

## Allocation of R&D Equipment Expenditure Based on Organisation Discipline Profiles

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**Abstract:** *Sufficient and state-of-the-art research equipment is one component required to maintain the research competitiveness of a R&D organisation. This paper describes an approach to inform more optimal allocation of equipment expenditure levels in a large and diverse R&D organisation, such as CSIRO. CSIRO is Australia's national science agency, is comprised of individual research units and conducts R&D across many disciplines. CSIRO's research equipment expenditure allocations have been to some extent based on both previous years' expenditures and current operating performance. In an effort to refine this process, a method was developed to consider the difference in expenditure profiles across research areas and calculate a benchmark (or expected level) for research units within CSIRO. The approach also allowed CSIRO to compare its actual equipment expenditure levels to benchmark (or expected) levels derived from expenditure data from US academic institutions. This comparison found that CSIRO's overall level of expenditure was below the benchmark levels and assisted in guiding the allocation of available funds more fairly across research units with different equipment needs.*

*Several datasets were used for this analysis. R&D equipment expenditure patterns across disciplines are available for USA academic institutions and the differences in levels between disciplines was calculated. For example, in the Biological Sciences equipment expenditure is 3% of total R&D expenditure, whereas in Physics it is 3-fold greater. Using research publication subject classifications, discipline profiles were constructed for the entire CSIRO and each of its units. Publication subject categories were also mapped to the research fields used by the USA source. These datasets were combined to determine an overall benchmark value for CSIRO and each unit. The value varied by a factor of 2.2 fold across individual CSIRO units. Actual equipment expenditure for CSIRO was determined using internal finance records. This was compared to the benchmark levels and some units were below the calculated benchmark values and a few were close to or above.*

*The results of this study were considered by CSIRO managers when deciding equipment expenditure allocations and the implications of the findings for the organisation are discussed. Furthermore, it was found that there are very few studies on research equipment expenditure readily available and it is hoped that this study will encourage further discussion and research on this topic.*

Keywords: *Research and development expenditures, laboratory equipment, research equipment, benchmarking, organisation, management*

## **Problem Statement**

Methods to ensure capital resources are optimally allocated are of interest to Research and Development (R&D) organisations. In large organisations that are scientifically diverse, resource allocation is further complicated because there are differences in capital resource requirements between science areas. Allocation approaches used by institutions are often limited because they are largely retrospective and are based on current operating performance and/or what was allocated in previous years. In addition they do not examine trends in expenditure levels across different disciplines.

Funding, buildings, researchers and support staff, equipment, consumables and operating items are examples of R&D inputs and these inputs are suitable for benchmarking against other organisations. Research equipment expenditures are studied in this paper as they are more suited to benchmarking than some other inputs because similar items are purchased by research organisations worldwide and the equipment market is international (Georghiou, Halfpenny, and Flanagan 2001). In addition, laboratory equipment expenditure levels across different research areas are available for academic institutions in the USA from the National Science Board (2012, 2014). Examination of these data sets shows that expenditure levels differ between disciplines. For example, in the Biological Sciences equipment expenditure is 3% of total R&D expenditure, whereas in Physics it is 3-fold higher. Georghiou *et al* (2001) also highlights that different science areas will have different levels of infrastructure, including equipment, and labour for optimal outputs.

Georghiou and Halfpenny (1996) noted that despite equipment being a critical component to research progress, there is little information available on how to fund and manage it. We have also noted that there is very little information available on this topic. This study describes an approach to allow more optimal allocation of research equipment and is useful to large diverse organisations because it considers the equipment needs across different disciplines. It is based on benchmarking our organisation, CSIRO, against US academic institutions and is the foundation of the allocation process described and discussed.

## Observations

### *a) R&D Expenditure Levels*

R&D expenditure levels are considered to be indicative of innovative capacity because technological progress is dependent upon R&D effort. Expenditure levels are widely reported as a science and technology indicator and a common example is a country's gross domestic expenditures on R&D as a percentage of total gross domestic product. This is considered to be an indicator of a country's degree of R&D intensity and is often used as a summary statistic for international comparisons.

There are several types of input required for successful R&D outputs and outcomes and these include funding, buildings, researchers and support staff, equipment, consumables and operating items. The allocation of these resources at optimal levels, particularly capital resources, is obviously crucial to R&D organisations. The allocation process should ideally consider the needs of different organisational units and consider future requirements which may not necessarily reflect those of the past. The extent of change within the different units may also be dissimilar. Resource allocations should ideally anticipate these changes to some degree or at the very least reflect them as they occur.

Resource allocation in large diversified companies and R&D organisations is often based on current operating performance and/or allocations in previous years (Bower, 1986; Scholefield, 1994). Allocating resources for research equipment using these approaches is not optimal. Ideally, resources would be allocated based on the potential for creating value in the future rather than past or current needs. This, however, can be difficult to assess and requires a good understanding of both the relative potential for value creation across all application areas and the organisation's competitive position in each area, as well as anticipating future changes in requirements.

