Analysis of Australian business and research specialisation in antimicrobial resistance technology

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1. Introduction

Rising rates of antimicrobial resistance (AMR) is one of the major threats to the delivery of effective healthcare worldwide (Stewart et al., 2019, Naughtin et al., 2022). Over 700,000 deaths annually are due to antibiotic-resistant micro-organisms (OECD, 2016). Technology to manage AMR, and its associated risks, is rapidly evolving in Australia and internationally. AMR is also actively growing as a research domain with just under 1 million scholarly works published on AMR-related topics between 1950 and 2021 (see Figure 1). Over the past decade (2012-2021) the number of publications annually exceeded 45,000 (LENS, 2022). The growth is expected to continue despite a short-term COVID-related decline in 2021.

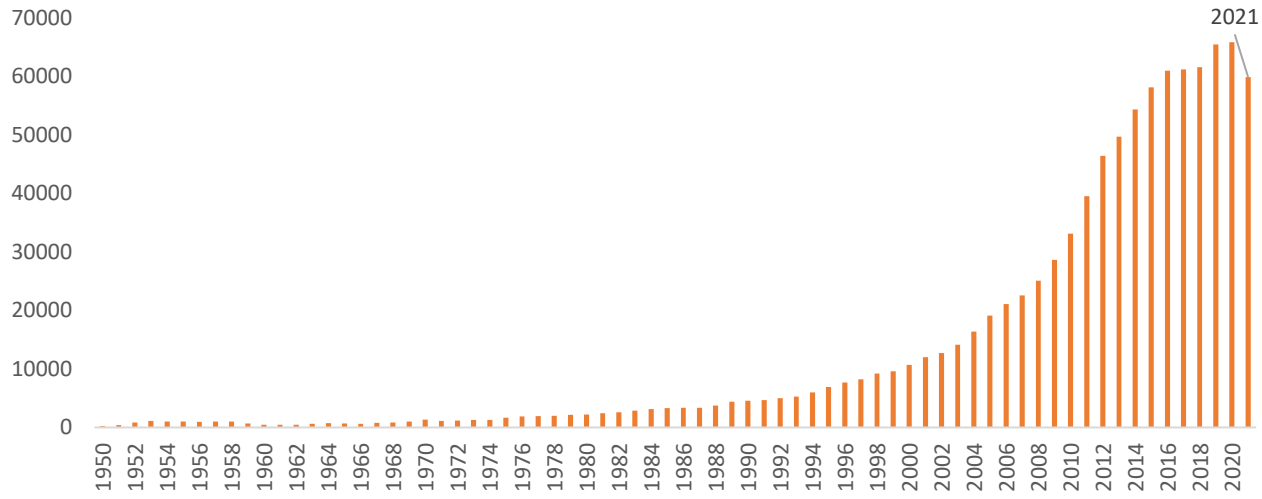

Figure 1 Count of AMR-related publications globally between 1950 and 2021.

Data source: LENS (LENS, 2022)

The following section, determines how Australia is positioned in the AMR-domain, compared with its international peers, when accounted for scientific, business and patent activity in the domain. The section aims to identify global leaders in the field and focuses on potential Australian competitive advantage. To do this, an analysis of AMR-related publications and patents was undertaken using revealed technology advantage (RTA) index

and bibliometric analysis. Revealed technology advantage index is well-regarded and broadly used by researchers and international organisations as it provides an indication of the relative advantage and specialisation of a given region in certain technology domain(s) (Bratanova et al., 2022, Dernis et al., 2019, OECD, 2021). Bibliometric analysis in this research complemented the RTA analysis and explored the key themes in AMR research and their interplay with respect to the technologies of interest (see Appendix for detail on the methodology and the datasets).

The data was collected through database searches of publications and patents (LENS) (LENS, 2022) and of businesses (Crunchbase) (Crunchbase, 2022) to describe how Australia and it's institutes and/or companies are positioned with respect to:

(a) the numbers of scholarly publications and patents,

(b) the dynamics of scholarly publications and patents, and

(c) business activity.

2. AMR publications and patent dynamics over time and across geographies since 1950

Scholarly publications in AMR domain

AMR research in Australia and overseas has expanded over the past three decades at a substantially faster rate than the average across all research domains, globally. Between 1991 and 2021 the number of publications across all fields of research globally increased by almost 5-fold, while AMR-related research increased by around 13-fold. In Australia the number of AMR-related publications in 2018 was 42-times the level of 1991. The growth slowed down between 2019 and 2021 (

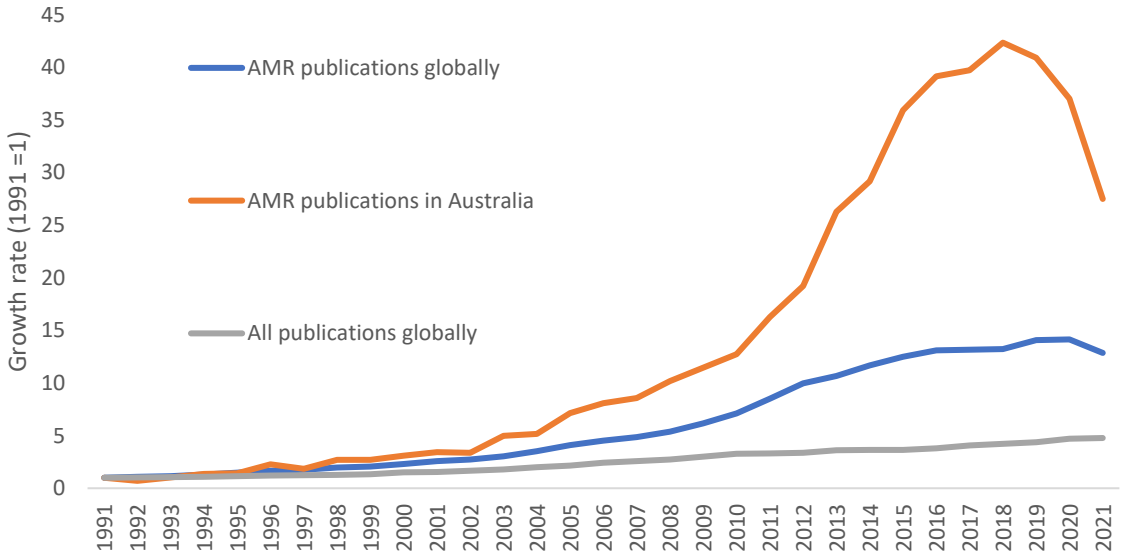

Figure 2) with the largest decline in the number of AMR publications observed in 2021. The 2021 decline was likely associated with the impact of the pandemic including the reallocation of research fundings towards the research projects directly focused on COVID-19, disruption of clinical research, lockdowns affecting work of scientists and clinicians, and

an overall decline in academic and venture funding that reportedly affected multiple fields of research in Australia and internationally (Walker et al., 2021, Ravenscroft and Gardiner, 2020, Squazzoni et al., 2021). The 2021 decline in the number of publications is therefore expected to be temporal, rather than indicating a reverse of the growth trajectory.

More detailed analysis of Australian data on LENS (LENS, 2022) demonstrated that between 1950 and 2021, Australian authors published 24,543 scholarly works in a form of journal articles, books, book chapters or conference papers that related to AMR. This is equivalent to 1.4% of all the scholarly publications over that period (1,770,121). In the past 5 years (July 2017- June 2022) the proportion of AMR-related research in Australia increased to 2.1%, promoting Australia to rank 7th in the world based on total number of AMR publications while ranking 9th in the world by the total count of published scholarly works across all research domains.

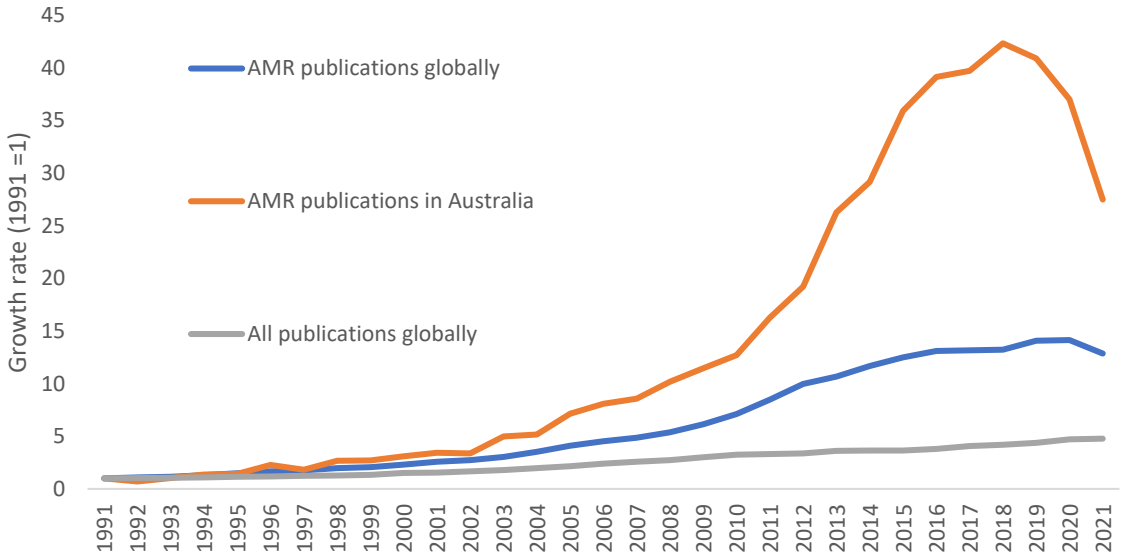

Figure 2 AMR publications growth rate globally and in Australia compared with the growth of scholar publications overall.

