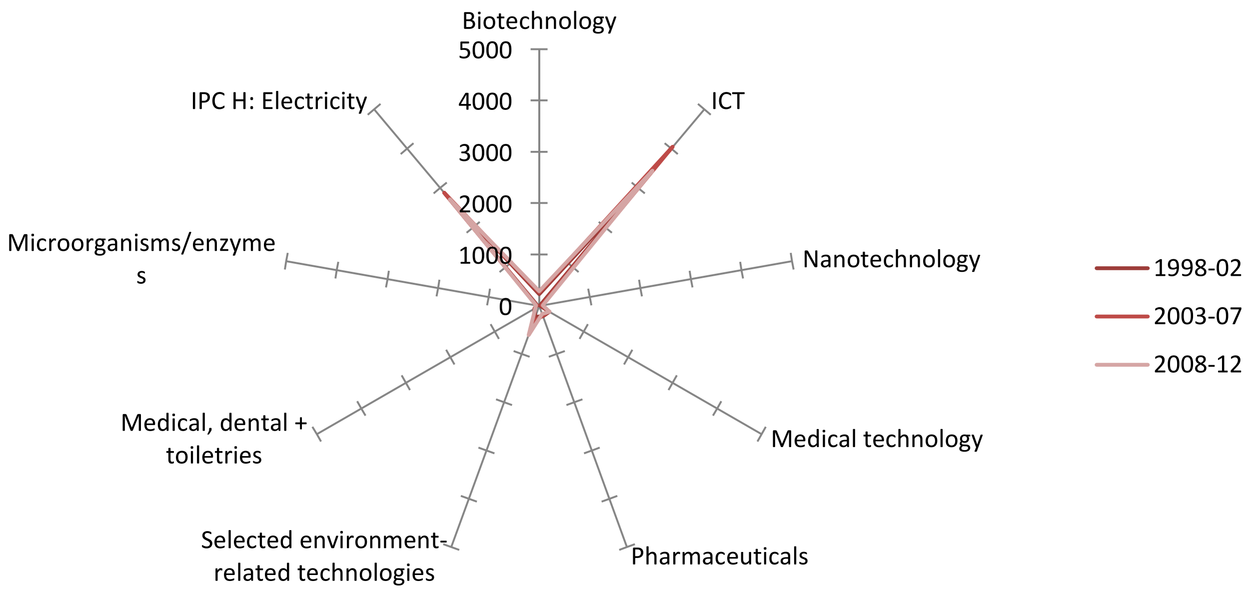


Data: OECD STI Scoreboard

Outputs

Note: scales not comparable across country charts

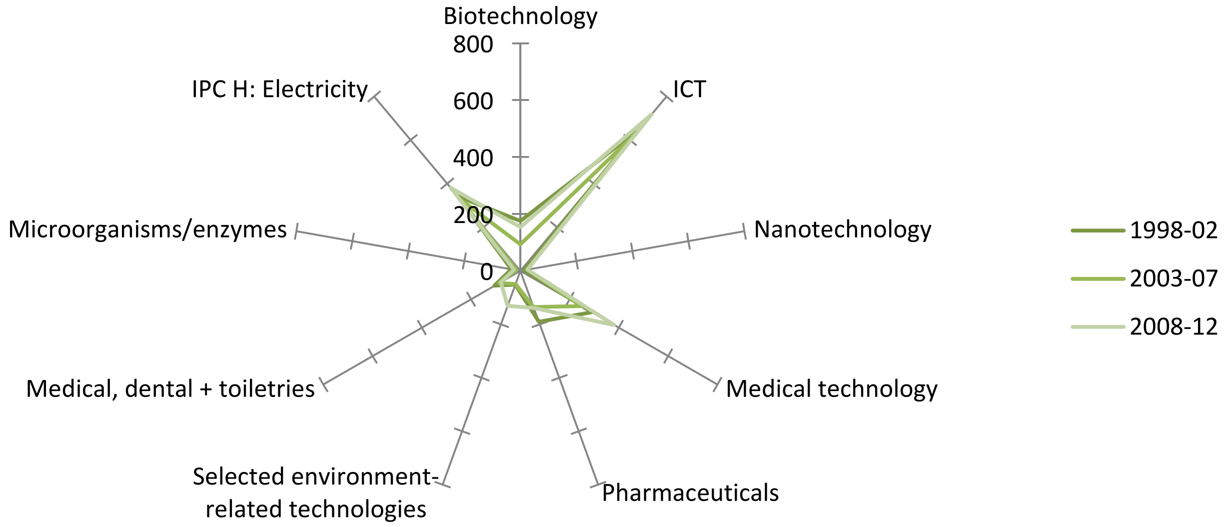
Figure 36. **Patent applications by field and through time – Finland**



