Edge Factors: Scientific Frontier Positions of Nations

Mikko Packalen
University of Waterloo

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Abstract

A key decision in scientific work is whether to build on novel or well-established ideas. Because exploiting new ideas is often harder than more conventional science, novel work can be especially dependent on interactions with colleagues, the training environment, and ready access to potential collaborators. Location may thus influence the tendency to pursue work that is close to the edge of the scientific frontier in the sense that it builds on recent ideas. We calculate for each nation its position relative to the edge of the scientific frontier by measuring its propensity to build on relatively new ideas in biomedical research. Text analysis of 20+ million publications shows that the United States and South Korea have the highest tendencies for novel science. China has become a leader in favoring newer ideas when working with basic science ideas and research tools, but is still slow to adopt new clinical ideas. Many locations remain far behind the leaders in terms of their tendency to work with novel ideas, indicating that the world is far from flat in this regard.

Keywords: science; novelty; impact factor; new ideas; idea adoption

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1. Introduction

Knowledge production is an increasingly global endeavor. In spite of robust increases in scientific production by the traditional leaders – including the United States, the United Kingdom, and Japan – their relative share has decreased in recent decades because the pace of growth in science by other nations – including China, South Korea, India, and Brazil – has been even more rapid (Freeman, 2013; National Science Board, 2016). The share of international collaborations has also increased, as has the share of citations to papers with foreign authors (Freeman, 2013, National Science Board, 2016). This spread of knowledge production has not been unexpected. It was anticipated long ago by Marshall (1920) that improved communication technologies would make it easier to learn about new discoveries regardless of location and that this would lead to the pursuit of creative work in more diverse places.

While this perspective suggests a diminishing influence for location in scientific work, location may in fact continue to have considerable import in science. This is because learning about which new ideas exist may not have been an important benefit of location for quite some time and because location likely still impacts the fertility of creative work in other important ways. Lucas (2004), for example, has emphasized the continuing dependence of knowledge production activities on location through the benefits that accrue from daily interactions with colleagues, the training environment, and ready access collaborators.

One potential remaining influence of location stems from the fact that when new ideas are first discovered, they are often raw and poorly understood. The ideas only gradually mature into useful advances after a community of scientists tries them out and develops them. But such work is hard, harder than work that builds on well-established ideas. One indication that work that tries out new ideas is indeed harder than more conventional science is that such work is linked with larger team size (Packalen and Bhattacharya, 2016). Thus, when a scientist seeks to build on a recent advance, it is beneficial to be surrounded by a community of scholars with whom to debate about which new ideas to try out and how (Marshall, 1920; Kuhn, 1962, 1977; Usher, 1929). Daily interactions with colleagues, the training environment, and ready access to potential collaborators thus become especially important in work that is close to the edge of the scientific frontier in the sense that the work builds on recent advances.

Because such local factors influence the fertility of the debates that seek to unlock the mysteries of new ideas, the tendency to work with new ideas can be expected to vary by location. This mechanism – and thus the import of location – may even be increasingly influential, for Jones (2010) shows that reaching the scientific frontier now involves even more work than before as evidenced by increases in training times, specialization, and teamwork.

Therefore, even as the pursuit of science spreads to more diverse places, location may well continue to have an important influence on *what kind of science* is pursued – through the impact that location may have on the ability to work with novel ideas. Identifying where barriers to knowledge adoption still exist is thus crucial for understanding the role of location in knowledge production and for designing policies that can help eliminate the remaining barriers.

We calculate each nation's propensity to publish biomedical work that is close to the edge of the scientific frontier in the sense that it builds on relatively recent ideas. The results reveal each nation's position on the scientific frontier: what share of its contributions to biomedical science build on relatively new ideas vs. well-established ideas. Our empirical analysis is focused on biomedicine because it is an important area of science and because of the availability of the Pubmed/MEDLINE database on over 24 million biomedical research papers.

We refer to our constructed measure of novelty as *the edge factor*. Whereas the familiar impact factor measures scientific influence (Garfield, 1955, 1972), the edge factor measures an aspect of novelty of scientific work – the tendency to build on ideas close to the edge of the scientific frontier. A common characteristic for these two measures is that for each entity they both quantify the average of a characteristic (rather than the total number of novel contributions or the total number of received citations).

We selected countries as the unit of analysis because borders continue to influence scientist interactions and because many important science policy decisions are set at the national level. However, similar to the impact factor, the edge factor too can be constructed also for many other units of analyses. For example, the approach can be utilized to evaluate the novelty of research published by a journal or institution. It can also be applied to analyze the novelty of individual scientists' publications and examine which scientist-level characteristics promote the trying out of new ideas. Furthermore, the edge factor can be utilized to compare to what extent funding agencies succeed in their often-stated aim of supporting novel work. The focus on countries in the present paper is thus just one possible application. But this focus is useful

because it provides way to utilize this concept – the edge factor – to shed light on a long-standing question about to what extent the spread of modern communication technologies has eradicated location-based barriers to the adoption of new ideas. At the same time, this application illustrates the potential of the edge factor in other contexts.

We emphasize that the impact factor and the edge factor capture distinct aspects of science – impact and novelty – regardless of the specific setting in which they are employed. Moreover, the edge factor and the impact factor are complementary tools in policy evaluation and design. For optimal science policy requires that both influence and novelty are rewarded. One reason why rewarding influence alone is not enough is that rewarding novelty directly helps solve a coordination problem that is inherent in the formation of a vibrant scientific community to a new area of investigation (Besancenot and Vranceaunu, 2015; Packalen and Bhattacharya, 2017). A singular focus on citation counts can lead to stagnant science because impact factors under-reward scientists who try out new ideas, thereby stifling work that helps ideas mature and makes more meaningful advances possible. Another related reason to reward novel work is that useful work that tries out a new idea need not be influential in the traditional sense; such work can have scientific value – in terms of helping unlock the mysteries of the new idea – even when it merely demonstrates which research paths do not work.

In recent decades, many – including the editor of *Science* (Alberts, 2013) – have raised alarm about the science community's obsession with impact factors. The obsession with impact may have already led to less healthy science, as the rise of citation metrics has coincided with a decline in the novelty of biomedicine (Rzhetzky et al., 2015). By using measures like the edge factor in conjunction with impact-based metrics, university administrators and funding agencies can strike a better balance between rewarding innovative but risky work that develops ideas early on and rewarding work that takes advantage of the ideas in their more mature stages. Making reward structures even slightly more favorable to scientific novelty would encourage scientists to pursue more innovative research paths and lead to healthier, less stagnant, science. To be sure, the edge factor is <u>not</u> meant to displace the impact factor. Instead, it is ideally used as a complementary metric that captures a different aspect of science.

As in the closest prior work (Packalen and Bhattacharya, 2017), the focus here is on the novelty of idea inputs, as opposed to the novelty of the combination of idea inputs. Novelty of combinations is a focus in several recent analyses (Wang et al., 2016; Lee et al., 2015; Rzhetzky

et al., 2015; Boudreau et al., 2016; Foster et al., 2015). Both foci come with their advantages, as discussed in Packalen and Bhattacharya (2017). The focus on the use of new ideas makes it possible to include on a larger number of ideas in the analysis than is computationally feasible in an analysis of combinatorial novelty. Analysis of the use of new ideas is also important because the trying out of new ideas is so central to scientific progress. For without new ideas science eventually stagnates – combinatorial novelty alone cannot overcome it.

Similar to the closest prior work (Packalen and Bhattacharya, 2017)., we use text analysis to determine the ideas that each paper built upon and also the vintage of those ideas. There are two main differences between the present study and this prior work. First, there is a shift in substantive focus – from ranking journals to ranking nations. Second, in the present approach the novelty of each contribution is allowed to depend not just on the vintage of ideas employed in it but also on what types of ideas they are. This is important because a paper that employs a 10-year old research tool may represent novel work but the same need not be true for a paper that examines a gene of the same vintage. This methodological innovation yields a more finely grained measurement of each entity's distance to the edge of the scientific frontier. Importantly, this methodological advance can be utilized in various applications beyond the present analysis.

2. Methods

In this section, we first describe the data sources (MEDLINE biomedical publications database, NLM Journal Categories, the UMLS Metathesaurus, and the MeSH vocabulary). In subsection 2.2 we explain why the analysis is focused on years 1988-2016, and in subsection 2.3 we explain why the location of each contribution is determined based on the first author's affiliation. In subsection 2.4 we explain how the research area of each contribution is determined.

In subsection 2.5 we explain how we use the UMLS metathesaurus to determine the ideas that each paper built upon and also how the vintage of each idea is determined. In subsection 2.6 we explain how we define a contribution (by determining links from each paper to each research area and each idea category), how we measure the idea category of each idea based on the UMLS metathesaurus, why the resulting contribution-level analysis is preferable to a paper-level analysis, and also how the novelty of each contribution is determined.

In subsection 2.7 we explain how the overall edge factor for each nation is calculated: we first determine the nation's edge factor separately for each (idea category, research area) pair based on all the nation's contributions linked to that pair; afterwards we calculate the nation's overall edge factor as a weighted sum of its edge factors across all (idea category, research area) pairs. Finally, in subsection 2.8 we explain how the approach developed here differs from the approach used in closest prior work.

2.1 Data Sources

2.1.1 MEDLINE Database on Biomedical Research Publications

Our source for information on scientific publications is the MEDLINE database (https://www.nlm.nih.gov/bsd/pmresources.html). MEDLINE is a comprehensive database on life sciences with a focus on biomedicine in particular. The database contains information on over 24 million journal articles.

For each journal article in MEDLINE, we make use the following variables: publication year, affiliation of the first author, text of the title and abstract, journal where the article was published, and MeSH keywords. The acronym "MeSH" stands for *Medical Subject Headings*; the MeSH vocabulary is a controlled vocabulary of over 87,000 terms (https://www.nlm.nih.gov/mesh/). Publications in MEDLINE indexed with MeSH keywords; we use the MeSH keywords to determine article type (we focus the analysis on original research articles) and whether an article represents applied or basic science (section 2.4).

2.1.2 Broad Subject Terms for MEDLINE Journals

Our source for the research area of each article is the broad subject terms that are assigned by the National Library of Medicine for journals in the MEDLINE database (https://wwwcf.nlm.nih.gov/serials/journals/index.cfm). We show further below how articles in the MEDLINE database are distributed across the journal categories in this database (section 2.4).

2.1.3 Unified Medical Language System (UMLS) Metathesaurus

As our source for information on which words and word sequences represent meaningful concepts in biomedicine and which concepts are synonyms, we use the 2017 version of the Unified Medical Language System (UMLS) metathesaurus (https://www.nlm.nih.gov/research/umls/). The UMLS metathesaurus links over 5 million terms that appear in one or more of over 150 medical vocabularies.

In addition to determining the synonyms for each term, the UMLS database assigns each term to one or more of 127 semantic types (https://semanticnetwork.nlm.nih.gov). We use the semantic type of each term to represent the idea category of the term (section 2.6.1). Further below we list examples of ideas and idea categories captured by this approach (section 2.6.2).

2.2 Sample of Papers

When we determine the vintage of each idea (section 2.5.2), we use the sample of all papers in the MEDLINE database. By contrast, when we calculate for each location its propensity to publish novel work, we limit the sample of papers in several ways. First, we limit the analysis to original research papers, thereby excluding editorials, reviews, etc. However, in a robustness analysis, we include all papers in the sample. Second, we limit the analysis to papers published during 1988-2016. This is because the coverage for affiliation data in the MEDLINE database begins in 1988. Third, we limit the analysis to papers for which the available text on the title and the abstract of the article in the database includes at least 200 characters and no more than 5000 characters. However, in a robustness analysis, we conduct the analysis without this character limit. The number of articles that are included in our main specification is shown by publication year in Figure S1 (Web Appendix).

2.3 Country of Each Scientific Publication

We assign each paper to a country based on the affiliation string for the first author of the paper. We limit the analysis to first authors because for most papers published before 2014 the affiliation information in MEDLINE is limited to the first author of each paper. Figure S2 (Web

Appendix) shows by publication year the share of papers that we were able to match to a country. For ease of exposition we limit the number of locations by combining some countries that publish a smaller number of biomedical publications to regions. Figure S3 (Web Appendix) shows the share of papers by location (country or region) and time period.

2.4 Journal Categories and Journal Category Groups

We use the journal categories (Broad Subject Terms) to represent the research area of each paper. On average, each original research article published during 2015-2016 is linked to 1.49 journal categories. Table S1 (Web Appendix) shows the distribution of links from papers to journal categories during this time period. As is discussed in detail further below (section 2.6.1), papers from journals that are linked to multiple journal categories are considered to have contributed to multiple research areas.

In our main specification, all journal categories are included in the analysis. In secondary analyses, we conduct three separate analyses – each limits the analysis to one of the following three groups of journal categories: "Applied", "Basic Science", and "Other (Both Applied and Basic Science)".

To conduct these secondary analyses, we assign each journal category to one of the three journal category groups. Here we make use of the MeSH keywords affixed to each MEDLINE article and the "A-C-H" model (Weber, 2014) that classifies papers along the translational axis based on the MeSH keywords. Specifically, using the MeSH codes we first determine each paper's position on the translational axis as specified by the A-C-H model: "H status" (human) is assigned to papers with either the MeSH code B01.050.150.900.649.801. 400.112.400.400 (Human) or the Mesh code M01 (Person), "C status" (cells and molecules) is assigned to papers with any of the following MeSH codes (or codes that appear in the MeSH subtrees of these MesH codes): A11 (Cells), B02 (Archaea), B03 (Bacteria), B04 (Viruses), G02.111.570 (Molecular Structures), and G02.149 (Chemical Processes), and "A status" (animal) is assigned to papers with the MeSH code B01 (Eukaryota) and papers with any of the codes in the subtree of this MeSH code B01 except the aforementioned MeSH code for "Human".

We thus construct three separate indicator variables ("H status", "A status", "C status"). In the A-C-H model, papers with "H status" have an applied aspect to them, and papers with

either “A status” or “C status” have a basic science aspect to them. More than one of these indicator variables will be positive for papers that have both an applied and a basic science aspect to them.

For each journal category, we next calculate the average of each of these three dummy variables (“H status”, “A status”, “C status”) among all papers linked to that journal category. Denoting these variables as “Average H status”, “Average A status”, and “Average C status”, we use them to classify journal categories to three journal category groups as follows. Journal categories that satisfy conditions “Average H status > Average C status” and “Average H status > 0.2” are assigned to journal category group “Applied”. Journal categories that satisfy “Average H status < Average C status” and “Average A status < 0.8” and “Average C status > 0.5” are assigned to journal category group “Basic Science”. (We thus exclude journal categories that focus heavily on veterinary medicine from this category even though such journal categories are located early along the translational axis in the A-C-H model; this happens in the A-C-H model because the model does not distinguish between veterinary medicine and animal studies as precursor to human medicine). The remaining journal categories are assigned to journal group category “Other (Both Applied and Basic Science)”. The result of this approach for determining the journal category group of each journal category is shown in the last column of Table S1.

2.5 Identifying Ideas and the Vintage of Ideas

2.5.1 Using the UMLS metathesaurus to identify ideas from text

We employ text analysis to discern which ideas each research paper built upon. We treat each of the 5+ million terms in the comprehensive United Medical Language System (UMLS) metathesaurus as representing ideas. To identify which of these ideas each research paper in the MEDLINE database built upon, we search the title and abstract of each publication for all the terms in the UMLS metathesaurus.

Thus, the first step in the text analysis is to determine for each article in the MEDLINE database which UMLS terms appear in it. Further below we also show a list of examples of ideas identified by this approach (section 2.6.2).

2.5.2 Calculating the vintage of each idea

The vintage of the idea represented by a UMLS term is determined based on how long ago the UMLS term was first mentioned in a biomedical research paper. We interpret the mention of a relatively new term as indicative of work that builds on ideas close to the edge of the scientific frontier. We refer to the year of first appearance of a term as the cohort year of the term. In a robustness analysis, we set the cohort year of each term as the earliest year the UMLS term or any of its synonyms appears in the MEDLINE data (synonyms are determined based on the synonym information in the UMLS metathesaurus). The results from this robustness analysis show that our results are not driven by relabeling of old ideas.

Because of the sparsity of publications in MEDLINE with a publication year before 1946, the cohort year of ideas (i.e. the year of first appearance) does not reflect the ideas' true vintage well for ideas that are new to biomedicine before 1950. Thus, we exclude from the analysis all terms with cohort before 1950.

Further below we show examples of cohort years assigned to terms using this approach (section 2.6.2).

2.6 Contribution-Level Analysis

2.6.1 Defining a contribution as a link from a paper to an (idea category, research area) pair

In determining the novelty of biomedical work, we seek to control for the idea category of each idea. Thus, we aim to compare the use of novel ideas against the use of more established ideas from the same idea category. The rationale for seeking to control for the idea category is the following: how recent ideas should be considered novel depends on what type of an idea it is. For example, a paper that employs a 10-year old research tool may represent novel work but the same need not be true for a paper that examines a gene of the same vintage.

To control for the idea category in the present analysis, we take advantage of the fact that the UMLS metathesaurus classifies terms to 127 semantic types (these are listed further below in section 2.6.2). We treat each of these UMLS semantic types as representing one idea category.

We make use of these idea categories as follows. After determining which UMLS terms are mentioned in each paper, we determine which UMLS categories are represented by these terms. We then treat a paper that mentions terms from K different idea categories as K separate contributions. The underlying assumption in this approach is that work that mentions at least one idea from an idea category advances our understanding of how ideas from that idea category work. Thus, work that mentions ideas from multiple categories advances our understanding on multiple dimensions; hence we treat it as multiple contributions.

Table S2 (Web Appendix) shows the number of links to each idea category from papers published during 2015-2016. As was mentioned above in section 2.5.2, we only include in the analysis those terms that have cohort year 1950 or later.

In our main analysis, we calculate the overall edge factor based on links to any of the 127 idea categories (the edge factor is an average across all idea categories). In a secondary analysis, we calculate the edge factor separately for each of the following four groupings of idea categories: "Clinical and Anatomy", "Drugs and Chemicals", "Basic Science and Research Tools", and "Miscellaneous". To conduct this analysis, we link each idea category to one of these four idea category groups. The last column of Table S2 shows which idea category belongs to which idea category group. This secondary analysis reveals for each country whether any barriers to new idea adoption are limited by to certain types of ideas. The decision to link each of the 127 idea categories to one of four groups was made for expositional purposes – it implies that for each country we must report four separate numbers.

What kind of work should be considered novel is likely to depend also on the research area. For example, use of a 10-year old research tool may be novel work in public health research but not in biotechnology research. To address this issue, we also determine the links from papers to research areas. We use the National Library of Medicine (NLM) journal categories as proxies for research areas (these journal categories were listed in section 2.4, Table S1).

Thus, after determining the ideas mentioned in each paper, we determine which idea categories are linked to these ideas as well as which research areas are linked to the journal where the paper is published. We define a *contribution* as an (idea category, research area) pair linked to a paper.

In our approach, a paper is considered to contribute to our understanding of all the (idea category, research area) pairs linked to it. A paper can make multiple contributions, depending on how many (idea category, research area) pairs are linked to it. A paper that mentions ideas from K idea categories, and is published in a journal that is linked to J journal categories, is treated as K*J separate contributions.

