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Developing science and technology – the role of Big Tech

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Abstract

This work aims to conduct a scientometric study on the research published by digital platforms known as Big Tech (Amazon, Apple, Facebook, Google and Netflix), giving an overview of the publications' growth, distribution by document's types, research themes and affiliations' profile. All data was retrieved from the Scopus' database, only publications in English and that had an associated DOI (digital object identifier) were considered. Given Big Tech's financial and development strategies, they are present in many markets outside their core activity, enabling them to be at the forefront in innovation. Hence, Big Tech invest in research related activities such as scientific publishing, showing a great surge in their levels of publications from 2015 onwards. "Computer Science" is the most popular journal subject area in which they tend to publish. In the publications' authorship there were no outstanding international partnerships found, with the Big Tech companies' researchers being the main authors, nonetheless a propensity to work with universities was identified. These results help to profile Big Tech's research activity, thematically technology-driven and without a clear scientific collaboration network.

Keywords: Big Tech, research, scientometric, publication, digital platforms

1. Introduction

Research is at the heart of the current economic paradigm, one in which firms value scientific investigation and human capital (Hall and Jaffe, 2018), allowing the incorporation of technology and innovation diffusion (Tocan, 2012) to make use of the workforce know-how in a network environment. These companies invest in infrastructures and resources, in addition to promote ventures with other innovation agents such as universities or scientific institutes, consequently building networks (Meyer-Krahmer and Schmoch, 1998). Generally, private firms are much more inclined to patenting than the publication of scientific articles, unlike universities (Meyer, 2000), hence the potential complementarity between them. This collaboration of public and private organizations is welcomed and encouraged by political actors, like the European Commission, seeing this as a key driver of a knowledge strategy policy (Verspagen, 2006).

The act of publish per se does not assure immediate benefits, for publications' success lies on the display and interest it garners among the scientific and the entrepreneurship communities (Baron and Russell-Bennett, 2016), therefore researchers must design a strategy aiming at this with presentations at conferences. These events, when propelled by industrialists, can provide a gateway for academic research to a broader audience (Spencer, 2001).

The interest in science and technology (S&T) has grown over the last decades, supporting this claim is the increasing involvement in R&D activities by most firms and their willingness to leave paper "trails" in terms of knowledge-based outputs (Rotolo et al., 2022).

Large technological companies such as Google, Facebook, Apple, Netflix, Microsoft or Amazon, known variously as Big Tech, FAANGs or GAFAMs display a dominant social and political influence (Birch and Bronson, 2022) on today's society, going beyond their worldwide economic hegemony. The digital services provided became the source for such impact, being present in essential sectors such as advertising, mobile operating systems, social media, among others (Moore and Tambini, 2021), when supplying these, Big Tech gain access to a range of data and information of such extent, that issues like privacy trespassing are raised (Prainsack, 2019). In recent years, Big Tech have diversified the way they apply their investments (Klinge et al., 2022), be it by backing academic research, the acquisition of startups and small firms (which their policies enhance) (Jacobides and Lianos, 2021), or by way of their researchers co-authoring scientific publications.

This paper wants to give an overview of the publications authored by investigators affiliated with Big Tech, the partnerships signed with different institutions and the subjects covered by the produced research. Additionally, although not intending to study Big Tech's investments on R&D activities, the presence in conferences and assorted events or items promoting research conducted will be target of analysis. For conferences act not just as publications' promotion but as fruitful meetings between scientists whose interaction fosters more research (Wang et al., 2017).

This article is divided in the following sections. Firstly, a literature review framing the scientific research process environment (publication, funding, collaborations), as well as Big Tech's scientific activity and broad research patterns (themes, frequent partnerships). Secondly, a section presenting the data and methodology used and the main findings. Then, a discussion of the results will be conducted. Finally, a conclusion considering the contribute of Big Tech to science and technology.

2. Research Framework

2.1. Research Environment

Publication

Collaboration between academia and private firms places a knowledge and technological transfer (Beise and Stahl, 1999), propelling an innovative environment that makes such alliances a self-evident advantage for all. Overtime, universities have grown accustomed and willing to build a dynamic relation with industry, with trust between them becoming crucial to overcame barriers (Bruneel et al., 2010). The reason and aims of the conducted research are of different order for the two parts, when targeting a journal to publish, a more business or commercial themed one may adjust the academic research to a more practical use (Spencer, 2001). However, the scientific identity or academic customs are not inconsistent with more commercial minded views of entrepreneurs (Boardman and Ponomariov, 2009) or those of industry, that can blend its interests with academic aims (Goldfarb, 2008).