Data source: LENS (LENS, 2022)

Worldwide, top five organisations that were the most productive in AMR-related publications over the past three decades included Harvard University, National Institutes of Health, Boston Children's Hospital, Spanish National Research Council and University of London. Two Australian institutes were among the top 50 institutes globally by AMR publications, with lead organisations in this field being the University of Queensland (global rank 23), followed by the University of Melbourne (global rank 47). Other leading Australian institutions are presented in Figure 3.

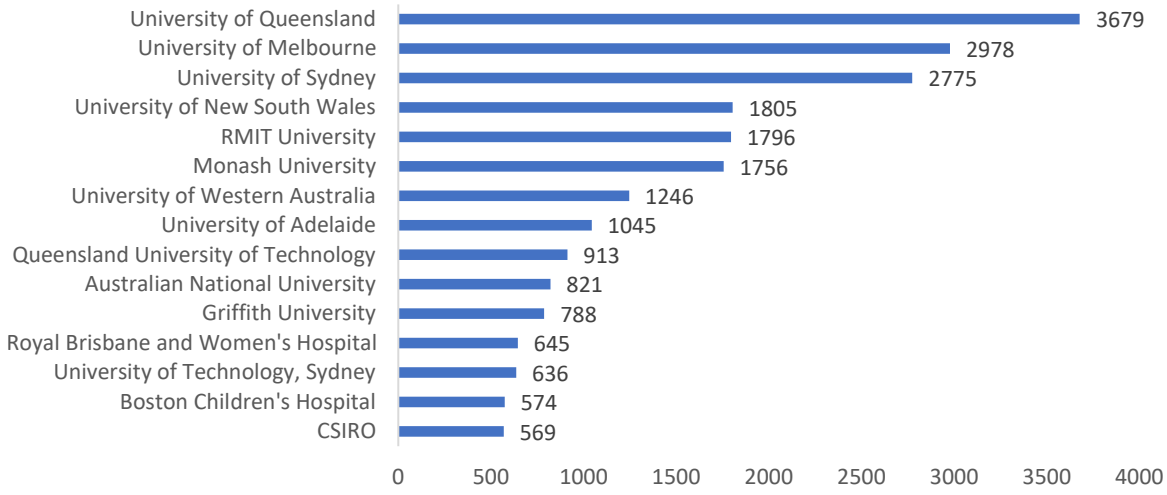

Figure 3 Top 15 Australian institutes by the number of AMR scholarly publications in 1991-2021

Data source: LENS (LENS, 2022)

Patent documents in AMR domain

A search on LENS for AMR-related patents returned almost 1.4 million patent documents globally between 1991 and 2021, with Australia among the global top ten jurisdictions based on total patent document count over this period (Figure 4).

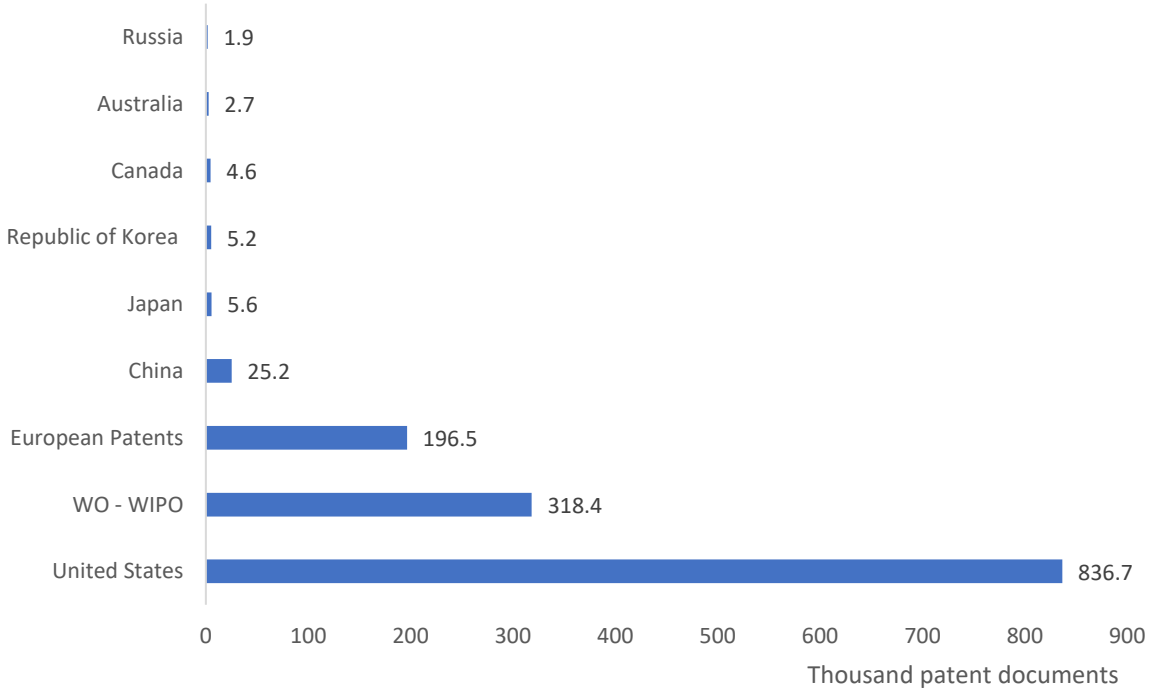

Figure 4 Top ten jurisdictions by the patent document count over 1991-2021

Source: LENS

Figure 5 Top 20 AMR patent applicants (left box) and owners (right box) globally over 1991-2021.

Source: LENS

The major applicants and owners of patents related to AMR were commercial organisations including transnational corporations. The list of top 20 included cross-sector technology corporations such as Procter&Gamble, DuPont, Pioneer and also included large medtech and pharmaceutical players such as Pfizer, Roche, Bristol Myers Squibb, Novartis, Merck among others (Figure 5). One chemical company (BASF) was among the top patent applicants and owners along with one agrochemical company (Monsanto Technology) as a patent owner.

Figure 6 Top 20 AMR patent applicants (left box) and owners (r
2022 (01.07.2017-30.06.2022)

Source: LENS

Over the past five years to July 2022, a new set of leading companies formed amongst the patent applicants and owners relating to AMR. Some of these were companies increased their patent activity during the pandemic, including Ecolab, Johnson& Johnson's subsidiaries Ethicon and Janssen, others were newer players such as Syngenta, Immatics and Regeneron (Figure 6).

Within the Australian patenting jurisdiction there were a total of 910 AMR-related patent records identified over the past 5 years. The lists of top ten patent applicants or owners were dominated by AMR-specific companies (e.g., Ares Genetics, Contrafect, Melinta Therapeutics, Green Impact Holding, Technophage, Iasis Molecular Sciences) with fewer representation of global tech companies (Table 1). There was one Australian medtech company among the top 10 AMR-patent holders in Australia – Next Science.

Table 1 Top ten patent applicants and patent owning companies in Australia in the AMR domain over 2017-2022

Company	Patent document count	Short description of services	Headquarter
Top patent applicants			
Becton Dickinson	23	Medtech multinational company	USA
Ecolab (Usa	15	Biotech (water, hygiene and infection prevention solutions)	USA
Ares Genetics	11	Medtech (infectious disease services and solutions)	Austria
Contrafect	9	Biotech (biologic therapies for drug-resistant infectious diseases)	USA
Melinta Therapeutics	8	Biopharmaceutics (design and development of novel broad-spectrum antibiotics)	USA
Green Impact Holding	7	microbiology (development of textiles and other materials with self-disinfecting properties)	Switzerland
BD Kiestra	6	Medtech (laboratory automation solutions)	Netherlands
Top patent owners			
Elanco New Zealand	5	Agtech (animal food solutions)	New Zealand
Unilever Global IP	5	Consumer goods company	UK
Janssen Pharmaceuticals	4	Biopharmaceutics	Belgium
Technophage Investigacao	4	Biopharmaceutics (biological and chemical products for infection, neurosciences and ophthalmology)	Portugal
Viotika Life Sciences	4	Biotech (AMR solutions)	Canada
X4 Pharmaceuticals	4	Biopharmaceutics (solutions in diseases of the immune system and biology)	Austria
Eleszto Genetics / Eleszto Genetika	3	Biotech (genetic modification solutions)	Hungary

Iasis Molecular Sciences	3	Medtech (preventative and eco-conscious antimicrobial solutions)	USA
Next Science Ip Holdings Pty LTD	3	Medtech (healthcare technologies to curb AMR)	Australia

3. Revealed technology advantage analysis

Revealed technology advantage analysis is widely used in economic research to measure and monitor the relative performance of economies in innovation, technology development and adoption and specifically technology specialisations of countries and regions (OECD, 2021). The RTA index is defined as the share of a region's publications in a particular technology field relative to other regions and other technologies [4]. The values ranging between zero and one indicate that the region holds no specialisation in the selected technology domain, while index values greater than 1 indicate a relative specialisation compared with other regions and other technologies.

Based on the RTA for scholarly publications in AMR domain between 2000 and 2021, Australia ranked 11th on the global scale, while Switzerland, Denmark and South Africa were the leading nations (see Figure 7).