Note that a paper that mentions multiple ideas from an idea category results in the same number contributions as a paper that mentions only one idea from the idea category.

The number of links listed in the second column of Table S1 is the number of links to (idea category, research area) pairs associated with each research area. Similarly, the number of links listed in the second column of Table S2 is the number of links to (idea category, research area) pairs associated with each idea category. On average, each paper published during 2015-2016 is linked to linked to 6.26 (idea category, research area) pairs. Therefore, in our approach each paper is, on average, counted as 6.26 contributions.

A limitation of the approach pursued here is the inherent assumption that, synonyms aside, all ideas within an idea category are treated as though they are equally close to one another although in reality some are closer than others. Similarly, all ideas within a category are treated as though they are equally distance is the same to all ideas outside the idea category. A potentially important direction for future work is to explore a more fine-grained approach that either calculates a pairwise between each idea category or calculates a pairwise distance between each idea.

When determining whether a contribution represents novel work, we only consider the age of the newest term linked to the (idea category, research area) pair from the paper in question. Researcher's choice is between using any new ideas or only well-established ideas from this idea category. This is discussed in more detail next.

2.6.2 The novelty of a contribution

Above we defined a contribution as a link from a paper to an (idea category, research area) pair; these links are inferred from the UMLS terms that appear in the title and abstract of the paper. The novelty of each contribution is determined in three steps.

Step 1. Age of each UMLS term that links a paper to the (idea category, research area) pair. First, for each contribution associated with a paper, we determine the age of each term that links the paper to the (idea category, research area) pair in question. Age of each term is calculated by subtracting the cohort year of the term from the publication year of the paper.

Step 2. Age of the newest UMLS term that links a paper to the (idea category, research area) pair. Second, for each contribution we determine the age of the newest term that links the paper to the (idea category, research area) pair. We refer to the cohort year of the newest term that links a paper to the (idea category, research area) pair as the cohort year of the contribution.

Step 3. Novelty of the contribution relative to other contributions to the (idea category, research area) pair among papers published in the same year. The relative novelty of a contribution is then determined by comparing the vintage of the contribution to the vintages of all the other contributions linked to the same (idea category, research area) pair, among papers published in the same year. The interpretation is that a paper that links to an idea category reflects a choice faced by a scientist: one can choose work with at least one relatively new idea from this idea category, or one can choose to work with only well-established ideas from this idea category. The comparison is also limited by research area because whether the use of an idea represents novel work is expected to depend on the context where it is used. The reason for limiting the comparison to papers published in the same year is obvious: because the rate of scientific progress need not be the same over time, the use of a 10-year old research tool may represent novel work in one year but not in some other year.

Having determined all contributions linked to an (idea category, research area) pair among papers published in the same year, we order the contributions based on their vintage (age of the newest term linked to that (idea category, research area) pair from each paper). We then construct an indicator variable that captures the relative novelty of each contribution: in our baseline specification, contributions that are in the top 5% based on their vintage are considered novel work (the indicator variable is 1 for such contributions and 0 otherwise). In robustness analyses, we construct the indicator variable using alternative choices for the cutoff percentile (top 1%, top 5%, or top 20%). Figure S4 (Web Appendix) shows the distribution of the cohort of *all* contributions based on papers published during 2015-2016. Figure S5 (Web Appendix) in turn shows the distribution of cohort of *novel* contributions when novelty of a contribution is determined based on the top 5% status and also the when novelty of a contribution is determined

based on one of the alternative cutoffs (top 20%, top 10%, or top 1%). When the top 5% cutoff is used, then for all post-2004 cohorts the majority of contributions with that cohort are deemed novel by our approach, and for all pre-2004 cohorts at most a minority of contributions are deemed novel by our approach.

Table S3 (Web Appendix) shows examples of ideas, as represented by UMLS terms, captured by our approach. The table also shows the idea category of each term. Some terms appear multiple times because these terms are linked to multiple UMLS categories by the UMLS metathesaurus. As in related prior work (*15*), the list of terms shows that the approach used here captures ideas that are widely recognized to have been important inputs in biomedical work in recent decades (for expositional reasons the list is focused on popular ideas – there are of course also many unpopular, less important ideas that are captured by our approach) and that for most terms the cohort year assigned to the term reflects the era when the idea represented by the term entered biomedicine.

2.7 Calculation of the Edge Factor

2.7.1 Novelty of a nation's contributions linked to a specific each (idea category, research area) pair

Normalization of contribution-level novelty indicators. Having determined the contributions of each paper (i.e. which (idea category, research area) pairs are linked to from each paper) and which contributions are novel (i.e. which contributions have the top 5% status based on their vintage), we next normalize the novelty variable within contributions to each (idea category, research area) pair so that the average of the normalized novelty variable is 100 within each (idea category, research area) pair. In implementing the normalization, we combine data from multiple years. For example, in our main specification we combine data from 2015-2016.

Location-level novelty scores for each (idea category, research area) pair. Using the normalized contribution-level novelty variable, we then calculate for each location its propensity for novel work within each (idea category, research area) pair. That is, for each location we calculate the mean of the normalized novelty variable based on all of the location's contributions linked to a specific (idea category, research area) pair. We refer to each such average of the

novelty variables as the edge factor of the location for the specific (idea category, research area) pair. An edge factor above (below) 100 indicates an above (below) average tendency for work that builds on relatively novel ideas. In our main specification, these edge factors are calculated based on papers published during 2015-1016.

2.7.2 Calculating the overall edge factor

Having determined the relative novelty of each location's contributions separately for each (idea category, research area) pair – the location's edge factor for that (idea category, research area) pair – we construct the overall edge factor for each nation as a weighted sum of these (idea category, research area) pair specific edge scores.

Weights. In our main specification, we use as weights the frequency at which each (idea category, research area) pair is encountered in biomedicine. In other words, the weight of an edge factor for an (idea category, research area) pair is the total number of papers linked to it from any location during the time period.

A justification for selecting these weights is that those (idea category, research area) pairs that are encountered more often in biomedicine are, by revealed preference, considered more important by scientists. The ability to pursue cutting-edge work in an often-encountered (idea category, research area) pair is thus arguably more valuable than is the ability to pursue cutting-edge work in a rarely encountered (idea category, research area) pair. The implicit assumption in this approach is that, even though it is not yet known which (idea category, research area) pairs will be the most important sources of future progress in biomedicine, the past is the best predictor of the future.

Because the overall scientific frontier position for a nation (the edge factor) is calculated as a weighted sum over its position across all (idea category, research area) pairs, the resulting measure for the nation reflects its overall capability across all of biomedicine, as opposed to only the nation's capabilities in areas where it has concentrated most of its own activities. Accordingly, the edge factor is high only if the country has significant capabilities across different areas of biomedicine; expertise in a narrow subset of biomedicine is not enough.

However, in a secondary analysis we show that the results are robust to the case when the edge factor is calculated using as weights each country's own number of papers that link to a

given (idea category, research area) pair. Hence, the results from this alternative specification reflect the novelty of the work actually pursued by the nation – emphasizing more the novelty of the nation's work in areas where it publishes a lot – rather than the nation's capabilities across all of biomedicine.

Cells with missing observations. Not all locations have publications linked to every (idea category, research area) pair. The results are mainly insensitive to how such missing cells are handled. One reason for this is that while there are 13,394 (idea category, research area) pairs with positive weights, the 3,000 largest (idea category, research area) pairs as measured by their weight account for the vast majority (82%) of the total weight with most of them large enough for also the small and mid-sized nations to be active in them. In our main specification, we handle the cells with missing observations by replacing the nation's edge factor for that cell with the nation's weighted average across the other cells (those (idea category, research area) pairs for which the location does have publications linked to it). The weights used in this calculation are the same weights as discussed above. In an alternative specification, we replace cells with missing edge scores with 0 (the worst possible edge score). In another alternative specification, we replace cells with missing edge scores with 100 (by definition the average novelty score for every (idea category, research area) pair). In both cases the results are similar to the results for the main specification (see section 3.2).

2.8 Comparison of the Approach with the Approach Used in Closest Prior Work

The approach employed here has two main differences with the closest prior work (Packalen and Bhattacharya, 2017). In addition to the shift in substantive focus – from ranking journals to ranking nations – the present analysis is conducted at the contribution-level, with contribution defined as a link from a paper to an (idea category, research area) pair. By contrast, in this prior work, the analysis was conducted at the paper-level. That is, here the novelty score for an entity is calculated first at the contribution-level separately for each (idea category, research area) pair and the overall novelty score for the entity is then calculated as a weighted sum across these each (idea category, research area) pairs. By contrast, in the prior work (Packalen and Bhattacharya, 2017) the novelty score for an entity was calculated at the paper-level either without controlling for either the idea category or the research area, or by only controlling for the research in a

manner that essentially uses as weights the entity's own involvement in the research area (in this prior work the research area was determined based on the appearance of 6-digit MeSH terms; the entity of interest in this prior work was a journal, here it is a nation).

The advantage of the approach pursued in the present analysis is thus not only that the present approach controls for the idea category but also that the present approach uses as weights the (idea category, research area) pair's overall importance in biomedicine (as measured by the total number of contributions linked to it). This yields a better reflection of an entity's capabilities in biomedicine compared to the case when the weights represent the distribution of the entity's own involvement across different areas of biomedicine.

3. Results

3.1 Main Results

Figure 1 shows the edge factor for each nation based on papers published during 2015-2016. The edge factor is normalized so that the average edge factor across all contributions is 100. An edge factor of 110 for a nation indicates that on average the nation's contributions build on relatively new ideas 10% more often compared to the average contribution in the same research area. Markers drawn in red (blue) indicate edge factors that are well above (well below) average. Markers drawn in gray indicate edge factors that are approximately average.

The results show that the United States and South Korea have the most advanced positions on the scientific frontier: scientists working in these nations build on cutting-edge ideas more often than do scientists in other locations. The propensity for novel science is well above average also in Singapore and Taiwan. Countries that come after these four countries have approximately average propensity for novel science. Such countries include China, Canada, most western European countries (including the United Kingdom and Germany), Australia, and South Africa. Other countries (including Turkey, India, Brazil, and Iran) come further behind – scientists in these countries have clearly below average propensities for novel work.

Confidence intervals and results for alternative specifications (shown in Table S4 (Web Appendix) and discussed in detail below in subsection 3.2) indicate that in most cases these

results are robust. The one exception is Saudi Arabia, for which results from alternative specifications suggest a below average tendency for novel work.

Countries examined here thus have quite different propensities for work with newer ideas in biomedicine. This indicates that location continues to exert considerable influence on what kind of science is pursued. Furthermore, even developed nations are not on an equal footing in the pursuit of novel scientific work: in some developed nations scientists take advantage of opportunities created by the arrival of new ideas much more often than do scientists in other nations.

Figure 2 shows the change in the edge factor for each nation from the 1990s to present. South Korea, Taiwan, and China have leapfrogged most developed nations. Whereas the United States is still among the leaders, the relative positions of Switzerland and the United Kingdom are less advanced now than they were in the 1990s. Overall some convergence appears to have taken place as the lagging nations are no longer as far behind the leaders. This suggests that the world of ideas may have become somewhat flatter. Analysis of the edge factor by 5-year time periods (shown in Table S5 (Web Appendix)) indicates that most changes that occur are persistent. The changes thus reflect systematic changes in capabilities rather than merely year-to-year random variations.

In our approach, we compare each contribution only to other contributions that use ideas from the same idea category and are linked to the same research area (the 127 idea categories include "Amino Acid, Peptide, or Protein" and "Pharmacologic Substance"; the 125 research areas include "Biochemistry" and "Neoplasms"; see Table S1 and Table S2 for the full lists). Table 1 shows the edge factor separately for four groupings of idea categories: "Clinical and Anatomy", "Drugs and Chemicals", "Basic Science and Research Tools", and "Miscellaneous", and for three groupings of research areas: "Applied", "Basic Science", and "Other (Both Applied and Basic Science)".

For most nations, the edge factor is similar across these groupings, suggesting that the pursuit of novel work is generally dependent on capabilities that some countries possess but others lack. One important exception is China. China's contributions linked to the idea category grouping "Basic Science and Research Tools" now have the second highest propensity for novel work (after Singapore), but its contributions linked to idea category groupings "Clinical and Anatomy" and "Drugs and Chemicals" are well below average in terms of their novelty. This

result serves to highlight an important feature of our approach: it can be used to reveal not just whether a nation is facing barriers in new idea adoption but where in the idea space those barriers lie.

While in Table 1 we divided papers to just three groups based on their research area (i.e. basic, applied, and other), it is important to note that the restriction to just three bins on this dimension was made for expositional purposes. The edge factors can also be reported separately for each of the 125 research areas (listed in Table S2). For example, funding agencies could use such field-level analyses of novelty across to determine in which scientific fields their own country is closest to the frontier and use this information (in conjunction with other relevant metrics) when deciding where to allocate limited research dollars.

3.2 Confidence Intervals and Results from Alternative Specifications

Table S4 (Web Appendix) shows the confidence intervals and results from a variety of alternative specifications. For ease of comparison, the results from the main specification are reported again in column (1d).

Confidence intervals reported column (1e) are constructed using a bootstrap method. We first generate each of 1000 artificial samples by re-sampling with replacement from the (idea category, research area) pairs until the total weighted number of observations (i.e. contributions) in each constructed sample is at least as large as the total weighted number of observations is in the original sample. Next, we calculate the edge factor for each nation in each constructed artificial sample. We then eliminate the largest 2.5% and the smallest 2.5% of the values in the edge factor distribution for each nation among these constructed bootstrapped samples. The extremes of remaining edge factor values form the 95% confidence interval for the edge factor of each nation.

The calculated confidence intervals indicate that scientists in the four top nations are clearly above average in their propensity to use new ideas, that scientists in most developed nations have approximately an average propensity to use new ideas, and that scientists in developing nations have a below average propensity to use new ideas.

The analysis reported in column (2) differs from the main specification in terms of how those (idea category, research area) pairs are treated for which a nation has no contributions

linked to it: now the edge factor for such (idea category, research area) pairs are replaced with 0, reflecting the most pessimistic scenario about the nation's capabilities for that (idea category, research area) pair. By contrast, in the main specification these missing observations are replaced with the average edge score for the nation for (idea category, research area) pairs for which the nation does have observations. Comparison of the main results (column 1c) against the results in column (2) shows that while the edge factor decreases somewhat for the smaller nations (as expected), the results remain qualitatively unchanged. The fact that regardless of the approach the nations near the top of the rankings included also smaller and medium sized nations (in terms of their scientific output, as indicated by Table S3), and the fact that some larger countries are far down in the rankings (most notably India), demonstrate that the results are not driven solely by the size of a country's scientific workforce.

The analysis reported in column (3) differs from the main specification in how the weights for the edge factor for each (idea category, research area pair) are calculated. Here, for each country the weight for an (idea category, research area) pair is the country's own total number of research publications linked to the same (idea category, research area) pair. Thus, the overall edge factor is the same as the average of the nation's novelty scores across all of its contributions. By contrast, in the main specification weight for each (idea category, research area) pair is the same for all nations: it is the total number of papers linked to that (idea category, research area) pair. Comparison of the main results (column 1) against the results reported in column (3) shows that the results are robust to this alternative specification.

The analyses reported in columns (4-6) differ from the main specification in that the dummy variable indicating novelty of a contribution is now constructed using top 20%, top 10% and top 1% cutoffs. By contrast, in the main specification this dummy variable is constructed using the top 5% cutoff. Comparison of the main results (column 1) against results reported in columns (4-6) indicates that while the main results are qualitatively robust – leaders do better than laggards regardless of the measure – the relative position of the United States improves as one moves to a narrower cutoff (from 5% to 1%) and China's relative position improves when one moves to a wider cutoff (from 5% to 10% and 10% to 20%). A possible explanation is that countries may differ in terms of how many of their institutions are on the very edge of the frontier ("the bleeding edge"), so that some countries to fare better when novelty is calculated based on a narrower measure. For example, the U.S. may have many of the very top institutions

in the world (in terms of their tendency to work with new ideas) but most of its institutions may be further down in the pack. In another country, such as China, institutions may be more homogenous in terms of the scientists' tendency to work with new ideas. The differences may also be driven by variation in where the new ideas are first born (the United States may be disproportionately the origin of new ideas – and thus receive a disproportionate share of the very first mentions of new terms – but scientists working in China may be relatively more eager to build on the new ideas).

The analysis reported in column (7) differs from the main specification in that now the cohort of each UMLS term is the year of the earliest mention of that term or any of its synonyms, with synonyms specified by the UMLS. In contrast, in the main specification the cohort year is the year of the earliest mention of the term itself. Comparison of the main results (column 1) against the results reported in column (7) shows that the conclusions from the main specification are robust in this way as well.

The analysis reported in column (8) differs from the main specification in that the analysis now includes all publications in MEDLINE as opposed to only regular research articles. The analysis reported in column (9) in turn differs from the main specification in that the analysis now includes also publications for which the text information on the title and abstract is less than 200 characters or more than 5000 characters – in the main specification such publications were excluded from the analysis. Comparison of the main results (column 1) against the results reported in columns (8) and (9) show that the results are robust also to these alternative specifications.

4. Discussion

While our results show that differences persist even among developed nations in their propensity to work with new ideas, the results do not reveal the specific mechanisms driving these differences. One potential driver of these cross-locational differences stems from the difficulty of working with new ideas. Because novel science is harder than conventional science, novel science is more dependent on interactions with colleagues. The fertility of these scientist interactions depends on factors such as the extent of complementary tacit knowledge that is

embedded in people and is transferred to others in meetings (Lucas 2004; Lucas and Moll, 2014). Cross-national variation in the extent and depth of human capital investments can thus lead to cross-national variation in the tendency to adopt new ideas.

Of course, not all fruitful interactions are limited by location, as is evidenced by the fact that a quarter of science now involves international collaborations (Freeman, 2013; National Science Board, 2016). However, the rise of long-distance collaborations can also be a source of cross-national differences in new idea adoption: a nation can gain an advantage if its scientists can form distant collaborations relatively easily. In this regard, China's special relationship with the United States in science (Freeman and Huang, 2015) has likely helped propel it to the scientific frontier. An important topic for future work is to explore to what extent Chinese scientists working at the frontier started their work in the U.S. This link would potentially have major implications for other nations that are seeking to advance their position relative to the scientific frontier. A related topic worthy of future exploration is quantifying to what extent national borders still limit collaboration opportunities and what are the implications of collaboration barriers for each country in terms of the novelty of its scientific output.

Willingness to try out new ideas can vary by location also due to differences in scientist demographics. For example, given that early-career scientists are the most likely to work with new ideas (Packalen and Bhattacharya, 2016), and given that the increase in the extent of science in China is so recent and thus many of its scientists are early on their careers, the novelty of science in China may be driven in part by the youth of its scientists. Cross-national differences in new idea adoption and China's remarkably ability to leapfrog in this regard may also be driven in part by differences in incentives to pursue novel work: it has long been understood that nations without vested interests in existing technologies have an elevated incentive to explore new ideas (Brezis et al., 1993; Mokyr, 1994). Some of the variation in new idea adoption can also be driven by variation in where the ideas are first born, and by remaining delays in the spread of awareness about which new ideas exist.