Next to the inter-organizational aspect, another important feature for collaborations' exposure is the existence and recurrence of international partnerships, i.e., authors affiliated to different organizations and of different nations. The chance to publish and to do it in well-regarded (international) journals is always greater with internationally co-authorship (Barjak and Robinson, 2008), although assembling the research team is a difficult task, it bears advantages (multitude of skills, various problem-solving approaches).

To publish, especially at an international level, requires the harbor of strong technical capabilities (Penner-Hahn and Shaver, 2005), additionally, to pursuit long-term research is a task considered only by large companies with means to proceed with it (Li et al., 2015). For only companies with an organized core framework can sustain the demands of innovation, including the development of ties with scientific institutions (Schiuma and Carlucci, 2018). Hence, besides the signaling and reputation-building advantage, publishing fosters network channels with other researchers (Camerani et al., 2015), resulting on a prolific exchange of ideas or even the recruitment of some of them for their teams.

Another approach to publishing is using it as a defense mechanism with preemptive publication of results. This translates in inhibiting competitors from a significant advantage: the use of this information to a forthcoming project, hampering the patentability of the published idea for rivals (Parchomovsky, 2000), but at the same time it ends up promoting a competitive environment and higher investment in R&D by the disputing firms. In fact, it is important to underline that there is a positive relationship between the disclosure of research and financial performance of firms that opt to publish (Rotolo et al., 2022).

Conferences and Funding

To meet approval and credibility, most publications tend to join traditional and novel elements (Teplitskiy et al., 2022). The importance of published research is perhaps better experienced at scientific conferences, that act as quality appraisers and means to quicken publication process (Spiegel and Toivanen, 2022), though there are many features that condition a paper's acceptance such as the type (empirical, theoretical, experimental), the authorship (sole or in collaboration), among others. Conferences are doorways to international partnership and reflect research's utility because the share of knowledge is vital to greater innovation efficiency

(Jefferson et al., 2018). They can also be seen as part of professional development, means to new publications, or a way to establish a research network (Spilker et al., 2020).

Key factors surrounding conferences are the preparation procedures (registration and submission), the assessment boards and, particularly, the scientific journals (Dimitrios et al., 2014). There is a solid connection between a conference presentation and the likelihood of publishing in a high-quality academic journal (Gorodnichenko et al., 2021), furthermore conferences provide visibility to scientific work. Moreover, there are several criteria to consider a publication like relevance, quality, productivity, goals, or long-term viability, all weigh in on peer reviews and rankings (Geuna and Martin, 2003).

Conferences also require substantial financial pledges (Rowe, 2018) to have a well-organized and successful end. Thus, these meetings are supported by outer funding, usually sponsorships that can have a private and/or public source. Sponsors also tend to have a balanced perspective of research purpose and value, thus the concern of a new research paradigm focused on short-term results efficiency is contradicted by how they perceive knowledge's value (Goldfarb, 2008).

Governments have made significant efforts to fund research which includes a direct public investment and specific tax policy (Jacob and Lefgren, 2007) towards linked activities. However, private firms have gained preeminence, especially in developed countries, in scientific funding (Holman and Elliot, 2018), raising concerns like design and selection bias, partial analysis of data, threat for openness, among others. As for the influence of the financing on productivity or the relationship between funding and research quality, governments encourage academia and private firms to work together (Godin, 2003), ever-changing research efficiency paradigm.

Public-funded research is still primarily targeted to the article publication and to broad range projects (Beaudry and Allaoui, 2012). In turn, private corporations, growingly attached to universities, are linked to publication productivity (Behrens and Gray, 2001; Ahmed et al., 2023) and different end-results in addition to articles such as development of products, or the setting up of new enterprises (Gulbrandsen and Smeby, 2005). Concerning the themes studied, both public and private financiers can promote interdisciplinarity (Lyall et al., 2013), with the success of such venture relying on its potential scope and the institutional framework behind the research team.

