Bibliometric assessment of the National Physical Laboratory's (NPL) Quantum Test & Evaluation (QTE) programme

National Physical Laboratory

21 April 2023

Outline of presentation

- Introduction
- Methodology
- Findings:
  - Overall scientific performance of NPL's core QT departments
  - Comparative assessment of NPL in QT research relative to key comparators
  - Scientific performance of NPL's key collaborators in QT research
- Open discussion

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Objectives of the study

- The National Physical Laboratory's (NPL) develop, maintains and implements national measurement standards in the UK
- Through its Quantum Programme, it supports UK-based companies aiming to introduce new quantum technologies (QT) to the market
- As part of this programme, NPL launched, in April 2020, its Quantum Test and Evaluation (QTE) programme to bolster R&I capacity in the field of QT, both internally and within its collaborators (firms, universities, research institutes)
- NPL is seeking to establish a baseline against which to assess QTE's impacts in follow-up studies and, where possible, get a preliminary appreciation of its impacts
- In response to this need and using indicators of high relevance to the QTE mission, this bibliometric assessment presents an exploratory analysis, over the past 9 years, of:
  - The overall scientific performance of NPL's core QT departments
  - A comparative assessment of NPL in QT research relative to key comparators
  - The scientific performance of NPL's key collaborators in QT research

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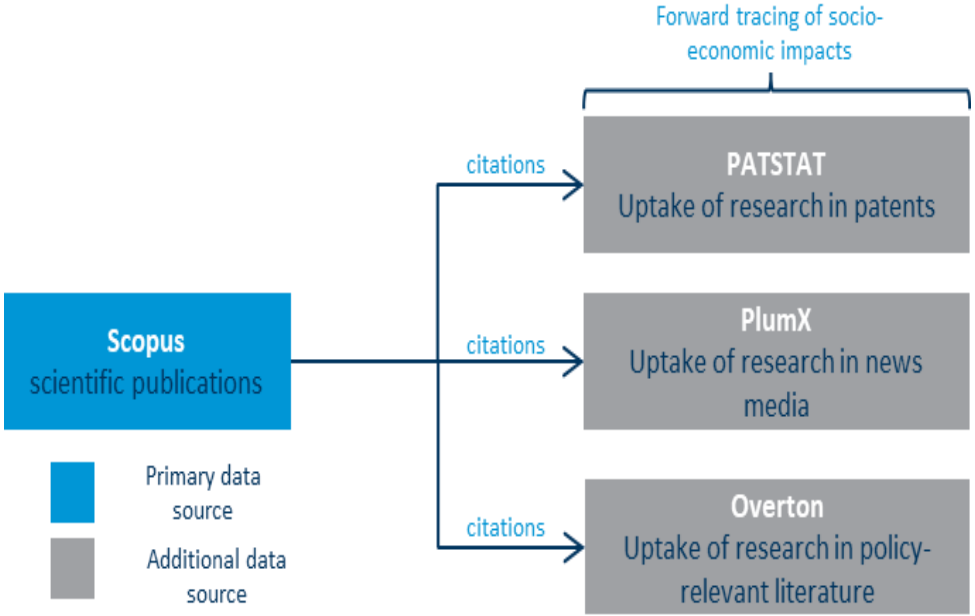
Data sources and their integration

- **Scopus**, Elsevier's comprehensive, expertly curated abstract and citation database, covers more than 35,000 titles from more than 11,000 publishers
- Only peer-reviewed sci pubs (hereafter papers) were used (mainly journal articles, reviews and conference papers)
- Papers in Scopus were linked to other data to quantitatively track some of the socio-economic impacts of research
  - **PATSTAT:** Track research uptake in innovation
  - **PlumX:** Track research uptake in media
  - **Overton:** Track research uptake in policy



Study period

- To establish a baseline against which to subsequently document progress achieved under the QTE programme, trends over the past 9 years (2013–2021) were analyzed
- The study period was also divided into three 3-year periods to document change over time, the last period (2019–2021) overlapping with the creation of the QTE programme
  - Still too early to detect its effect since there is a lag between the start of a programme and its initial outputs/impacts
- Given the small number of yearly papers observed for some of the study's units of analysis, indicators were in some cases computed using 3-year moving periods (2013–2015, 2014–2016, …) to obtain more reliable trends
- **Impact in scientific papers, in policy and in news:** The period 2019–2021 is only based on 2019 since papers in 2020 and 2021 did not accumulate citations over a sufficient period to obtain reliable values
- **Impact in patents:** For a similar reason, uptake of papers in patents is not computed beyond 2017. The periods 2016–2018 and 2017–2019 are thus incomplete and the periods 2018–2020 and 2019–2021 are missing

Units of analysis

This project calculates bibliometric indicators for the whole of the World in QT research as well as for the following units of analysis:

Overall scientific performance of NPL's core QT departments:

- All papers by NPL
- QT Papers by NPL's core QT departments[1]
- Non-QT papers by NPL
- All Papers funded by NQTP

Comparative assessment in QT research:

- World in QT pubs dataset
- UK in QT pubs dataset
- NPL in QT pubs dataset[2]
- NQTP in QT pubs dataset
- EPSRC in QT pubs dataset
- UKRI in QT pubs dataset

- **NPL's Top Collaborators:**[3]
- Imperial College London
- University College London
- Physikalisch-Technische Bundesanstalt
- Royal Holloway University of London
- Istituto Nazionale di Ricerca Metrologica
- Chalmers University of Technology
- University of Cambridge
- Heriot-Watt University
- University of Surrey
- University of Oxford
- …

QT Thematic dataset

- The peer-reviewed research publications in scope of the comparative assessment of NPL were retrieved using a keyword-based query designed to capture papers of high relevance to QT:
  - Recall: 70%
  - Precision: 90%

Bibliometric Indicators

To measure QT research through publication output and trends, this project calculates the bibliometric indicators listed below:

Indicators of growth:

- Output volume (number of publications)
- Growth in output volume (CAGR)

Indicators showing collaboration patterns:

- International co-publication rate (and average number of partnering countries on publications)
- Public–private co-publication rate

Indicators of citation impact:

- Citation impact within the scientific community (various metrics)
- Citation impact within news media
- Citation impact within the patent literature
- Papers cited by the private sector
- Citation impact within policy-relevant literature

Bibliometric Indicators

Indicators of growth:

- **Number of publications:** Total number of publications (full counting)
- **Compound annual growth rate (CAGR):** The compound annual growth rate (CAGR) measures the rate at which a given entity's production changed over a number of years, taking compounding effects into account

Indicators showing collaboration patterns:

- **International co-publication rate (ICR):** Share of an entity output (weighted average for regions) in international co-publications (full counting)
- **Public–private co-publication rate (PPR):** The proportion of an entity's papers that are published in collaboration (i.e., co-published) between the public and private economic sectors

Bibliometric Indicators

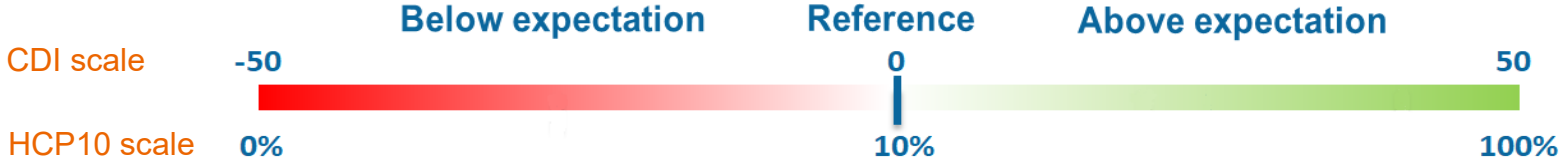
Indicators of scientific impact:

- **Average of Relative Citations (ARC):** A measure of the observed scientific impact of research conducted by an entity, based on an average of the number of citations that each of its papers received, relative to the average number of citations received by world papers published the same year, in the same subfield and in the same document type.
- **Field-weighted CiteScore (FWCS):** Every published paper is given the FWCS of the journal in which it is published. The FWCS of a given entity is simply an average of the FWCS scores of its articles. This provides a metric of the prestige/influence of the journals in which papers were published.

Bibliometric Indicators

Indicators of scientific impact:

- **Citation Distribution Index (CDI):** This indicator better reflects the “average” level of impact in highly skewed citation distributions than ARC (or equivalent such as MNCS, FWCI), especially for entities with few publications. The reference (or expected value is 0). The min score is -50 and the max score is +50. In practice, scores above 20 are considered very high.
- **Top 10 Highly Cited Publications (HCP10):** Share of publications falling within the 10% most cited publications in Scopus by year, subfield and document type. Since close to 50% of all citations are to publications in the top 10%, this indicator is often used as a proxy for research excellence. Values above the expected score of 10% point to strong performances.