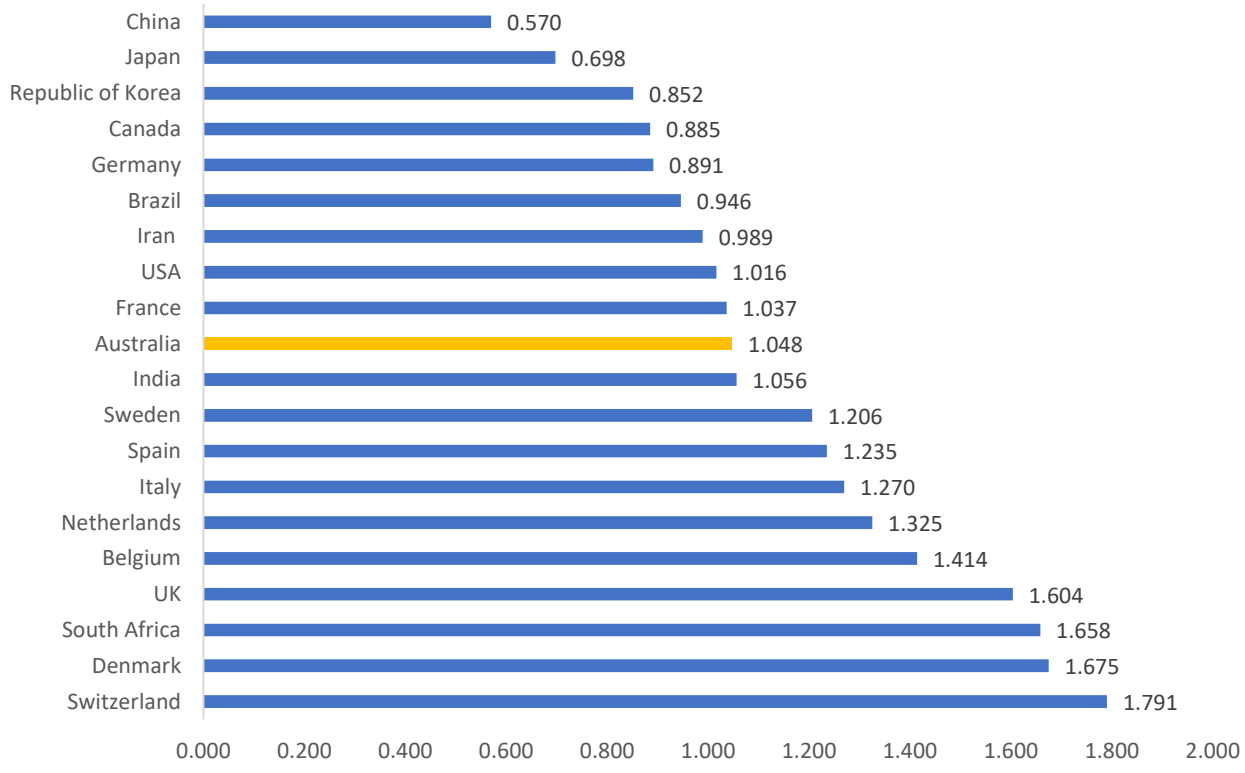

Figure 7 Revealed technology advantage index over 2000-2021 based on scholarly publications for the leading 20 nations

Data source: LENS (LENS, 2022)

Analysis of RTA index dynamics demonstrates that the RTA index for Australian AMR-related research has been around the mark of one and mainly on a growth path since 2000 (see Figure 8). It indicated that Australia has grown a specialisation in AMR research more recently.

Germany and the USA had similar RTA index dynamics to Australia, although the index fell below one during the last decade for both countries. Interestingly, the UK and Switzerland which were once leaders in specialisation of AMR research showed to have the sharpest decline in RTA index after 2018, most likely accelerated due to re-directing of research efforts to COVID-19.

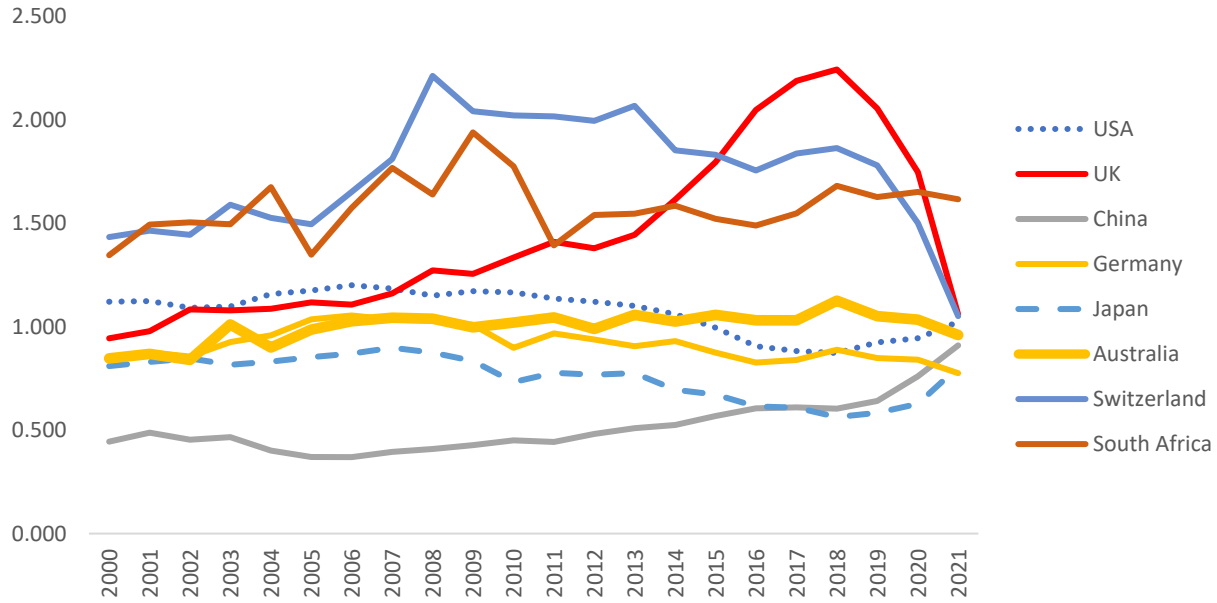

Figure 8 The dynamics of revealed technology advantage index for selected countries.

Data source: LENS (LENS, 2022)

RTA analysis of AMR-related patent applications shows that over the past two decades Australia was among the top 10 jurisdictions (see Figure 9). However, with an RTA index of less than one, no AMR specialisation with respect to patents is distinguishable for Australia[1].

[1] It is important to note that some Australian companies are likely applying for patents in different jurisdictions including to the World Intellectual Property Organization (WIPO).

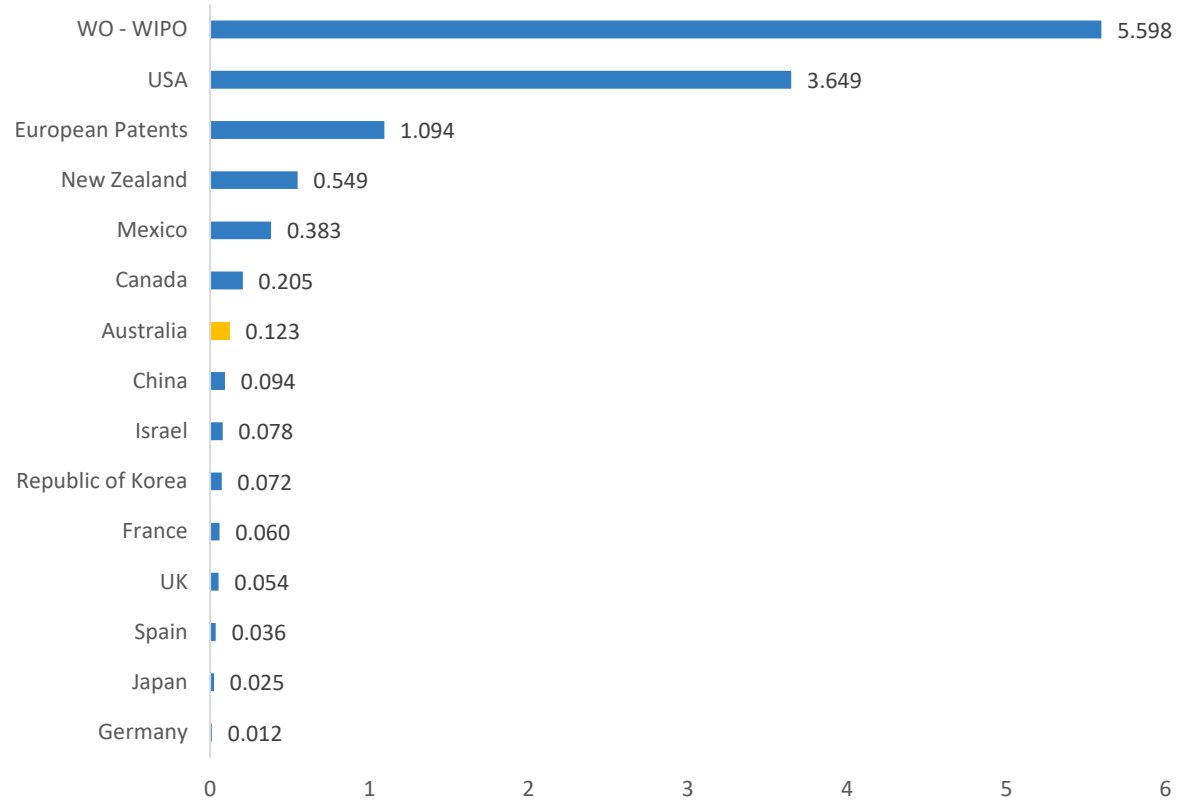

Figure 9 Revealed technology advantage index for AMR-related patent applications over 2000-2021 for the leading 15 patent jurisdictions.