Our results are consistent with findings from Hidalgo and Hausman (2009) which measured the complexity of each country's production structure based on its exports and found large differences in the capabilities of nations. Their analysis was motivated by the idea that each nation's capabilities determine the input varieties that it can fruitfully use in production. Our work, by contrast, is motivated by the idea that capabilities determine whether a nation's

scientists can take advantage of the opportunities created by the arrival of new ideas. Moreover, whereas in this related work the complexity of goods production is measured indirectly based on exports, the edge factor is calculated directly based on the measured idea inputs. Common to these analyses is the belief that the capabilities of a nation affect which inputs it uses and both analyses are aimed at constructing new measures that reflect those capabilities.

Our finding that nations continue to differ in their ability to pursue novel science is in line with cross-country comparisons of scientific impact as measured by citations (Freeman, 2013; National Science Board, 2016). The ability to take advantage of scientific opportunities continues to vary across locations in spite of the "death of distance" phenomenon, because locational differences in capabilities persist as shown by Jones et al. (2008), Agrawal and Goldfarb (2008), Ding et al. (2010) and Packalen and Bhattacharya (2015).

But some aspects of our results also differ from the results obtained through traditional analyses of scientific productivity. Data on the tendency to produce highly cited papers point to the United States as a leader that remains far ahead of most western European nations and even further ahead of South Korea, Taiwan and China (Freeman, 2013; National Science Board, 2016; Freeman and Huang, 2015; Bornmann et al., 2017; Yu et al., 2014). Our analysis on the use of new ideas, by contrast, suggests that South Korea, Taiwan and China have caught up with western Europe and are now close to the United States in terms of their tendency to work with cutting-edge ideas. Moreover, we find that China is now a leader in favoring newer ideas when working with new basic science ideas and research tools.

The finding that some countries are among the leaders in terms of their edge factor but lag in terms of their impact is not surprising. Prior studies have found novelty and impact to correlate only imperfectly (Packalen and Bhattacharya, 2017; Wang et al., 2016; Lee et al., 2015). Moreover, work on an idea early – when the idea is still raw – may well have less impact than work that builds on more established ideas which properties are better understood. The early work on the idea is still crucial: it helps the idea develop and thus makes more significant advances possible. Moreover, countries investing heavily in novel science can reap significant benefits also for themselves from their focus: early work on an idea can help the country develop capabilities that enable it to take advantage of the later, more fertile, opportunities linked to the same idea.

5. Conclusion

Our analysis has shown that countries continue to differ in their ability to take advantage of cutting-edge ideas. Even across developed nations, sizable differences persist in terms of the tendency at which each nation's scientists build on recent advances. Hence, in spite of the arrival of modern communication technologies – which now facilitate almost instantaneous access to each new idea from almost anywhere in the world – the world of ideas is not yet flat. A likely explanation for this is that access to an idea does not guarantee that a scientist can take advantage of it in a productive way soon after its initial discovery. Instead, because new ideas are often raw and poorly understood, the ability to fruitfully build upon an idea depends on local factors such as daily interactions with colleagues, the training environment, and ready access to potential collaborators. Because these factors vary across locations but are beneficial or even necessary in helping scientists unlock the mysteries of new ideas, geographic differences in the tendency to exploit new ideas continue to persist.

Currently, the tendency to build on new ideas in biomedicine is highest in United States and South Korea. While China has leapfrogged most developed nations in terms of its overall tendency to work with new ideas, this progress has been uneven across idea types. In terms of applying basic science ideas, China has already caught up with the leaders, but in terms of applying new clinical knowledge, China remains below average. This result highlights an important benefit of the approach developed here: the approach can be used to show not only whether differences in new idea adoption persist, but also where in the idea space any remaining barriers lie.

An important direction for future work is to examine what are the best approaches for overcoming barriers in idea adoption. For example, it would be useful to uncover whether the scientific frontier is best reached through an approach where resources are first directed to a handful of fields or universities or through a more diversified approach, and whether smaller countries can elect to specialize in narrow areas or whether the unpredictability of where in the ideas space important future advances come from render it necessary for even smaller countries to develop and maintain broad capabilities so that they can take early advantage of new advances no matter where in the idea space those yet unforeseen new advances are born.

Extending the analysis to patent data would also be useful as it would facilitate exploration of links between scientific frontier positions and technological frontier positions. Such analysis could reveal to what extent funding scientists working near the edge of the scientific frontier is a pre-condition for a country to obtain the capability to pursue inventions near the edge of the technological frontier – inventions that build on recent scientific and technological advances.

In analyses of science, the metric introduced here – the edge factor – holds considerable potential beyond cross-national comparisons. Ever since Garfield (1955, 1972), the focus in empirical analyses of knowledge production has been on measuring influence. This focus on impact in science policy has recently been decried by many, including Alberts (2013) and Osterloh and Frey (2015). For the theory of knowledge production implies that science policy decisions should be guided by not just the influence of scientific work but also what kind of science is being pursued – novel or conventional (Kuhn 1962; Besancenot and Vranceanu 2015). Because new ideas are raw when they are first born, they need the attention and revision by many scientists to mature into useful advances. But such work is risky, and without explicit incentives for novel work, too many choose to pursue well-trodden research paths in areas where many other scientists also work and thus the prospects of receiving citations are better. A potential consequence of excessive focus on impact is thus that science becomes stagnant, a phenomenon which appears to have already occurred in biomedicine (Rzhetzky et al., 2015).

Of course, given the absence of metrics that capture novelty, the obsession with impact has been inevitable. The edge factor is a valuable tool for this very reason. By providing an approach that can be used to measure the novelty of scientific work of a nation, a journal, an institution, or even an individual scientist, the edge factor allows university administrators and funding agencies to re-structure their reward systems so that scientists are rewarded based on not just the impact of their work but also the novelty of their work. When scientists are rewarded based on *both* the impact and novelty of their work, more scientists can be expected to pursue novel research paths, leading to healthier, less stagnant science.

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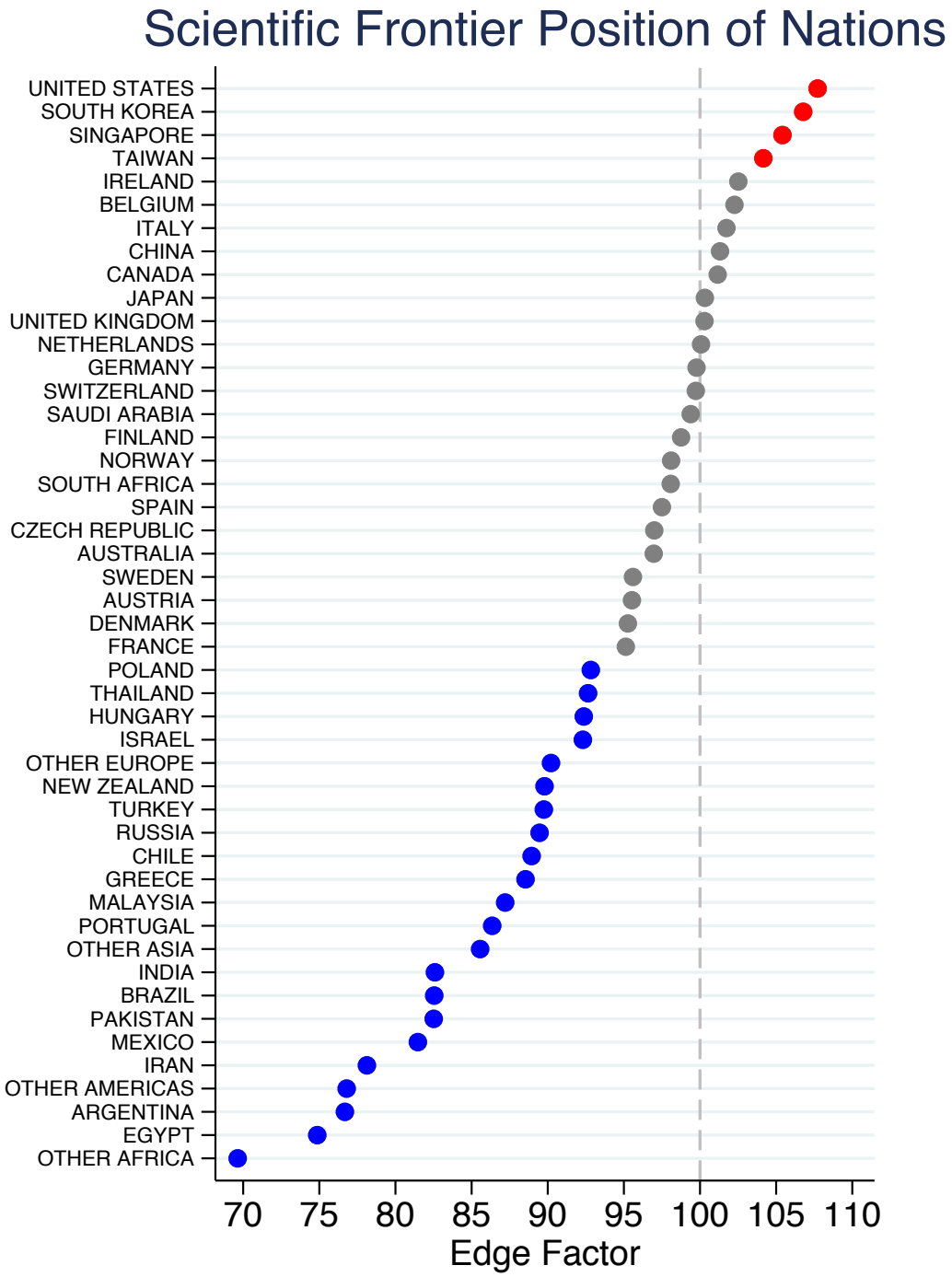

Figure 1. Overall Scientific Frontier Position by Location. Edge factors are calculated using text analysis and data on biomedical research papers published during 2015-2016. Scatter points are colored to indicate edge factors that are well above average (red), about average (grey), and well below average (blue). An edge factor above 100 indicates an above average tendency for work that builds on relatively new ideas (a contribution is considered novel if it is in the top 5% by the age of the newest idea it builds upon; the comparison group for each contribution is all other papers published in the same year and linked to the same (idea category, research area) pair).

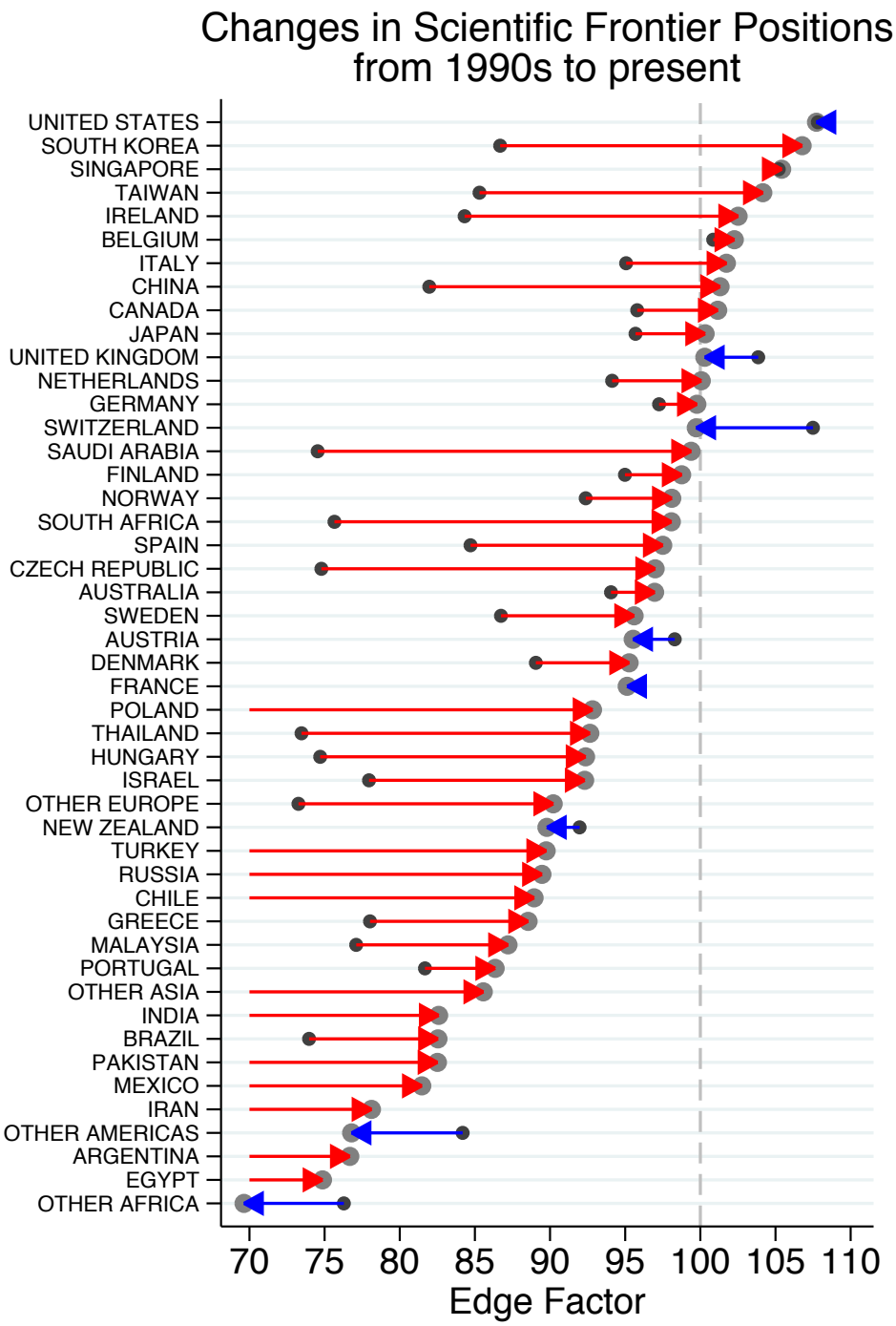

Figure 2. Change in Scientific Frontier Position by Location from 1990s to present. Edge factors are calculated using text analysis and data on biomedical research papers published during 1990-1999 and 2015-2016. Smaller scatter points indicate the edge factors for 1990s, larger points for 2015-6. Red (blue) arrows indicate edge factors that increased (decreased) from 1990s to 2015-2016. An edge factor above 100 indicates an above average tendency for work that builds on relatively new ideas (a contribution is considered novel if it is in the top 5% by the age of the newest idea it builds upon; the comparison group for each contribution is all other papers published in the same year and linked to the same (idea category, research area) pair).

Table 1. Edge Factors by Idea Category Type and by Research Area Type.

(1a)	(1b)	(1c)		(2a)	(2b)	(2c)	(2d)		(3a)	(3b)	(3c)
Location	Number of Contributions	2015-6		Clinical and Anatomy	Drugs and Chemi-cals	Basic Science and Research Tools	Miscel-laneous		Applied	Basic Science	Other (Both Applied and Basic Science)
UNITED STATES	2853661	108		105	121	110	105		106	108	108
SOUTH KOREA	374227	107		111	103	105	105		103	109	106
SINGAPORE	52541	105		109	106	115	108		108	110	112
TAIWAN	177229	104		99	100	105	105		100	101	107
IRELAND	39495	103		107	88	108	98		99	101	108
BELGIUM	95644	102		109	120	99	98		103	106	102
ITALY	384029	102		105	117	94	101		99	103	103
CHINA	1734035	101		95	88	113	101		102	100	103
CANADA	375846	101		99	94	102	105		101	99	105
JAPAN	554589	100		104	106	103	92		94	104	101
UNITED KINGDOM	494917	100		100	105	100	100		98	102	100
NETHERLANDS	233631	100		106	87	100	97		95	103	100
GERMANY	539888	100		95	112	104	97		96	102	100
SWITZERLAND	123779	100		97	118	105	93		94	102	102
SAUDI ARABIA	34855	99		96	84	91	96		90	92	98
FINLAND	59534	99		96	78	106	96		89	99	102
NORWAY	63699	98		99	88	103	98		97	97	104
SOUTH AFRICA	43179	98		107	81	76	98		100	92	89
SPAIN	278504	98		98	96	96	99		92	99	101
CZECH REPUBLIC	44024	97		97	86	95	92		95	97	89
AUSTRALIA	320955	97		99	94	95	97		96	95	100
SWEDEN	138949	96		94	102	97	93		91	98	96
AUSTRIA	65039	96		94	103	100	94		91	100	96
DENMARK	105066	95		98	91	96	96		92	95	101
FRANCE	305065	95		96	101	95	93		91	97	95
POLAND	113074	93		95	85	83	91		95	89	84
THAILAND	40080	93		95	79	73	94		91	81	92
HUNGARY	28574	92		84	94	93	85		88	89	87
ISRAEL	76781	92		96	78	95	90		88	95	94
OTHER EUROPE	107712	90		91	79	82	84		85	83	88
NEW ZEALAND	38946	90		90	111	88	93		92	95	90
TURKEY	157825	90		101	79	69	93		87	85	91
RUSSIA	51759	89		77	91	93	85		86	85	84
CHILE	23794	89		98	76	75	91		95	86	83
GREECE	46646	89		95	88	76	86		86	87	86
MALAYSIA	37997	87		87	64	81	90		87	83	83
PORTUGAL	65523	86		92	84	85	93		92	91	85
OTHER ASIA	60973	86		87	84	73	81		85	78	82
INDIA	291215	83		83	70	73	95		86	83	80
BRAZIL	274896	83		83	74	71	96		83	82	82
PAKISTAN	27511	83		78	93	74	80		81	79	77
MEXICO	54997	81		81	72	72	86		82	76	80
IRAN	121035	78		87	62	68	82		77	76	81
OTHER AMERICAS	30787	77		82	76	64	96		87	78	78
ARGENTINA	40775	77		85	76	69	86		82	79	78
EGYPT	48649	75		85	75	58	81		76	75	74
OTHER AFRICA	90041	70		87	57	55	73		76	68	72

Notes to Table 1:

All numbers in columns 1b and 1c are calculated based on papers published during 2015-2016. Numbers in columns 2a-d and columns 3a-3c are also calculated based on papers published during 2015-2016 for all countries for which the number of contributions reported in column 1c is at least 200000. For countries that fall below this threshold, the numbers in columns 2a-d and columns 3a-3c are calculated based on papers published during 2010-2016 (in order to decrease the variability of the edge factors reported in these columns).

Column 1a: Location.

Column 1b: Number of contributions based on which the edge factor in column (1c) is calculated. A contribution is defined as a link from a paper to an (idea category, research area) pair. A paper can link to multiple (idea category, research area) pairs because a paper can mention UMLS terms from multiple idea categories, and because a UMLS term can be linked to multiple idea categories, and because a paper may be linked to multiple research areas.

Column 1c: Edge factor for the baseline specification.

Columns 2a-d: Edge factors for each of the four idea category groups "Clinical and Anatomy", "Drugs and Chemicals", "Basic Science and Research Tools", and "Miscellaneous". See Table S1 for which idea categories (as represented by UMLS categories for UMLS terms) are included in each idea category group.