Bibliometric Indicators

Indicators of impact beyond the scientific community: The below indicators are normalised shares of publications cited at least once by the citing source. All shares are normalised relative to the database (Scopus) reference within each publication year/subfield/document type combination. Compared to indicators of scientific impact (previous slide), the normalisation is based on the difference from (rather than the ratio to) the reference value. The resulting scores are thus percentage point differences relative to reference value (0); positive scores indicate uptake higher than expected.

- Normalised share of publications cited by patents
- Normalised share of publications cited by the private sector
- Normalised share of publications cited in news media
- Normalised share of publications cited in policy-relevant literature

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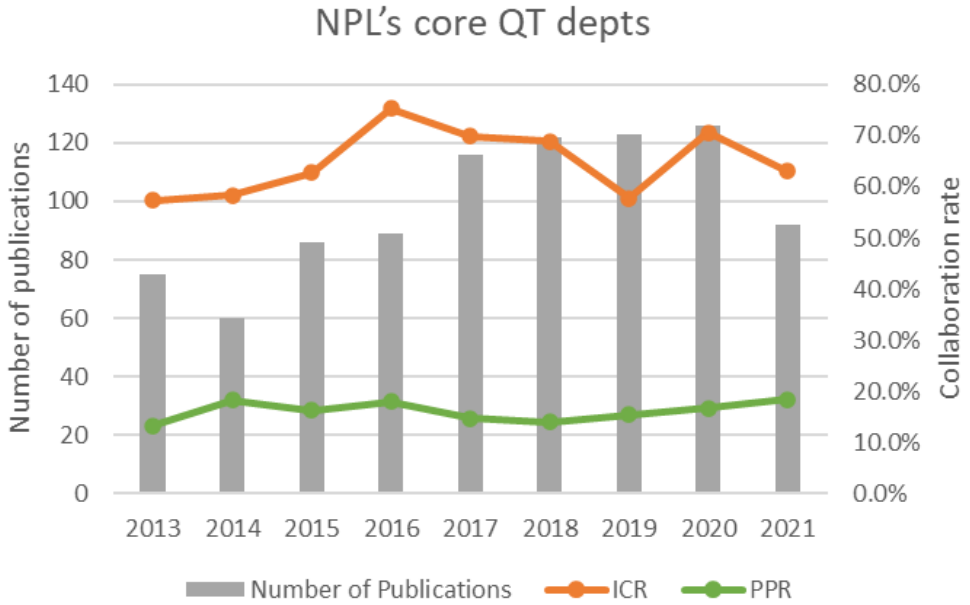
Findings – NPL's core QT departments

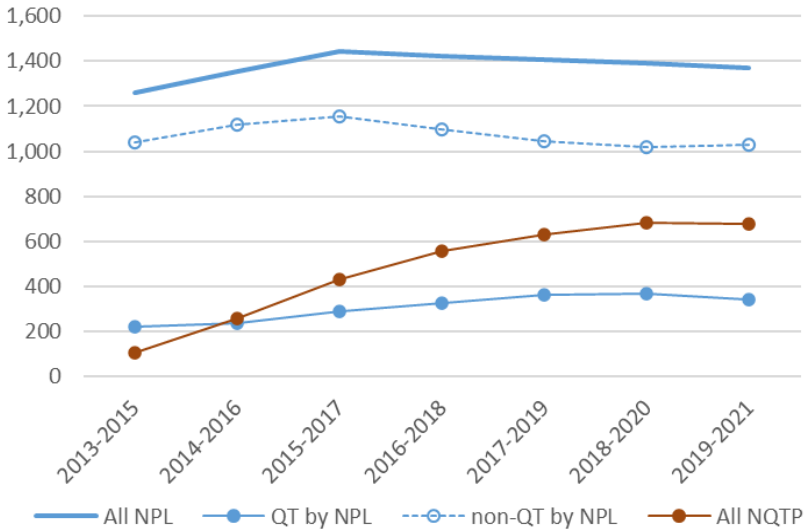
Output volume and collaboration

- From 2013 to 2021, the number of QT papers by NPL's core QT depts increased from 75 to 92 and peaked in 2020 (126)
- The number of publications decreased 30% in 2021
- The ICR mostly ranged between 60% and 70% and the PPR mostly ranged between 13% and 19%



Findings – NPL's core QT departments

Volume and growth relative to NPL overall and NQTP overall

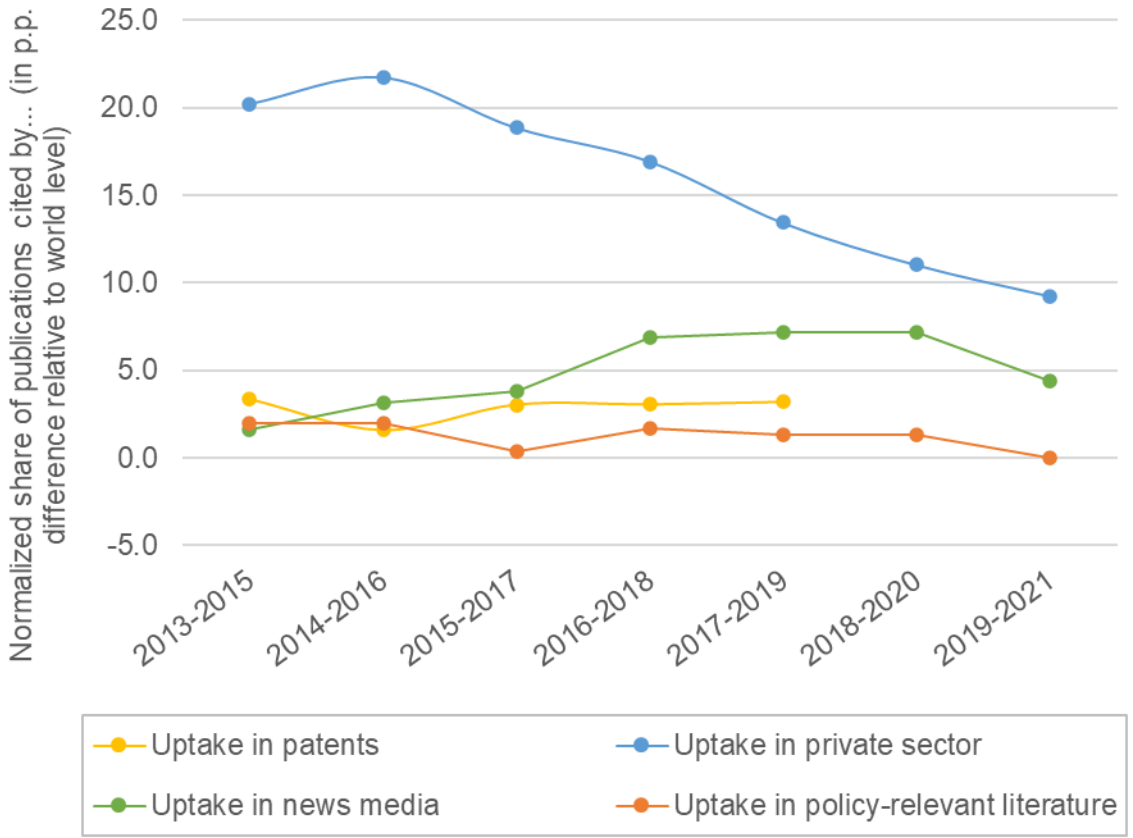


- The number of NPL's QT papers increased from 221 in 2013–2015 to 341 in 2019–2021 (CGAR of 2.6%; CAGR computed on the yearly data)
- The increase in the number of NPL's non-QT papers (or all NPL papers) is marginal (CGAR of 0.9%)
- The number of NQTP-funded papers rose from 107 in 2013–2015 to 676 in 2019–2021 leading to a very high CAGR of 49%. This is to be expected for a newly established programme (started in 2014)

Findings – NPL's core QT departments

Other citation impacts

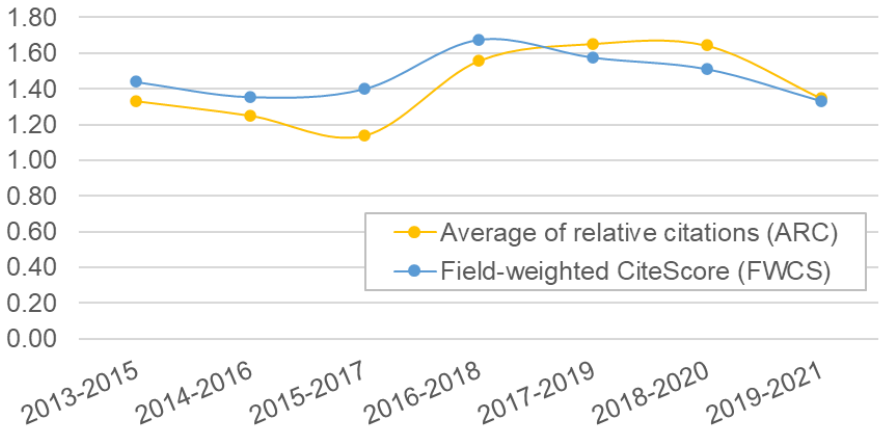
- The citation of NPL's QT research by the private sector is well above world level (by +10 p.p. in the most recent period) but has been steadily decreasing over time. Note that the world baseline (32% over the entire period) is significantly higher for this dimension than the other three.
- Uptake in news media has been increasing over the study period and is +4.4 p.p. above world level (2%).
- Uptake in patents and in the policy-relevant literature was closer to world level but still generally above it. It was also generally stable across the entire period. For the former, it was +3.2 p.p. above world level (5.9%) in 2013–2017 while it was +1.3 p.p. above it (0.7%) for the latter in 2013–2019.