Data: OECD STI Scoreboard

Note: scales not comparable across country charts

Figure 37. **Patent applications by field and through time – Ireland**

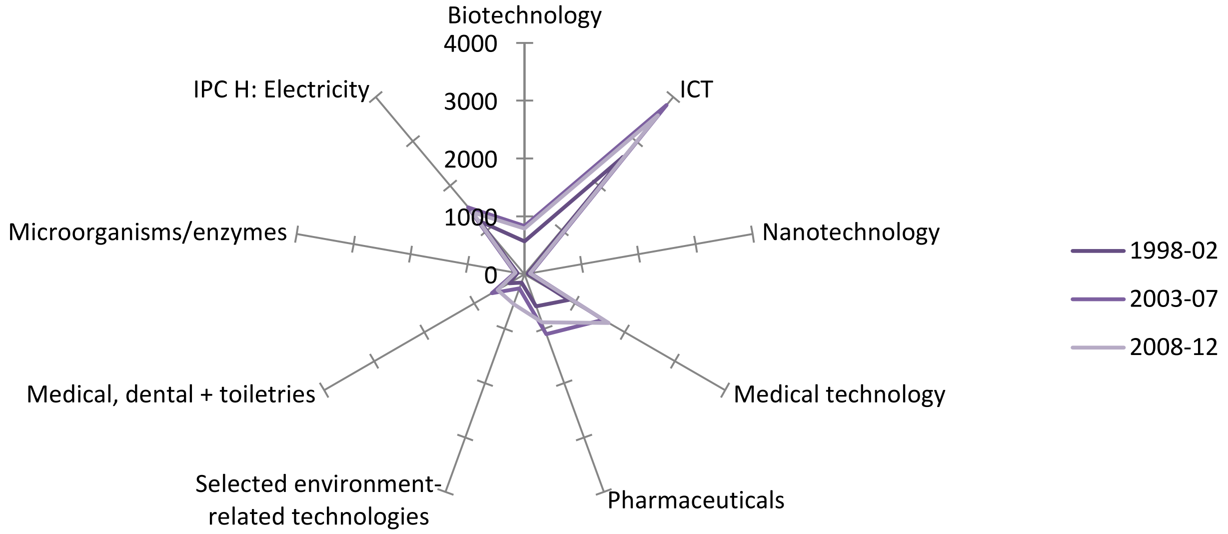


Data: OECD STI Scoreboard

Note: scales not comparable across country charts

Outputs

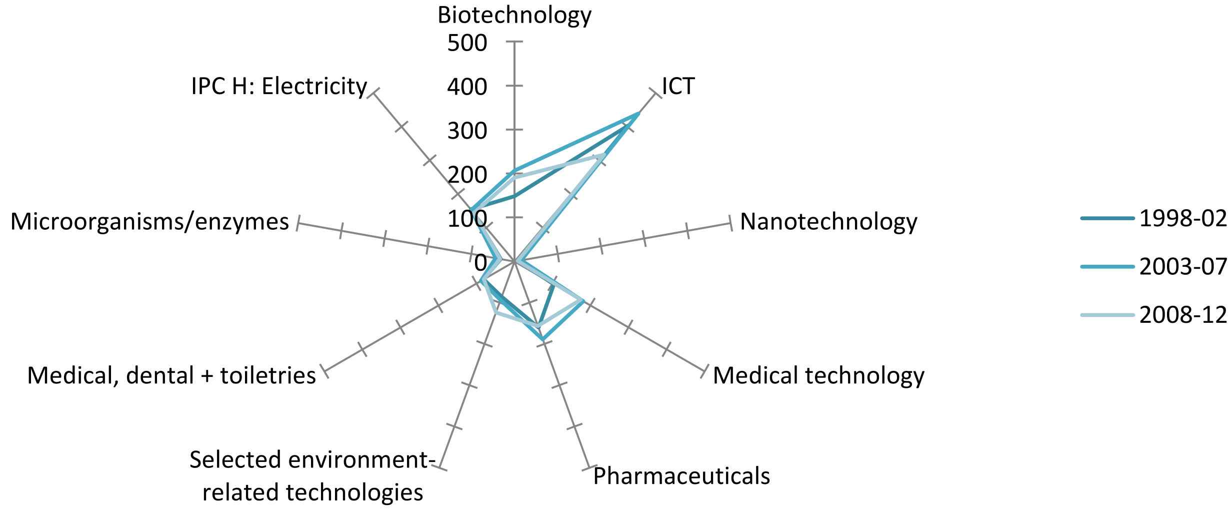
Figure 38. **Patent applications by field and through time – Israel**