The study outlined in this paper describes an alternative approach to research equipment expenditure allocations. It describes a method that is applicable to diverse R&D organisations that span many disciplines and application areas. Levels of equipment expenditure in other organisations are also examined as they provide a competitive benchmark for comparison. Whilst the method does not consider the future potential for creating value and anticipating future needs, it does take into account differences in the types and equipment requirements across an organisation.

### *b) R&D Equipment Expenditures across Disciplines*

The availability of current and sufficient equipment is a key component to a successful R&D organisation. Current and state-of-the-art equipment is necessary to maintain competitiveness and to attract high calibre researchers into the organisation. The relative importance of R&D equipment as an input is highlighted in the recommendations for external peer review of research organisations. The National Research Council (2012) recommends that equipment and facilities be considered as part of an assessment of ongoing research, together with evaluating the technical projects and the quality of research staff and management.

Equipment is more suited to benchmarking than some other R&D inputs because similar items are purchased by research organisations worldwide and the equipment market is international (Georghiou, Halfpenny, and Flanagan 2001). Collins, Couper and Record (1990) examined research expenditure in UK institutions across three sectors – industry, research council institutes and higher education institutions. Four disciplines were studied – biochemistry/pharmacology, chemistry, electrical engineering and electronics, and plant sciences. Whilst R&D equipment was not specifically examined, expenditure per researcher on non-pay items, including equipment, was measured. Overheads were excluded from this category. In universities, expenditure on non-pay items was the same for the three science disciplines and 2.6-fold higher for electrical engineering and electronics. Industry non-pay item expenditure levels on biochemistry/pharmacology were 3.2 times greater than electrical engineering and electronics levels. This study highlighted that R&D expenditure on non-pay items, including equipment, is dependent on the field of research and the sector in which the research is being conducted. Other studies in the open literature on equipment management, including expenditures by research field, are scarce.

Comprehensive R&D equipment expenditure data by research field is readily available from the National Science Foundation (NSF), which conducts an annual survey of US academic institutions on R&D funding sources and expenditures. Aggregated results from this survey are summarised in the Science and Engineering Indicators (2012, 2014) and provides a high level analysis of equipment expenditure trends in the US. The data behind this analysis is publically available making it possible to analyse equipment expenditure as a proportion of total R&D expenditure by research field. This enables an organisation or country to apply its research profile according to research field and compare itself to expenditure levels in US academic institutions. This comparison was undertaken for our organisation, CSIRO, to provide a greater appreciation of its current equipment situation and needs.

### *c) CSIRO and its Research Equipment Funding Allocations*

CSIRO (Commonwealth Scientific and Industrial Research Organisation), is Australia's national science agency and is one of the world's largest and most diverse Research and Development (R&D) organisations. It employs approximately 5,300 people and has an annual budget of AUD1.2 billion. CSIRO conducts research in a wide range of disciplines within the following science and engineering areas – Energy; Environment; Manufacturing, Materials and Mining; Information Sciences; Food, Health and Life Sciences Industries. Its research results are used in a wide range of market sectors, including food and agribusiness, energy sector (solar, oil and gas), mining equipment technology and services, advanced manufacturing and medical devices, and materials. In 2012-13, CSIRO was broadly organised into 5 Groups and its constituent 12 Divisions are allocated to one of these.

CSIRO's annual capital budgeting process, which includes allocations for research equipment, is run centrally in two stages. Firstly a decision on the total amount for research equipment for the whole organisation is made; followed by decisions on the allocation for each Division. Decision-making is a collective process involving the heads of the 5 Groups and the corporate executive responsible for science strategy. The heads of the 5 Groups know their Divisions within their area

of responsibility but they have much less knowledge of Divisions in other Groups.

This capital budgeting process shares a number of features with resource allocation in large diversified companies, with similar tendencies to allocate resources based on current operating performance and/or allocations in previous years (Bower, 1986; Scholefield, 1994). As discussed above, allocating resources for research equipment based on this approach is not optimum.

## Evaluation and Analysis of Concept

### *a) Calculation of R&D Equipment Expenditure Benchmark Values by Research Field*

Table 1 shows the research equipment expenditures by research fields in US academic institutions over a five-year time period. These results were calculated from the National Science Foundation (NSF) survey described in the previous section, which provides aggregated data for R&D equipment expenditure and total R&D expenditure by research field. This allows the calculation of the proportion of expenditure on R&D equipment by research field, as well as an overall dollar value. Fields in the Physical Sciences have the highest level of equipment expenditure and overall it is 3-fold higher than equipment expenditure in the Life Sciences. Equipment expenditure levels are lowest in the Social Sciences.