Columns 3a-c: Edge factors for each of the three types of research areas: "Applied", "Basic Science", and Other (Both Applied and Basic Science)". See Table S1 for which research areas (represented by journal categories) are included in each of these three research area types.

Web Appendix:

Edge Factors: Scientific Frontier Positions of Nations

Mikko Packalen

June 18, 2018

This PDF file includes:

Tables S1-S5
Figures S1-S5

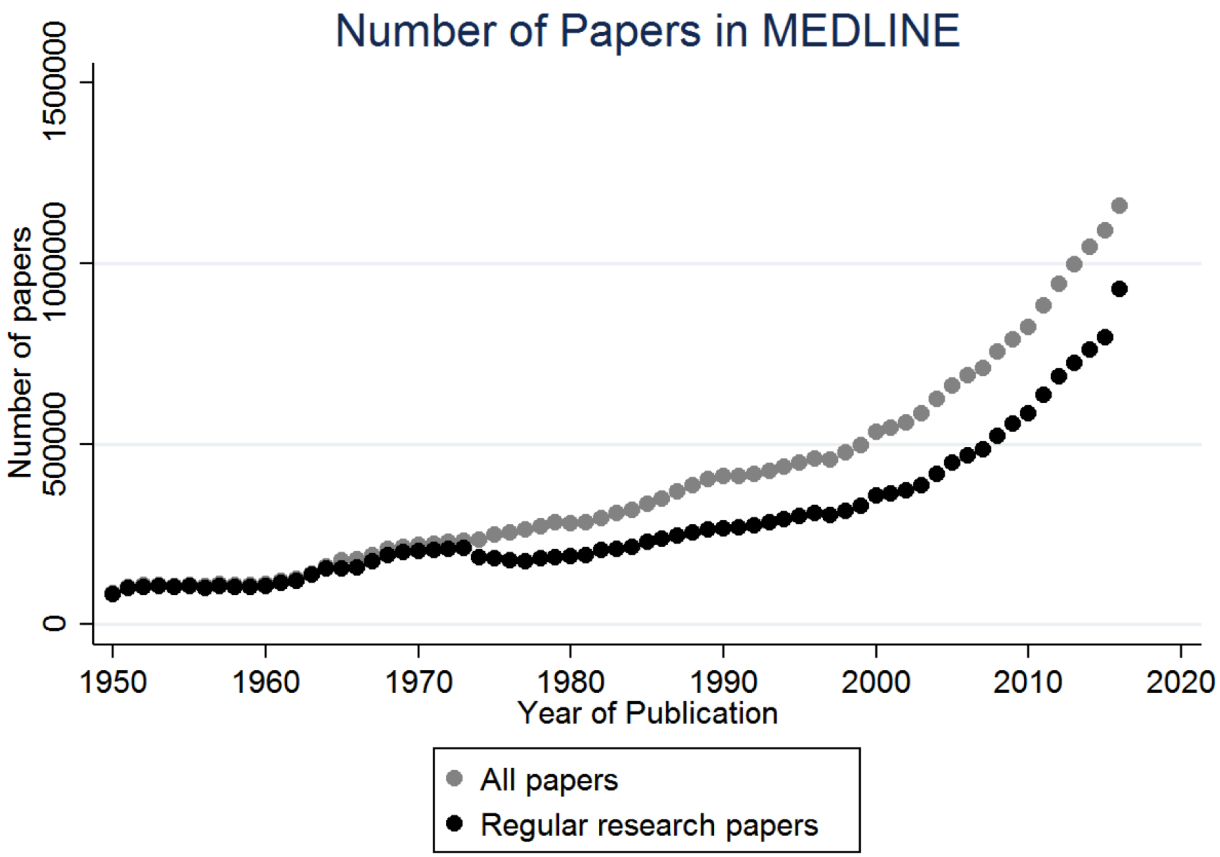

Figure S1. Number of papers per year in the MEDLINE database. Even after limiting the analysis to regular research papers (thereby excluding news items, editorials, etc.), the database includes mullions of papers for even the earlier decades allowing us to obtain an informative estimate of when each idea was new to the biomedical literature.

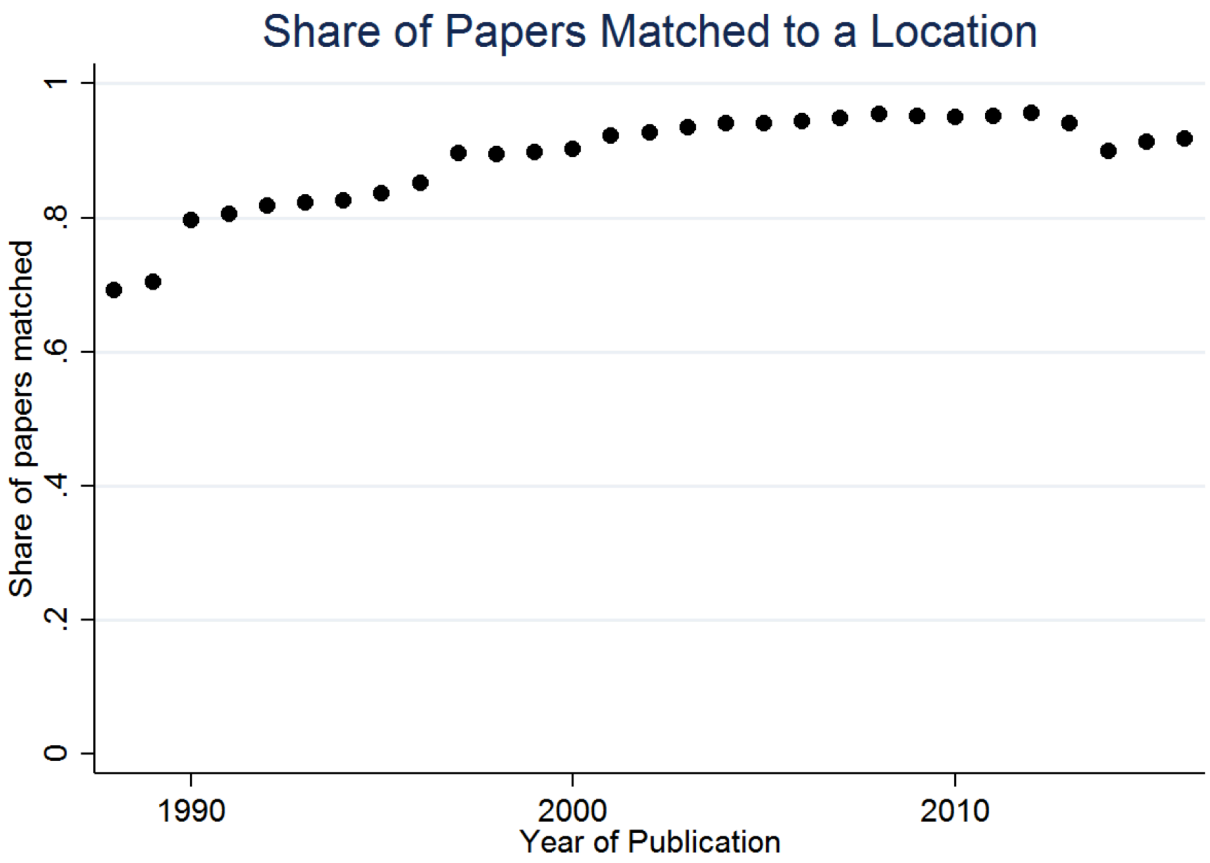

Figure S2. Share of papers matched to a location. The match rate is reasonably high even for 1990s. The decrease in the rate of matched papers in recent years is due to the fact that for those years some of the affiliation strings in MEDLINE include the affiliation string for multiple authors. The form of such entries makes it more difficult to match those papers to a country.

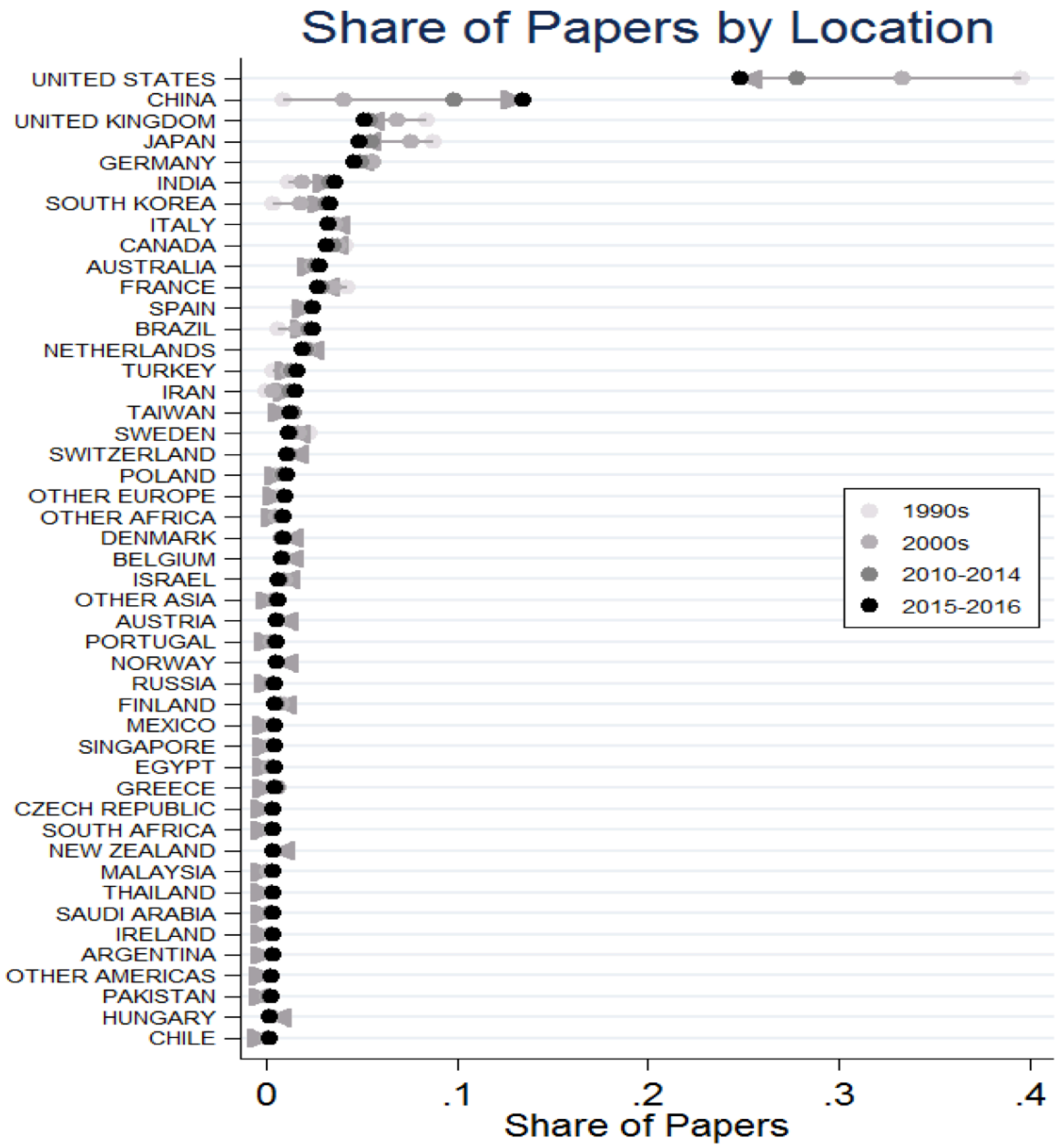

Figure S3. Share of papers by location. The U.S., U.K., Japan, Germany, and Italy have been among near the top in terms of extent of biomedical research production throughout the sample period, while China, India, and South Korea have become big centers of biomedical research production during the last two decades.

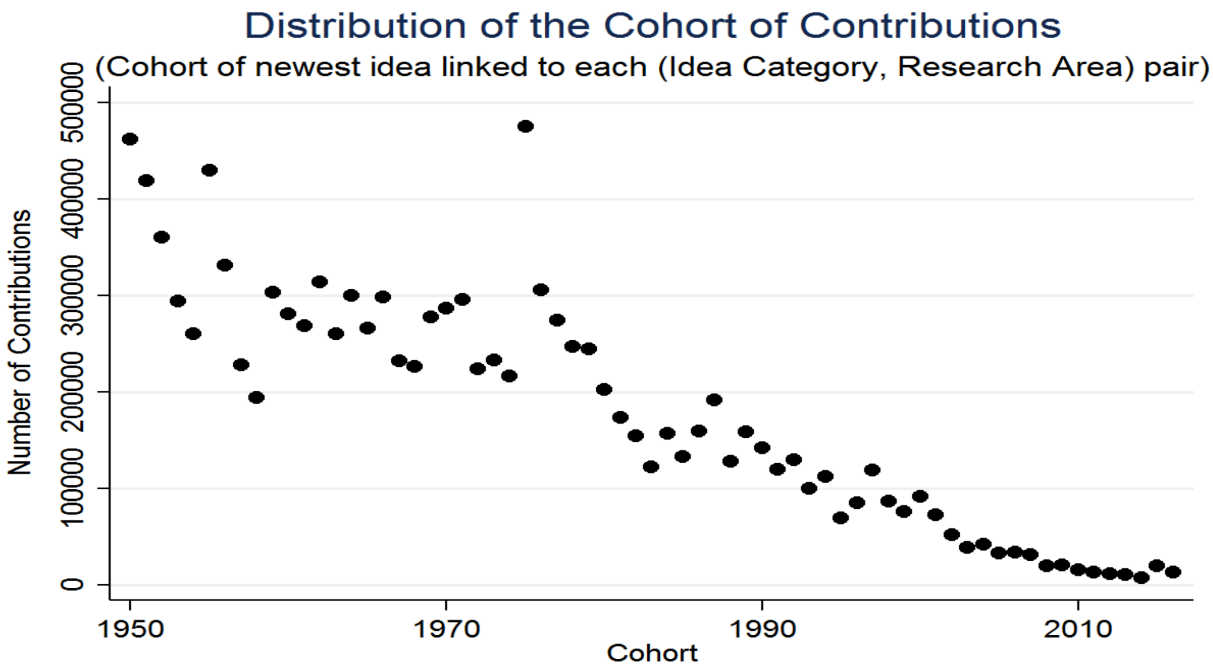

Figure S4. Distribution of the Cohort of Contributions. The number of contributions with cohort "1975" is disproportionately high because the comprehensive coverage of article abstracts in MEDLINE begins in 1975 (and thus a disproportionate number of terms are assigned cohort 1975 by our approach).

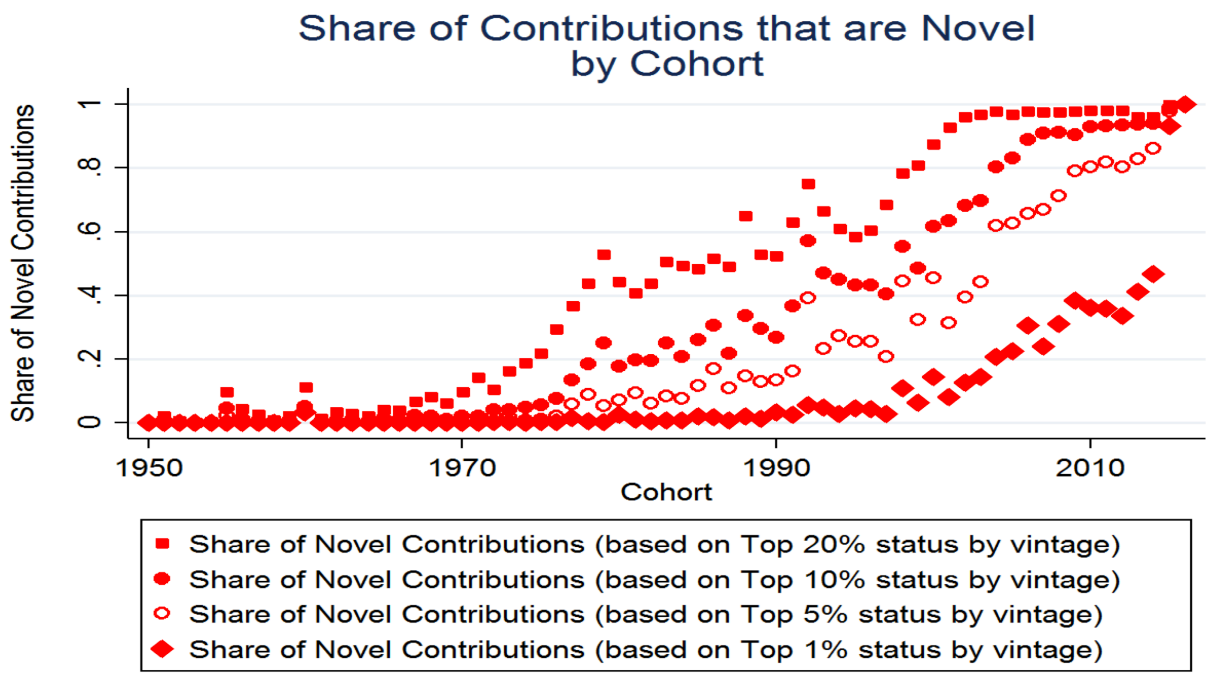

Figure S5. Share of Novel Contributions by Cohort. When the top 5% cutoff is used, then for all post-2004 cohorts the majority of contributions with that cohort are deemed novel by our approach, and for all pre-2004 cohorts at most a minority of contributions are deemed novel by our approach. Contributions with a very early cohort are never novel and contributions with the latest possible cohort ("2016") are all novel. Contributions with a cohort between these extremes are sometimes novel and other times not. This is because novelty is calculated by comparing the vintage of a contribution to the vintage of other contributions linked to the same (idea category, research area) pair. Hence, the cutoff cohort for novel contributions varies across (idea category, research area) pairs.

Table S1. Number of Links from Papers to Each Research Area.