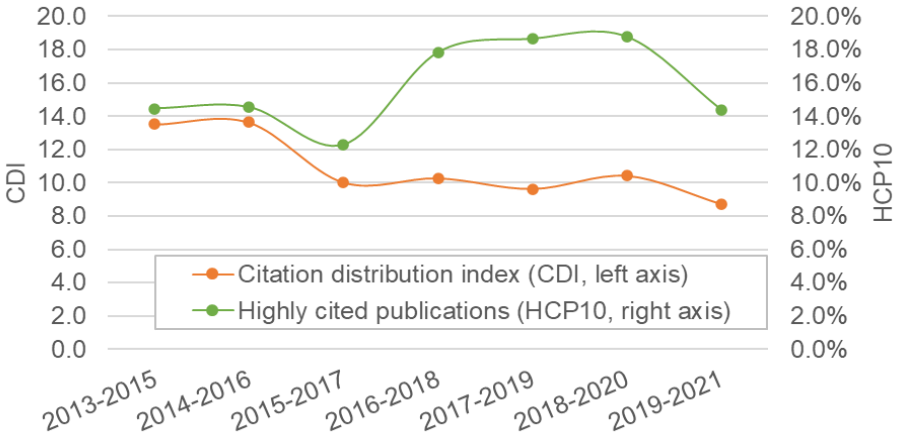


Findings – NPL's core QT departments

Scientific impact

- ARC and FWCS have always been above world level (1.00), mostly by at least 20% and 40%, respectively.
- For ARC, performance increased in 2016–2018 and remained at a similar level afterwards (~ 60% above world). This is particularly due to a very strong performance in 2018 which partly explains the decrease in 2019–2021. Still 2019–2021 remains above the early periods.
- FWCS increased until 2016–2018 and decreased back to a similar value as in the start of the study period in 2019–2021 (still with a good performance 33% above world level).
- The share of highly cited publications (HCP) followed a similar trend as the ARC which is more influenced by outliers (i.e., HCP) than the CDI. The scores were always above world level (mostly by at least by 4 p.p.).
- The CDI, which is less impacted by outliers (HCP), decreased from a high around 14 (world level = 0) in the first two periods to a stable and good performance at around 10.





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Comparative study

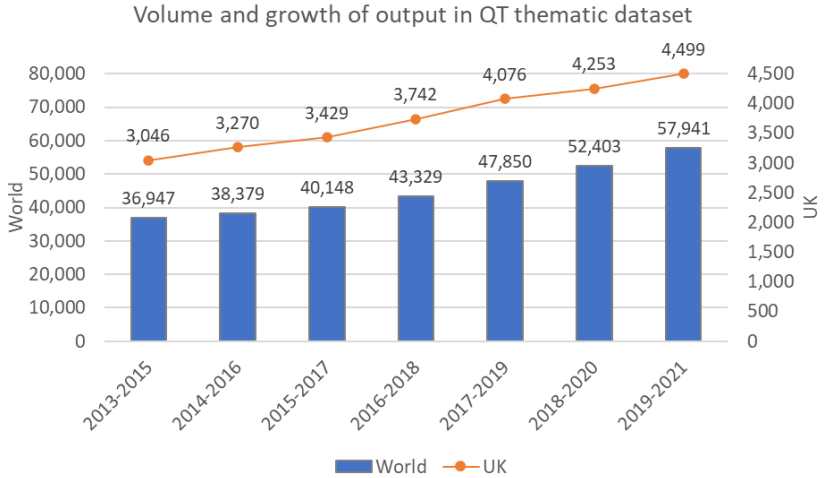
NPL vs. comparators overall in QT for the 2013–2021 period

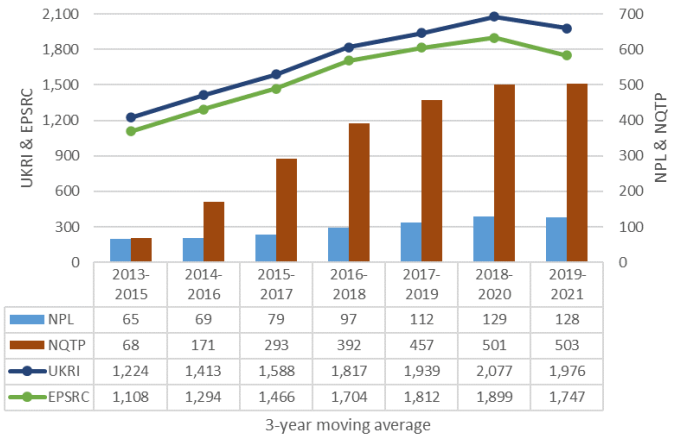
- Although the growth rate of NPL's QT publications is lower than that of comparators, both in the whole period and last 3 years, NPL's QT research had higher collaboration rates (both international (except compared to UK) and public-private collaboration).
- Despite not scoring higher than most comparators across all citation impact indicators (in science and beyond (altmetric)), NPL still stood out above the world on all those indicators in QT.

	Output volume & trend				Networking		Citation impact				Altmetric							
			CAGR								Share cited at least once by				Normalised share (in p.p.)**			
Entity	Papers	Trend*	2019–21	2013–21	ICR	PPR	ARC	CDI	HCP10	FWCS	Patents	Private sector	News media	Policy lit.	Patents	Private sector	News media	Policy lit.
World	138,217		8.5%	7.3%	30.2%	6.4%	1.35	6.2	14.3%	1.28	7.4%	32.5%	4.3%	0.7%	2.9	3.8	2.3	0.1
UK	11,287		3.5%	7.0%	67.6%	11.4%	2.11	18.3	24.1%	1.72	8.7%	44.4%	9.0%	1.3%	4.2	16.3	6.7	0.6
NPL	**290**		**-11.5%**	**3.7%**	**62.1%**	**16.2%**	**1.72**	**14.1**	**19.5%**	**1.73**	**10.4%**	**47.2%**	**11.6%**	**2.1%**	**4.8**	**18.4**	**9.5**	**1.6**
NQTP	963		-2.7%	48.5%	49.5%	14.8%	2.98	26.7	33.5%	1.83	23.1%	61.6%	14.4%	3.0%	18.6	33.0	11.3	2.5
EPSRC	4,559		-10.3%	5.5%	57.7%	10.1%	2.33	21.7	26.9%	1.86	11.8%	52.1%	10.7%	1.4%	7.1	21.5	8.2	0.8
UKRI	5,017		-6.8%	6.2%	58.1%	10.2%	2.29	21.2	26.3%	1.81	11.0%	51.2%	10.4%	1.3%	6.4	21.0	7.8	0.7