*Table 1. Average Expenditures of Funds for Research Equipment at US Academic Institutions as Percentage of Total Academic R&D Expenditure by Field 2005-2009..*

NSF Fields of Science And Engineering	US Academic Institutions Research Equipment Expenditures as % of Total R&D Expenditure, 2005-09 (inclusive)
<b>All Fields</b>	<b>3.8</b>
<b>Computer Science</b>	<b>5.4</b>
<b>Environmental Science</b>	<b>4.8</b>
Atmospheric	6.0
Earth Sciences	4.3
Oceanography	5.6
Environ. Science NEC	2.7
<b>Life Sciences</b>	<b>2.6</b>
Agricultural Sciences	2.8
Biological Sciences	3.2
Medical Sciences (Including Vet. Med.)	2.2
Life Sciences NEC	3.4
<b>Mathematical Sciences</b>	<b>1.6</b>
<b>Physical Sciences</b>	<b>8.2</b>
Astronomy	5.2
Chemistry	8.1
Physics	8.9
Physical Sciences NEC	9.1
<b>Psychology</b>	<b>1.9</b>
<b>Social Sciences</b>	<b>1.0</b>
Economics	0.4
Political Science	0.4
Sociology	0.8
Social Sciences NEC	1.7
<b>Science NEC</b>	<b>7.6</b>
<b>Engineering</b>	<b>5.8</b>
Aeronautical/Astronomical	5.1
Bioengineering/Biomedical	5.2
Chemical	6.6
Civil	3.4
Electrical	5.5
Mechanical	7.0
Metallurgical/Materials	8.3
Engineering NEC	5.8

NEC = Not Elsewhere Classified

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Research and Development Expenditure Universities and Colleges: FY 2009.

Appendix table 5-6. R&D expenditures at academic institutions, by S&E field: Selected years, 1975–2009

Appendix table 5-14 Current expenditures for research equipment at academic institutions, by S&E field: Selected years, 1985–2009

The survey includes expenditure for indirect costs. The National Science Foundation describes research equipment as ‘movable items necessary for the conduct of organised research projects’. It is also noted that ‘generally, university equipment that cost less than \$5,000 would be classified under the cost category of ‘supplies’. However, private communication with the National Science Foundation indicates that institutions set their own thresholds and this may be as low as \$1,000 in some institutions. The overall value of equipment purchased below these thresholds is not known and it is therefore not possible to account for such equipment in this analysis. The survey results do not include data on research facilities and cyberinfrastructure as this information is collected in a separate mechanism, the Survey of Science and Engineering Research Facilities. In this survey, facilities are assessed by using metrics on research space, repairs and renovation; and cyberinfrastructure is assessed by networking, high-performance computing and data storage indicators.

### *b) CSIRO’s Research Profile*

CSIRO is a large multidisciplinary national science agency with total R&D expenditure of approximately AUD1.2 billion. During 2008-12, CSIRO produced 12,360 research publications that were captured in the Thomson-Reuters Web of Science (WoS) publication data base and the overwhelming majority of these (10,951, 89%) were journal articles. In addition, there were 751 conference proceedings papers and 657 reviews. The Web of Science database classifies research journals into approximately 250 subjects and the diversity of CSIRO’s research profile is evident by its publication profile according to Web of Science subjects. The two largest subjects for CSIRO are Environmental Sciences and Ecology, between them accounting for 14% of publications. Though slightly smaller in output, CSIRO also focuses heavily on the subjects Materials Science (Multidisciplinary), Plant Sciences and Astronomy & Astrophysics, each of which represent around 6% of CSIRO’s output. Overall, there are over 80 subjects in which CSIRO produced 40 or more publications during this 5-year period.

In 2013, CSIRO was comprised of 12 Divisions, each with a unique publication output profile. WoS subject area profiles have also been generated for each of these and Table 2 lists the largest subject areas for each Division. The multidisciplinary research profile of CSIRO is evident from this Table.

The next step in this study was to compare levels of equipment expenditure in CSIRO to levels in US academic institutions and to achieve this Web of Science subjects were mapped to the research fields used by the NSF. The resulting translation table is shown in the Appendix. A research profile for CSIRO and individual Divisions by research fields used by the NSF was then produced and the profile for CSIRO is shown in Figure 1. There are six fields each comprising more than 5% of CSIRO output. The largest is Biological Sciences, followed by Environmental Sciences, Earth Sciences, Chemistry, Physics and, lastly, Metallurgical and Materials Engineering.

*Table 2.* CSIRO Divisions and the Main Web of Science Subjects for their Research Publications produced between 2008-12.