2.2. Big Tech as Digital Platforms and Research Partners

The digital revolution paved the way for a new kind of business model: the platform economy (Brynjolfsson and Smith, 2000) with large-scale, cutting-edge technologically companies acting as the intermediaries between market participants (Frenken et al., 2020), enabling quicker and more efficient transactions between them, therefore, succeeding at matching with lower costs (Goldfarb and Tucker, 2019; House of Lords, 2019). Big Tech are examples of platform-based enterprises (Xue et al., 2020; Australian Competition and Consumer Commission, 2018) with a digital-driven business model, i.e., powered by big data, internet, and cloud computing, while assuming market leadership. Additionally, Big Tech differentiate themselves from competitors by their exponential growth, grounded on mimicking strong financial corporations' behaviour and by making considerable investments in R&D (Klinge et al., 2022).

Consumer behaviour shaped by digitalization favoured firms that had assimilated the technological transformation (e-commerce, for example), resulting in the entrance of Big Tech

on several industries (Verhoef et al., 2021), changing the competitive environment in many of these markets towards their dominance. This disruption brought Big Tech's innovative drive to new sectors (Schumacher, 2022) like healthcare and pharmaceuticals, but it was also met with criticism (data privacy and other ethical issues) leading these companies to conduct image campaigns stunts (Abdalla and Abdalla, 2021).

When tackling knowledge, ways to apply it or create new one, the exchange of ideas is essential, for it heightens the promise of the service or good being developed. As such, digital firms invest in R&D related activities (Hanusch and Pyka, 2007). Specific departments to propel R&D's innovation activity were created with tightly planning and preparation (Masoudnia and Szwejczewski, 2012).

Big Tech, as platform owners, have the privilege of engaging in innovation within the platform environment, furthermore the ease with which they connect people in a costless manner (Kenney and Zysman, 2019). Furthermore, this social network capacity of their services has the potential to bundle information gathering, its handling and supply, as well as knowledge production (Nentwich and Konig, 2014). Thus, scientific research, like publications in journals, is an example of such value creation that entangles these advantages.

Big Tech end up nurturing partnerships with universities and research institutions, like other relevant companies in the past (Freeman and Louçã, 2001). Resulting in the juxtaposition of a corporate innovation system with a corporate production system (Rikap and Lundvall, 2020) where the dynamic innovative development ferrets out the production and trade of commodities. One could add that business governance is designed to shape (Grodal, 2022) and align with the technological innovation process and vice-versa (von Tunzelmann, 2003). Additionally, small enterprises with transforming ideas or products end up seeing their labour integrated in big global digital platforms, because Big Tech usually acquire them (Hoberg and Phillips, 2022). This last phenomenon can be described as a capital accumulation instigated by the ambition of knowledge concentration, for swift paced technological industries are inclined to develop more concentrated (Winter and Nelson, 2009) in a Schumpeterian fashion (Fagerberg et al., 2004).

Enjoying the knowledge liaison with universities, scientific institutions, start-ups, and other firms, Big Tech have produced an increasing number of publications. This scientific burst is linked to the agenda of knowledge concentration pushed by Big Tech (Santesteban and Longpre, 2020), testified in their tight confidentiality (Dolata, 2017) when developing research and their reluctancy in disclosing it, regardless of the means or the positive impact it might have.

3. Data and Methodology

Data was obtained through Scopus, with the search query being made in the affiliations field, in addition, several iterations of the name of the Big Tech companies studied: Facebook, Apple, Amazon, Netflix and Google were searched. Only publications in English were considered.

Scopus, like Web of Science, is a journal-based classification system, hence the journal instead of the individual paper defines the research area (Waltman and Van Eck, 2012). As such, Scopus offers a multi-disciplinarity class system. One whose wide coverage of a given research topic can be too tolerant in assigning journals to categories (Wang and Waltman, 2016), contrasting with a publication-based classification system that could surpass the overlap that might taint the multidisciplinary class system; however, such endeavour is difficult to attain.

After attaining the initial dataset, data was filtered to only include publications prior to 2022 and after the foundation dates of the respective companies, hence the sample period goes from 1981 to 2021. Publications that lacked DOI (digital object identifier) were also removed from analysis. Note that publications include the following categories: articles and conference papers, all the other categories were removed like editorials, book chapters, reviews, notes, erratum, and retractions. The datasets were checked for duplicates.

Then, when tackling the information on affiliations (through the Scopus API) the issue of false positives was raised, i.e., papers not related to Big Tech nonetheless appearing on the database- Some false positives were identified, for they incorporate a string with one of Big Tech's names in the related fields (for instance, Amazon forest themed papers in the Amazon datafile, or companies with the word "Apple" in their name).