Comparative study

Volume and growth of output in QT thematic dataset



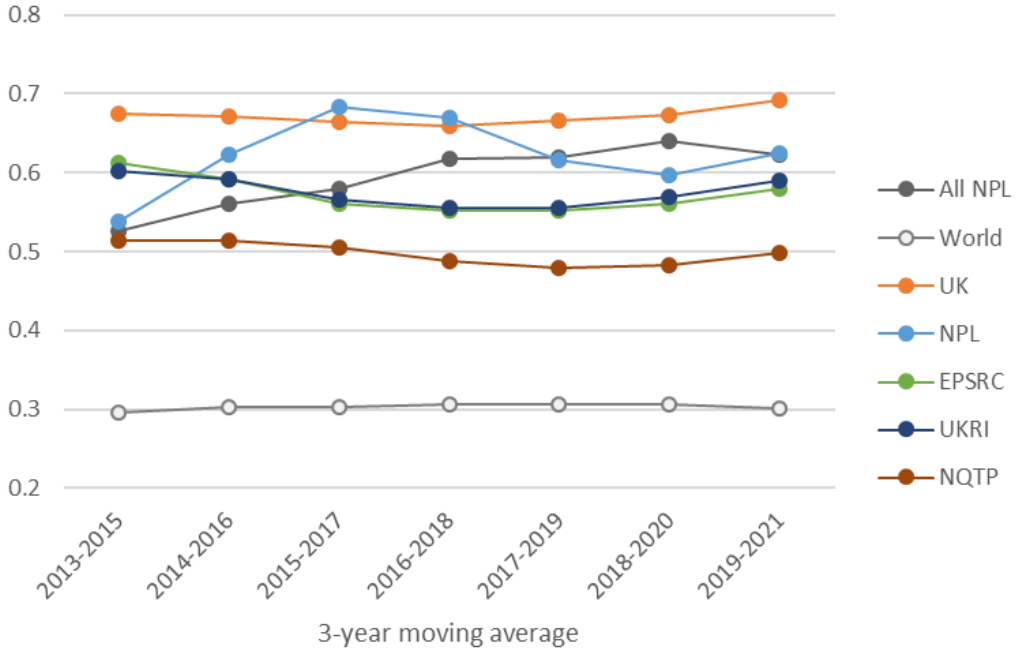


	2013-2015	2014-2016	2015-2017	2016-2018	2017-2019	2018-2020	2019-2021
NPL	65	69	79	97	112	129	128
NQTP	68	171	293	392	457	501	503
UKRI	1,224	1,413	1,588	1,817	1,939	2,077	1,976
EPSRC	1,108	1,294	1,466	1,704	1,812	1,899	1,747

- The QT literature, both worldwide and nationwide in the UK, increased between 2013 and 2021 with a high CAGR (7.3% and 7.0%, respectively) (computed on yearly data).
- The 3-year moving period of papers funded by UKRI and EPSRC show a decrease in the last period, while for NPL and NQTP, it did not decrease in the last period. However, the yearly growth rate of NPL's paper is lower than for all three comparators; only by a small margin relative to UKRI and EPSRC.
- As previously explained, the high growth for NQTP is to be expected for a newly established funding programme (launched in 2014).

Comparative study

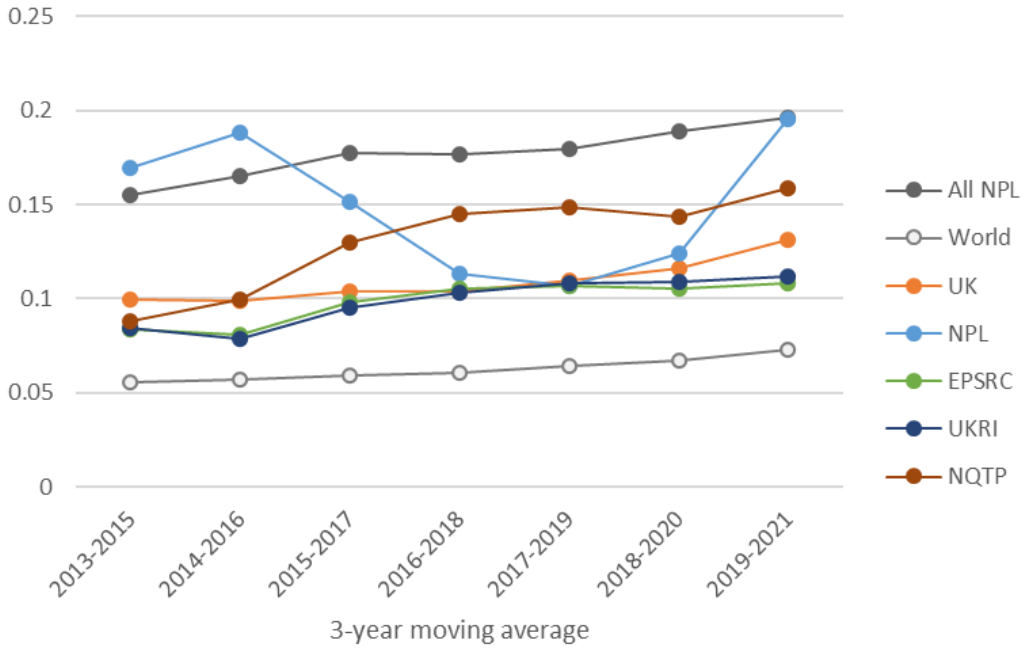
International co-publication rate (ICR) in QT thematic dataset



- The UK has maintained a high ICR in QT research compared to the global average (~ 70% vs. ~ 30% in 2019–2021)
- NPL's ICR in QT is higher than other comparators and only slightly lower than for the UK
- NPL's highest ICR in QT was achieved in 2015–2017 (68.4%)
- Since 2017–2019, the ICR of EPSRC and UKRI is very close to that of NPL in QT. Only NQTP is lower by a notable margin.

Comparative study

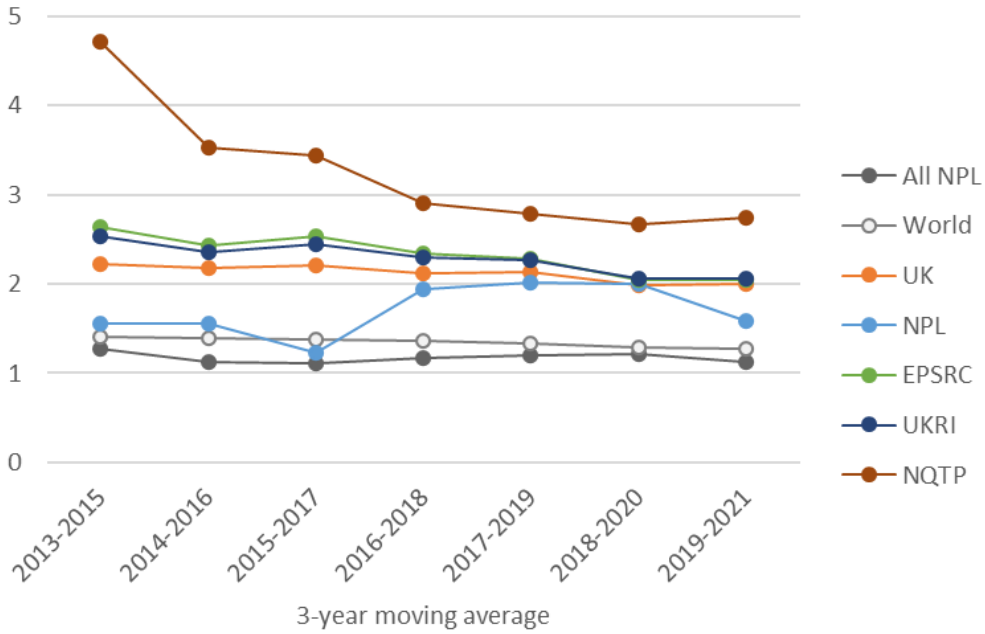
Public-private collaboration rate (PPR) in QT thematic dataset



- The PPR of the UK's QT papers was higher than the global average (~ 13% vs. ~ 7% in 2019–2021).
- The PPR of NPL in QT experienced a valley in the periods from 2016–2018 to 2018-2020. During that timeframe, it was close to the UK level but still above world level.
- Prior to and after that valley, NPL had the highest score relative to comparators in QT. It reached its highest score (19.5%) in 2019–2021 close to NPL's overall score.

Comparative study

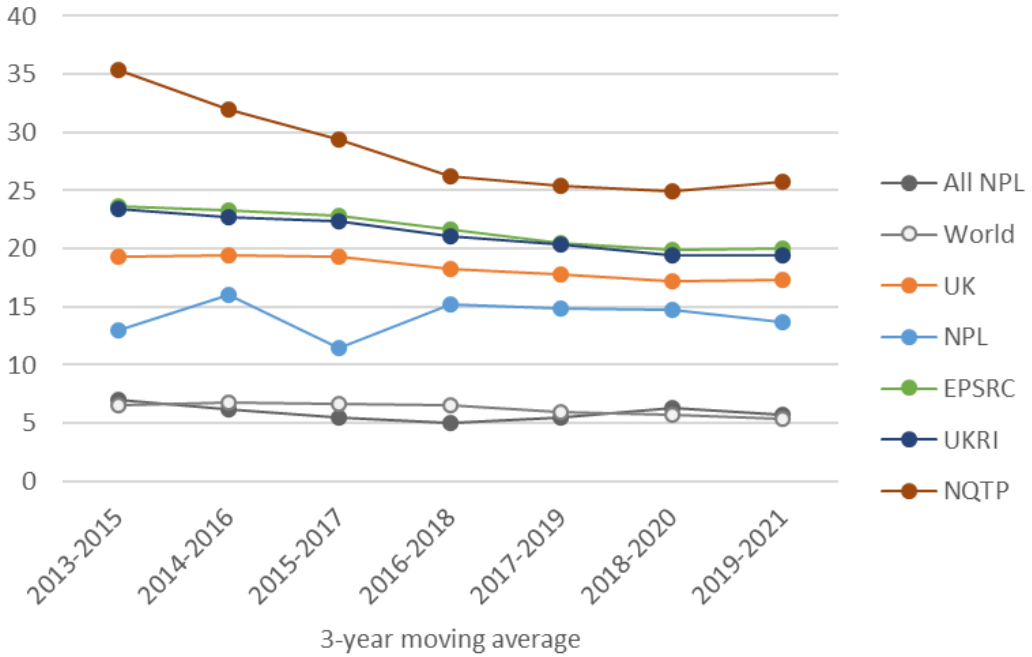
Average of relative citations (ARC) in QT thematic dataset