CSIRO Division	Main Web of Sciences Research Publications Classifications
CSIRO Animal, Food and Health Sciences	Food Science & Technology Veterinary Sciences Biotechnology & Applied Microbiology Nutrition & Dietetics Agriculture, Dairy & Animal Science Genetics & Heredity Virology Microbiology
CSIRO Astronomy and Space Science	Astronomy & Astrophysics
CSIRO Earth Science and Resource Engineering	Geosciences, Multidisciplinary Geochemistry & Geophysics Energy & Fuels Engineering, Chemical Materials Science, Multidisciplinary
CSIRO Ecosystems Science	Ecology Environmental Sciences Entomology Zoology Forestry Biodiversity Conservation Agriculture, Multidisciplinary Plant Sciences
CSIRO Energy Technology	Environmental Studies Energy & Fuels Chemistry, Physical Engineering, Chemical Electrochemistry Materials Science, Multidisciplinary
CSIRO Information and Communication Technology	Engineering, Electrical & Electronic Telecommunications Computer Science, Information Systems Computer Science, Theory & Methods Computer Science, Artificial Intelligence
CSIRO Land and Water	Environmental Sciences Water Resources Geosciences, Multidisciplinary Soil Science Engineering, Environmental Engineering, Civil Agronomy
CSIRO Marine and Atmospheric Research	Oceanography Marine & Freshwater Biology Meteorology & Atmospheric Sciences Fisheries Environmental Sciences Ecology
CSIRO Materials Science and Engineering	Geosciences, Multidisciplinary Materials Science, Multidisciplinary Physics, Applied Chemistry, Physical Chemistry, Multidisciplinary Polymer Science Nanoscience & Nanotechnology Physics, Condensed Matter Biochemistry & Molecular Biology
CSIRO Mathematical and Information Sciences	Statistics & Probability Engineering, Chemical Mathematics, Interdisciplinary Applications
CSIRO Plant Industry	Plant Sciences Agronomy Genetics & Heredity Agriculture, Multidisciplinary Horticulture Biochemistry & Molecular Biology
CSIRO Process Science and Engineering	Biotechnology & Applied Microbiology Metallurgy & Metallurgical Engineering Materials Science, Multidisciplinary Engineering, Chemical Mineralogy Mining & Mineral Processing



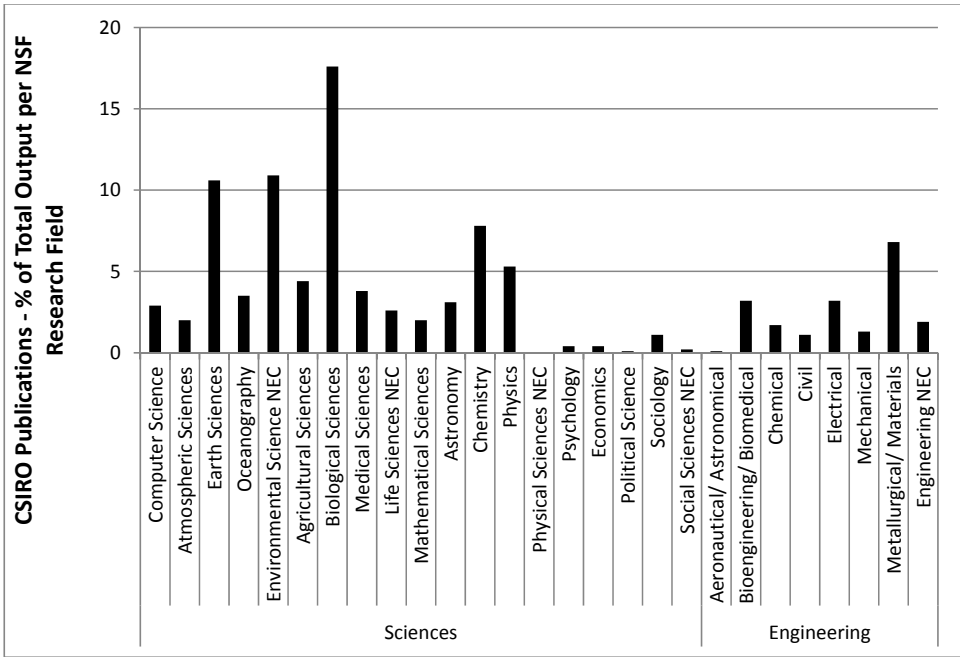


Figure 1. CSIRO Publication Output by National Science Foundation Science and Engineering Fields, 2008-12.

c) CSIRO’s R&D Equipment Expenditure and Comparison to US Academic Institutions

The following steps were taken to calculate benchmark values for CSIRO and its Divisions and are summarised in Figure 2. The research profile for each entity based on research publications was determined as described in section 3 above. The benchmark equipment expenditure percentages for each contributing research field (see Table 1) was then multiplied by the percentage of publications in the research field and expressed as a percentage. These values were then totalled to provide an overall benchmark value for CSIRO and each Divisions and this was then compared to the actual expenditure as a percentage of total R&D expenditure calculated (Table 3). CSIRO’s average actual expenditure for a four-year period was also calculated from internal finance records.