Data: OECD STI Scoreboard

Note: scales not comparable across country charts

Figure 39. **Patent applications by field and through time – New Zealand**

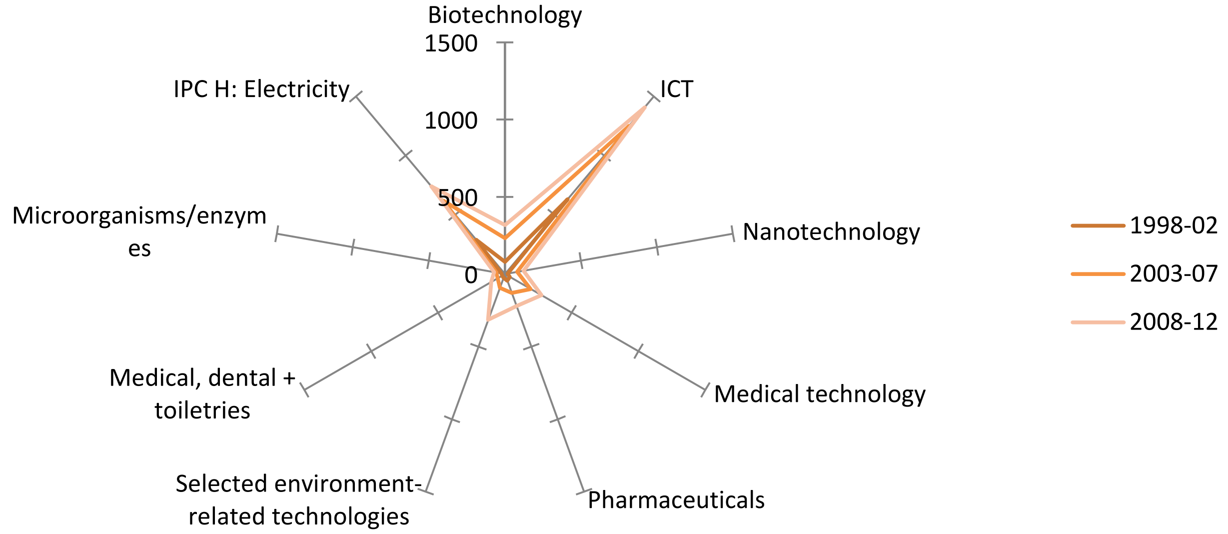


Data: OECD STI Scoreboard

Note: scales not comparable across country charts

Outputs

Figure 40. **Patent applications by field and through time – Singapore**



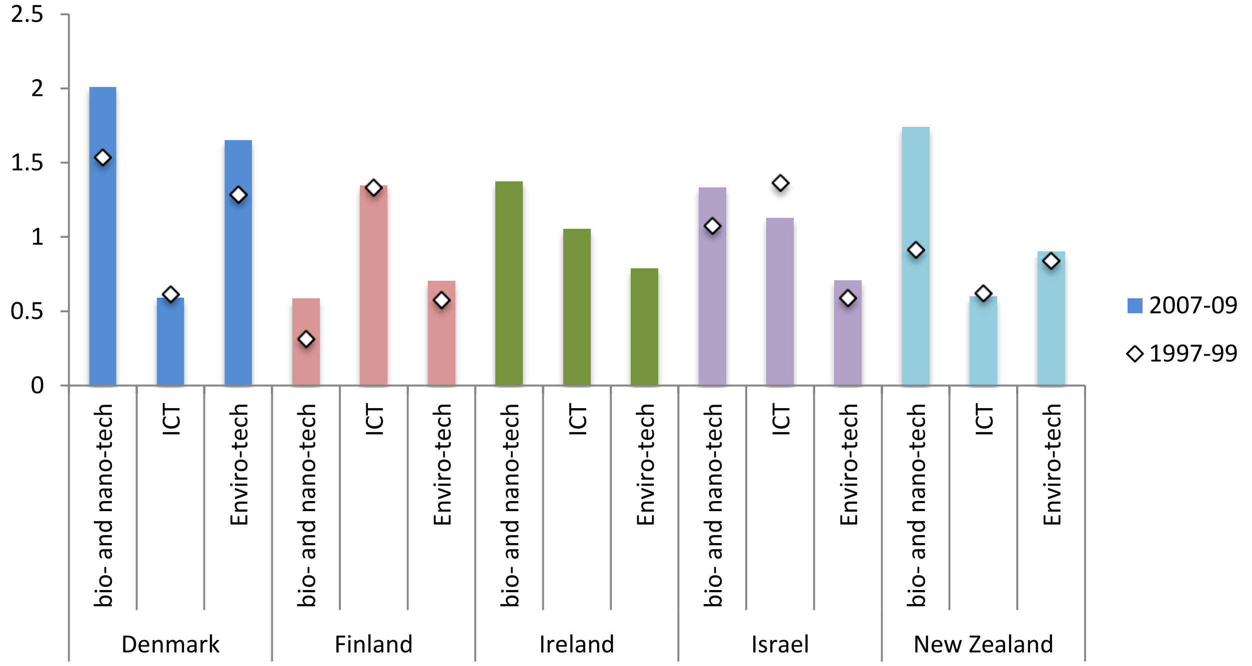
Data: OECD STI Scoreboard

Note: scales not comparable across country charts

Indications of changes in industry strengths, based on patents

Figure 41 attempts to identify the technological areas in which the SAEI's members have an internal focus. Based on the number of patents relative to other areas, the majority of members appear to have a particular and growing focus on bio and nano-tech. Finland is the exception here, producing comparatively fewer patents in bio and nano-tech than other areas, but exhibiting a strong focus on ICT. While a useful proxy for specialisation, consideration should be given to the differences in patenting cultures between technology fields when interpreting this measure.

Figure 41. **Revealed technology advantage in selected fields (1997-9/2007-9)**



Data: OECD Scoreboard 2013

Note: RTA defined as country's share of patents in stated technology field divided by the country's share in all patent fields. The index is equal to zero when the country holds no patent in a given sector and is equal to 1 when the country's share in the sector equals its share in all fields (i.e. no specialisation).

Niche competencies – Based on co-citation analysis

In an attempt to assess output performance with greater granularity, the following charts illustrate the niche competencies that exist across the SAEI countries. Niche competencies are specific, typically interdisciplinary areas where countries are dominant in the production of literature. Competencies are identified using co-citation analysis, which identifies clusters of literature based on pairs of publications that are cited across multiple articles. These clusters are grouped into competencies based on their common publications and then attributed to the countries that are the leading authors by the scale of their contribution.

As opposed to analysis of standard journal fields, niche competencies are able to identify narrow, multidisciplinary strengths which are often missed when fractionalised into traditional, high-level discipline categories.

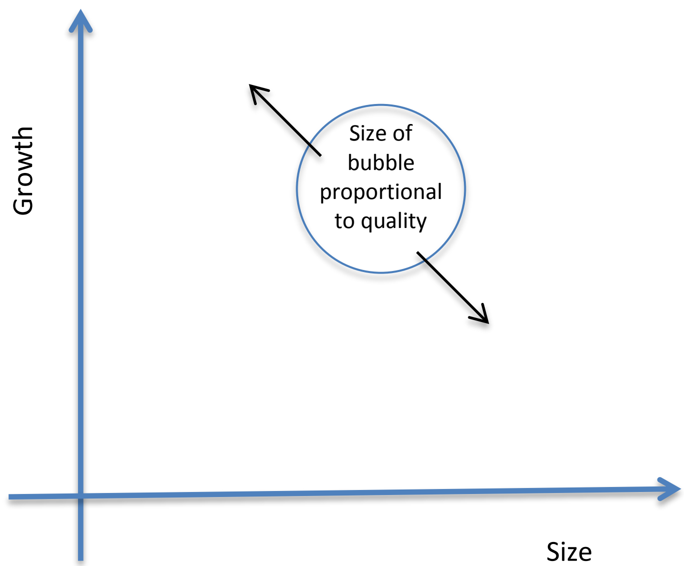
The charts below illustrate the type, number and scale of competencies in each of the SAEI members. For interpretation:

- The **x-axis** represents the scale of the competency in terms of the total (fractional) number of publications produced in that area;
- The **y-axis** represents the annual growth in the number of publications the country is contributing to each competency, averaged over a 5-year period; and,
- The **bubble size** is proportional to the relative contribution of the country to the competency's overall citation count (an indication of the quality of the country's contribution).

In addition, where the key words are printed in **bold text** the country is the leading contributor to that competency. The text accompanying each competency represents the associated top keywords.