Research Area (Journal Category)	Links	Research Area Group
Medicine	669881	Other (Both Applied and Basic Science)
Science	599469	Basic Science
Neoplasms	524947	Other (Both Applied and Basic Science)
Biochemistry	499331	Basic Science
Molecular Biology	470936	Basic Science
Neurology	404341	Other (Both Applied and Basic Science)
Chemistry	381274	Basic Science
Pharmacology	283555	Other (Both Applied and Basic Science)
Biology	264824	Basic Science
Cell Biology	256341	Basic Science
General Surgery	247670	Applied
Environmental Health	233734	Other (Both Applied and Basic Science)
Allergy and Immunology	216658	Basic Science
Microbiology	196761	Basic Science
Cardiology	192365	Applied
Biomedical Engineering	191269	Other (Both Applied and Basic Science)
Biotechnology	184539	Basic Science
Biophysics	174613	Basic Science
Vascular Diseases	174607	Other (Both Applied and Basic Science)
Physiology	172288	Other (Both Applied and Basic Science)
Public Health	163958	Applied
Pediatrics	163047	Applied
Nutritional Sciences	161807	Other (Both Applied and Basic Science)
Toxicology	158233	Other (Both Applied and Basic Science)
Psychiatry	155919	Applied
Gastroenterology	129905	Other (Both Applied and Basic Science)
Endocrinology	127616	Other (Both Applied and Basic Science)
Psychology	122978	Applied
Genetics	121180	Basic Science
Nursing	116035	Applied
Ophthalmology	112186	Other (Both Applied and Basic Science)
Chemistry Techniques, Analytical	107968	Other (Both Applied and Basic Science)
Pulmonary Medicine	103534	Applied
Orthopedics	102817	Applied
Diagnostic Imaging	101475	Applied
Dentistry	101252	Applied
Pathology	99477	Other (Both Applied and Basic Science)
Metabolism	98272	Other (Both Applied and Basic Science)
Communicable Diseases	96646	Other (Both Applied and Basic Science)
Therapeutics	95906	Other (Both Applied and Basic Science)
Veterinary Medicine	95394	Other (Both Applied and Basic Science)
Radiology	95332	Applied
Behavioral Sciences	91608	Applied
Brain	90578	Other (Both Applied and Basic Science)
Nanotechnology	87781	Basic Science
Hematology	87705	Other (Both Applied and Basic Science)
Geriatrics	82363	Applied
Botany	81144	Other (Both Applied and Basic Science)
Physics	80223	Other (Both Applied and Basic Science)
Gynecology	76024	Applied
Genetics, Medical	75252	Other (Both Applied and Basic Science)
Health Services	74519	Applied
Psychophysiology	70549	Applied
Obstetrics	69653	Applied
Virology	68388	Basic Science
Technology	66620	Other (Both Applied and Basic Science)
Urology	65771	Applied
Reproductive Medicine	63949	Other (Both Applied and Basic Science)
Drug Therapy	63105	Other (Both Applied and Basic Science)
Zoology	62592	Other (Both Applied and Basic Science)
Medical Informatics	61238	Applied
Transplantation	59013	Other (Both Applied and Basic Science)
Health Services Research	53889	Applied
Traumatology	53820	Applied
Nephrology	51255	Other (Both Applied and Basic Science)
Physical and Rehabilitation Medicine	50756	Applied
Rheumatology	50730	Other (Both Applied and Basic Science)
Dermatology	49397	Other (Both Applied and Basic Science)
Epidemiology	48742	Applied
Social Sciences	47935	Applied
Sports Medicine	45323	Applied
Tropical Medicine	44027	Other (Both Applied and Basic Science)
Otolaryngology	43871	Applied
Computational Biology	43373	Basic Science
Radiotherapy	42859	Applied
Parasitology	40296	Other (Both Applied and Basic Science)
Substance-Related Disorders	39722	Applied
Complementary Therapies	39646	Other (Both Applied and Basic Science)
Anti-Infective Agents	38006	Basic Science
Neurosurgery	37052	Applied
Acquired Immunodeficiency Syndrome	34489	Other (Both Applied and Basic Science)
Nuclear Medicine	33864	Other (Both Applied and Basic Science)
Education	33318	Applied
Emergency Medicine	32612	Applied
Critical Care	32054	Applied
Anesthesiology	31729	Applied
Perinatology	31395	Applied
Clinical Laboratory Techniques	30107	Other (Both Applied and Basic Science)
Embryology	29322	Other (Both Applied and Basic Science)
Pharmacy	28546	Other (Both Applied and Basic Science)
Palliative Care	27801	Applied
Psychopharmacology	27246	Applied
Internal Medicine	24728	Applied
Occupational Medicine	20677	Applied
Statistics as Topic	20049	Applied
Antineoplastic Agents	19027	Other (Both Applied and Basic Science)
Primary Health Care	18607	Applied
Jurisprudence	17346	Other (Both Applied and Basic Science)
Histology	15443	Basic Science
Hospitals	14323	Other (Both Applied and Basic Science)
Audiology	13697	Applied
Sexually Transmitted Diseases	11994	Other (Both Applied and Basic Science)
Anatomy	11926	Other (Both Applied and Basic Science)
Ethics	11039	Applied
Bacteriology	10395	Basic Science
Speech-Language Pathology	10150	Applied
Women's Health	9976	Applied
Histocytochemistry	8834	Basic Science
Chemistry, Clinical	8529	Other (Both Applied and Basic Science)
Forensic Sciences	8528	Other (Both Applied and Basic Science)
Military Medicine	7359	Applied
Orthodontics	5106	Applied
Anthropology	4340	Applied
Laboratory Animal Science	3784	Other (Both Applied and Basic Science)
Vital Statistics	3672	Other (Both Applied and Basic Science)
History of Medicine	3580	Applied
Disaster Medicine	3491	Applied
Teratology	1938	Other (Both Applied and Basic Science)
Podiatry	1671	Applied
Aerospace Medicine	1591	Applied
Family Planning Services	1396	Applied
Chiropractic	648	Applied
Osteopathic Medicine	385	Applied
Library Science	226	Applied

Table S2. Number of Links from Papers to Each Idea Category.

Idea Category	Links	Idea Category Group
Finding	606119	Clinical and Anatomy
Amino Acid, Peptide, or Protein	529613	Basic Science and Research Tools
Pharmacologic Substance	527933	Drugs and Chemicals
Quantitative Concept	495874	Miscellaneous
Intellectual Product	485671	Miscellaneous
Laboratory Procedure	478481	Clinical and Anatomy
Gene or Genome	470078	Basic Science and Research Tools
Research Activity	380742	Basic Science and Research Tools
Therapeutic or Preventive Procedure	374185	Clinical and Anatomy
Disease or Syndrome	353348	Clinical and Anatomy
Molecular Function	303528	Basic Science and Research Tools
Functional Concept	289601	Miscellaneous
Clinical Attribute	282872	Clinical and Anatomy
Diagnostic Procedure	261596	Clinical and Anatomy
Manufactured Object	244287	Miscellaneous
Qualitative Concept	239603	Miscellaneous
Cell Function	231778	Basic Science and Research Tools
Genetic Function	202810	Basic Science and Research Tools
Organic Chemical	200841	Drugs and Chemicals
Mental Process	184553	Clinical and Anatomy
Health Care Activity	182871	Clinical and Anatomy
Cell	172497	Basic Science and Research Tools
Idea or Concept	166488	Miscellaneous
Nucleic Acid, Nucleoside, or Nucleotide	155993	Basic Science and Research Tools
Spatial Concept	140830	Miscellaneous
Molecular Biology Research Technique	135534	Basic Science and Research Tools
Neoplastic Process	125951	Clinical and Anatomy
Body Part, Organ, or Organ Component	121709	Clinical and Anatomy
Temporal Concept	121231	Miscellaneous
Medical Device	119522	Clinical and Anatomy
Biomedical Occupation or Discipline	117883	Miscellaneous
Cell Component	113613	Basic Science and Research Tools
Population Group	112704	Miscellaneous
Pathologic Function	108290	Clinical and Anatomy
Professional or Occupational Group	106552	Miscellaneous
Activity	97839	Miscellaneous
Mental or Behavioral Dysfunction	88458	Clinical and Anatomy
Indicator, Reagent, or Diagnostic Aid	84232	Clinical and Anatomy
Organ or Tissue Function	80670	Clinical and Anatomy
Plant	79846	Miscellaneous
Natural Phenomenon or Process	78537	Basic Science and Research Tools
Educational Activity	76874	Clinical and Anatomy
Biologically Active Substance	70188	Drugs and Chemicals
Sign or Symptom	69915	Clinical and Anatomy
Eukaryote	69229	Basic Science and Research Tools
Bacterium	68427	Basic Science and Research Tools
Cell or Molecular Dysfunction	65978	Basic Science and Research Tools
Hazardous or Poisonous Substance	62697	Drugs and Chemicals
Laboratory or Test Result	61984	Clinical and Anatomy
Injury or Poisoning	61553	Clinical and Anatomy
Conceptual Entity	61528	Miscellaneous
Social Behavior	60906	Miscellaneous
Mammal	57221	Miscellaneous
Organism Function	55354	Basic Science and Research Tools
Biomedical or Dental Material	55315	Drugs and Chemicals
Organism Attribute	54953	Miscellaneous
Virus	51368	Basic Science and Research Tools
Occupation or Discipline	50613	Miscellaneous
Individual Behavior	48054	Miscellaneous
Body Location or Region	47276	Clinical and Anatomy
Health Care Related Organization	46763	Miscellaneous
Classification	46324	Miscellaneous
Nucleotide Sequence	45571	Basic Science and Research Tools
Occupational Activity	45153	Miscellaneous
Phenomenon or Process	44693	Basic Science and Research Tools
Element, Ion, or Isotope	43951	Basic Science and Research Tools
Physiologic Function	43616	Clinical and Anatomy
Geographic Area	40627	Miscellaneous
Experimental Model of Disease	38736	Clinical and Anatomy
Amino Acid Sequence	38461	Basic Science and Research Tools
Machine Activity	36253	Miscellaneous
Tissue	36151	Basic Science and Research Tools
Immunologic Factor	35682	Basic Science and Research Tools
Organism	32501	Basic Science and Research Tools
Inorganic Chemical	27299	Drugs and Chemicals
Animal	25586	Miscellaneous
Food	24315	Miscellaneous
Age Group	23986	Miscellaneous
Daily or Recreational Activity	23540	Miscellaneous
Chemical Viewed Functionally	21956	Drugs and Chemicals
Fish	21900	Miscellaneous
Family Group	21721	Miscellaneous
Biologic Function	21506	Basic Science and Research Tools
Substance	20164	Basic Science and Research Tools
Group	19705	Miscellaneous
Body Space or Junction	18744	Clinical and Anatomy
Congenital Abnormality	18684	Clinical and Anatomy
Clinical Drug	17971	Drugs and Chemicals
Fungus	17966	Basic Science and Research Tools
Research Device	17100	Basic Science and Research Tools
Governmental or Regulatory Activity	16215	Miscellaneous
Body Substance	16146	Basic Science and Research Tools
Chemical Viewed Structurally	15715	Drugs and Chemicals
Chemical	14247	Drugs and Chemicals
Patient or Disabled Group	13280	Miscellaneous
Organization	11961	Miscellaneous
Receptor	11335	Basic Science and Research Tools
Human-caused Phenomenon or Process	10689	Basic Science and Research Tools
Bird	9043	Miscellaneous
Acquired Abnormality	9040	Clinical and Anatomy
Regulation or Law	8969	Miscellaneous
Anatomical Abnormality	8896	Clinical and Anatomy
Environmental Effect of Humans	8268	Miscellaneous
Body System	7871	Clinical and Anatomy
Group Attribute	7303	Miscellaneous
Behavior	6400	Miscellaneous
Embryonic Structure	5498	Basic Science and Research Tools
Professional Society	4272	Miscellaneous
Event	3825	Miscellaneous
Reptile	3289	Miscellaneous
Hormone	2983	Drugs and Chemicals
Self-help or Relief Organization	2927	Miscellaneous
Archaeon	2620	Basic Science and Research Tools
Vitamin	2514	Drugs and Chemicals
Language	2422	Miscellaneous
Anatomical Structure	2293	Clinical and Anatomy
Physical Object	2017	Miscellaneous
Amphibian	1918	Miscellaneous
Molecular Sequence	1453	Basic Science and Research Tools
Antibiotic	861	Drugs and Chemicals
Drug Delivery Device	790	Drugs and Chemicals
Fully Formed Anatomical Structure	104	Clinical and Anatomy
Entity	78	Miscellaneous
Human	44	Miscellaneous
Vertebrate	15	Miscellaneous

Table S3: Examples of UMLS Terms.

A UMLS term that is linked to multiple UMLS categories is treated as multiple separate observations; each such link represents one observation. All (UMLS term, UMLS category) pairs are first ranked based on the number of times the UMLS term is the newest term in a paper among all terms that belong to the same UMLS category.

We present 4 separate lists, one for each of the following four groups of idea categories that we use in the paper (Table S2 shows how the 127 UMLS categories map into these 4 category groups): “Clinical and Anatomy”, “Drugs and Chemicals”, “Basic Science and Research Tools”, and “Miscellaneous”

The rankings are constructed separately for each of these 4 idea category groups and for each decade, with the decade determined based on the cohort year of the UMLS term. The cohort year of a UMLS term is the year the term is first mentioned in the MEDLINE database. For each UMLS term the table also lists the earliest cohort of any of the term’s synonyms that appear in the UMLS metathesaurus.

For each decade we only present the top 25 UMLS terms. The analysis in the paper is based on all UMLS terms, not only the UMLS terms presented here. The focus on on a narrow set of popular UMLS terms here is for expositional convenience only.

Explanations for the columns:

Column (1): Decade of cohort; calculated based on the first number in column (6).
Column (2): Rank within decade of cohort; calculated based on column (3) and the first number in column (6).
Column (3): Number of times the UMLS term appears in a paper and is the newest term in the paper from that idea category. Calculated based on papers published during 2010-2016.
Column (4): Cumulative share of earliest mentions, calculated based on column (3) separately for each decade of cohort..
Column (5): The UMLS term.
Column (6): Cohort of term, set as the earliest year the term is mentioned in MEDLINE. The number in parenthesis is the earliest cohort of any synonym of the term (including the term itself).
Column (7): The UMLS category of the term; in our analysis this represents the idea category of the term.

The UMLS term lists for the 4 idea category groups appear in this order below: “Clinical and Anatomy”, “Drugs and Chemicals”, “Basic Science and Research Tools”, and “Miscellaneous”.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
CLINICAL AND ANATOMY (1st of 4 idea category groups)						
2010s	1	780	1.98%	granulomatosis with polyangiitis	2011 (1949)	Disease or Syndrome
2010s	2	698	3.76%	H7N9	2010 (1949)	Disease or Syndrome
2010s	3	388	4.75%	fecal microbiota transplantation	2011 (2001)	Therapeutic or Preventive Procedure
2010s	4	365	5.68%	middle east respiratory syndrome	2013 (1974)	Disease or Syndrome
2010s	5	279	6.39%	eosinophilic granulomatosis with polyangiitis	2012 (2012)	Disease or Syndrome
2010s	6	182	6.85%	ecigarette user	2011 (2010)	Finding

2010s	7	176	7.30%	H7N9 influenza	2012 (2012)	Disease or Syndrome
2010s	8	150	7.68%	patientderived xenograft model	2010 (1989)	Experimental Model of Disease
2010s	9	150	8.06%	vascularized composite allotransplantation	2011 (1991)	Therapeutic or Preventive Procedure
2010s	10	146	8.43%	auditory neuropathy spectrum disorder	2010 (1996)	Disease or Syndrome
2010s	11	143	8.80%	hoarding disorder	2010 (2010)	Mental or Behavioral Dysfunction
2010s	12	132	9.13%	prostate health index	2010 (1949)	Laboratory Procedure
2010s	13	125	9.45%	severe fever with thrombocytopenia syndrome	2011 (2011)	Disease or Syndrome
2010s	14	117	9.75%	tedizolid	2011 (2011)	Clinical Attribute
2010s	15	114	10.0%	C3 glomerulopathy	2010 (2010)	Disease or Syndrome
2010s	16	112	10.3%	severe fever with thrombocytopenia syndrome virus	2012 (2011)	Disease or Syndrome
2010s	17	108	10.6%	primary biliary cholangitis	2015 (1949)	Disease or Syndrome
2010s	18	107	10.8%	florbetapir	2010 (2010)	Indicator, Reagent, or Diagnostic Aid
2010s	19	102	11.1%	fusion biopsy	2012 (2011)	Diagnostic Procedure
2010s	20	92	11.3%	mixed adenoneuroendocrine carcinoma	2011 (1963)	Neoplastic Process
2000s	1	4562	1.88%	STEMI	2000 (2000)	Finding
2000s	2	4516	3.75%	STEMI	2000 (1994)	Disease or Syndrome
2000s	3	3811	5.33%	everolimus	2000 (2000)	Laboratory Procedure
2000s	4	3292	6.69%	creactive protein hs	2000 (2000)	Laboratory Procedure
2000s	5	3055	7.95%	castrationresistant prostate cancer	2004 (1983)	Neoplastic Process
2000s	6	2977	9.18%	cardiac resynchronization therapy	2000 (2000)	Therapeutic or Preventive Procedure
2000s	7	2928	10.3%	multidetector computed tomography	2000 (1992)	Diagnostic Procedure
2000s	8	2888	11.5%	transcatheter aortic valve implantation	2005 (1990)	Therapeutic or Preventive Procedure
2000s	9	2485	12.6%	positron emission tomography computed tomography	2002 (1991)	Diagnostic Procedure
2000s	10	2313	13.5%	triplenegative breast cancer	2006 (2006)	Finding
2000s	11	2131	14.4%	endoscopic submucosal dissection	2004 (2004)	Therapeutic or Preventive Procedure
2000s	12	2041	15.3%	triplenegative breast cancer	2006 (2006)	Neoplastic Process
2000s	13	1985	16.1%	CXCL10	2001 (1983)	Laboratory Procedure
2000s	14	1968	16.9%	transcranial direct current stimulation	2000 (1987)	Therapeutic or Preventive Procedure
2000s	15	1618	17.6%	transcatheter aortic valve replacement	2006 (1990)	Therapeutic or Preventive Procedure
2000s	16	1540	18.2%	transcriptome sequencing	2007 (2007)	Laboratory Procedure
2000s	17	1455	18.8%	tigecycline	2002 (2002)	Clinical Attribute

2000s	18	1443	19.4%	MELD score	2001 (2001)	Clinical Attribute
2000s	19	1434	20.0%	MELD score	2001 (2001)	Laboratory Procedure
2000s	20	1355	20.5%	takotsubo cardiomyopathy	2000 (1976)	Disease or Syndrome
1990s	1	16494	2.08%	fmri	1994 (1988)	Diagnostic Procedure
1990s	2	16180	4.12%	optical coherence tomography	1991 (1991)	Diagnostic Procedure
1990s	3	12851	5.75%	percutaneous coronary intervention	1991 (1991)	Therapeutic or Preventive Procedure
1990s	4	9244	6.92%	adiponectin	1999 (1999)	Laboratory Procedure
1990s	5	8538	7.99%	microarray analysis	1998 (1989)	Laboratory Procedure
1990s	6	7631	8.96%	chromatin immunoprecipitation	1998 (1949)	Laboratory Procedure
1990s	7	6933	9.83%	MMP9	1991 (1991)	Laboratory Procedure
1990s	8	6657	10.6%	pyrosequencing	1998 (1998)	Laboratory Procedure
1990s	9	6447	11.4%	autism spectrum disorder	1992 (1992)	Finding
1990s	10	6188	12.2%	diffusion tensor imaging	1994 (1994)	Diagnostic Procedure
1990s	11	5886	13.0%	NAFLD	1998 (1977)	Disease or Syndrome
1990s	12	5528	13.7%	autism spectrum disorder	1992 (1981)	Mental or Behavioral Dysfunction
1990s	13	5398	14.4%	gene expression profiling	1998 (1989)	Laboratory Procedure
1990s	14	4795	15.0%	autism spectrum disorders	1992 (1982)	Mental or Behavioral Dysfunction
1990s	15	4314	15.5%	tacrolimus	1992 (1992)	Laboratory Procedure
1990s	16	4295	16.0%	BRCA1	1993 (1993)	Laboratory Procedure
1990s	17	3722	16.5%	ghrelin	1999 (1989)	Laboratory Procedure
1990s	18	3535	17.0%	highly active antiretroviral therapy	1996 (1970)	Therapeutic or Preventive Procedure
1990s	19	3534	17.4%	microcomputed tomography	1990 (1975)	Diagnostic Procedure
1990s	20	3138	17.8%	statin therapy	1993 (1993)	Therapeutic or Preventive Procedure
1980s	1	30408	1.53%	polymerase chain reaction	1986 (1986)	Laboratory Procedure
1980s	2	19973	2.53%	western blot	1981 (1981)	Laboratory Procedure
1980s	3	18078	3.45%	primary endpoint	1980 (1980)	Indicator, Reagent, or Diagnostic Aid
1980s	4	17719	4.34%	HIV1	1986 (1986)	Laboratory or Test Result
1980s	5	17599	5.23%	VEGF	1987 (1982)	Laboratory Procedure
1980s	6	17530	6.11%	vascular endothelial growth factor	1982 (1982)	Therapeutic or Preventive Procedure
1980s	7	15337	6.88%	tissue engineering	1984 (1984)	Therapeutic or Preventive Procedure
1980s	8	15075	7.64%	NSCLC	1981 (1976)	Neoplastic Process