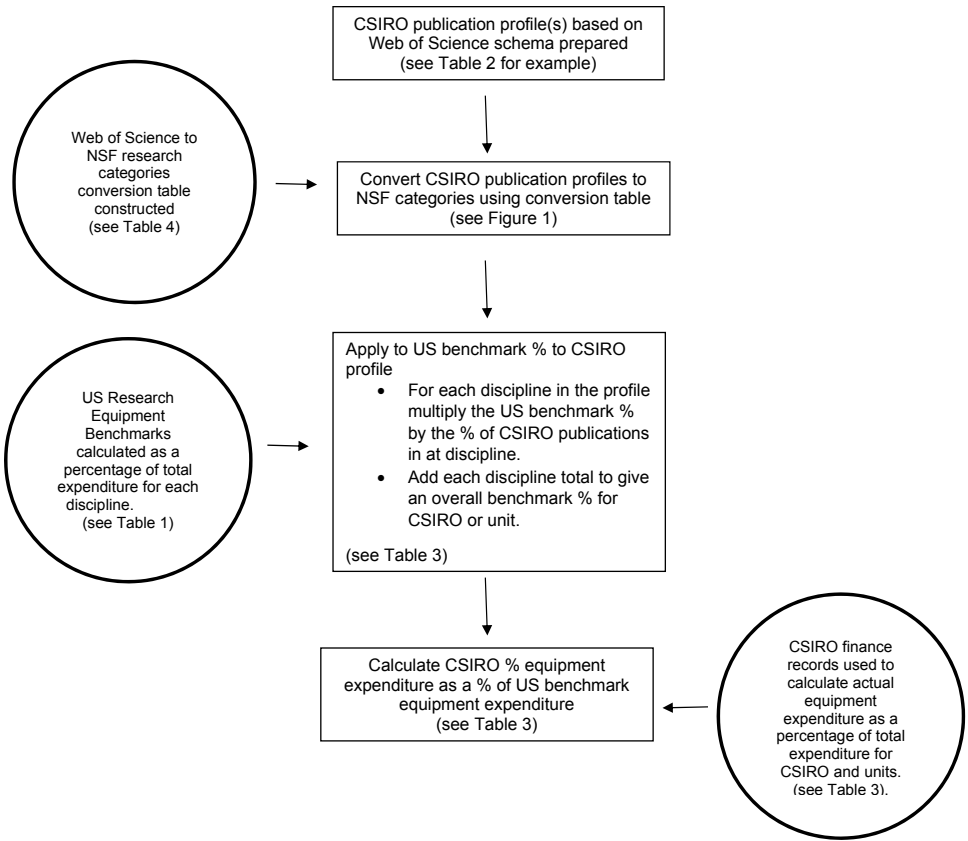


Figure 2. Flow Diagram of Benchmark and Actual Equipment Expenditures.  
NSF = National Science Foundation

CSIRO defines its assets as items over AUD3,000 (approximately USD2,250) with an enduring value in use. They are categorised into several classes including Land, Buildings, Vehicles, Office, Scientific and IT. Only items in the Scientific category were included in this study. The AUD3,000 threshold value is relatively high in the Australian public sector, however, it has been nominally constant for at least the last 15 years and therefore has decreased in real terms. These values do not include major research facilities such as the Australian Square Kilometre Array Pathfinder, although some smaller items associated with this may be included in R&D equipment expenditure. CSIRO also includes overheads as part of its overall R&D expenditure, as does the NSF.

In 2012-13 financial year, CSIRO’s total R&D expenditure was AUD1.16 billion. At the whole-of-organisation level, actual R&D equipment expenditure was one-third lower than the calculated benchmark value. Whilst this was recognised as a serious issue, overall budget constraints did not allow the organisation to meet the benchmark expenditure level. One Division is above the

benchmark value and another is close to the value. Of the remaining Divisions, all were 85% or lower, with 3 Divisions being less than half of its benchmark level.

*Table 3. CSIRO and its Divisions - Total R&D Expenditure, Equipment Benchmark Percentage and Actual Equipment Expenditure Percentage.*

CSIRO Unit	FY 2012-13 Total R&D Expenditure (AUD millions)	4-year average (2010 to 2013, inclusive)		CSIRO Expenditure as a % of Benchmark Expenditure
		Equipment Benchmark (% of expenditure)	Equipment Actual (% of expenditure)	
Whole of organisation	1162.5	4.8	3.4	67
Animal, Food and Health Sciences	154	3.6	2.6	72
Astronomy and Space Science	41	5.3	4.5	85
Earth Science and Resource Engineering	94	5.6	3.2	57
Ecosystems Science	115	3.3	1.5	46
Energy Technology	48.5	7	8.3	119
Information and Communication Technology	71	5.3	1.5	28
Land and Water	94	3.8	2.2	58
Marine and Atmospheric Research	127	4.4	2.8	64
Materials Science and Engineering	173	7.3	4.9	67
Mathematical and Information Sciences	47	4.3	0.8	19
Plant Industry	125	3.5	3.3	94
Process Science and Engineering	73	6.8	3.8	56

#### *d) Equipment Expenditure Trends in US Academic Institutions*

The benchmark data source for this study is from the NSF which collects data from US academic institutions. It was chosen because it is readily available and covers many institutions over a long time period. Data is also classified on a research field basis and no other data set as complete as this has been identified. This is the main reason why this dataset was chosen for this study. The US data set is comprehensive, covers a wide range of academic institutions and it is generally considered that US R&D is of good quality globally. In addition, the survey is updated every second year and this allows for ongoing evaluation.