- Generally, most entities experienced a decrease in scientific impact. This is most notable for the UK, EPSRC and UKRI in QT as well as for NPL's total output (see slide notes for possible explanation).
- The strong decline for NQTP, at the start of the study period, is most likely reflecting convergence to NQTP's "true" score as it matured and started producing more output following its creation in 2014.
- From 2013–2015 to 2019–2021, NPL's ARC in QT slightly increased. It nevertheless remains lower than other comparators but higher than for the whole of NPL's papers and than the world in QT. From 2016–2018 to 2018–2020, it was on par with the UK average in QT.
- Note the world in QT was slightly higher than the reference level (1.00) for the subfield/year/doc type combinations in which QT papers were published.

Comparative study

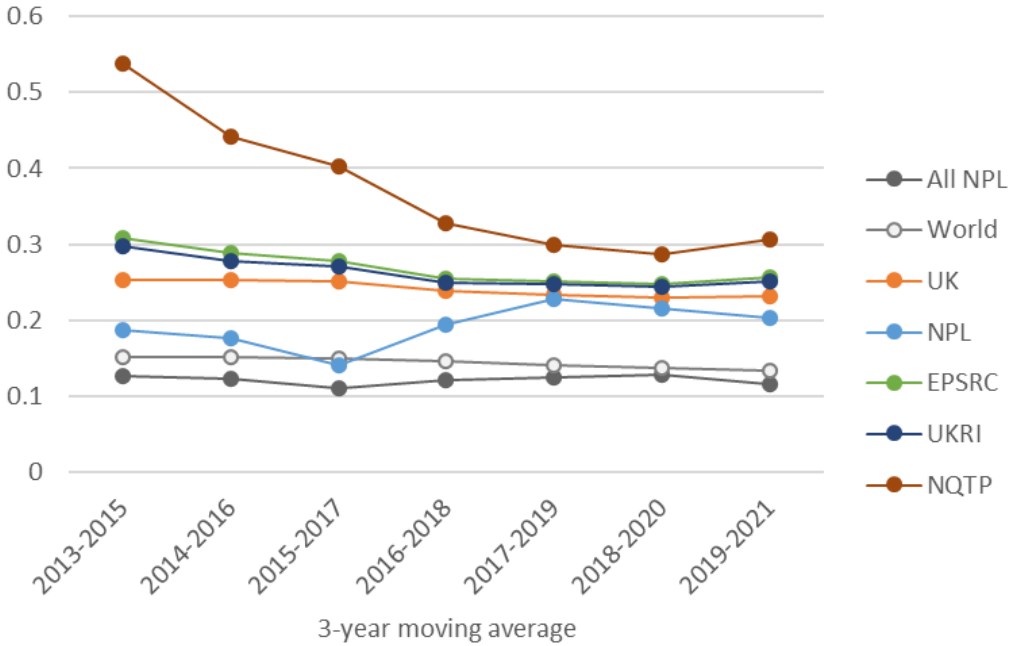
Citation distribution index (CDI) in QT thematic dataset



- The patterns for the CDI are similar to those observed for the ARC.
- While a slight decreasing trend in CDI was observed for all comparators, the impact of NPL's QT papers showed a slight increase (disregarding the second 3-year period).
- The CDI of NPL's QT papers was lower than that of other comparators, but still higher than for the world and NPL's papers overall.

Comparative study

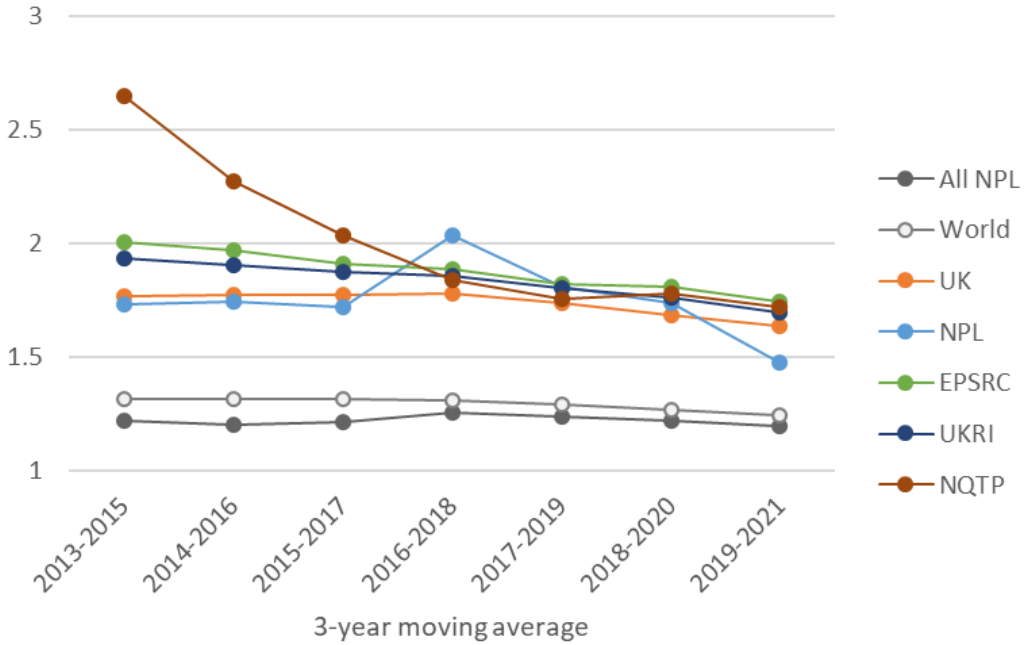
Top 10% Highly cited publications (HCP10) in QT thematic dataset



- The patterns for HCP10 are even more similar to those observed for the ARC than was the case comparing the CDI to the ARC. This is to be expected given the stronger impact of HCP on the ARC than the CDI.

Comparative study

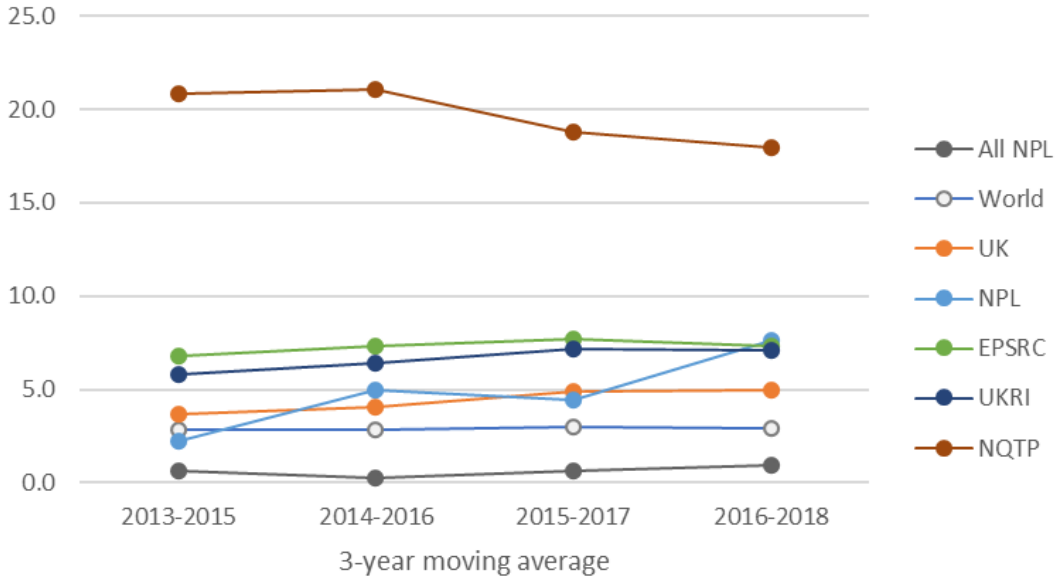
Field-weighted CiteScore (FWCS) in QT thematic dataset



- The patterns for the prestige of the journals in which papers were published (FWCS) are again similar to those for the ARC. Key differences include:
  - NQTP no longer stands out above EPSRC and UKRI in recent periods. This shows that despite being published in similarly influential venues, NQTP's papers achieve higher scientific impact than other comparators.
  - NPL scored close to or above the UK in QT in four periods; it scored first in 2016–2018. Additionally, the average prestige of the journals in which NPL's QT papers were published was markedly above world level and the average for NPL as a whole.