1980s	9	14097	8.35%	western blot analysis	1982 (1981)	Laboratory Procedure
1980s	10	13523	9.04%	HIV infection	1986 (1986)	Clinical Attribute
1980s	11	12977	9.69%	neuroimaging	1982 (1982)	Diagnostic Procedure
1980s	12	12828	10.3%	antiretroviral therapy	1985 (1985)	Therapeutic or Preventive Procedure
1980s	13	11657	10.9%	EGFR	1980 (1977)	Laboratory Procedure
1980s	14	11549	11.5%	atomic force microscopy	1988 (1976)	Laboratory Procedure
1980s	15	11367	12.0%	LCMS	1982 (1970)	Laboratory Procedure
1980s	16	10204	12.5%	HIV infection	1986 (1983)	Disease or Syndrome
1980s	17	9567	13.0%	human immunodeficiency virus	1986 (1983)	Disease or Syndrome
1980s	18	9546	13.5%	confocal microscopy	1981 (1981)	Laboratory Procedure
1980s	19	8799	14.0%	interleukin6	1987 (1987)	Laboratory Procedure
1980s	20	8322	14.4%	PTSD	1982 (1949)	Mental or Behavioral Dysfunction
1970s	1	71568	2.12%	biomarkers	1973 (1949)	Clinical Attribute
1970s	2	44237	3.43%	magnetic resonance imaging	1978 (1949)	Diagnostic Procedure
1970s	3	40954	4.64%	body mass index	1975 (1975)	Diagnostic Procedure
1970s	4	35912	5.71%	biomarker	1973 (1949)	Clinical Attribute
1970s	5	34725	6.74%	body mass index	1975 (1970)	Clinical Attribute
1970s	6	34105	7.75%	body mass index	1975 (1975)	Finding
1970s	7	27597	8.56%	body mass index BMI	1978 (1978)	Clinical Attribute
1970s	8	23495	9.26%	flow cytometry	1977 (1971)	Laboratory Procedure
1970s	9	18772	9.82%	treatment options	1971 (1950)	Therapeutic or Preventive Procedure
1970s	10	17892	10.3%	T cells	1970 (1970)	Laboratory Procedure
1970s	11	17877	10.8%	HPLC	1973 (1969)	Laboratory Procedure
1970s	12	17627	11.4%	risk assessment	1973 (1973)	Health Care Activity
1970s	13	15331	11.8%	ELISA	1971 (1971)	Laboratory Procedure
1970s	14	13416	12.2%	CD8	1979 (1979)	Laboratory Procedure
1970s	15	12428	12.6%	interventional	1971 (1971)	Diagnostic Procedure
1970s	16	11965	12.9%	neurodegeneration	1976 (1976)	Finding
1970s	17	11292	13.3%	cancer progression	1979 (1979)	Pathologic Function
1970s	18	11170	13.6%	neurodegenerative diseases	1979 (1965)	Disease or Syndrome
1970s	19	10573	13.9%	poor outcome	1975 (1975)	Finding

1970s	20	10449	14.2%	working memory	1977 (1949)	Mental Process
1960s	1	59518	2.01%	immunohistochemistry	1964 (1964)	Diagnostic Procedure
1960s	2	48580	3.65%	mouse model	1965 (1965)	Experimental Model of Disease
1960s	3	38862	4.96%	sequencing	1962 (1962)	Laboratory Procedure
1960s	4	24939	5.81%	scanning electron microscopy	1963 (1963)	Diagnostic Procedure
1960s	5	24752	6.64%	colorectal cancer	1962 (1962)	Finding
1960s	6	23258	7.43%	colorectal cancer	1962 (1949)	Neoplastic Process
1960s	7	19812	8.10%	ethnicity	1966 (1966)	Clinical Attribute
1960s	8	15572	8.62%	ethnicity	1966 (1966)	Finding
1960s	9	14815	9.13%	crosstalk	1966 (1966)	Injury or Poisoning
1960s	10	13656	9.59%	scanning electron microscopy	1963 (1963)	Laboratory Procedure
1960s	11	13069	10.0%	COPD	1967 (1949)	Disease or Syndrome
1960s	12	12966	10.4%	ischemic stroke	1963 (1963)	Finding
1960s	13	12852	10.9%	coherent	1961 (1961)	Finding
1960s	14	12795	11.3%	immunosuppression	1964 (1964)	Pathologic Function
1960s	15	12684	11.7%	transmission electron microscopy	1964 (1949)	Laboratory Procedure
1960s	16	12680	12.1%	chart review	1966 (1957)	Health Care Activity
1960s	17	12659	12.6%	ischemic stroke	1963 (1962)	Disease or Syndrome
1960s	18	12121	13.0%	high risk of	1961 (1955)	Finding
1960s	19	11154	13.4%	NMR spectroscopy	1965 (1961)	Diagnostic Procedure
1960s	20	11087	13.7%	inflammatory bowel disease	1964 (1964)	Finding
1950s	1	222028	4.98%	strategies	1955 (1955)	Educational Activity
1950s	2	213336	9.77%	strategies	1955 (1949)	Mental Process
1950s	3	75034	11.4%	quality of life	1959 (1959)	Sign or Symptom
1950s	4	69350	13.0%	risk factors	1959 (1959)	Finding
1950s	5	58653	14.3%	encoding	1956 (1953)	Mental Process
1950s	6	56850	15.6%	documented	1950 (1950)	Health Care Activity
1950s	7	45073	16.6%	quality of life	1959 (1959)	Finding
1950s	8	25692	17.1%	options	1950 (1950)	Therapeutic or Preventive Procedure
1950s	9	24733	17.7%	risk factor	1959 (1959)	Finding
1950s	10	24543	18.3%	pharmacokinetics	1955 (1949)	Physiologic Function

1950s	11	23834	18.8%	immune responses	1950 (1949)	Organ or Tissue Function
1950s	12	23790	19.3%	immunohistochemical	1956 (1956)	Laboratory Procedure
1950s	13	23673	19.9%	encoded	1953 (1953)	Mental Process
1950s	14	22955	20.4%	hepatocellular carcinoma	1951 (1949)	Neoplastic Process
1950s	15	22021	20.9%	computed tomography	1956 (1949)	Diagnostic Procedure
1950s	16	21976	21.4%	high risk	1955 (1955)	Health Care Activity
1950s	17	21905	21.9%	hepatocellular carcinoma	1951 (1951)	Finding
1950s	18	20433	22.3%	triggers	1955 (1949)	Clinical Attribute
1950s	19	19918	22.8%	animal model	1954 (1954)	Experimental Model of Disease
1950s	20	19524	23.2%	laparoscopic	1950 (1949)	Diagnostic Procedure
DRUGS AND CHEMICALS (2nd of 4 idea category groups)						
2010s	1	856	1.29%	crizotinib	2010 (2010)	Pharmacologic Substance
2010s	2	851	2.57%	vemurafenib	2011 (2011)	Pharmacologic Substance
2010s	3	686	3.61%	enzalutamide	2012 (2012)	Pharmacologic Substance
2010s	4	465	4.31%	ibrutinib	2012 (2012)	Pharmacologic Substance
2010s	5	457	5.00%	ruxolitinib	2010 (2010)	Pharmacologic Substance
2010s	6	449	5.68%	nivolumab	2013 (2013)	Pharmacologic Substance
2010s	7	438	6.34%	afatinib	2011 (2011)	Pharmacologic Substance
2010s	8	433	7.00%	pembrolizumab	2014 (2013)	Pharmacologic Substance
2010s	9	410	7.61%	sofosbuvir	2013 (2013)	Pharmacologic Substance
2010s	10	384	8.19%	dabrafenib	2012 (2012)	Pharmacologic Substance
2010s	11	336	8.70%	simeprevir	2013 (2008)	Pharmacologic Substance
2010s	12	329	9.20%	tofacitinib	2010 (2008)	Pharmacologic Substance
2010s	13	326	9.69%	regorafenib	2011 (2011)	Pharmacologic Substance
2010s	14	318	10.1%	brentuximab vedotin	2010 (2003)	Pharmacologic Substance
2010s	15	311	10.6%	dolutegravir	2011 (2011)	Pharmacologic Substance
2010s	16	308	11.1%	empagliflozin	2012 (2012)	Pharmacologic Substance
2010s	17	268	11.5%	canagliflozin	2010 (2010)	Pharmacologic Substance
2010s	18	256	11.9%	vismodegib	2010 (2010)	Pharmacologic Substance

2010s	19	251	12.2%	ponatinib	2011 (2011)	Pharmacologic Substance
2010s	20	230	12.6%	nintedanib	2012 (2010)	Pharmacologic Substance
2000s	1	6248	2.61%	bevacizumab	2001 (1992)	Pharmacologic Substance
2000s	2	3130	3.93%	sorafenib	2004 (2004)	Pharmacologic Substance
2000s	3	3016	5.19%	imatinib	2001 (2001)	Pharmacologic Substance
2000s	4	2694	6.32%	bortezomib	2002 (2002)	Pharmacologic Substance
2000s	5	2646	7.43%	everolimus	2000 (1997)	Pharmacologic Substance
2000s	6	2501	8.48%	sunitinib	2005 (2005)	Pharmacologic Substance
2000s	7	2377	9.47%	erlotinib	2002 (2002)	Pharmacologic Substance
2000s	8	2290	10.4%	adalimumab	2002 (2002)	Pharmacologic Substance
2000s	9	1993	11.2%	cetuximab	2000 (1984)	Pharmacologic Substance
2000s	10	1932	12.0%	CXCL10	2001 (1974)	Pharmacologic Substance
2000s	11	1844	12.8%	rivaroxaban	2006 (2005)	Pharmacologic Substance
2000s	12	1801	13.6%	ranibizumab	2003 (2003)	Pharmacologic Substance
2000s	13	1788	14.3%	lenalidomide	2004 (2001)	Pharmacologic Substance
2000s	14	1771	15.1%	zoledronic acid	2000 (2000)	Clinical Drug
2000s	15	1527	15.7%	rosuvastatin	2001 (2001)	Pharmacologic Substance
2000s	16	1471	16.3%	gefitinib	2002 (2002)	Pharmacologic Substance
2000s	17	1469	16.9%	SP600125	2001 (2001)	Pharmacologic Substance
2000s	18	1454	17.5%	tigecycline	2002 (1999)	Organic Chemical
2000s	19	1371	18.1%	zoledronic acid	2000 (2000)	Pharmacologic Substance
2000s	20	1200	18.6%	denosumab	2005 (2005)	Pharmacologic Substance
1990s	1	16209	3.94%	IL10	1990 (1990)	Pharmacologic Substance
1990s	2	12716	7.03%	antiapoptotic	1992 (1992)	Chemical Viewed Functionally
1990s	3	11306	9.78%	carbon nanotubes	1992 (1969)	Chemical Viewed Structurally
1990s	4	7256	11.5%	rituximab	1997 (1987)	Pharmacologic Substance
1990s	5	6735	13.1%	paclitaxel	1993 (1993)	Pharmacologic Substance
1990s	6	3940	14.1%	IL13	1993 (1992)	Pharmacologic Substance
1990s	7	3747	15.0%	clopidogrel	1991 (1991)	Pharmacologic Substance
1990s	8	3408	15.8%	gemcitabine	1990 (1985)	Pharmacologic Substance
1990s	9	3402	16.7%	docetaxel	1993 (1993)	Pharmacologic Substance

1990s	10	2994	17.4%	trastuzumab	1998 (1990)	Pharmacologic Substance
1990s	11	2937	18.1%	carbon nanotube	1992 (1969)	Chemical Viewed Structurally
1990s	12	2738	18.8%	sirolimus	1994 (1975)	Organic Chemical
1990s	13	2699	19.4%	infliximab	1998 (1958)	Pharmacologic Substance
1990s	14	2687	20.1%	biodiesel	1994 (1994)	Organic Chemical
1990s	15	2651	20.7%	tacrolimus	1992 (1991)	Pharmacologic Substance
1990s	16	2296	21.3%	atorvastatin	1994 (1994)	Pharmacologic Substance
1990s	17	2210	21.8%	linezolid	1997 (1997)	Pharmacologic Substance
1990s	18	2138	22.3%	dendrimers	1990 (1980)	Biomedical or Dental Material
1990s	19	2104	22.9%	endocannabinoid	1997 (1991)	Biologically Active Substance
1990s	20	1940	23.3%	LY294002	1994 (1994)	Pharmacologic Substance
1980s	1	14480	2.61%	IL6	1987 (1982)	Pharmacologic Substance
1980s	2	13347	5.02%	VEGF	1987 (1952)	Pharmacologic Substance
1980s	3	9907	6.81%	signaling molecule	1982 (1982)	Biologically Active Substance
1980s	4	8898	8.42%	interleukin6	1987 (1982)	Pharmacologic Substance
1980s	5	6787	9.64%	HER2	1987 (1987)	Pharmacologic Substance
1980s	6	6216	10.7%	statins	1983 (1949)	Pharmacologic Substance
1980s	7	6056	11.8%	IL8	1989 (1969)	Pharmacologic Substance
1980s	8	5397	12.8%	3UTR	1984 (1984)	Biologically Active Substance
1980s	9	4941	13.7%	oxaliplatin	1989 (1989)	Clinical Drug
1980s	10	4814	14.5%	brainderived neurotrophic factor	1985 (1985)	Pharmacologic Substance
1980s	11	4691	15.4%	ciprofloxacin	1983 (1983)	Pharmacologic Substance
1980s	12	4630	16.2%	ciprofloxacin	1983 (1983)	Organic Chemical
1980s	13	4199	17.0%	IGF1	1980 (1974)	Pharmacologic Substance
1980s	14	3791	17.7%	propofol	1984 (1980)	Pharmacologic Substance
1980s	15	3571	18.3%	vascular endothelial growth factor	1982 (1952)	Pharmacologic Substance
1980s	16	3538	19.0%	interleukin	1980 (1980)	Pharmacologic Substance
1980s	17	3535	19.6%	protein kinase C	1981 (1981)	Pharmacologic Substance
1980s	18	3490	20.2%	interleukin1	1980 (1970)	Pharmacologic Substance
1980s	19	3433	20.8%	fluconazole	1985 (1985)	Clinical Drug
1980s	20	3298	21.4%	temozolomide	1988 (1988)	Clinical Drug

1970s	1	13252	2.36%	monoclonal antibodies	1971 (1971)	Clinical Drug
1970s	2	10750	4.28%	doxorubicin	1972 (1949)	Organic Chemical
1970s	3	8736	5.84%	logran	1973 (1973)	Pharmacologic Substance
1970s	4	8044	7.27%	intron	1978 (1978)	Pharmacologic Substance
1970s	5	7741	8.65%	monoclonal antibodies	1971 (1971)	Pharmacologic Substance
1970s	6	7047	9.91%	cisplatin	1971 (1970)	Pharmacologic Substance
1970s	7	6346	11.0%	immunomodulator	1976 (1949)	Pharmacologic Substance
1970s	8	5985	12.1%	peroxisome proliferator	1975 (1975)	Hazardous or Poisonous Substance
1970s	9	5841	13.1%	tumor necrosis factor	1975 (1975)	Pharmacologic Substance
1970s	10	5465	14.1%	rapamycin	1975 (1975)	Organic Chemical
1970s	11	4992	15.0%	25hydroxyvitamin D	1973 (1973)	Vitamin
1970s	12	4797	15.8%	pristine	1974 (1974)	Hazardous or Poisonous Substance
1970s	13	4339	16.6%	IL1	1976 (1970)	Pharmacologic Substance
1970s	14	4319	17.4%	pristine	1974 (1974)	Organic Chemical
1970s	15	4179	18.1%	25hydroxyvitamin D	1973 (1968)	Pharmacologic Substance
1970s	16	4053	18.8%	antimicrobial peptide	1979 (1979)	Pharmacologic Substance
1970s	17	3232	19.4%	resveratrol	1978 (1978)	Pharmacologic Substance
1970s	18	3122	20.0%	LDL cholesterol	1972 (1955)	Biologically Active Substance
1970s	19	2682	20.5%	angiogenic factor	1973 (1972)	Biologically Active Substance
1970s	20	2639	20.9%	tumor markers	1973 (1973)	Biologically Active Substance
1960s	1	52920	7.17%	ligands	1960 (1949)	Chemical
1960s	2	15286	9.24%	superoxide dismutase	1969 (1969)	Organic Chemical
1960s	3	13413	11.0%	COPD	1967 (1967)	Pharmacologic Substance
1960s	4	10744	12.5%	superoxide dismutase	1969 (1949)	Pharmacologic Substance
1960s	5	9858	13.8%	molecular target	1969 (1969)	Chemical Viewed Functionally
1960s	6	9517	15.1%	xenografts	1962 (1949)	Biomedical or Dental Material
1960s	7	9335	16.4%	xenograft	1962 (1949)	Biomedical or Dental Material
1960s	8	9068	17.6%	opioids	1968 (1968)	Biologically Active Substance
1960s	9	8209	18.7%	allograft	1963 (1949)	Biomedical or Dental Material
1960s	10	7872	19.8%	biomaterials	1967 (1967)	Biomedical or Dental Material
1960s	11	6333	20.6%	bioi	1960 (1960)	Inorganic Chemical