Data source: LENS (LENS, 2022)

Note: "WO – WIPO" denotes World Intellectual Property Organization

4. Tracking of business activity in AMR-related fields

Business activity in AMR domain was tracked based on the data available on Crunchbase platform. Crunchbase has arguably the largest collection of data on investment and venture capital activities around the world, that covers over 1 million companies globally and over 47,500 thousand companies in Australia (Crunchbase, 2022).

At the time of this study, there were 198 AMR-related companies on Crunchbase worldwide. Only three AMR-related companies were headquartered in Australia. These included a Melbourne-based company *Diag-Nose Medical,* working on non-invasive rhinology diagnostics that would promote antibiotic stewardship for clinicians; a Sydney-based company *SpeeDx,* specialising in molecular diagnostic solutions; and a company *Terragen Biotech,* headquarted in Coolum Beach, an agri-biotechnology company developing solution to reduce the reliance on chemical-based agricultural products.

Expert consultations helped to identify additional Australian companies that work in the AMR field but were not detected by the Crunchbase search. For example, *LBT Innovations*, based in Adelaide (SA) is an ASX-listed company that provides AI and other automated solutions for clinical laboratories. While the company is listed on Crunchbase, it was not

detected by the search as its description didn't include any of the AMR search terms (see Appendix for detail on search terms and strategy). It is likely, therefore, that the business activity analysis above underestimates the number of companies actually working in AMR domain in Australia.

5. Bibliometric analysis of AMR publications

Bibliometric analysis has been increasingly used by researchers to investigate and map the evolution of research topics and problems across various disciplines (Aria and Cuccurullo, 2017, Visser et al., 2021, Xu et al., 2021, Pham et al., 2023). We performed bibliometric analysis using RStudio's Bibliometrix package with Biblioshiny application (Aria and Cuccurullo, 2017). The purpose of this analysis was to identify the trending topics and emerging technologies in AMR research and to further explore Australian research specialisation in AMR. To do this, a co-word analysis (network approach) was applied to the publications data for Australia. The analysis was performed for a set of scholarly works published over 2000-2021. The time period was selected to ensure the analysis is reflective of systematic trends in the AMR publications and is representative of the established topics. A subsequent analysis of a smaller dataset (July 2017-June 2022) was performed to investigate emerging themes and trends in AMR publications.

Two methods from a family of co-word analysis techniques were used to perform the analysis.

1. Co-word network analysis, which allows to build a conceptual structure of the bibliographic collection and shows the links between concepts through the co-occurrence of terms. In other words, co-word analysis draws clusters and maps of key words sourced from authors' keywords, titles and/or abstracts (Aria and Cuccurullo, 2022, Aria and Cuccurullo, 2017). Colours of the nodes on the network map represent thematic clusters. The size of the nodes and the font represent the occurance of the word - the larger the size of the nod and the font, the more frequently it occurs in the bibliometric dataset. The lines represent word co-occurrence, with the thicker lines denoting more frequent co-occurrence.
2. Thematic map analysis. Clusters of keywords are mapped into themes using the two characteristics – density and centrality. These characteristics form dimensions of thematic maps. Density (y-axis) measures internal strengths of a network, while centrality (x-axis) measures the degree of interaction of the network with other networks (Zehra and Urooj, 2022, Pham et al., 2023). Nodes on the thematic map represent themes. Themes are characterised based on their positions on the quadrants of the map.

- High values of density and centrality define the *hot topics* or *motor topics*– the topics that are well developed and highly relevant to the conceptual framework of the domain.

- High centrality values in combination with lower values of density form the *basic topics*, these topics are significant for the domain and are cross-cutting to different areas of the domain.
- Lower centrality and lower density define *peripheral topics.* These topics are marginally interesting for the domain or not fully developed.
- Lower centrality and higher density define *niche topics,* strongly developed within the domain, but still marginal.

5.1 Bibliometric analysis of Australian AMR publications

Thematic map analysis demonstrated that key themes in the domain were concentrated in the right part of the graph showing high levels of centrality of the themes. These included *antimicrobial resistance*, which is the most frequently used term among the selected keywords, *antibiotic*, *biofilm* and *pseudomonas aeruginosa*, one of the common causes of infections in humans. Analysis also showed that several diseases appeared among the themes associated with AMR: tuberculosis, malaria and cancer were among the themes with lower relevance but high development (see Figure 10). The appearance of diseases such as malaria, cancer and tuberculosis were expected as antimicrobials are actively used in treatments of conditions associated with diseases hence increasing the threat of AMR emergence. Surprisingly, COVID was not identified in the analysis as a key theme in Australia.

Bacteria-specific terms appeared among the top themes in the past two decades picked up in the thematic map analysis, including *staphylococcus aureus*, *pseudomonas aeruginosa*, *escherichia coli*.

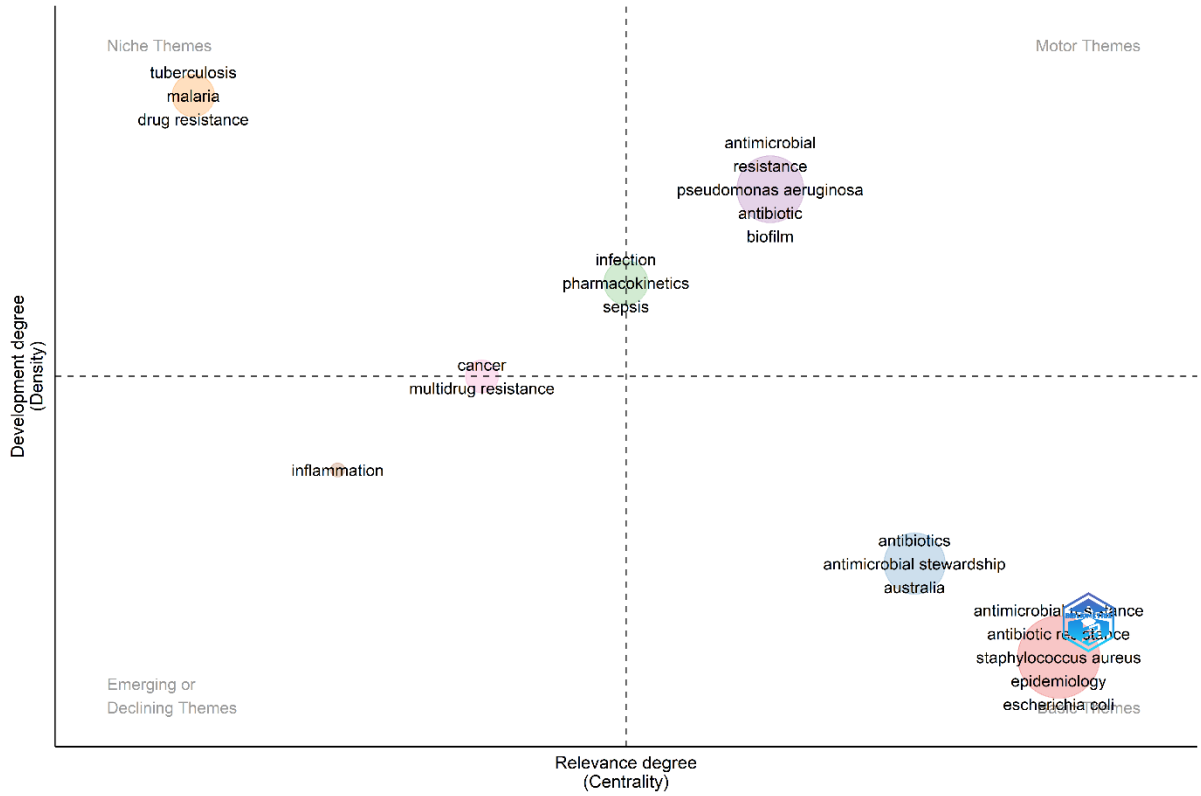

Figure 10 Thematic map: Australian AMR publication over 2000-2021

Note: Key thematic map parameters: number of words: 1000; min cluster frequency: 5; number of labels: 5, label size: 0.2; clustering algorithm: Louvain. LENS search input: Australia only, 01.01.2000 – 31.12.2021, selected publications types

A closer look at the Australian AMR publications of the past 5 years, showed that some themes moved up to the motor themes (e.g. *sepsis*, *drug resistance*) while others (e.g. *pharmacokinetics*, *pseudomonas aeruginosa*) descended to the list of peripheral themes (see Figure 11). The themes that appeared high by both the degree of development and relevance were *epidemiology*, *public health* and *infection control*. This move was likely driven by the pandemic-associated research.

Thematic maps analysis also demonstrated that not all of the key search terms used to generate the publications datasets appeared popular among Australian researchers. The leading keywords were *antimicrobial* and *antibiotic resistance*, followed by *antimicrobial stewardship* and more recently – *multidrug resistance*. Other keywords didn't appear to be mentioned often enough to form a separate theme.