Comparative study

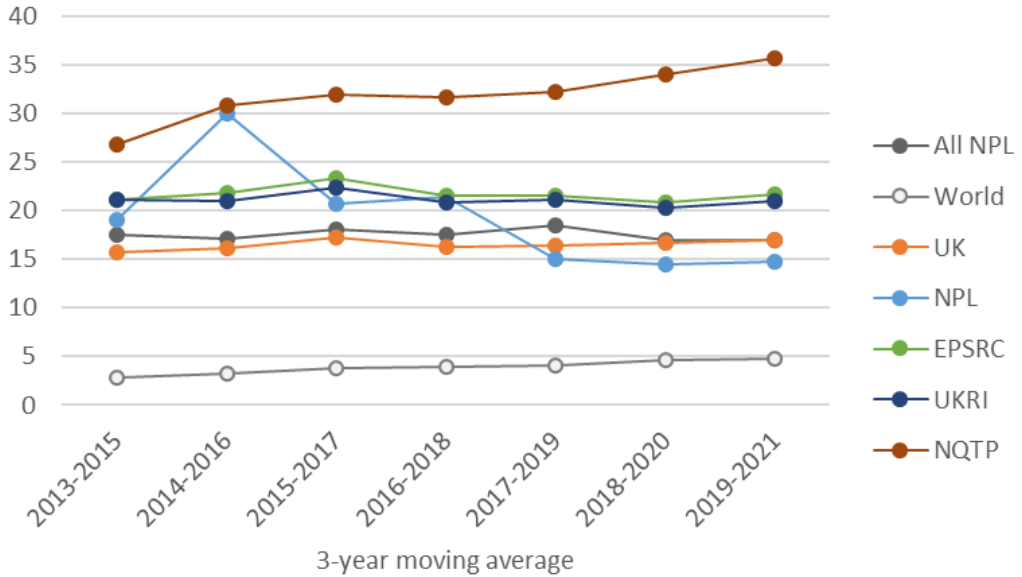
Normalized share of publications cited by patents in QT (p.p. difference relative to world)



- NQTP ranked first for its share of papers receiving at least one citation from patents, but its score has been decreasing while it showed a constant increase for the other entities.
- The normalized share for NPL's QT papers has increased more markedly than for its comparators. As a consequence, NPL ranked second to NQTP in the most recent period with a +7.6 p.p. (very close to EPSRC and UKRI) difference relative to NPL's corresponding world level (4.1%, see slide note #2).

Comparative study

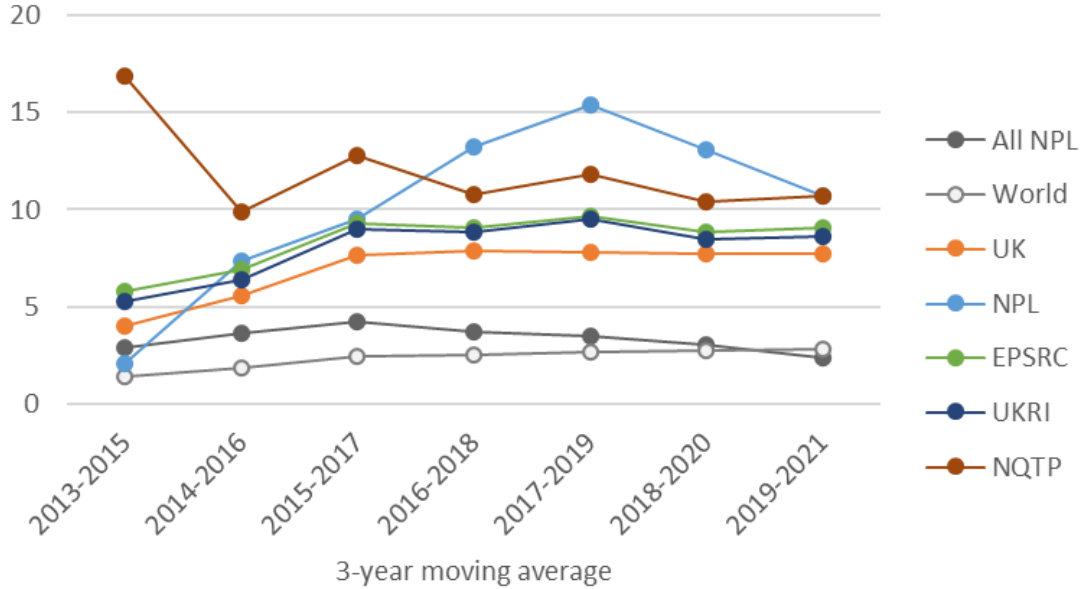
Normalized share of publications cited by the private sector in QT (p.p. difference relative to world)



- NQTP, EPSRC, and UKRI scored well above the UK and the world for their uptake by the private sector. Plus, their performance was very stable throughout the study period.
- NPL registered the second strongest performance (in addition to NQTP) in QT for uptake by the private sector in the first half of the study period.
- NPL then experienced a decrease that brought it slightly below the UK level in QT, but still well above (+14.7 p.p.) world level (29.9% in 2019–2021).

Comparative study

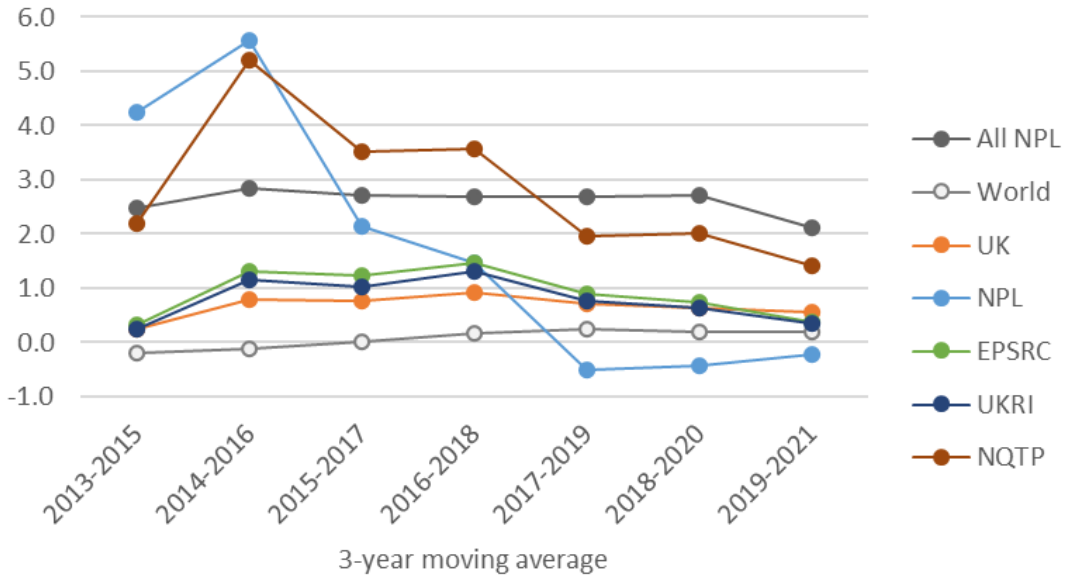
Normalized share of publications cited in news media in QT (p.p. difference relative to world)



- For the uptake of research findings in news media, NQTP again ranks first among comparators roughly +10 p.p. above world level.
- In the first three to four 3-year periods, scores increased for NPL, EPSRC, UKRI and the UK in QT.
- The increase was more pronounced for NPL who scored first to NQTP from 2016–2018 to 2018–2020.
- In the most recent 3-year period, NPL was close to NQTP with a score +10.7 p.p. above world level (5.3%).

Comparative study

Normalized share of publications cited by policy literature in QT (p.p. difference relative to world)



- The uptake of NPL's QT papers in the policy-relevant literature was close to that observed for NPL's total output at the start of the study period and topped all comparators in QT.
- However, its score went down markedly after 2014–2016 such that it ended last below world level in the last three periods.
- The normalized scores for the UK, EPSRC and UKRI in were similar and somewhat stable throughout the study period.