The proportion of total R&D equipment expenditure in US academic institutions has declined from 4.1% in 2005 to 3.2% in 2012, whereas actual total expenditure has increased (Figure 3). The Science and Technology Indicators (2014) indicate that FY 2012 equipment expenditure 'fell to the lowest levels measured in constant dollars since FY 2001'. There is no information available to indicate whether or not these levels of equipment expenditure are adequate but it is likely that they are not in some US institutions, especially given the drastic downturn in the US economy following the Global Financial Crisis. Witonsky (2011) noted in a report covering all types of US laboratories, including academic, hospital and biotechnology laboratories, that the economic downturn had greater impact on equipment budgets than any other laboratory expenditure category. In addition, there may have been other external factors contributing to this decline.

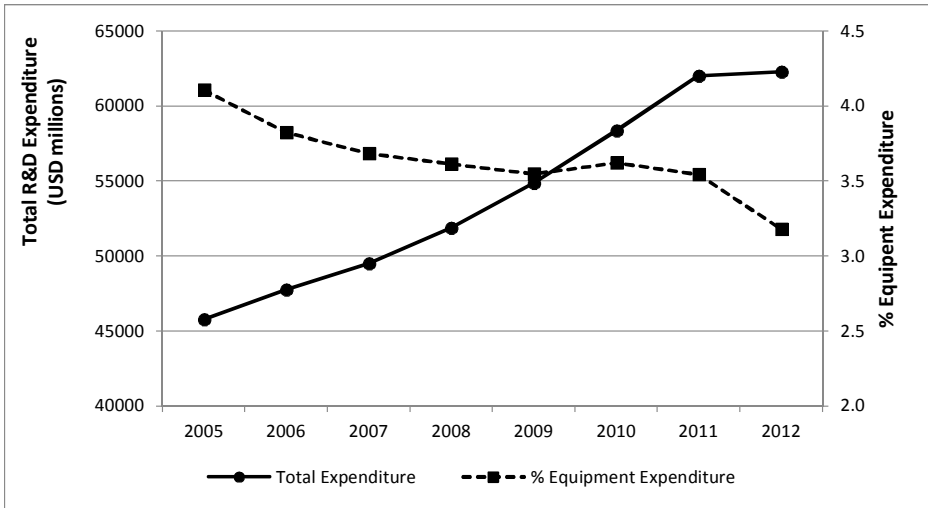


Figure 3. Trends in R&D Equipment and Total Expenditures in US Academic Institutions, 2005-12. DATA SOURCE: Science and Technology Indicators, National Science Board, 2014.

## Reflect and Recommend Solutions

This paper explores a new approach to inform the allocation of R&D equipment expenditures and outlines the implications of the findings to our organisation, CSIRO. The method could also be applied to other large multidisciplinary organisations because it considers the variation in equipment needs across a range of disciplines.

There were several implications of this study to CSIRO. The study confirmed the anecdotal evidence that the organisation was spending less on its R&D equipment than the benchmark figure suggested to be optimal and provided an approximate quantification on the extent of this gap. It was not, however, possible to allocate additional funds to make up this short fall. The study also highlighted to the organisation the differences in capital intensity of different research fields and how this applied to the organisation. The process provided a clear and easily understood basis for allocations for R&D equipment. Consequently, the initial notional allocations, resulting from simply applying the 'algorithm' to each Division, were perceived as a fair and equitable starting point for making final allocations. Discussion among the decision-makers was then restricted to whether there were any exceptional circumstances that would warrant changing the allocations at the Group level. Generally there were not; the allocations at the Group level were accepted and then small adjustments were made within each Group to take account of the circumstances of each Division in that particular year, for example, the need to purchase an unusually expensive piece of equipment. More recently, the method has assisted managers to understand the equipment needs across the organisation following a significant restructure and continues to guide discussions on allocations.

The study used an organisational research profile based on the Web of Science publication classification but it could readily be replaced with other publication classification schemes or other parameters, such as financial or human resources data, provided it was allocated on a field of research basis. Not only was the approach applicable to an entire organisation, but it was possible to examine smaller parts of the organisation in more detail.

Whilst benchmarking CSIRO would ideally involve gathering data from peer national research agencies, this was not attempted. The benchmark data source for this study is from the NSF which collects data from US academic institutions. It was chosen because it is readily available and covers many institutions over a long time period. Data is also classified on a research field basis and no other data set as complete as this has been identified. This is the main reason why this dataset was chosen for this study. The US data set is comprehensive, covers a wide range of academic institutions and it is generally considered that US R&D is of good quality globally. In addition, the survey is updated every second year and this allows for ongoing evaluation. The Main Science and Technology Indicators (2014) from the OECD provides data on two capital expenditure categories – ‘land and buildings’ and ‘instruments and equipment’ – by research sector for its member countries. This was also examined but not used because information on expenditure per research field is only provided for the combined capital expenditure categories and, therefore, is not at the required level of detail for the purposes of this study. Ideally it would be more optimal for CSIRO to benchmark against other government R&D organisations but this information is not available. In addition, CSIRO does have a reasonably high level of publication output and it is generally considered within the organisation that the publication research profile is a sound representation of its overall research profile.

It is important to note the approach described in this study should be used to provide guidance rather than absolute answers because of some limitations as outlined below.