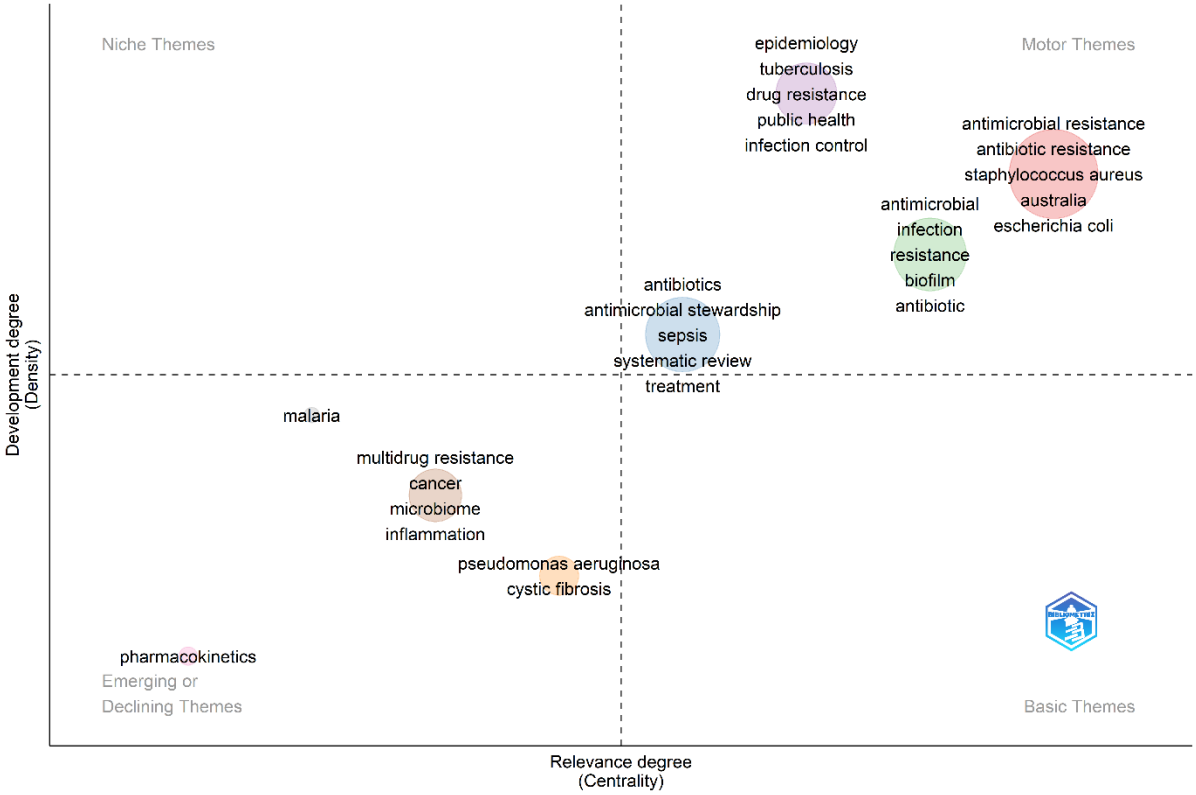

Figure 11 Thematic map analysis: Australian AMR publication of the past 5 years (2017-2022)

Note: Key Thematic map parameters: number of words 1000; min cluster frequency 5; number of labels 5, label size 0.3; clustering algorithm – Louvain. LENS search input: Australia only, past 5 years (01 Jul 2017- 30 Jun 2022), selected publications type

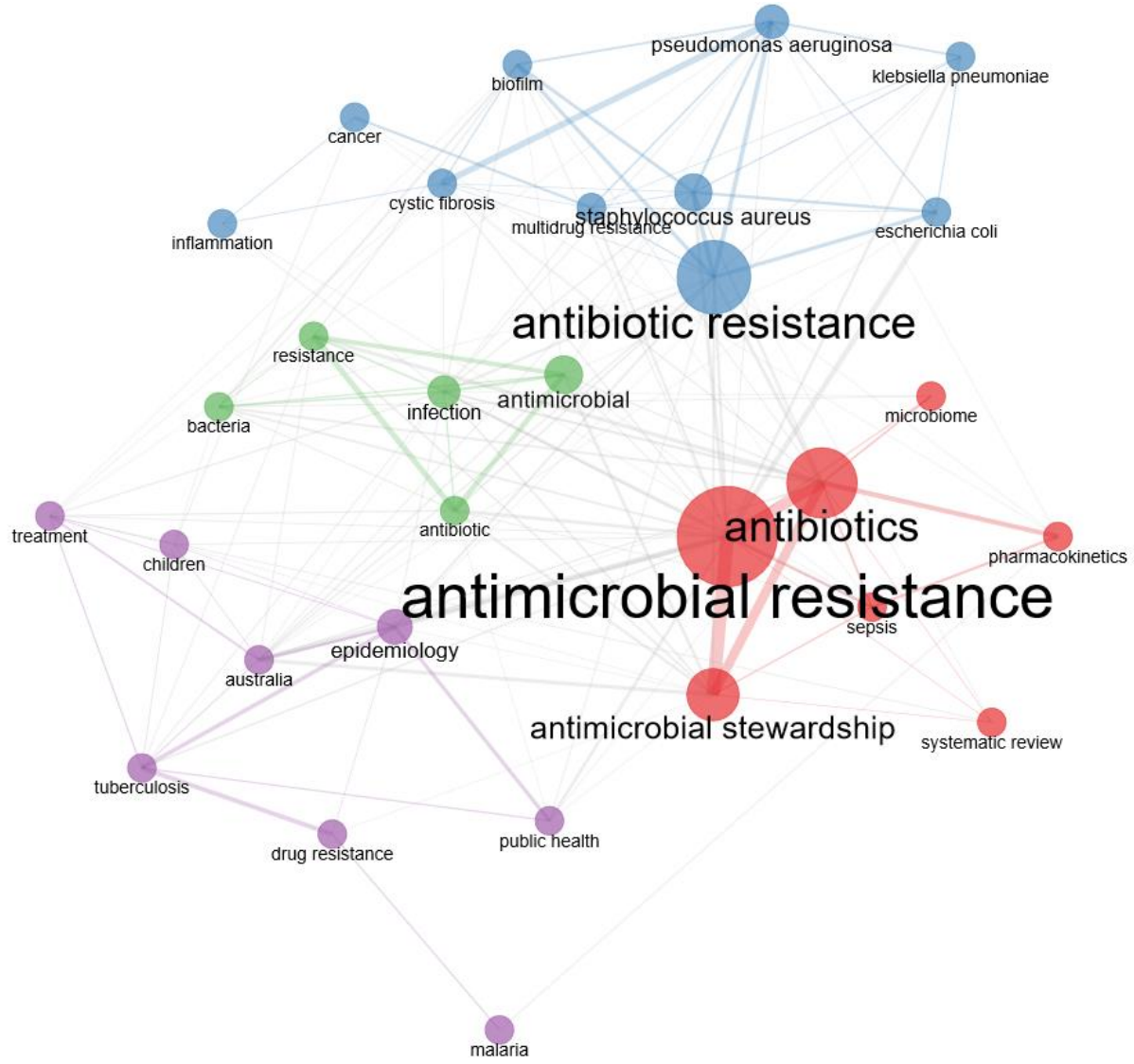

Figure 12 Co-occurrence network analysis of Australian AMR publications (2017-22)

Note: Co-occurrence network parameters: number of nodes 30; min number of edges 2; normalization: association; repulsion force: 0.1; clustering algorithm – Louvain. LENS search input: Australia only, past 5 years (01 Jul 2017- 30 Jun 2022); selected publication types

Co-occurrence network analysis showed that key themes formed four clusters as shown by different colors in Figure 12. The bubble and font sizes reflect the frequency of key word occurrence while lines represent words co-occurrence. A cluster in red included most of the very frequently used terms including *AMR*, *antibiotics* and *antimicrobial stewardship* complemented by *microbiome* and *pharmacokinetics*. Bacteria-specific terms coupled with specific diseases (e.g. *cancer*, *cystic fibrosis*) and *biofilm* were concentrated in a different cluster denoted by blue dots and associated with *antibiotic resistance*. Purple cluster appeared to link the terms related to *epidemiology* and *public health*.

Interestingly, analysis of AMR-related publications from UK over the same period returned similar patterns (Figure 13). However, the red cluster formed around major search terms also featured COVID-19.

The next section focuses on specific AMR-related technologies, including omics technology, mRNA vaccines and autogenous vaccines.