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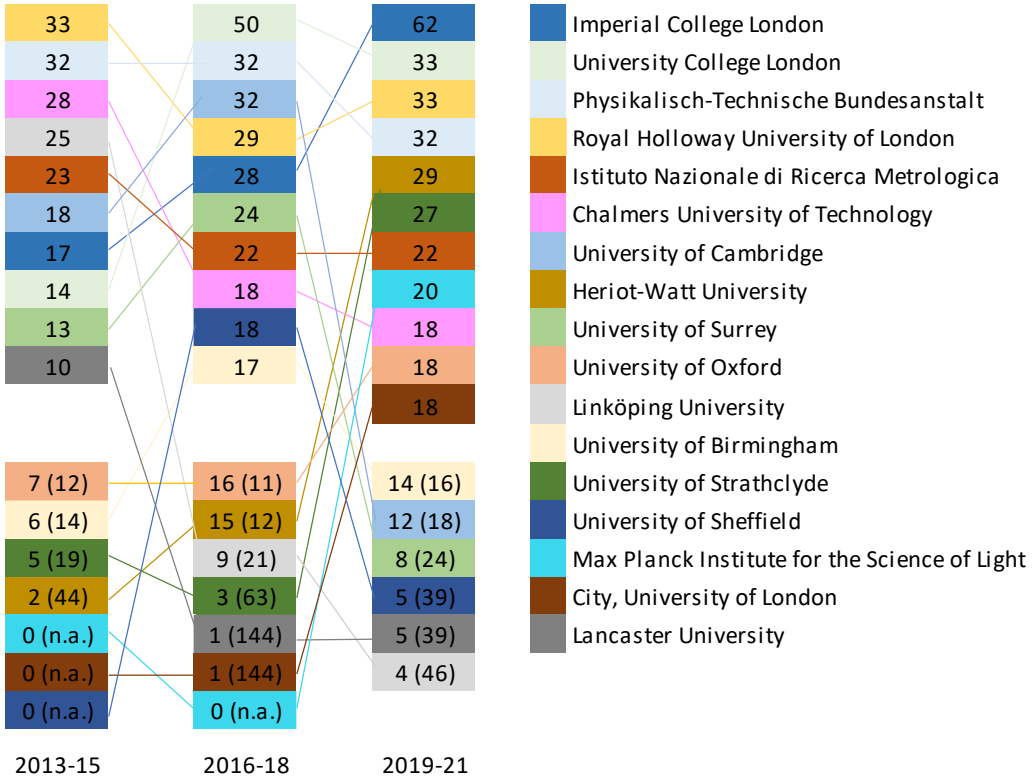
Collaborators in QT

Collaborators in ranked order over time periods*

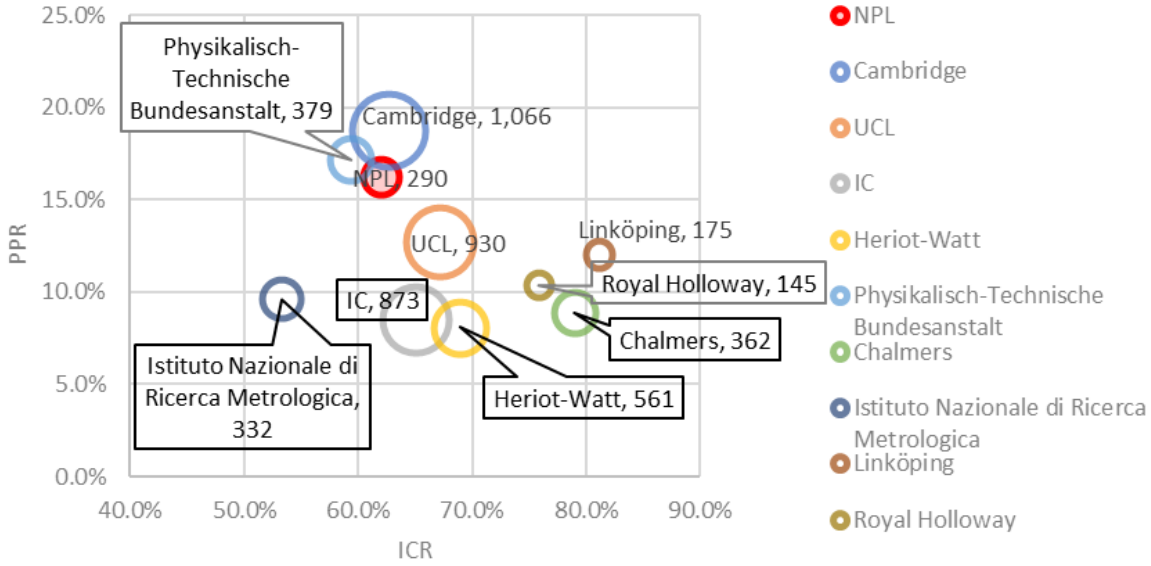
- Top NPL collaborators in 2019–2021 include Imperial College London, University College London, Royal Holloway University of London, Physikalisch-Technische Bundesanstalt and Heriot-Watt University.
- Note the sharp rise for Imperial College London (in 1st place in 2019-2021, with more than twice the number of QT co-publications with NPL than any other collaborator).
- University of Strathclyde also progressed markedly as an NPL collaborator in QT rising from 13th place in 2013-2015 to 6th in 2019–2021.



* Each of NPL's collaborators are presented in all three periods if they make the top 10 in at least one period. For the top 10 positions, the number of QT co-publications with NPL is indicated within each box. When a collaborator falls outside the top 10 in a given period, the actual rank was added in parentheses next to the number of co-publications.

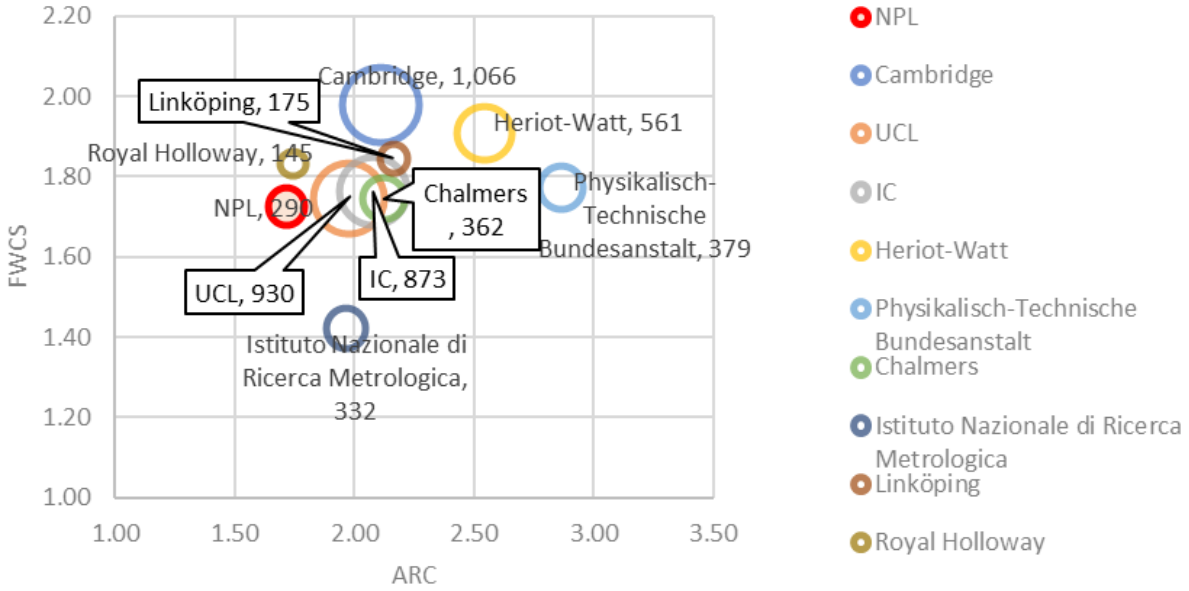
Collaborators – research performance in QT (2013-2021)

- Most of NPL's key collaborators have a bigger production in QT than NPL except the Linkoping and Royal Holloway.
- Among its key collaborators, NPL comes in the lower half in terms of int. coll. rate (ICR, 63%) which ranges from 59% to 81% across selected comparators.
- NPL's public-private coll. rate (PPR) is higher than for most of its collaborators except for the University of Cambridge and Phyikalisch-Technische Bundesanstalt.