1. The method uses a research publication output to define the research profile of the organisation. This would not be applicable to an organisation whose publication profile does not reasonably reflect its research areas. If this is the case, financial or human resources data would be a better choice. This could include private R&D companies or applied R&D organisations that do not publish to the same extent as academic organisations.
2. It is likely that the levels of R&D equipment in US academic institutions are probably not optimal, especially in recent years, due economic conditions. This should be kept in mind if an organisation is using this approach to determine optimal R&D equipment expenditure levels.
3. The definition of ‘R&D equipment’ varies between organisations as well as within different parts of an organisation and it is not possible to readily account for this variation. At the lower end of the monetary scale, the threshold cost values of equipment and supplies varies between organisations. CSIRO classed equipment in this study as equipment assets valued at AUD3,000 (approximately USD2,250) and above. This was slight different to the US equipment data as this was collected from multiple institutions and the threshold varied from USD1,000 to 5,000. Both sources did not include major

research infrastructure. Geoghiou (2001) also highlights that there are ‘methodological, conceptual and practical challenges involved in any attempt to systematically benchmark research equipment.’

4. The National Science Foundation data provides a level of R&D equipment expenditure for academic institutions. It is likely that this level would also apply to organisations for which producing new knowledge is important. This level, however, may not be appropriate for other types of institutions such as industrial ones.

A survey of UK universities (Georghiou and Halfpenny, 1996) showed in 1994/95 they spent 13% of their research income on research equipment. This is higher than levels reported in US academic institutions and there are likely to be differences in survey methodologies, as well as different funding and reporting approaches. The higher UK level does not appear to be due to adequate or more equipment being available in UK universities because 79% of UK university departments indicated that they were unable to perform critical experiments due to inadequate equipment. It was also found that 38% of researchers surveyed indicated that their equipment was older than their international peers and it had a higher cost for repairs and maintenance. In addition, it was found that the research equipment required to remain competitive is becoming more expensive. Values of these increased costs were provided as follows:

1. Replacement of equipment with equivalent functionality averaged 1.37 times the original cost of current equipment.
2. The cost of new equipment with a level of functionality similar to the current state of the field as the original item was when it was purchased averaged 1.56 times the original cost.
3. Replacement with state-of-the-art equipment averaged 2.67 times the original cost.

Whilst this report was produced some time ago and it is likely that the actual increases reported may have changed; it highlights that for an organisation to maintain its relative competitiveness it needs allow additional funds to replace out-of-date equipment.

Our study does not consider the age and condition current R&D equipment and an understanding of this in CSIRO would require further investigation. If, however, an organisation is not sufficiently spending on its R&D equipment, it is very likely that it is not replacing equipment as it ages. It is therefore likely to have a significant amount of out of date equipment, as well as equipment requiring repair, in its laboratories.

R&D equipment undoubtedly has a key role in producing research outputs. Whether or not the equipment is being used optimally in terms of output is difficult to assess between types of institutions and different research fields. A broad assumption would be that academic institutions aim to produce more publications in research journals whereas industrial institutions would produce more intellectual property. There are also differences in publication and intellectual property output levels between research fields. CSIRO researchers in the environmental and space sciences produce relatively high levels of publications and low levels of patents, whereas its researchers in engineering fields tended to have higher patenting rates and biotechnology-related CSIRO researchers produced reasonable amounts of both publications and patents. To determine benchmark levels of output relative to equipment expenditure would therefore need to

take into account the research field and whether or not the institute has an industry or academic focus. Georghiou, Halfpenny, and Flanagan (2001) also highlights that different areas of science will have different levels of infrastructure, including equipment, and labour for optimal outputs.

## Conclusions

This study describes an alternative approach to inform the more optimal allocation of R&D equipment resources because it considers the variation in equipment needs across different disciplines. The approach would be useful to large diverse organisations, such as CSIRO, that span many disciplines and application areas. Levels of equipment expenditure in other organisations are also examined because it provides a competitive benchmark for comparison.

The study provided CSIRO an assessment of the level of equipment expenditure at the organisational level compared to other institutions. It also identified units within CSIRO with the lowest levels of equipment expenditure. This information is useful in both strategic and operational contexts.

This work could be further expanded by investigating the age and condition of current equipment and quantifying this at the organisational level, as well as further understanding optimal levels of equipment in relation to research outputs, such as intellectual property and publications. It would also be more relevant to benchmark CSIRO against national research agency peers rather than academic institutions. The study also noted how little information on R&D equipment management and expenditure is available in the literature and it is hope that this work will stimulate further discussion on the topic.

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**Appendix:**

Table 4.