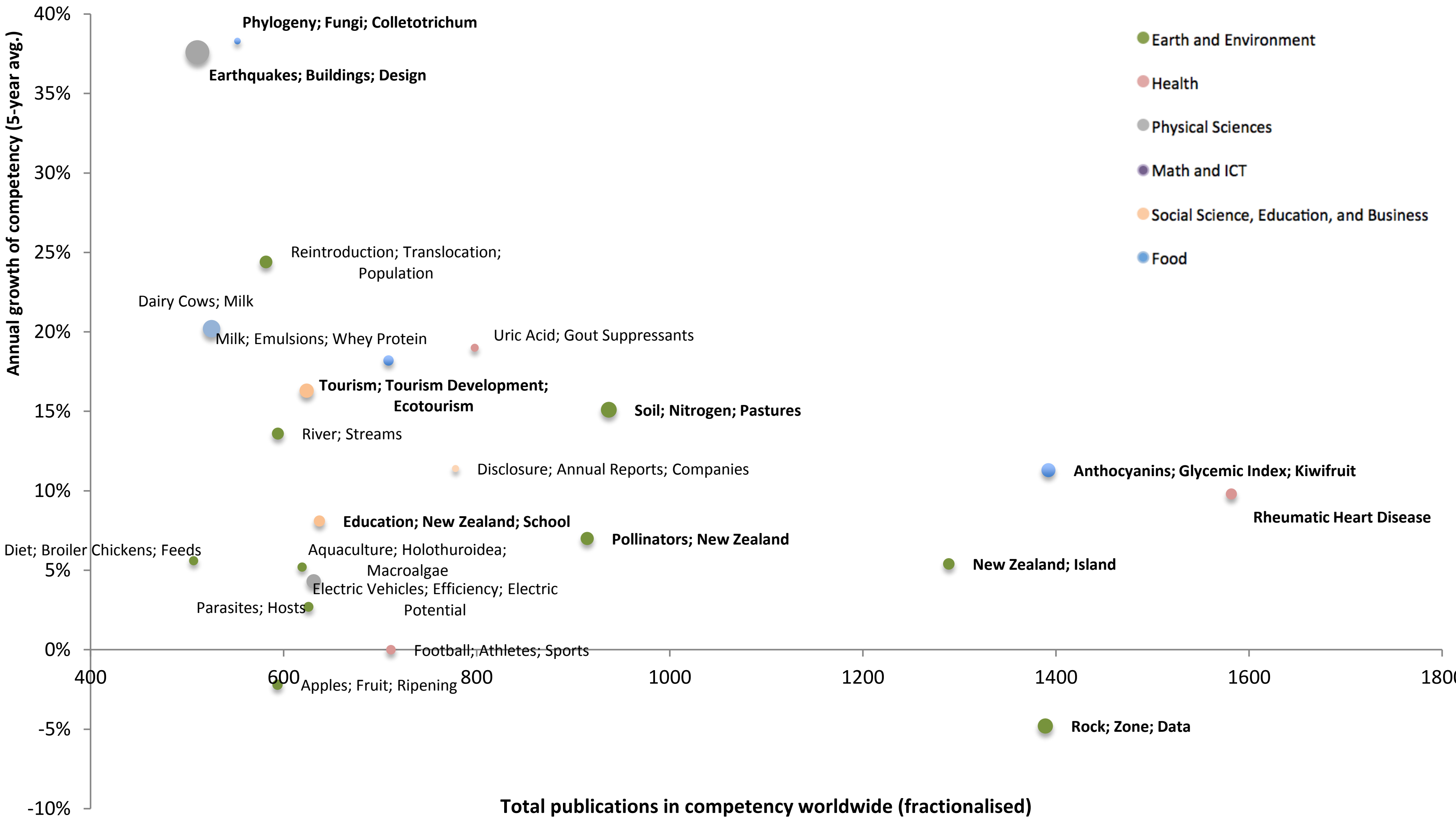
Further information on the methodology of co-citation analysis and the identification of competencies can be found in the Elsevier SciVal user guide, accessible here.

Interpretation of niche competency charts:



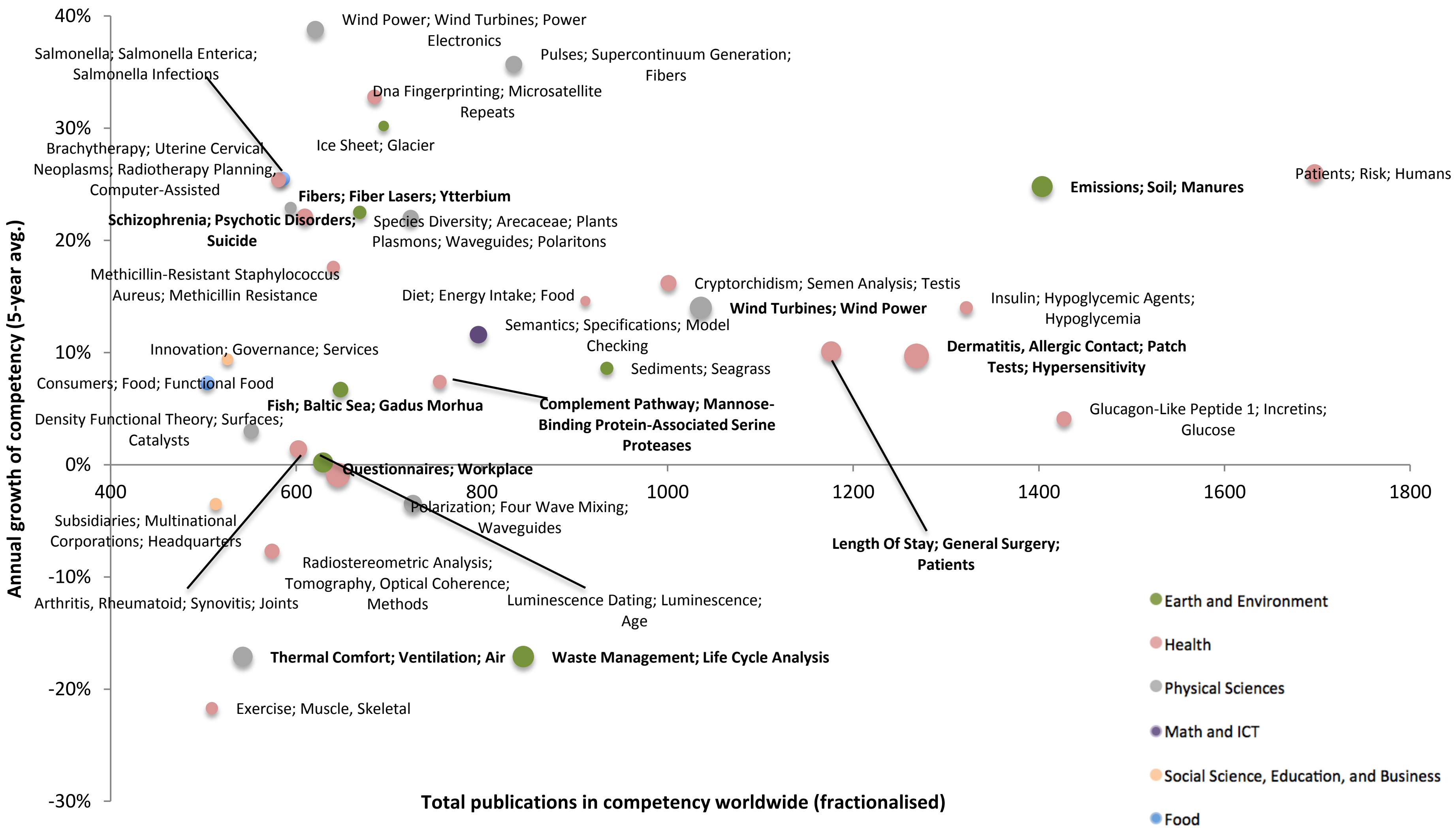
Outputs

Figure 42. **Niche competencies by fractional contribution (size) and % growth - New Zealand (2009-2013)**



Data: Elsevier SciVal

Figure 43. **Niche competencies by fractional contribution (size) and growth - Denmark (2009-2013)**



Data: Elsevier SciVal

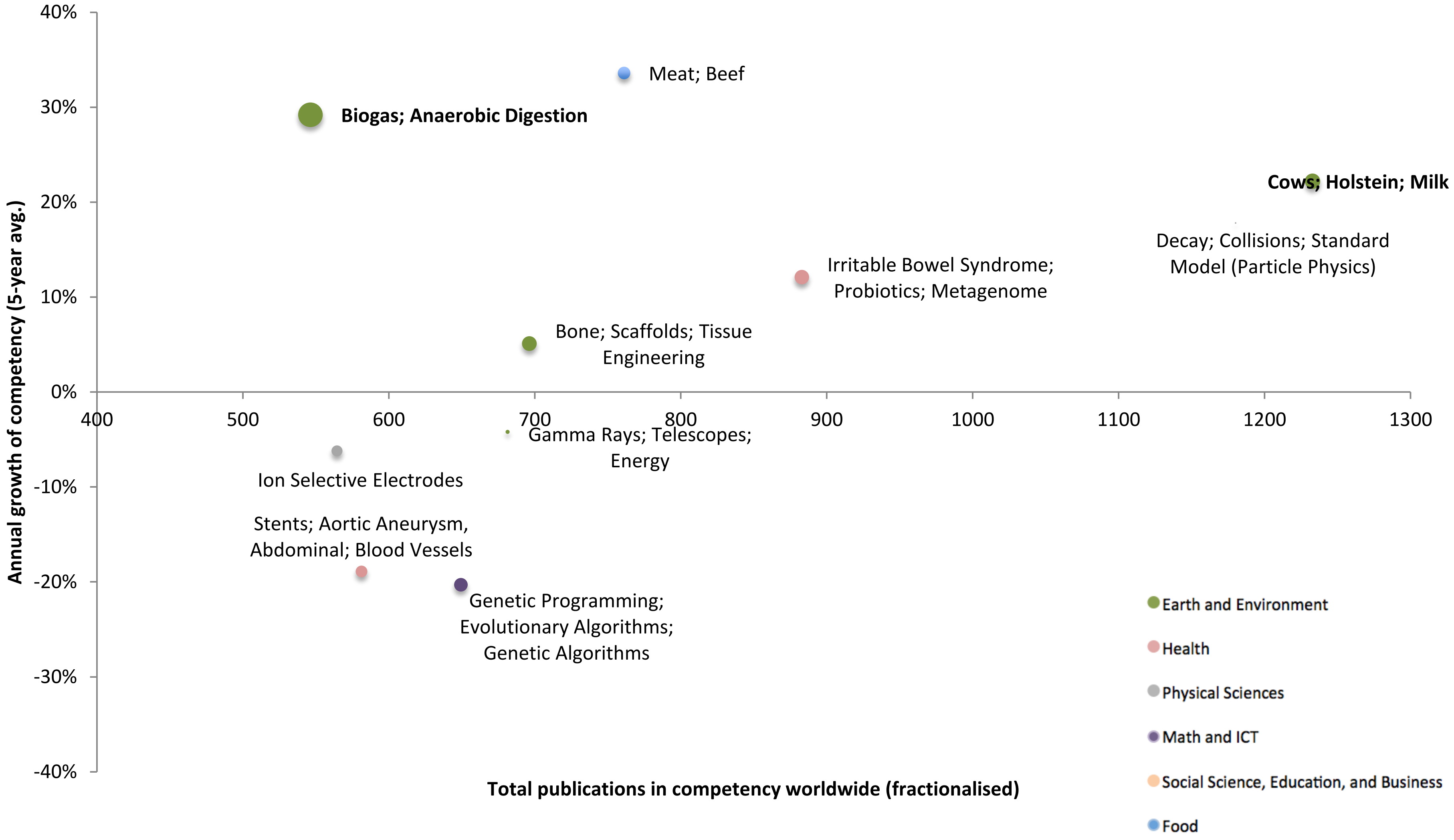
Omitted: 'Pain measurement, Pain threshold' (3103 publications, 2% growth)

Figure 44. **Niche competencies by fractional contribution (size) and growth - Finland (2009-2013)**