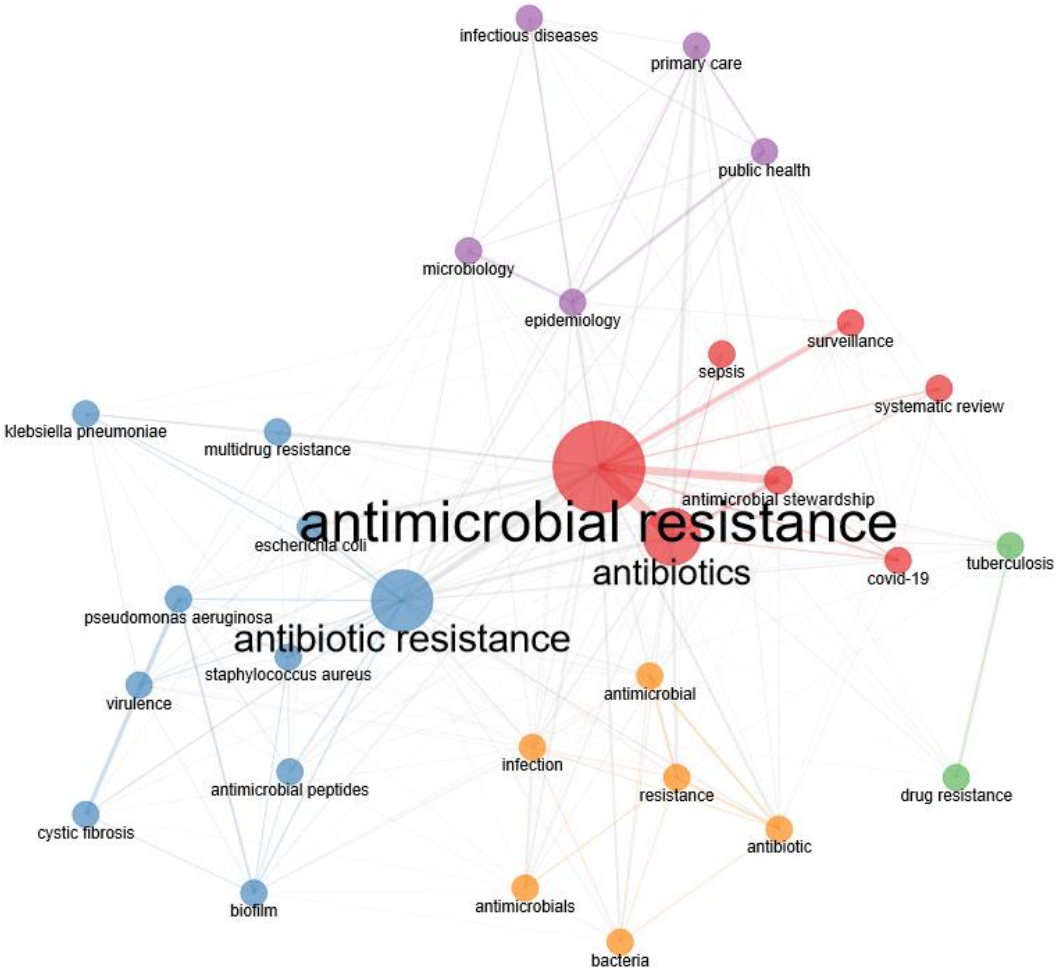

Figure 13 Co-occurrence network analysis of UK AMR publications (2017-22)

Note: Co-occurrence network parameters: number of nodes 30; min number of edges 2; normalization: association; repulsion force: 0.1; clustering algorithm – Louvain. LENS search input: UK only, past 5 years (01 Jul 2017- 30 Jun 2022); selected publication types

5.2 Bibliometric analysis of scholarly publications on particular AMR technologies

Omics technology

Between 2000 and 2021, 192 publications globally were discovered through the search, including 7 by authors affiliated with Australian organisations. As seen on Figure 14, the topic only started expansion in 2015.

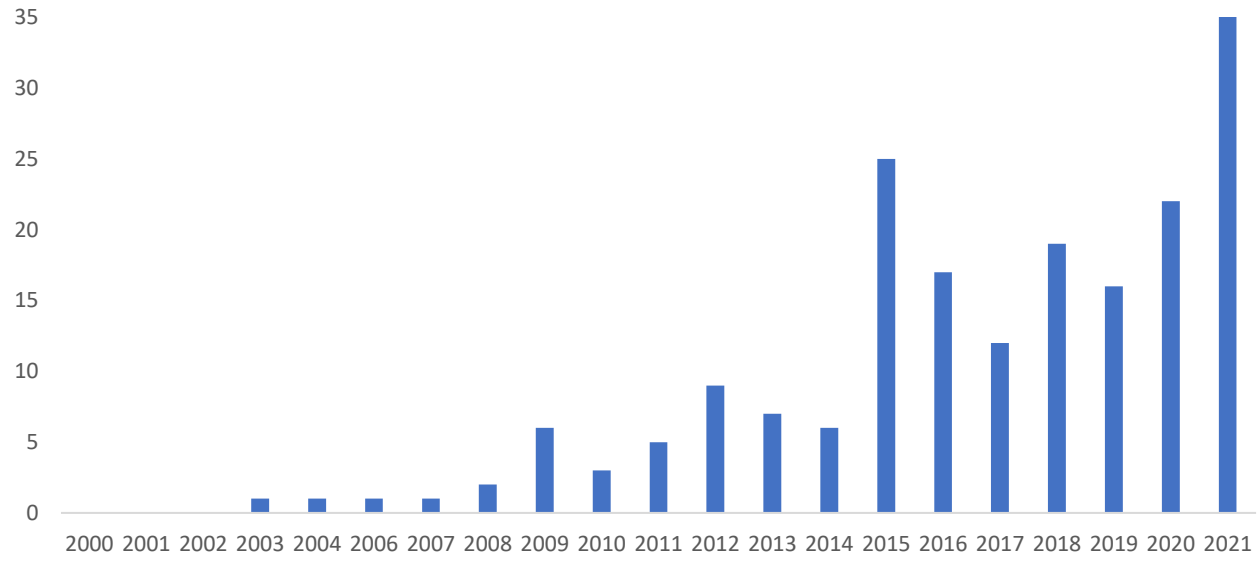

Figure 14 Scholarly works dynamics: omics technology and AMR publications

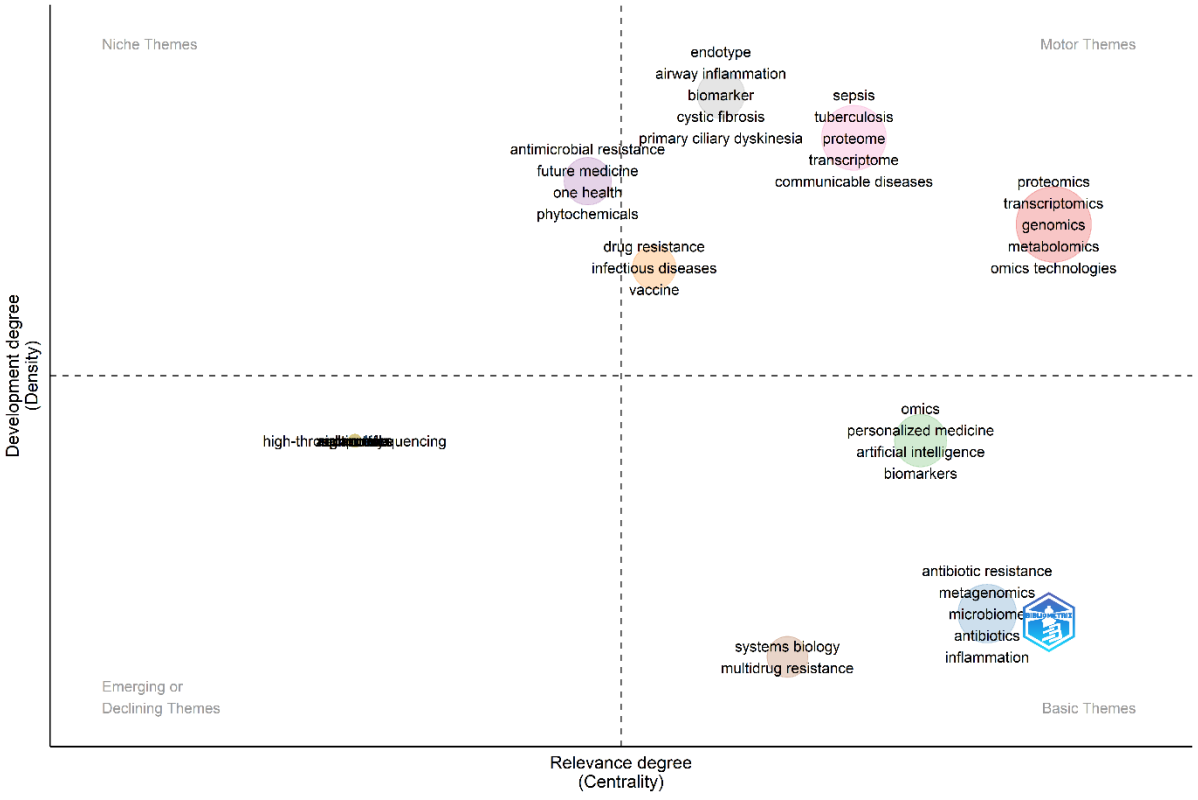

Figure 15 Thematic map for omics technology within AMR publications

Notes: (1) Key Thematic map parameters: number of words 1000; min cluster frequency 5; number of labels 5, label size 0.1; clustering algorithm – Louvain. LENS search input: globally 2000-2021, selected publications types. (2) A cluster in bottom left quadrant includes "salmonella" and "high-throughput sequencing"

Four groups of themes were identified as driving or motor themes and three groups among basic themes (see Figure 15). The co-occurance network analysis showed seven clusters most of which were small with only 2-3 nodes. The major cluster (in red) consisted of terms *proteomics*, *transcriptomics*, *genomics*, *metabolomics*, *drug resistance*, *virulence*.