*Translation of Web of Science Subjects to NSF Science and Engineering Fields.*

<b>NSF Fields of Science And Engineering</b>	<b>Web of Science Subjects</b>
<b>Computer Science</b>	Computer Science Artificial Intelligence, Computer Science Cybernetics, Computer Science Hardware Architecture, Computer Science Information Systems, Computer Science Interdisciplinary Applications, Computer Science Software Engineering, Computer Science Theory Methods
<b>Environmental Science</b>	
Atmospheric	Meteorology Atmospheric Sciences
Earth Sciences	Engineering Geological, Geochemistry Geophysics, Geography, Geography Physical, Geology, Geosciences Multidisciplinary, Limnology, Mineralogy, Paleontology, Soil Science, Water Resources
Environ. Science NEC	Ecology, Environmental Sciences, Remote Sensing
<b>Life Sciences</b>	
Agricultural Sciences	Agriculture Multidisciplinary, Agriculture Dairy Animal Science, Agronomy, Food Science Technology, Horticulture
Biological Sciences	Anatomy Morphology, Biochemical Research Methods, Biochemistry Molecular Biology, Biology, Biology, Biotechnology Applied Microbiology, Cell Biology, Developmental Biology, Entomology, Evolutionary Biology, Forestry, Genetics Heredity, Parasitology, Physiology, Plant Sciences, Marine Freshwater Fisheries, Microbiology, Microscopy, Mycology, Neuroimaging, Reproductive Biology, Ornithology, Veterinary Sciences, Virology, Zoology
Medical Sciences, including Vet. Med.	Allergy, Andrology, Anesthesiology, Audiology Speech Language Pathology, Cardiac Cardiovascular Systems, Chemistry Medicinal, Clinical Neurology, Critical Care Medicine, Dentistry Oral Surgery Medicine, Dermatology, Emergency Medicine, Endocrinology Metabolism, Gastroenterology Hepatology, Geriatrics Gerontology, Gerontology, Health Care Sciences Services, Hematology, Immunology, Infectious Diseases, Integrative Complementary Medicine, Medical Informatics, Medical Laboratory Technology, Medicine General Internal, Medicine Research Experimental, Neurosciences, Nursing, Nutrition Dietetics, Obstetrics Gynecology, Oncology, Ophthalmology, Otorhinolaryngology, Pathology, Pediatrics, Peripheral Vascular Disease, Pharmacology Pharmacy, Primary Health Care, Public Environmental Occupational Health, Radiology Nuclear Medicine Medical Imaging, Rehabilitation, Respiratory System, Rheumatology, Sport Sciences, Surgery, Toxicology, Transplantation, Tropical Medicine, Urology Nephrology
Life Sciences NEC	Biodiversity Conservation
<b>Mathematical Sciences</b>	Mathematical Computational Biology, Mathematics, Mathematics Applied, Mathematics Interdisciplinary Applications, Statistics Probability
<b>Physical Sciences</b>	
Astronomy	Astronomy Astrophysics
Chemistry	Chemistry Analytical, Chemistry Applied, Chemistry Inorganic Nuclear, Chemistry Multidisciplinary, Chemistry Organic, Chemistry Physical, Crystallography, Electrochemistry, Polymer Science
Physical Sciences NEC	Biophysics, Nanoscience Nanotechnology
Psychology	Behavioral Sciences, Psychiatry, Psychology Applied, Psychology Biological, Psychology Clinical, Psychology Developmental, Psychology Experimental, Psychology Mathematical, Psychology Multidisciplinary, Psychology Social
<b>Social Sciences</b>	
Economics	Agricultural Economics Policy, Business, Business Finance, Economics
Political Science	History, History Philosophy Of Science, International Relations, Political Science
Sociology	Agricultural Economics Policy, Business, Business Finance, Economics, Ergonomics, Ethics, Family Studies, Law, Philosophy, Public Administration, Social Issues, Social Sciences Biomedical, Social Sciences Interdisciplinary, Social Sciences Mathematical Methods, Social Work, Sociology, Substance Abuse
Social Sciences NEC	Anthropology, Archaeology, Architecture, Art, Communication, Education Educational Research, Education Scientific Disciplines, Environmental Studies, Health Policy Services, Hospitality Leisure Sport Tourism, Humanities Multidisciplinary, Information Science Library Science, Language Linguistics, Linguistics, Literature British Isles, Transportation
Science NEC	Imaging Science Photographic Technology, Multidisciplinary Sciences
<b>Engineering</b>	
Aeronautical/ Astronomical	Engineering Aerospace
Bioengineering/ Biomedical	Cell Tissue Engineering, Engineering Biomedical, Materials Science Biomaterials
Chemical	Engineering Chemical
Civil	Engineering Civil
Electrical	Engineering Electrical Electronic, Telecommunications
Mechanical	Automation Control Systems, Engineering Mechanical, Mechanics, Robotics
Metallurgical/ Materials	Materials Science Ceramics, Materials Science Characterization, Testing, Materials Science Coatings Films, Materials Science Composites, Materials Science Multidisciplinary, Materials Science Paper Wood, Materials Science Textiles, Metallurgy Metallurgical Engineering, Mining Mineral Processing
Engineering NEC	Agricultural Engineering, Energy Fuels, Engineering Environmental, Engineering Industrial, Engineering Manufacturing, Engineering Marine, Engineering Multidisciplinary, Engineering Petroleum, Instruments Instrumentation

NEC = Not Elsewhere Classified