Data: Elsevier SciVal

Outputs

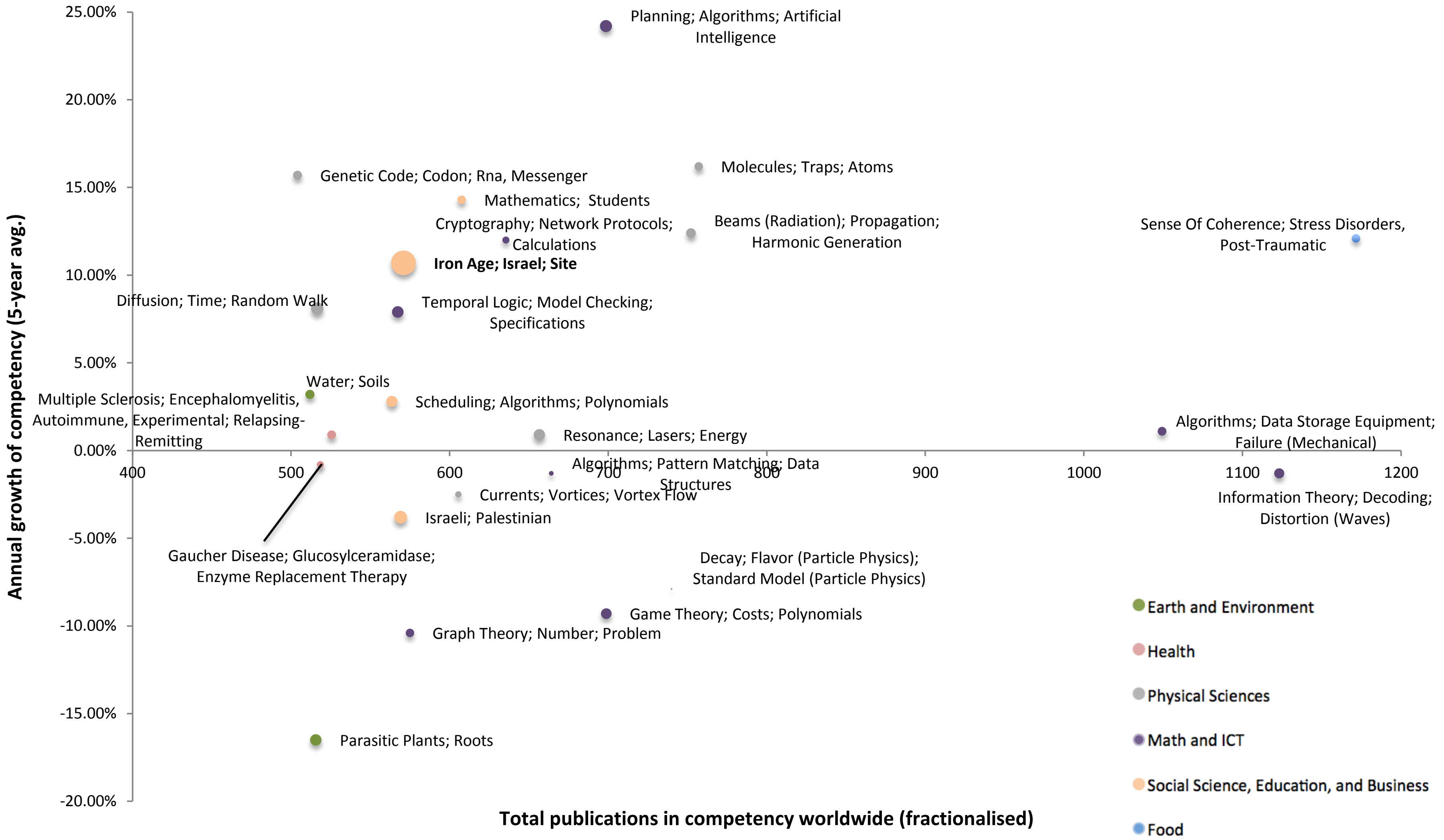
Figure 45. **Niche competencies by fractional contribution (size) and growth – Ireland (2009-2013)**



Data: Elsevier SciVal

Outputs

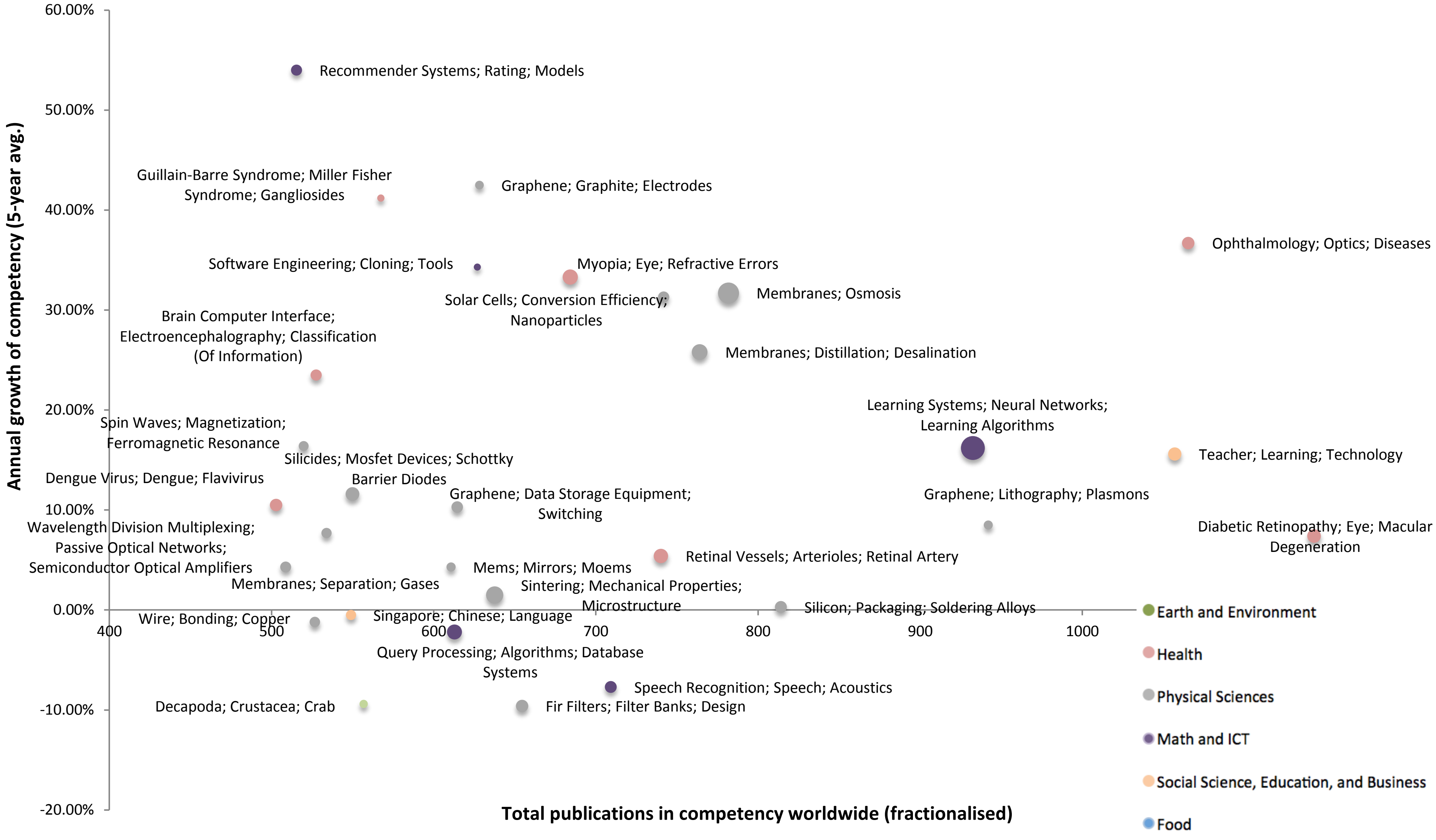
Figure 46. **Niche competencies by fractional contribution (size) and growth - Israel (2009-2013)**