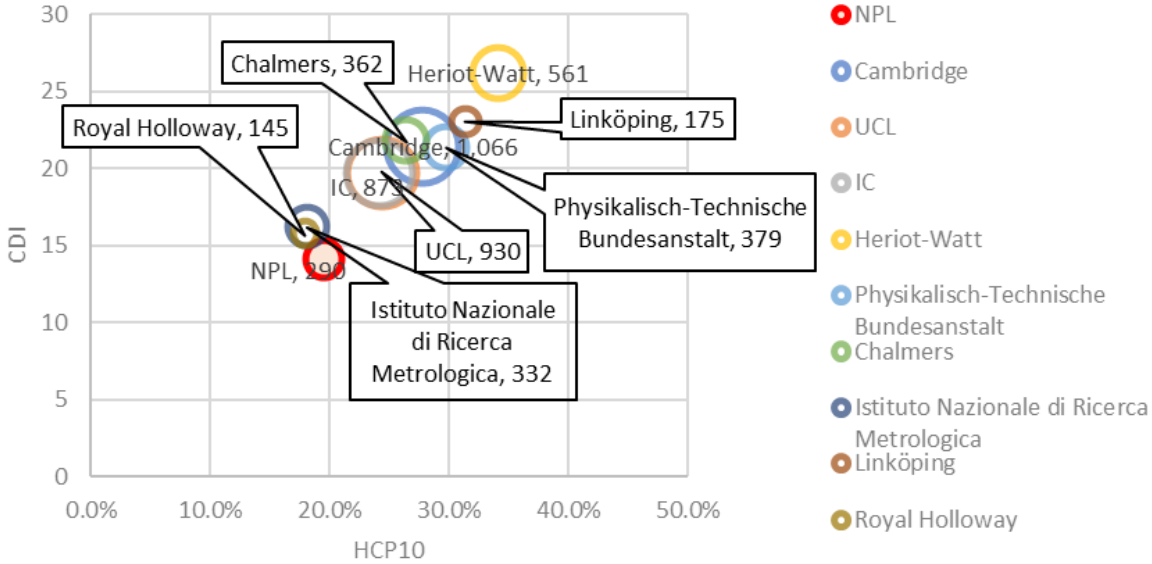
Collaborators – research performance (2013-2021)

- Compared to its key collaborators, NPL's ARC is the lowest and its FWCS is only higher than that of the Istituto Nazionale di Ricerca Metrologica.
- As such, NPL's collaboration likely have a very positive effect on its scientific impact in QT which is well above world level.
- Phyikalisch-Technische Bundesanstalt has the highest ARC while the University of Cambridge has the highest FWCS among all major collaborators.



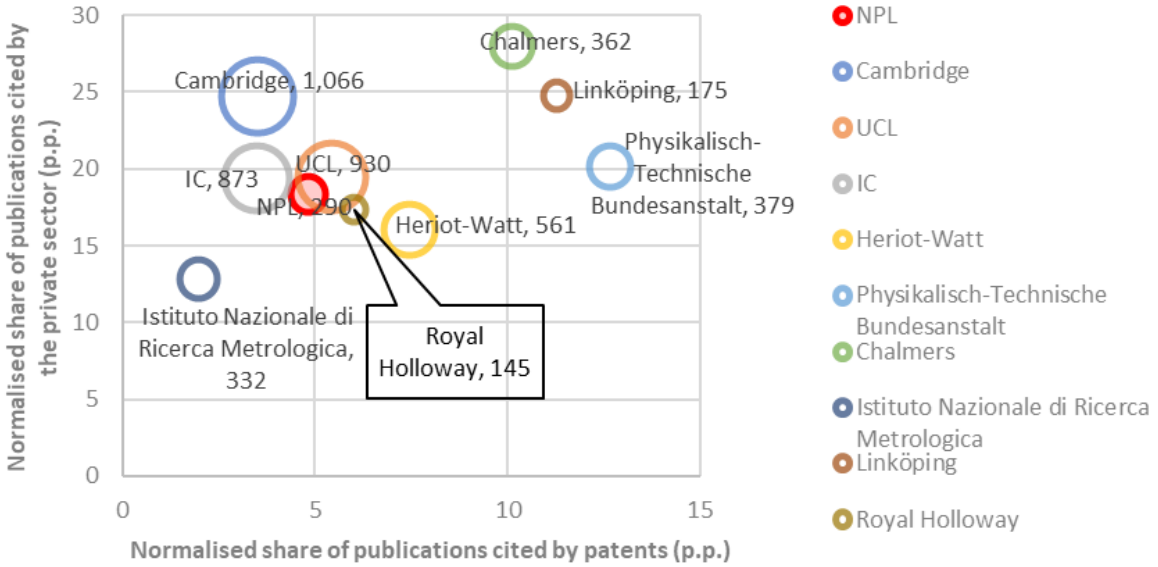
Collaborators – research performance (2013-2021)

- Similarly, to the ARC and FWCS, NPL scored lowest among its main collaborators in QT on HCP10 and CDI. This is not surprising as these four indicators are expected to correlate highly.
- Heriot-Watt University has the highest CDI and HCP10 among all major collaborators.



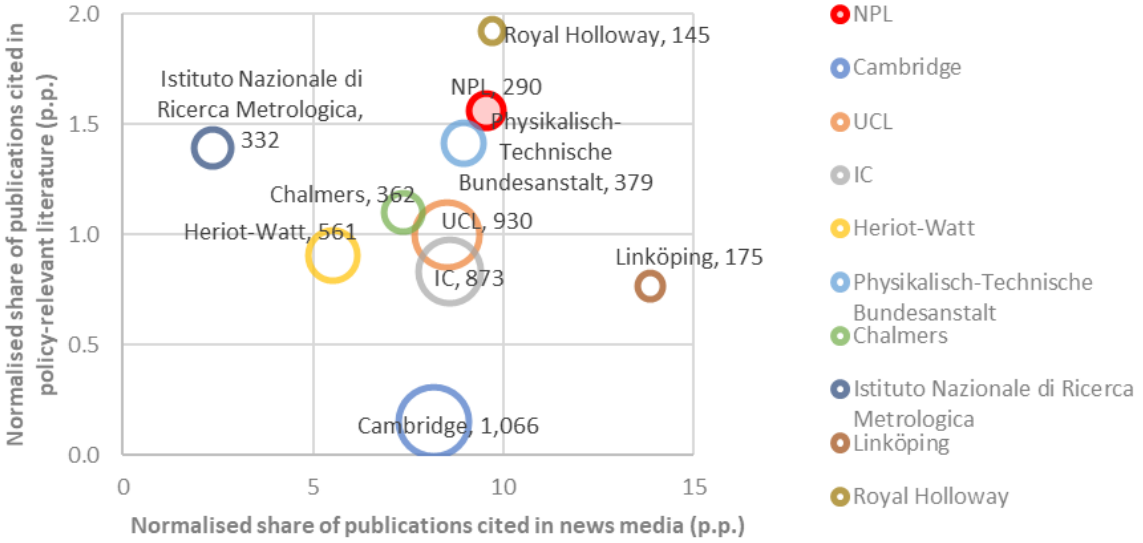
Collaborators – research performance (2013-2021)

- NPL is scoring near the bottom among its key collaborators both for uptake in patents and in private sector publications.
- Its uptake in patents is similar to that of other large contributors (Cambridge University and Imperial College London).
- On these dimensions, institutions that stand out most include Chalmers Univ of Tech, Linkoping University, and Phyikalisch-Technische Bundesanstalt.



Collaborators – research performance (2013-2021)

- Among its key collaborators, NPL is third for uptake in news media and second for uptake in policy citation.
- Linkoping University stands out on uptake in news media whereas Royal Holloway stands out in policy uptake.



Outline of presentation

- Introduction
- Methodology
- Findings:
  - Overall scientific performance of NPL's core QT departments
  - Comparative assessment of NPL in QT research relative to key comparators
  - Scientific performance of NPL's key collaborators in QT research
- Open discussion

Conclusion (Overall performance vs. comparators in QT)

- NPL's ICR and PPR in QT are higher than for other comparators (except relative to the UK for ICR where NPL was only slightly lower than the UK).
- Citation impact (in science and beyond (altmetric)) is lower than comparators but still higher than world average.

Conclusion (Trends vs. comparators in QT)

- QT research worldwide experienced a significant growth
  - The CAGR of QT publications is 6.3% and 5.5% in the World and UK respectively
  - NPL's CAGR is lower than it is for all other comparators
- Key findings on trend for other indicators
  - The scientific impact (based on ARC and HCP10) of comparators has mostly been decreasing over the past decade while it increased for NPL.
  - The normalized uptake in patents and news media increased more markedly for NPL than for its comparators in QT. As a consequence, NPL ranked second to NQTP in the most recent period (very close to EPSRC and UKRI) for patents. For news media, it scored first to NQTP from 2016–2018 to 2018–2020. In the last period, it was on par with NQTP.

Conclusion (Collaborators)

- NPL's key collaborators are from UK and other European countries
  - Imperial College London is the largest collaborator in terms of the number of co-publications
  - Physikalisch-Technische Bundesanstalt (Germany) is the largest collaborator outside UK
- Phyikalisch-Technische Bundesanstalt (Germany) performs better than other collaborators
  - 32 co-publications with NPL in each 3-yr period
  - Strong performance in collaboration, citation, innovation and policy (2nd in PPR, 1st in ARC, 1st in patent citation and 2nd in policy citation among selected collaborators)
- NPL's collaboration likely have a very positive effect on its scientific impact in QT which is well above world level

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Thank you!!!

19 April 2023