A part of publications examined in this study are not of Big Tech's full authorship, many of them resulting from priorly established partnerships, hence we are taking the liberty to consider all publications with one author affiliated to Big Tech as part of the latter's research output. Furthermore, some of the ideas conveyed and findings presented are not held by Big Tech.

All analyses were made using Microsoft Excel and R (R Core Team, 2021). Data from Scopus was loaded using an API key (Farrell, 2009) and the package "rscopus". As for the graphical analysis, among the packages used were "bibliometrix" (Dervis, 2019), "ggplot2" (Wickham, 2016), "readxl", "tidyverse" (Wickham et al., 2019), "ggrepel" (Slowikowski et al., 2018), "scales" (Wickham et al., 2016), "maps", "tidytext" (Silge and Robinson, 2016), "topicmodels"(Grün and Hornik, 2011), "stm" (Roberts et al., 2019), "openxlsx" (Walker and Braglia, 2018), "igraph" (Csardi and Nepusz, 2006), "countrycode" (Arel-Bundock et al., 2018), "widyr" (Silge and Robinson, 2016), "wpp2019" (Sevcikova and Sevcikova, 2017), "textstem" (Rinker, 2018), "glue", "ggthemes" (Arnold and Arnold, 2015), "gridExtra" (Auguie et al., 2017), "remotes", "cowplot" (Wilke et al., 2019), "forecast" (Hyndman and Khandakar, 2008), "hhi" (Waggoner and Waggoner, 2018), "wunderground", "ggcorrplot" (Kassambara and Kassambara, 2019) and "dplyr" (Foster et al., 2017).

Descriptive Analysis

The analysis conducted of the published research will focus on its volume, authorship, and influence. The bibliometric approach followed is a performance analysis (Donthu et al. 2021) relying on publication and citation metrics, like total number of publications, the document type categories of publications: article, conference paper, among other, the intensity overtime of the latter relevant categories and the total number of citations. Although incomplete, citations received by a paper offer a glimpse on the innovative contribute and scientific repercussion of a given paper, making a qualitative stance. The research network will be studied through the authors' affiliations, allowing a broad view of the alliances formed at an institutional level and at a nationality one. Regarding the themes covered by Big Tech's research output, a top five list of the journals where each Big Tech company publishes most often ensues. Finally, the journals are labelled according to their subject area (p.e., Computer Science, Engineering), the classification was made according to the journals' classification in SCImago Journal Rank (Godana, 2011), when unable to find said classification, journals were labelled N/A (not available).

Bibliometrics is present in the methodology steps described earlier, namely performance analysis, by focusing on the analysis of publication's metrics. These techniques are the

cornerstones of our methodology, allowing to assemble Big Tech's research most important contributions and to develop on the instituted partnerships' nature and dynamic.

4. Results

In the period of our data sample (1981-2021), we can find four different subperiods that allows us to perceive the publishing trends of Big Tech companies. Until 2008, there is a very low value of publications, almost residual in some cases due to some companies being very recent (Facebook or Netflix). From 2008 to 2014 there starts to be a slow rise, specially from Facebook and Google, with the other companies starting to lag. This latter trend being reinforced in the subsequent two periods: 2015-2018 and 2019-2021, where the difference becomes of intensity, with in the more recent years Google and Facebook presenting very high per year levels of publication as we will see later. Conference papers are most of the total research output published, representing about two-thirds of the total, the other third being articles.