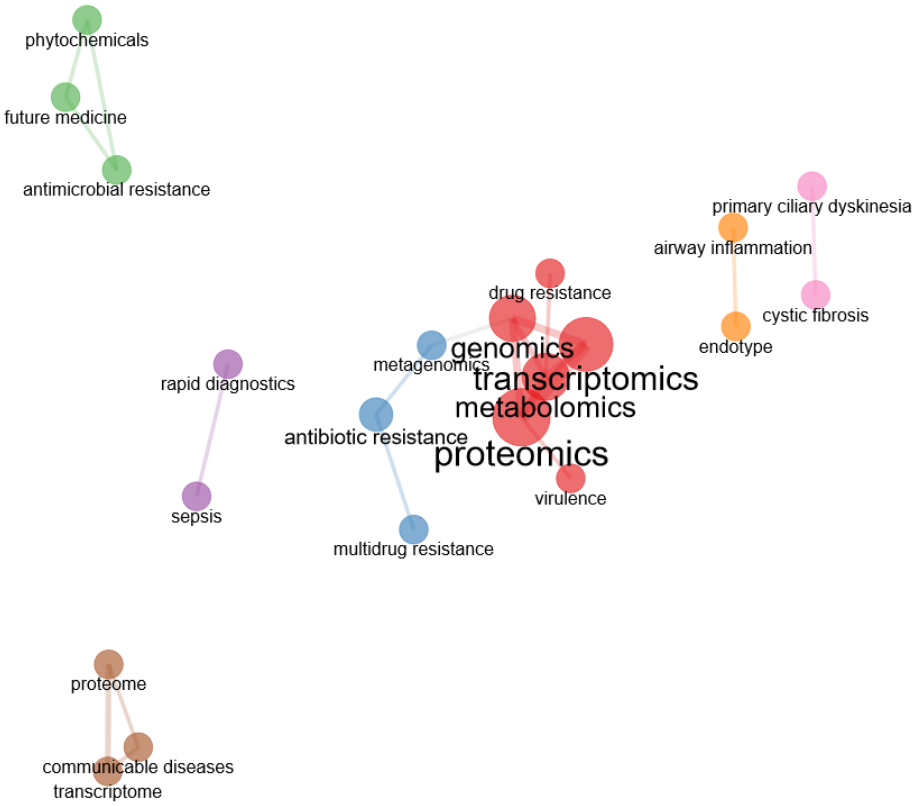

Figure 16 Co-occurance network analysis for omics technology within AMR publications globally

mRNA vaccines

The search for publications featuring *mRNA vaccines* among AMR-related publications returned 74 scholarly documents published globally between 2000 and 2021, none of those were authored by Australian authors. The largest thematic cluster among these scholarly

works was formed around *coronavirus* (*COVID-19*).

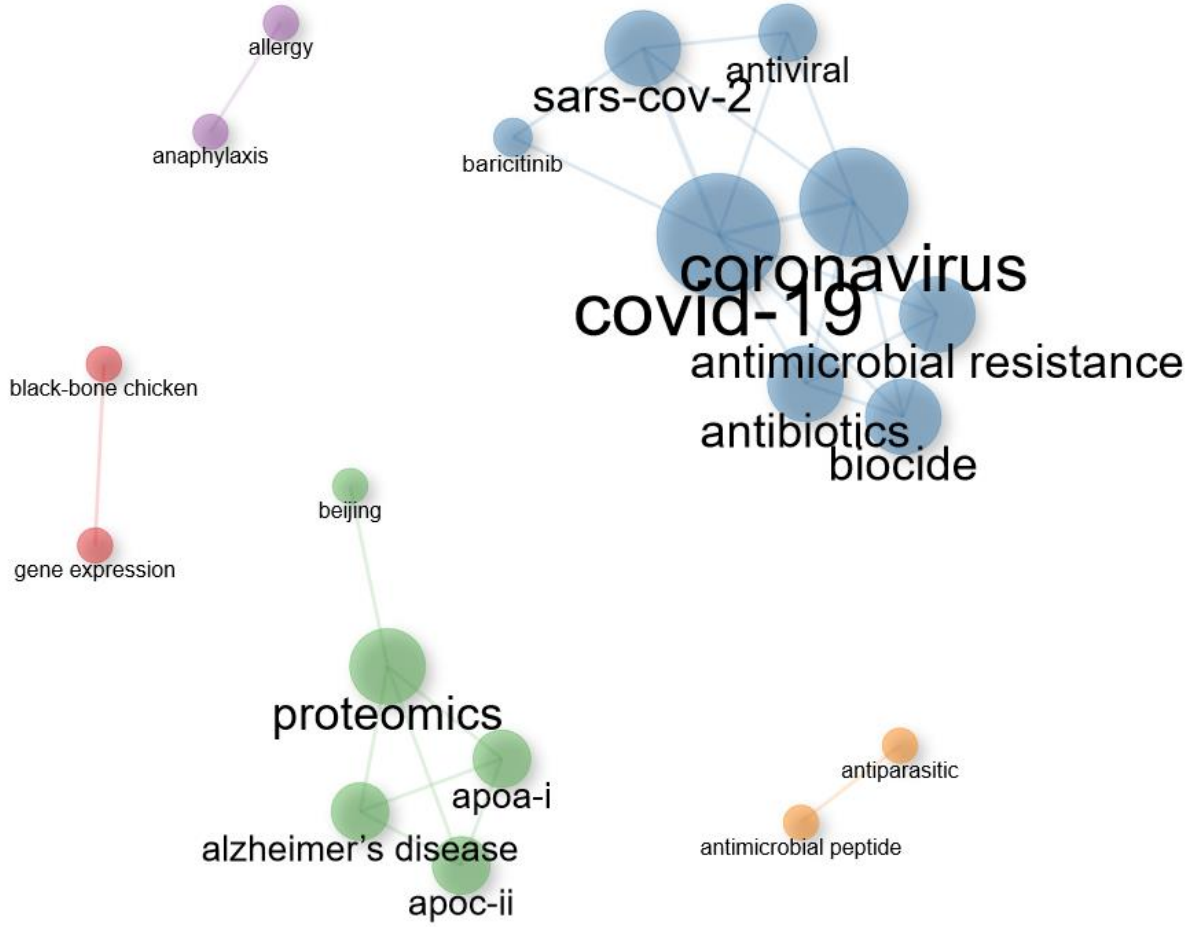

Figure 17 Thematic map analysis in a form of network map for mRNA vaccines and AMR publications, globally, 2000-21

Note: thematic map in a form of four quadrants and co-occurrence network analysis didn't return interpretable results.

Autogenous vaccines

The search for publications related to *autogenous vaccines* and AMR returned 27 scholarly documents published between 2000 and 2021, two of those are authored by Australian authors. Network co-occurrence analysis demonstrated emergence of eight thematic clusters that were not connected. The largest cluster was formed by major themes of *antimicrobials*, *genomics* and *streptococcus suis* complemented by *diagnosis*, *epidemiology*

and economic terms (*economic assessment* and *cost of disease*).

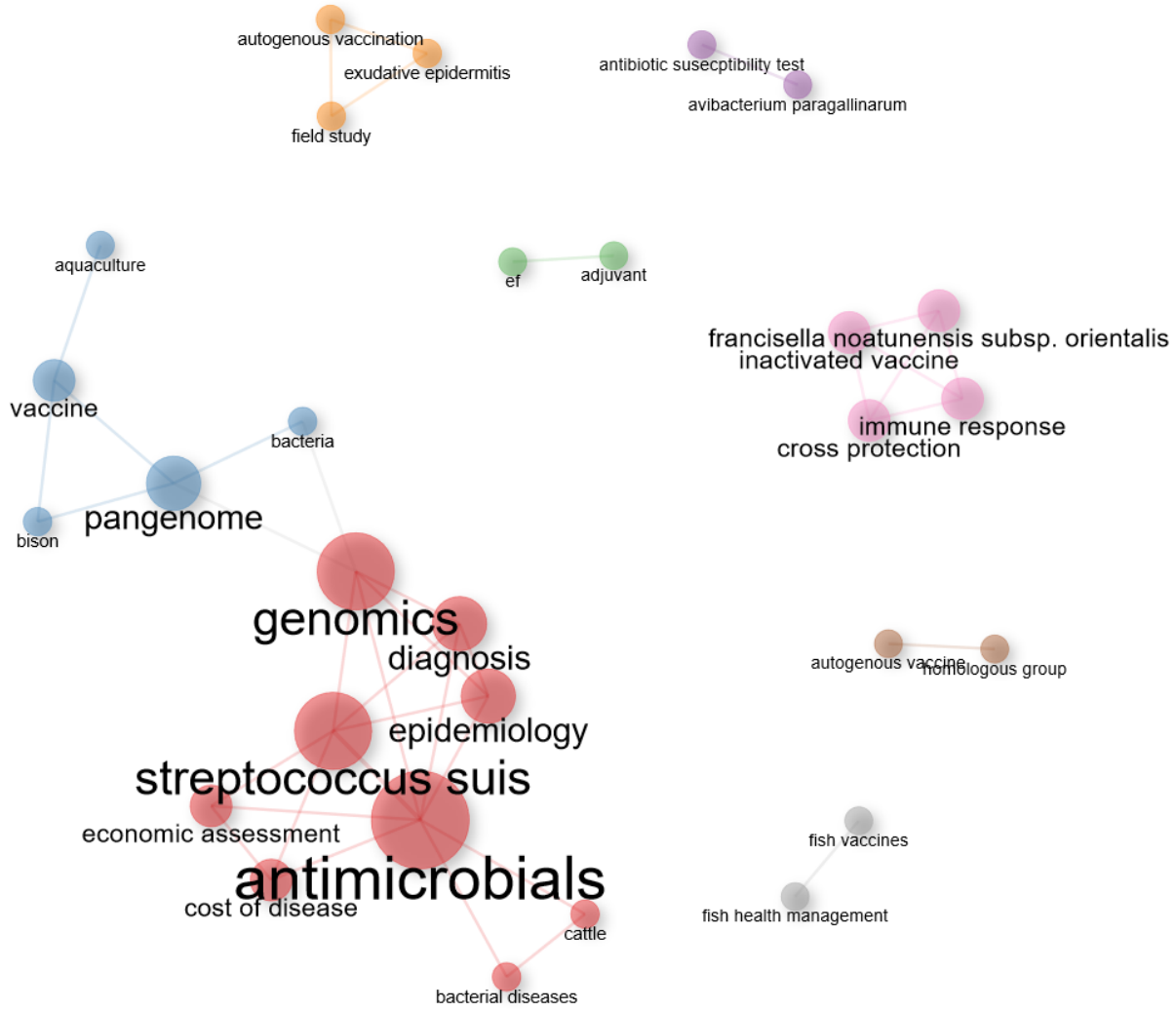

Figure 18 Thematic map analysis in a form of network map for mRNA vaccines and AMR publications, globally, 2000-21