Data: Elsevier SciVal

Omitted: 'Solitary Waves; Solitons; Bose-Einstein Condensates' (2922 publications, -11.3% growth); 'Approximation Algorithms; Polynomials' (2879.2 publications, -1.2% growth)

Figure 47. **Niche competencies by fractional contribution (size) and growth - Singapore (2009-2013)**



Data: Elsevier SciVal

Omitted: 'Magnetic Recording; Coercive Force; Films' (4013 publications, 11.3% growth); 'Inequalities; Bells; Quantum Cryptography' (3531 publications, 28% growth)

Publication Downloads

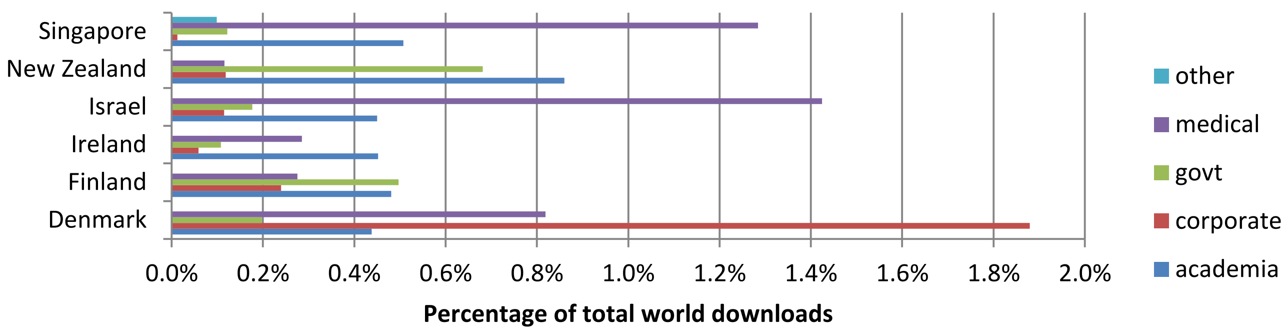
Serving as an indication of knowledge absorption and research dissemination, Figure 48Figure 49 show the extent to which publications of member countries are downloaded and the extent to which they themselves download research. As can be seen, corporations in Denmark are responsible for the largest portion of the country's downloads, while in Israel and Singapore it is medical institutes that are the largest consumers of research.

In terms of production, publications from Denmark, Finland, and Ireland are downloaded by a proportionally higher number of corporations than other institute types, while in New Zealand, Singapore, and Israel, the largest markets are government, academia, and medical institutes respectively.

Figure 50 illustrates the volume and location of downloaded research from SAEI countries as a percentage of total country downloads.

Countries as consumers of research

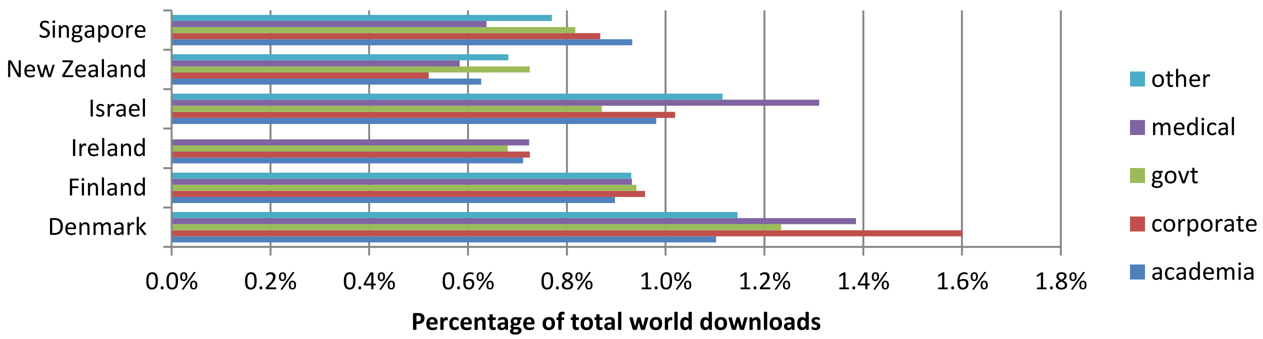
Figure 48. **Countries as consumers of downloaded publications (2008-12)**