1960s	12	5967	21.4%	dopaminergic	1964 (1964)	Pharmacologic Substance
1960s	13	5773	22.2%	hotspot	1961 (1961)	Pharmacologic Substance
1960s	14	5431	22.9%	CI 4	1960 (1960)	Pharmacologic Substance
1960s	15	5414	23.7%	hydrogels	1964 (1964)	Biomedical or Dental Material
1960s	16	5038	24.4%	pahs	1965 (1949)	Organic Chemical
1960s	17	4882	25.0%	immunosuppressive	1963 (1963)	Pharmacologic Substance
1960s	18	4712	25.7%	neurotransmitters	1962 (1955)	Biologically Active Substance
1960s	19	4677	26.3%	opioids	1968 (1949)	Pharmacologic Substance
1960s	20	3803	26.8%	allografts	1963 (1949)	Biomedical or Dental Material
1950s	1	17863	2.36%	remodelin	1950 (1950)	Pharmacologic Substance
1950s	2	17123	4.63%	oncogen	1950 (1949)	Hazardous or Poisonous Substance
1950s	3	15506	6.68%	lipopolysaccharide	1950 (1950)	Organic Chemical
1950s	4	13158	8.42%	malondialdehyde	1951 (1951)	Biologically Active Substance
1950s	5	11963	10.0%	mimics	1950 (1949)	Hazardous or Poisonous Substance
1950s	6	11734	11.5%	surfactant	1951 (1951)	Biologically Active Substance
1950s	7	11396	13.0%	arabidopsis thaliana	1955 (1955)	Organic Chemical
1950s	8	10802	14.5%	surfactant	1951 (1949)	Biomedical or Dental Material
1950s	9	8975	15.6%	surfactant	1951 (1951)	Chemical Viewed Functionally
1950s	10	8534	16.8%	pollutants	1950 (1950)	Hazardous or Poisonous Substance
1950s	11	7060	17.7%	predef	1950 (1950)	Pharmacologic Substance
1950s	12	7048	18.6%	streptozotocin	1959 (1959)	Organic Chemical
1950s	13	6844	19.5%	hydrogel	1955 (1955)	Pharmacologic Substance
1950s	14	6840	20.4%	cortisol	1954 (1949)	Pharmacologic Substance
1950s	15	6690	21.3%	interferon	1957 (1957)	Pharmacologic Substance
1950s	16	6588	22.2%	virulence factors	1952 (1949)	Hazardous or Poisonous Substance
1950s	17	6406	23.1%	dopamine	1952 (1949)	Pharmacologic Substance
1950s	18	6239	23.9%	neurotransmitter	1955 (1955)	Biologically Active Substance
1950s	19	5924	24.7%	surfactants	1951 (1951)	Chemical Viewed Functionally
1950s	20	5866	25.4%	agonist	1952 (1952)	Pharmacologic Substance

BASIC SCIENCE AND RESEARCH TOOLS (3rd of 4 idea category groups)						
2010s	1	663	.666%	mechanistic target of rapamycin	2010 (1971)	Amino Acid, Peptide, or Protein
2010s	2	658	1.32%	mechanistic target of rapamycin	2010 (1976)	Gene or Genome
2010s	3	648	1.97%	middle east respiratory syndrome coronavirus	2013 (1999)	Virus
2010s	4	403	2.38%	transcription activatorlike effector nucleases	2011 (2010)	Amino Acid, Peptide, or Protein
2010s	5	323	2.70%	AMPK1	2010 (1985)	Gene or Genome
2010s	6	304	3.01%	H7N9 virus	2013 (2013)	Virus
2010s	7	301	3.31%	C9ORF72	2011 (2011)	Gene or Genome
2010s	8	295	3.61%	schmallenberg virus	2012 (2012)	Virus
2010s	9	276	3.88%	talens	2010 (2010)	Amino Acid, Peptide, or Protein
2010s	10	256	4.14%	interleukin28b	2010 (2003)	Amino Acid, Peptide, or Protein
2010s	11	246	4.39%	crisprcas systems	2011 (2006)	Molecular Function
2010s	12	219	4.61%	mechanistic target of rapamycin complex 1	2010 (2002)	Amino Acid, Peptide, or Protein
2010s	13	214	4.82%	telocytes	2010 (2005)	Cell
2010s	14	191	5.02%	SRSF2	2011 (1991)	Amino Acid, Peptide, or Protein
2010s	15	182	5.20%	chromothripsis	2011 (1954)	Cell or Molecular Dysfunction
2010s	16	179	5.38%	CALR mutation	2013 (2013)	Cell or Molecular Dysfunction
2010s	17	164	5.54%	fukushima nuclear accident	2011 (2011)	Human-caused Phenomenon or Process
2010s	18	162	5.71%	beige adipocytes	2012 (2010)	Cell
2010s	19	151	5.86%	SRSF2	2011 (1991)	Gene or Genome
2010s	20	150	6.01%	ocriplasmin	2010 (1987)	Amino Acid, Peptide, or Protein
2000s	1	21210	3.08%	micrornas	2001 (1971)	Nucleic Acid, Nucleoside, or Nucleotide
2000s	2	12390	4.88%	microrna	2000 (1971)	Nucleic Acid, Nucleoside, or Nucleotide
2000s	3	9139	6.21%	nextgeneration sequencing	2007 (2005)	Molecular Biology Research Technique
2000s	4	8606	7.46%	small interfering RNA	2001 (1949)	Nucleic Acid, Nucleoside, or Nucleotide
2000s	5	6569	8.42%	GWAS	2007 (1982)	Molecular Biology Research Technique
2000s	6	4290	9.04%	induced pluripotent stem cells	2006 (1966)	Cell
2000s	7	3885	9.61%	th17 cells	2006 (1980)	Cell
2000s	8	3405	10.1%	deep sequencing	2000 (2000)	Molecular Biology Research Technique
2000s	9	3055	10.5%	mtorc1	2004 (2002)	Cell Component
2000s	10	2976	10.9%	IL17A	2003 (1988)	Amino Acid, Peptide, or Protein

2000s	11	2746	11.3%	IL17A	2003 (1988)	Gene or Genome
2000s	12	2667	11.7%	CD133	2000 (2000)	Amino Acid, Peptide, or Protein
2000s	13	2651	12.1%	inflammasome	2002 (2002)	Amino Acid, Peptide, or Protein
2000s	14	2532	12.5%	short hairpin RNA	2002 (1982)	Nucleic Acid, Nucleoside, or Nucleotide
2000s	15	2520	12.8%	exome sequencing	2009 (2009)	Molecular Biology Research Technique
2000s	16	2513	13.2%	CD133	2000 (1978)	Gene or Genome
2000s	17	2466	13.6%	norovirus	2002 (2002)	Amino Acid, Peptide, or Protein
2000s	18	2411	13.9%	small interfering rna	2001 (1949)	Nucleic Acid, Nucleoside, or Nucleotide
2000s	19	2318	14.3%	IL23	2000 (2000)	Molecular Function
2000s	20	2265	14.6%	long noncoding RNA	2007 (2003)	Nucleic Acid, Nucleoside, or Nucleotide
1990s	1	20439	1.19%	graphene	1992 (1992)	Element, Ion, or Isotope
1990s	2	20423	2.39%	realtime PCR	1996 (1989)	Molecular Biology Research Technique
1990s	3	18527	3.47%	single nucleotide polymorphisms	1994 (1966)	Nucleotide Sequence
1990s	4	17023	4.46%	IL10	1990 (1990)	Molecular Function
1990s	5	14482	5.31%	transcriptome	1997 (1997)	Nucleotide Sequence
1990s	6	14459	6.16%	caspase3	1997 (1949)	Gene or Genome
1990s	7	13862	6.97%	caspase3	1997 (1949)	Amino Acid, Peptide, or Protein
1990s	8	11694	7.65%	PI3K	1990 (1989)	Molecular Function
1990s	9	10248	8.25%	nanomaterials	1994 (1994)	Research Activity
1990s	10	9951	8.83%	qrtpcr	1997 (1992)	Molecular Biology Research Technique
1990s	11	9237	9.37%	IL10	1990 (1975)	Gene or Genome
1990s	12	8821	9.89%	MAPK	1990 (1959)	Molecular Function
1990s	13	8771	10.4%	quantitative realtime PCR	1999 (1989)	Molecular Biology Research Technique
1990s	14	8459	10.9%	MMP9	1991 (1991)	Molecular Function
1990s	15	8432	11.3%	IL10	1990 (1975)	Amino Acid, Peptide, or Protein
1990s	16	8158	11.8%	adiponectin	1999 (1966)	Gene or Genome
1990s	17	7965	12.3%	realtime polymerase chain reaction	1997 (1989)	Molecular Biology Research Technique
1990s	18	7533	12.7%	adiponectin	1999 (1982)	Amino Acid, Peptide, or Protein
1990s	19	7429	13.2%	single nucleotide polymorphism	1991 (1966)	Nucleotide Sequence
1990s	20	6443	13.5%	PI3K	1990 (1975)	Gene or Genome
1980s	1	52779	2.85%	signaling pathway	1984 (1949)	Cell Function

1980s	2	41362	5.10%	signaling pathway	1984 (1984)	Molecular Function
1980s	3	31713	6.81%	polymerase chain reaction	1986 (1986)	Molecular Biology Research Technique
1980s	4	29573	8.42%	RTPCR	1989 (1989)	Molecular Biology Research Technique
1980s	5	22089	9.61%	IL6	1987 (1987)	Molecular Function
1980s	6	17648	10.5%	western blotting	1981 (1980)	Molecular Biology Research Technique
1980s	7	16542	11.4%	western blot	1981 (1980)	Molecular Biology Research Technique
1980s	8	14755	12.2%	metaanalyses	1982 (1975)	Research Activity
1980s	9	13893	13.0%	MTT assay	1985 (1985)	Research Activity
1980s	10	13784	13.7%	HIV1	1986 (1984)	Virus
1980s	11	13393	14.4%	vascular endothelial growth factor	1982 (1982)	Molecular Function
1980s	12	12584	15.1%	bcl2	1984 (1984)	Molecular Function
1980s	13	12158	15.8%	tandem mass spectrometry	1981 (1952)	Molecular Biology Research Technique
1980s	14	11356	16.4%	RNA interference	1987 (1959)	Genetic Function
1980s	15	10633	17.0%	EGFR	1980 (1979)	Molecular Function
1980s	16	10614	17.6%	quantitative PCR	1989 (1989)	Molecular Biology Research Technique
1980s	17	10205	18.1%	human immunodeficiency virus	1986 (1983)	Virus
1980s	18	9966	18.6%	hepatitis C virus HCV	1989 (1961)	Virus
1980s	19	8766	19.1%	mscs	1980 (1980)	Molecular Function
1980s	20	8766	19.6%	VEGF	1987 (1987)	Gene or Genome
1970s	1	88250	3.17%	targeting	1971 (1969)	Cell Function
1970s	2	71032	5.73%	apoptosis	1972 (1965)	Cell Function
1970s	3	69386	8.23%	oxidative stress	1970 (1970)	Cell or Molecular Dysfunction
1970s	4	64508	10.5%	logistic regression	1974 (1974)	Research Activity
1970s	5	60211	12.7%	overexpression	1977 (1977)	Genetic Function
1970s	6	54912	14.7%	upregulation	1979 (1972)	Genetic Function
1970s	7	52661	16.6%	metaanalysis	1977 (1975)	Research Activity
1970s	8	45151	18.2%	reactive oxygen species	1977 (1949)	Element, Ion, or Isotope
1970s	9	37086	19.5%	upregulation	1979 (1979)	Molecular Function
1970s	10	36853	20.8%	mrna expression	1979 (1949)	Genetic Function
1970s	11	35969	22.1%	protein expression	1976 (1949)	Genetic Function
1970s	12	28786	23.2%	logistic regression analysis	1974 (1974)	Research Activity

1970s	13	23896	24.0%	overexpress	1977 (1977)	Genetic Function
1970s	14	23598	24.9%	randomized controlled trial	1970 (1970)	Research Activity
1970s	15	22945	25.7%	downregulation	1977 (1977)	Molecular Function
1970s	16	20421	26.5%	CD8	1979 (1976)	Immunologic Factor
1970s	17	19721	27.2%	T cells	1970 (1967)	Cell
1970s	18	17182	27.8%	FTIR	1975 (1972)	Research Activity
1970s	19	16625	28.4%	ANOVA	1971 (1971)	Gene or Genome
1970s	20	16541	29.0%	ANOVA	1971 (1971)	Amino Acid, Peptide, or Protein
1960s	1	86187	3.94%	mrna	1964 (1961)	Nucleic Acid, Nucleoside, or Nucleotide
1960s	2	83131	7.75%	targeted	1969 (1969)	Cell Function
1960s	3	60306	10.5%	gene expression	1961 (1949)	Genetic Function
1960s	4	45781	12.6%	crosssectional study	1961 (1954)	Research Activity
1960s	5	32420	14.0%	genomic	1961 (1949)	Gene or Genome
1960s	6	31775	15.5%	transcriptional	1966 (1949)	Genetic Function
1960s	7	24042	16.6%	extracellular matrix	1962 (1952)	Tissue
1960s	8	18772	17.5%	transcripts	1962 (1949)	Nucleic Acid, Nucleoside, or Nucleotide
1960s	9	18060	18.3%	casecontrol study	1967 (1967)	Research Activity
1960s	10	18018	19.1%	phylogenetic analysis	1964 (1949)	Research Activity
1960s	11	16077	19.9%	16S rrna	1968 (1966)	Nucleic Acid, Nucleoside, or Nucleotide
1960s	12	15664	20.6%	retrospective cohort study	1966 (1966)	Research Activity
1960s	13	15057	21.3%	translational	1963 (1949)	Genetic Function
1960s	14	14371	21.9%	chiral	1968 (1949)	Phenomenon or Process
1960s	15	14303	22.6%	COPD	1967 (1967)	Gene or Genome
1960s	16	14096	23.2%	DNA damage	1965 (1965)	Cell or Molecular Dysfunction
1960s	17	13568	23.8%	immunosuppression	1964 (1964)	Organism Function
1960s	18	13020	24.4%	transfection	1966 (1966)	Molecular Biology Research Technique
1960s	19	11614	25.0%	drug discovery	1964 (1964)	Research Activity
1960s	20	10962	25.5%	eukaryotes	1968 (1956)	Eukaryote
1950s	1	64715	3.69%	randomized	1953 (1949)	Research Activity
1950s	2	59508	7.09%	recombinant	1951 (1951)	Organism
1950s	3	56353	10.3%	simulations	1954 (1949)	Research Activity

1950s	4	33856	12.2%	selfreport	1953 (1953)	Research Activity
1950s	5	33379	14.1%	prospective study	1954 (1954)	Research Activity
1950s	6	25870	15.6%	polymorphisms	1952 (1949)	Genetic Function
1950s	7	17037	16.5%	cterminal	1952 (1952)	Amino Acid Sequence
1950s	8	16458	17.5%	oligomer	1958 (1958)	Amino Acid Sequence
1950s	9	16243	18.4%	reperfusion	1952 (1952)	Biologic Function
1950s	10	14279	19.2%	cloned	1958 (1949)	Cell
1950s	11	14238	20.0%	binding sites	1952 (1949)	Receptor
1950s	12	13733	20.8%	ecosystems	1959 (1956)	Natural Phenomenon or Process
1950s	13	13641	21.6%	genetic diversity	1959 (1949)	Natural Phenomenon or Process
1950s	14	11997	22.3%	binding site	1952 (1952)	Amino Acid Sequence
1950s	15	11940	23.0%	genomes	1957 (1949)	Gene or Genome
1950s	16	11873	23.7%	data collection	1952 (1952)	Research Activity
1950s	17	11186	24.3%	hepatocytes	1956 (1949)	Cell
1950s	18	11107	24.9%	binding site	1952 (1949)	Receptor
1950s	19	10352	25.5%	placebocontrolled	1954 (1953)	Research Activity
1950s	20	10160	26.1%	exon	1950 (1950)	Nucleic Acid, Nucleoside, or Nucleotide
MISCELLANEOUS (4th of 4 idea category groups)						
2010s	1	1105	3.28%	patient protection and affordable care act	2010 (1981)	Regulation or Law
2010s	2	569	4.98%	cha2ds2vasc score	2010 (2010)	Intellectual Product
2010s	3	262	5.76%	HASBLED score	2011 (2011)	Intellectual Product
2010s	4	173	6.27%	PAM50	2010 (2010)	Functional Concept
2010s	5	161	6.75%	vaping	2011 (1970)	Individual Behavior
2010s	6	155	7.21%	affordable care acts	2010 (1981)	Regulation or Law
2010s	7	148	7.65%	human connectome project	2011 (2011)	Biomedical Occupation or Discipline
2010s	8	100	7.95%	prostate imaging reporting and data system	2013 (2012)	Classification
2010s	9	100	8.25%	prostate imaging reporting and data system	2013 (2013)	Intellectual Product
2010s	10	79	8.48%	PIRADS	2012 (2012)	Classification
2010s	11	76	8.71%	level of evidence II	2010 (2010)	Conceptual Entity

2010s	12	74	8.93%	soft robotics	2011 (2001)	Occupation or Discipline
2010s	13	73	9.15%	3D printed model	2013 (2013)	Manufactured Object
2010s	14	69	9.35%	operation new dawn	2011 (2011)	Idea or Concept
2010s	15	58	9.53%	activity trackers	2012 (2012)	Manufactured Object
2010s	16	56	9.69%	standard uptake value ratio	2010 (1991)	Quantitative Concept
2010s	17	51	9.84%	national center for advancing translational sciences	2011 (1990)	Health Care Related Organization
2010s	18	51	10.0%	groningen frailty indicator	2010 (2010)	Intellectual Product
2010s	19	49	10.1%	grch37	2010 (2010)	Intellectual Product
2010s	20	48	10.2%	nannochloropsis oceanica	2011 (2011)	Plant
2000s	1	8547	5.76%	regenerative medicine	2000 (2000)	Biomedical Occupation or Discipline
2000s	2	7193	10.6%	metabolomics	2000 (1951)	Biomedical Occupation or Discipline
2000s	3	6827	15.2%	gene ontology	2000 (2000)	Intellectual Product
2000s	4	3136	17.3%	metagenomic	2000 (1987)	Occupation or Discipline
2000s	5	2883	19.2%	metabolomic	2000 (1951)	Biomedical Occupation or Discipline
2000s	6	2686	21.1%	DSM5	2000 (2000)	Intellectual Product
2000s	7	2172	22.5%	smartphone	2004 (2004)	Manufactured Object
2000s	8	1791	23.7%	metagenomics	2003 (1987)	Occupation or Discipline
2000s	9	1525	24.8%	theranostic	2000 (2000)	Biomedical Occupation or Discipline
2000s	10	1503	25.8%	smartphones	2004 (2004)	Manufactured Object
2000s	11	1438	26.7%	MELD score	2001 (2001)	Intellectual Product
2000s	12	1401	27.7%	RECIST	2000 (2000)	Intellectual Product
2000s	13	1287	28.6%	nanoribbons	2000 (2000)	Manufactured Object
2000s	14	1283	29.4%	model for endstage liver disease	2001 (1988)	Classification
2000s	15	1200	30.2%	response evaluation criteria in solid tumors	2000 (2000)	Intellectual Product
2000s	16	1171	31.0%	hapmap	2002 (2002)	Organism Attribute
2000s	17	1100	31.8%	common terminology criteria for adverse events	2003 (1991)	Intellectual Product
2000s	18	1042	32.5%	centers for medicare and medicaid services	2001 (1977)	Health Care Related Organization
2000s	19	1032	33.2%	montreal cognitive assessment	2005 (1960)	Intellectual Product
2000s	20	939	33.8%	agency for healthcare research and quality	2000 (1990)	Health Care Related Organization
1990s	1	27976	6.07%	microarray	1992 (1992)	Manufactured Object
1990s	2	16380	9.63%	proteomics	1997 (1997)	Biomedical Occupation or Discipline