Note: thematic map in a form of four quadrants and co-occurrence network analysis didn't return interpretable results.

A search for other technology specific publications among the AMR works returned the results not suitable for bibliometric analysis, specifically:

- Nanophotonic biosensors and AMR search returned 4 publications over 2000-2021
- A search for quantum dot sensors among AMR-related publications returned 28 papers published between 2000 and 2021, none of them is authored by Australian authors

6. Conclusions

AMR is a rapidly expanding domain of research and business activity both in Australia and overseas. The number of research publications in AMR has been continually expanding at the above-average pace over the past three decades. AMR is a complex global challenge and Australia is committed to contribute to its solution over the coming decades.

Bibliometric analysis showed that the leading AMR-related keywords among Australian publications were *antimicrobial* and *antibiotic resistance*, followed by *antimicrobial stewardship* and more recently – *multidrug resistance*.

Network analysis demonstrated that key terms formed four thematic clusters which appeared similarly structured and featured similar collection of terms for the Australian and the UK publications.

A closer look at the publications related to new and emerging AMR technologies (e.g. omics technology, mRNA vaccines and autogenous vaccines) demonstrated that these topics are not yet established in the research literature and have limited representation of Australian authors.

Appendix: Research Data and Method

RTA

The analysis was based on identification of revealed technology advantage (RTA) for Australia compared with the rest of the world. As per the OECD methodology (Dernis et al., 2019) and our previous research (Bratanova et al., 2022, Hajkowicz et al., 2023), we calculated two sets of RTA indices – for leading countries, using the data for research publication and patent applications as defined below:

$$RTA_{iT}^{p} = \frac{n_{iT}^{p} \ / \sum_T n_{iT}^{p}}{\sum_i n_{iT}^{p} / \sum_i \sum_T n_{iT}^{p}}$$

where, p denotes the group of RTA indices – RTA for patents, or RTA for research publications; n_{iT}^{p} - value of the parameter under consideration for region *i* for technology *T*. The numerator represents share of the parameter under consideration in all patent or research publications count for the region *i*. The denominator represents the share of research or patents activity across all regions.

Datasets

The search was undertaken across two datasets:

1. A. LENS.org: research publication – to track and trace research activity in research development through publications
   B. LENS.org: patents – to track and trace research activity in research commercialization through patent applications
2. Crunchabse - to track and trace business and investment activity

Search Time Periods

The search focused on the period of 2000-2021 with a particular emphasis on the past 5 years – July 2017 – June 2022.

Search Strategy

The search was conducted using the keywords defining AMR specific activities across the datasets (in business and innovation domains). The terms are adopted from AMR R&D study (details on the development and validation of search terms are to be provided).

The technology specific search terms were used in conjunction with the search terms to define (track and trace) the AMR-related publications in specific technology domain in Australia and internationally.

LENS search request for Abstract search:

(Abstract: (antibiotic alternatives) OR (antibiotic resistance) OR (antibiotic resistant) OR (antibiotic stewardship) OR (antibiotic surveillance) OR (antibiotics resistance) OR (antibiotics resistant) OR (antibiotics stewardship) OR (antibiotics surveillance) OR (antifungal resistance) OR (anti-fungal resistance) OR (antifungal resistant) OR (anti-fungal resistant) OR (antifungal stewardship) OR (anti-fungal stewardship) OR (antifungal surveillance) OR (anti-fungal surveillance) OR (antimicrobial resistance) OR (anti-microbial resistance) OR (antimicrobial resistant) OR (anti-microbial resistant) OR (antimicrobial stewardship) OR (anti-microbial stewardship) OR (antimicrobial surveillance) OR (anti-microbial surveillance) OR (antimicrobial use) OR (anti-microbial use) OR (antibiotic use) OR (antifungal use) OR (anti-fungal use) OR (fungicide resistance) OR (fungicide resistant) OR (multi drug resistance) OR (multi drug resistant) OR (multidrug resistance) OR (multi-drug resistance) OR (multidrug resistant) OR (multi-drug resistant) OR (multidrug-resistant) OR (multiple drug resistance) OR (multiple drug resistant)

OMICS TECHNOLOGIES and AMR search

(Abstract: ((omics AND technolog*) AND ((antibiotic alternatives) OR (antibiotic resistance) OR (antibiotic resistant) OR (antibiotic stewardship) OR (antibiotic surveillance) OR (antibiotics resistance) OR (antibiotics resistant) OR (antibiotics stewardship) OR (antibiotics surveillance) OR (antifungal resistance) OR (anti-fungal resistance) OR (antifungal resistant) OR (anti-fungal resistant) OR (antifungal stewardship) OR (anti-fungal stewardship) OR (antifungal surveillance) OR (anti-fungal surveillance) OR (antimicrobial resistance) OR (anti-microbial resistance) OR (antimicrobial resistant) OR (anti-microbial resistant) OR (antimicrobial stewardship) OR (anti-microbial stewardship) OR (antimicrobial surveillance) OR (anti-microbial surveillance) OR (antimicrobial use) OR (anti-microbial use) OR (antibiotic use) OR (antifungal use) OR (anti-fungal use) OR (fungicide resistance) OR (fungicide resistant) OR (multi drug resistance) OR (multi drug resistant) OR (multidrug resistance) OR (multi-drug resistance) OR (multidrug resistant) OR (multi-drug resistant) OR (multidrug-resistant) OR (multiple drug resistance) OR (multiple drug resistant))))

NANOPHOTONIC BIOSENSORS and AMR search

(Abstract: ((nanophoton* AND biosensor*) AND ((antibiotic alternatives) OR (antibiotic resistance) OR (antibiotic resistant) OR (antibiotic stewardship) OR (antibiotic surveillance) OR (antibiotics resistance) OR (antibiotics resistant) OR (antibiotics stewardship) OR (antibiotics surveillance) OR (antifungal resistance) OR (anti-fungal resistance) OR (antifungal resistant) OR (anti-fungal resistant) OR (antifungal stewardship) OR (anti-fungal stewardship) OR (antifungal surveillance) OR (anti-fungal surveillance) OR (antimicrobial resistance) OR (anti-microbial resistance) OR (antimicrobial resistant) OR (anti-microbial resistant) OR (antimicrobial stewardship) OR (anti-microbial stewardship) OR (antimicrobial surveillance) OR (anti-microbial surveillance) OR (antimicrobial use) OR (anti-microbial use) OR (antibiotic use) OR (antifungal use) OR (anti-fungal use) OR (fungicide resistance) OR (fungicide resistant) OR (multi drug resistance) OR (multi drug resistant) OR (multidrug resistance) OR (multi-drug resistance) OR (multidrug resistant) OR (multi-drug resistant) OR (multidrug-resistant) OR (multiple drug resistance) OR (multiple drug resistant))))

mRNA vaccines and AMR

(Abstract: ((mRNA AND vaccin*) AND ((antibiotic alternatives) OR (antibiotic resistance) OR (antibiotic resistant) OR (antibiotic stewardship) OR (antibiotic surveillance) OR (antibiotics resistance) OR (antibiotics resistant) OR (antibiotics stewardship) OR (antibiotics surveillance) OR (antifungal resistance) OR (anti-fungal resistance) OR (antifungal resistant) OR (anti-fungal resistant) OR (antifungal stewardship) OR (anti-fungal stewardship) OR (antifungal surveillance) OR (anti-fungal surveillance) OR (antimicrobial resistance) OR (anti-microbial resistance) OR (antimicrobial resistant) OR (anti-microbial resistant) OR (antimicrobial stewardship) OR (anti-microbial stewardship) OR (antimicrobial surveillance) OR (anti-microbial surveillance) OR (antimicrobial use) OR (anti-microbial use) OR (antibiotic use) OR (antifungal use) OR (anti-fungal use) OR (fungicide resistance) OR (fungicide resistant) OR (multi drug resistance) OR (multi drug resistant) OR (multidrug resistance) OR (multi-drug resistance) OR (multidrug resistant) OR (multi-drug resistant) OR (multidrug-resistant) OR (multiple drug resistance) OR (multiple drug resistant))))

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