Data: Elsevier SciVal

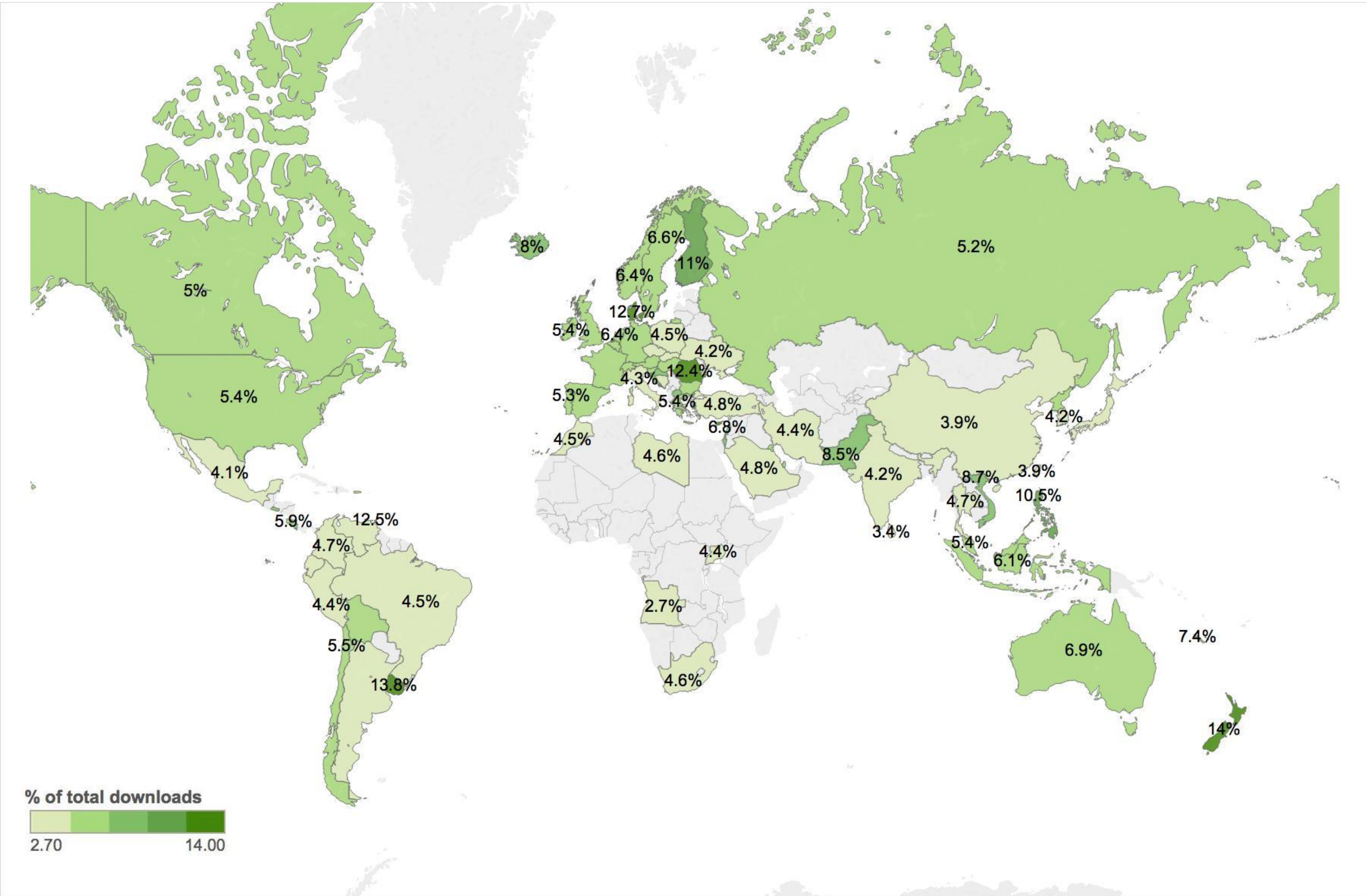
Countries as producers of research

Figure 49. **Countries as producers of downloaded publications (2008-12)**



Data: Elsevier SciVal

Figure 50. **SAEI country publications as percentage of foreign country downloads**



Data: Elsevier; SAEI

Tracking specialisations in the future

When assessed collectively, the metrics included in this annex provide a useful overview of system strengths and the efficacy of prioritisation attempts. Such exercises could be strengthened, however, with the inclusion of additional, and particularly more granular indicators of performance. Based on experience within the group, specific measures that may contribute to the accuracy and depth of analyses of prioritisation efforts include:

- **Better measures of research translation**. Such indicators would ideally give a sense of the extent to which research is being digested and used to create value - the ultimate metric of interest. Examples of measures that could be used include the number of references research publications receive in end-user material, such as patents and government policy documents. Information on the commercialisation of public research (e.g. through spinout companies and licensing) could also be useful in this regard.

- **Measures of dissemination**. Such indicators would be useful to gauge the penetration of research offshore and to provide a more detailed, granular picture of influence. Publication downloads are one such indicator that are useful in this area, however they capture only a narrow subset of users. Ideally, other indicators in this area would help to illustrate the diverse ways in which research may be accessed such as through corporate media, blogs, and government publications.

- **Measures of interdisciplinary research fields**. Given the broadness of journal disciplines, niche country strengths that may be sizable for small countries can often be lost when categorised into the traditional, high-level journal divisions. By looking at smaller, interdisciplinary categories and sub-categories of research, a more refined understanding of a country's performance could be ascertained. Analysis of competencies using co-citation analysis can be useful in this regard (see page 55), however such techniques at present cover only areas where countries are world leaders. A more complete analysis of sub-disciplines and multidisciplinary work, including those areas in which countries do not perform highly, would help to complete a system level picture and provide a useful counterfactual against which to compare areas of comparative strength (or weakness).

While the inclusion of these metrics would contribute additional depth and accuracy to analyses of system-level prioritisation efforts, it should be noted that a more sophisticated evaluation likely using econometric techniques would be required in order to effectively assess the impact of prioritisation attempts with confidence. Such an analysis would require a more complete set of information to control for appropriate factors such as salaries and economic conditions, though could paint a clearer picture of the relative contribution of different inputs (e.g. graduates, funding, infrastructure). Future work of the Initiative may wish to focus on such questions.