1990s	3	15358	12.9%	proteomic	1997 (1997)	Biomedical Occupation or Discipline
1990s	4	11317	15.4%	knockout mice	1992 (1978)	Mammal
1990s	5	9075	17.4%	nanomaterials	1994 (1986)	Manufactured Object
1990s	6	6885	18.9%	nanowires	1993 (1993)	Manufactured Object
1990s	7	6540	20.3%	SF36	1991 (1991)	Intellectual Product
1990s	8	5950	21.6%	nanotechnology	1991 (1991)	Occupation or Discipline
1990s	9	5366	22.7%	innate immune response	1993 (1949)	Organism Attribute
1990s	10	5090	23.8%	nanorods	1999 (1999)	Manufactured Object
1990s	11	4868	24.9%	men who have sex with men	1991 (1991)	Population Group
1990s	12	4702	25.9%	systems biology	1993 (1993)	Biomedical Occupation or Discipline
1990s	13	4546	26.9%	evidencebased practice	1993 (1993)	Functional Concept
1990s	14	4522	27.9%	support vector machine	1998 (1998)	Quantitative Concept
1990s	15	4458	28.9%	centers for disease control and prevention	1991 (1971)	Health Care Related Organization
1990s	16	4438	29.8%	nanofibers	1994 (1994)	Manufactured Object
1990s	17	4331	30.8%	clinical practice guidelines	1990 (1990)	Intellectual Product
1990s	18	4168	31.7%	evidencebased medicine	1992 (1992)	Biomedical Occupation or Discipline
1990s	19	3897	32.5%	affymetrix	1995 (1995)	Health Care Related Organization
1990s	20	3826	33.3%	innate immune responses	1995 (1949)	Organism Attribute
1980s	1	39848	4.54%	hazard ratio	1980 (1980)	Quantitative Concept
1980s	2	39599	9.06%	comorbidities	1986 (1970)	Idea or Concept
1980s	3	17746	11.0%	progressionfree survival	1983 (1983)	Quantitative Concept
1980s	4	15786	12.8%	stakeholder	1981 (1981)	Conceptual Entity
1980s	5	15321	14.6%	bioinformatics	1989 (1988)	Biomedical Occupation or Discipline
1980s	6	15038	16.3%	healthrelated quality of life	1982 (1982)	Idea or Concept
1980s	7	13421	17.8%	molecular dynamics simulations	1981 (1973)	Machine Activity
1980s	8	11555	19.2%	focus groups	1980 (1977)	Group
1980s	9	10754	20.4%	biodiversity	1988 (1968)	Qualitative Concept
1980s	10	10658	21.6%	transgenic mice	1982 (1982)	Mammal
1980s	11	10558	22.8%	electronic database	1980 (1980)	Intellectual Product
1980s	12	8609	23.8%	microfluidic	1988 (1988)	Occupation or Discipline
1980s	13	8220	24.7%	nanostructures	1986 (1986)	Manufactured Object

1980s	14	6864	25.5%	bioinformatic	1988 (1988)	Biomedical Occupation or Discipline
1980s	15	6864	26.3%	primary outcome measure	1981 (1981)	Qualitative Concept
1980s	16	6852	27.1%	propensity score	1987 (1987)	Quantitative Concept
1980s	17	6804	27.8%	gene expression profiles	1989 (1989)	Quantitative Concept
1980s	18	6312	28.6%	nanostructure	1986 (1986)	Manufactured Object
1980s	19	6123	29.3%	quantum dots	1987 (1987)	Manufactured Object
1980s	20	6114	30.0%	african americans	1980 (1949)	Population Group
1970s	1	109968	4.43%	targeting	1971 (1949)	Functional Concept
1970s	2	71641	7.32%	odds ratio	1970 (1970)	Quantitative Concept
1970s	3	62961	9.86%	magnetic resonance imaging	1978 (1978)	Professional or Occupational Group
1970s	4	58091	12.2%	expression level	1979 (1979)	Quantitative Concept
1970s	5	54297	14.4%	metaanalysis	1977 (1977)	Intellectual Product
1970s	6	52768	16.5%	nanoparticles	1978 (1978)	Manufactured Object
1970s	7	34573	17.9%	inclusion criteria	1976 (1949)	Qualitative Concept
1970s	8	33562	19.2%	dataset	1970 (1949)	Intellectual Product
1970s	9	32970	20.6%	apoptotic	1972 (1972)	Qualitative Concept
1970s	10	26379	21.6%	scenarios	1974 (1949)	Functional Concept
1970s	11	25440	22.7%	IC50	1970 (1965)	Quantitative Concept
1970s	12	24189	23.6%	gold standard	1979 (1979)	Qualitative Concept
1970s	13	23802	24.6%	databases	1971 (1949)	Intellectual Product
1970s	14	22336	25.5%	transgenic	1972 (1972)	Animal
1970s	15	22291	26.4%	odds ratios	1978 (1970)	Quantitative Concept
1970s	16	18359	27.1%	comorbidity	1970 (1970)	Idea or Concept
1970s	17	18025	27.9%	patient outcome	1970 (1970)	Idea or Concept
1970s	18	17325	28.6%	risk assessment	1973 (1973)	Intellectual Product
1970s	19	17232	29.3%	scaffolds	1975 (1949)	Manufactured Object
1970s	20	16241	29.9%	nonsmall cell lung cancer	1976 (1976)	Conceptual Entity
1960s	1	89643	3.02%	targeted	1969 (1949)	Functional Concept
1960s	2	56711	4.93%	software	1965 (1960)	Manufactured Object
1960s	3	54652	6.77%	ongoing	1960 (1949)	Idea or Concept
1960s	4	53347	8.57%	genomic	1961 (1961)	Biomedical Occupation or Discipline

1960s	5	51686	10.3%	optimization	1960 (1960)	Activity
1960s	6	51434	12.0%	sequencing	1962 (1962)	Functional Concept
1960s	7	44072	13.5%	sequencing	1962 (1962)	Intellectual Product
1960s	8	38380	14.8%	time point	1960 (1955)	Temporal Concept
1960s	9	36566	16.0%	dosedependent	1960 (1960)	Quantitative Concept
1960s	10	35745	17.2%	animal models	1962 (1954)	Animal
1960s	11	32058	18.3%	colorectal cancer	1962 (1962)	Conceptual Entity
1960s	12	30573	19.3%	automated	1960 (1949)	Functional Concept
1960s	13	28157	20.3%	transcripts	1962 (1962)	Intellectual Product
1960s	14	27647	21.2%	providers	1960 (1949)	Functional Concept
1960s	15	26162	22.1%	colorectal cancer	1962 (1962)	Intellectual Product
1960s	16	24749	22.9%	overall survival	1963 (1963)	Quantitative Concept
1960s	17	23419	23.7%	ethnicity	1966 (1966)	Qualitative Concept
1960s	18	22479	24.5%	algorithms	1963 (1949)	Intellectual Product
1960s	19	21854	25.2%	ex vivo	1964 (1964)	Functional Concept
1960s	20	19862	25.9%	ethnicity	1966 (1949)	Population Group
1950s	1	101395	2.49%	risk factors	1959 (1959)	Intellectual Product
1950s	2	67299	4.15%	quality of life	1959 (1959)	Idea or Concept
1950s	3	62097	5.68%	encoding	1956 (1953)	Activity
1950s	4	62041	7.21%	encoding	1956 (1956)	Idea or Concept
1950s	5	52107	8.50%	downstream	1950 (1950)	Spatial Concept
1950s	6	50147	9.73%	researchers	1954 (1949)	Professional or Occupational Group
1950s	7	46112	10.8%	documented	1950 (1950)	Intellectual Product
1950s	8	41331	11.8%	technologies	1956 (1949)	Occupation or Discipline
1950s	9	38756	12.8%	options	1950 (1949)	Functional Concept
1950s	10	33842	13.6%	modulating	1955 (1949)	Spatial Concept
1950s	11	31872	14.4%	intraoperative	1950 (1950)	Temporal Concept
1950s	12	30024	15.2%	categorized	1957 (1952)	Activity
1950s	13	29996	15.9%	encode	1953 (1953)	Activity
1950s	14	29951	16.6%	older adult	1951 (1951)	Age Group
1950s	15	28595	17.3%	lifestyle	1959 (1956)	Social Behavior

1950s	16	28278	18.0%	perioperative	1957 (1957)	Temporal Concept
1950s	17	26289	18.7%	older adult	1951 (1949)	Population Group
1950s	18	25647	19.3%	emergency department	1957 (1957)	Health Care Related Organization
1950s	19	25130	19.9%	encoded	1953 (1953)	Activity
1950s	20	25019	20.6%	multidisciplinary	1952 (1949)	Occupational Activity

Table S4. Bootstrapped Confidence Intervals and Robustness of Overall Frontier Positions of Nations to Alternative Specifications.

(1a)	(1b)	(1c)	(1d)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Location	Number of Contributions	2010s; same as column 1c in Table 1	Bootstrapped 95% Confidence Intervals		Set missing values equal to 0	Weight by number of own contri-butions	Use UMLS synonym data to determine cohort of each term	Top 20% novel status used	Top 10% novel status used	Top 1% novel status used	All papers (not just original res. papers)	No upper, lower limits on number of char-acters
UNITED STATES	2853661	108	(106..109)		108	107	102	105	114	108	107	108
SOUTH KOREA	374227	107	(104..110)		105	107	108	108	99	107	108	106
SINGAPORE	52541	105	(100..111)		98	108	99	103	118	106	106	105
TAIWAN	177229	104	(101..107)		102	103	107	107	98	103	105	104
IRELAND	39495	103	(97..108)		95	100	98	98	109	101	102	100
BELGIUM	95644	102	(99..106)		99	102	99	100	104	104	101	101
ITALY	384029	102	(99..104)		101	103	100	102	100	102	103	102
CHINA	1734035	101	(99..103)		101	102	105	102	95	102	101	101
CANADA	375846	101	(99..104)		101	101	98	100	105	99	101	102
JAPAN	554589	100	(98..103)		99	103	100	100	100	100	101	100
UNITED KINGDOM	494917	100	(98..103)		100	100	97	98	105	100	100	100
NETHERLANDS	233631	100	(97..103)		99	100	99	99	100	100	100	100
GERMANY	539888	100	(98..102)		99	99	97	98	101	100	99	99
SWITZERLAND	123779	100	(96..103)		97	100	97	98	102	100	101	99
SAUDI ARABIA	34855	99	(94..106)		90	94	95	95	82	97	98	98
FINLAND	59534	99	(94..103)		94	98	100	98	96	98	99	98
NORWAY	63699	98	(93..103)		94	95	96	95	96	97	97	99
SOUTH AFRICA	43179	98	(92..104)		90	101	99	103	92	100	96	97
SPAIN	278504	98	(95..100)		97	97	98	98	92	99	97	97
CZECH REPUBLIC	44024	97	(92..102)		89	102	98	99	92	98	99	97
AUSTRALIA	320955	97	(95..99)		96	97	97	97	96	98	97	97
SWEDEN	138949	96	(92..99)		94	96	96	95	92	96	96	96
AUSTRIA	65039	96	(91..100)		91	97	96	97	99	96	96	96
DENMARK	105066	95	(92..99)		93	95	97	96	99	97	95	95
FRANCE	305065	95	(93..98)		94	96	95	96	98	98	95	96
POLAND	113074	93	(89..96)		90	93	94	93	90	90	93	93
THAILAND	40080	93	(87..98)		85	92	96	95	84	93	95	92
HUNGARY	28574	92	(86..99)		82	94	94	93	86	95	94	90
ISRAEL	76781	92	(88..96)		89	93	95	94	90	94	92	92
OTHER EUROPE	107712	90	(87..94)		88	90	92	90	88	90	92	90
NEW ZEALAND	38946	90	(84..96)		83	91	90	90	96	93	98	93
TURKEY	157825	90	(86..94)		87	91	95	94	84	90	90	89
RUSSIA	51759	89	(83..95)		79	89	87	86	90	86	90	89
CHILE	23794	89	(82..97)		78	88	95	92	71	96	87	89
GREECE	46646	89	(84..93)		83	92	98	93	81	92	90	90
MALAYSIA	37997	87	(82..93)		79	89	91	86	86	84	92	87
PORTUGAL	65523	86	(82..91)		82	86	91	89	87	86	88	87
OTHER ASIA	60973	86	(81..90)		81	83	91	87	82	87	86	85
INDIA	291215	83	(80..86)		81	81	89	86	80	84	84	82
BRAZIL	274896	83	(80..85)		81	85	91	87	76	79	84	83
PAKISTAN	27511	83	(75..91)		69	81	85	83	83	81	81	83
MEXICO	54997	81	(77..86)		76	83	89	85	75	79	82	80
IRAN	121035	78	(74..82)		76	79	89	84	70	79	79	78
OTHER AMERICAS	30787	77	(71..83)		70	86	88	82	78	73	81	77
ARGENTINA	40775	77	(72..82)		70	79	84	80	77	72	81	78
EGYPT	48649	75	(69..80)		68	74	89	83	65	78	75	74
OTHER AFRICA	90041	70	(65..74)		65	72	81	76	69	70	71	70

Notes to Table S4:

All numbers are calculated based on papers published during 2015-2016.

Column 1a: Location.

Column 1b: Number of contributions based on which the edge factor in column (1c) is calculated. See notes to Table 1.

Column 1c: Edge factor for the baseline specification.

Column 1d: Bootstrapped 95% confidence interval for the edge factor in the baseline specification.

Column 2: When there are no observations for an (idea category, research area) pair for a location, the edge factor for that that (idea category, research area) pair is set to 0; in the baseline specification (shown in column 1c) the edge factor is set to the weighted average of the edge factor for all other (idea category, research area) pairs.

Column 3: When the overall edge factor is calculated for a location, the weight of the edge factor for each (idea category, research area) pair is the location's own number of papers linked to that (idea category, research area) pair; in the baseline specification (shown in column 1c) the weight is the number of papers from any location that are linked to that (idea category, research area) pair.

Column 4: The vintage of each UMLS term is determined based on the earliest year of appearance of the UMLS term or any of its synonyms (as indicated in the UMLS); in the baseline specification (shown in column 1c) vintage is determined based on the earliest year of appearance of the UMLS term.

Column 5: When the dummy variable that indicates the novelty of a contribution relative to other contributions in the comparison group is constructed, a 20% cutoff level is used, so that the 20% of the contributions with the most recent cohort are assigned the novel status; in the baseline specification (shown in column 1c) the corresponding cutoff is 5%.

Column 6: Same as Column (5) but now a 10% cutoff is used.

Column 7: Same as Column (5) but now a 1% cutoff is used.

Column 8: The analysis includes all types of publications in MEDLINE; in the baseline specification (shown in column 1c) only original research papers are considered.

Column 9: The analysis includes also those papers for which MEDLINE has either less than 200 characters of text or more than 5000 characters of text; in the baseline specification (shown in column 1c) only those original research papers are included for which the text information in MEDLINE falls within those bounds.

Table S5. Overall Scientific Frontier Positions of Nations by Time Period.

(1a)	(1b)	(1c)		(2a)	(2b)	(2c)	(2d)	(2e)	(2f)
Location	Number of Contributions	2015-6		1990-94 with 1990s weights	1995-9, with 1990s weights	2000-4, with 1990s weights	2005-9, with 1990s weights	2010-4, with 1990s weights	2015-6, with 1990s weights
UNITED STATES	2853661	108		107	108	109	109	109	109
SOUTH KOREA	374227	107		82	87	102	106	105	107
SINGAPORE	52541	105		89	105	102	108	109	104
TAIWAN	177229	104		90	85	89	95	101	105
IRELAND	39495	103		74	84	97	100	106	99
BELGIUM	95644	102		101	101	104	108	107	106
ITALY	384029	102		94	95	95	99	102	103
CHINA	1734035	101		79	82	98	97	98	101
CANADA	375846	101		93	96	98	100	101	100
JAPAN	554589	100		95	96	100	101	101	102
UNITED KINGDOM	494917	100		103	104	103	103	104	101
NETHERLANDS	233631	100		93	94	99	103	102	100
GERMANY	539888	100		96	97	101	102	102	103
SWITZERLAND	123779	100		105	107	105	104	104	103
SAUDI ARABIA	34855	99		83	75	65	85	87	95
FINLAND	59534	99		95	95	96	93	96	99
NORWAY	63699	98		90	92	90	97	99	100
SOUTH AFRICA	43179	98		75	76	84	84	84	96
SPAIN	278504	98		79	85	90	92	96	99
CZECH REPUBLIC	44024	97		70	75	87	90	94	97
AUSTRALIA	320955	97		92	94	96	96	98	98
SWEDEN	138949	96		87	87	90	94	97	98
AUSTRIA	65039	96		99	98	99	102	99	99
DENMARK	105066	95		89	89	91	94	97	96
FRANCE	305065	95		97	96	97	101	99	97
POLAND	113074	93		59	68	73	77	87	92
THAILAND	40080	93		79	73	73	75	79	85
HUNGARY	28574	92		72	75	80	83	85	94
ISRAEL	76781	92		79	78	87	93	94	95
OTHER EUROPE	107712	90		74	73	76	77	82	89
NEW ZEALAND	38946	90		92	92	92	93	95	87
TURKEY	157825	90		70	67	72	69	82	86
RUSSIA	51759	89		57	68	68	65	81	89
CHILE	23794	89		49	62	74	74	85	89
GREECE	46646	89		71	78	78	80	84	90
MALAYSIA	37997	87		57	77	94	68	80	81
PORTUGAL	65523	86		81	82	74	88	93	84
OTHER ASIA	60973	86		70	64	70	69	76	85
INDIA	291215	83		57	61	65	68	74	78
BRAZIL	274896	83		81	74	74	75	77	79
PAKISTAN	27511	83		53	56	57	75	77	81
MEXICO	54997	81		73	69	70	73	74	79
IRAN	121035	78		32	36	56	66	72	74
OTHER AMERICAS	30787	77		81	84	71	77	74	70
ARGENTINA	40775	77		58	65	69	69	75	74
EGYPT	48649	75		49	67	62	65	67	71
OTHER AFRICA	90041	70		77	76	66	67	67	63

Notes to Table S5:

Column 1a: Location.

Column 1b: Number of contributions based on which the edge factor in column (1c) is calculated. See notes to Table 1.

Weights below refer to how the edge factor for each (idea category, research area) pair is weighted when the overall edge factor for a location is calculated. When "2015-6 weights" are used, the weight for each (idea category, research area) pair is the total number of papers published during 2015-2016 that are linked to that (idea category, research area) pair.

Column 1c: Edge factors for 2015-2016 (calculated using 2015-6 weights).

Column 2a. Edge factors for 1998-1994, calculated using 1990s weights.

Column 2b. Edge factors for 1995-1999, calculated using 1990s weights.

Column 2c. Edge factors for 2000-2004, calculated using 1990s weights.

Column 2d. Edge factors for 2005-2009, calculated using 1990s weights.

Column 2e. Edge factors for 2010-2014, calculated using 1990s weights.

Column 2f. Edge factors for 2015-2016, calculated using 1990s weights.