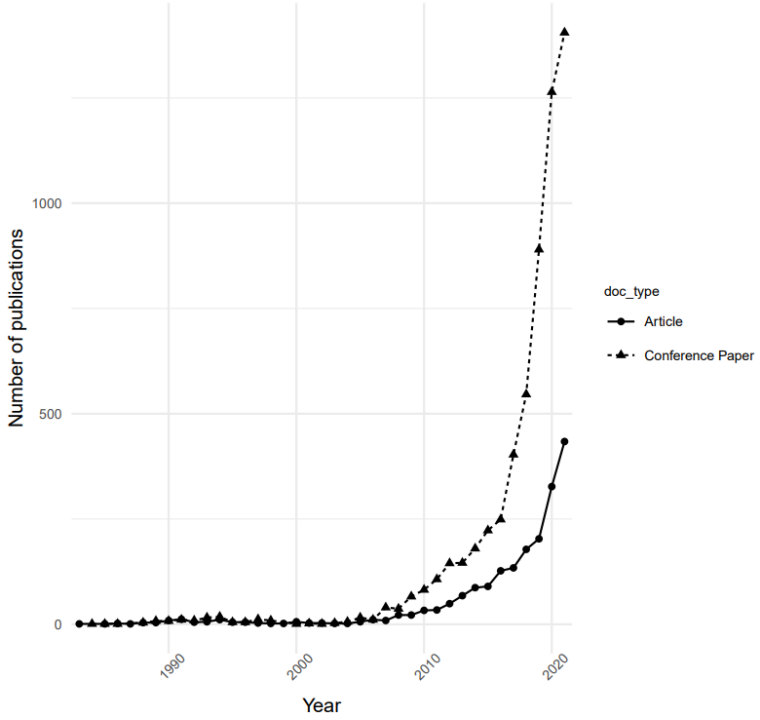

Figure 1 - Conference Papers and Articles by Big Tech overtime

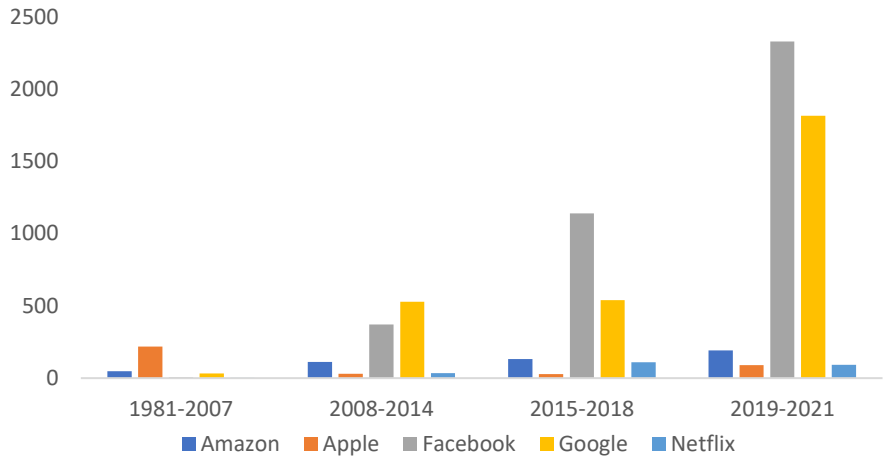

Figure 2 - Publications by Big Tech (individually) overtime

Regarding the subject area of Big Tech's published output, there is a clear dominance of "Computer Science", as seen in figure (3), this does not come as a surprise, since digital platforms main activities are related to this area. There are also some interesting values recorded in the subject areas of "Engineering", "Physics and Astronomy" and "Social Sciences". Therefore, the main subjects of Big Tech's published research are in STEM (Science, technology, engineering, and mathematics) areas. Additionally, when looking at the top five journals for Big Tech, i.e., the journals where they publish the most, all of them are relevant in the "Computer Science" area (figure (4)).

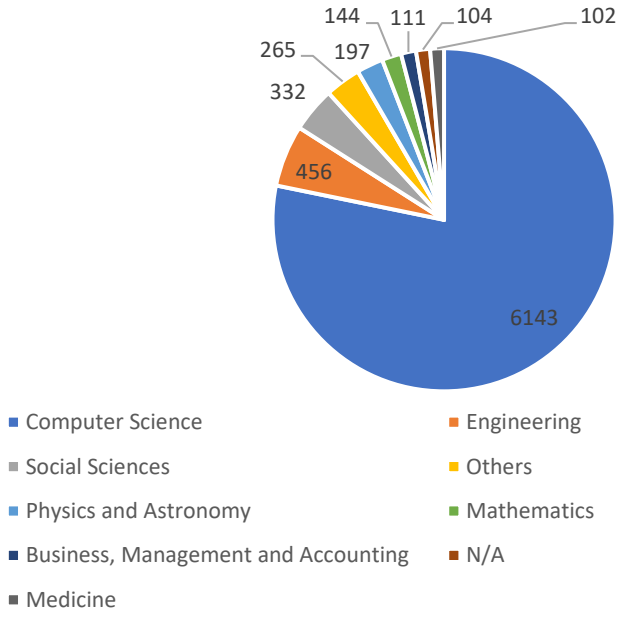

Figure 3 – Big Tech publications by subject area

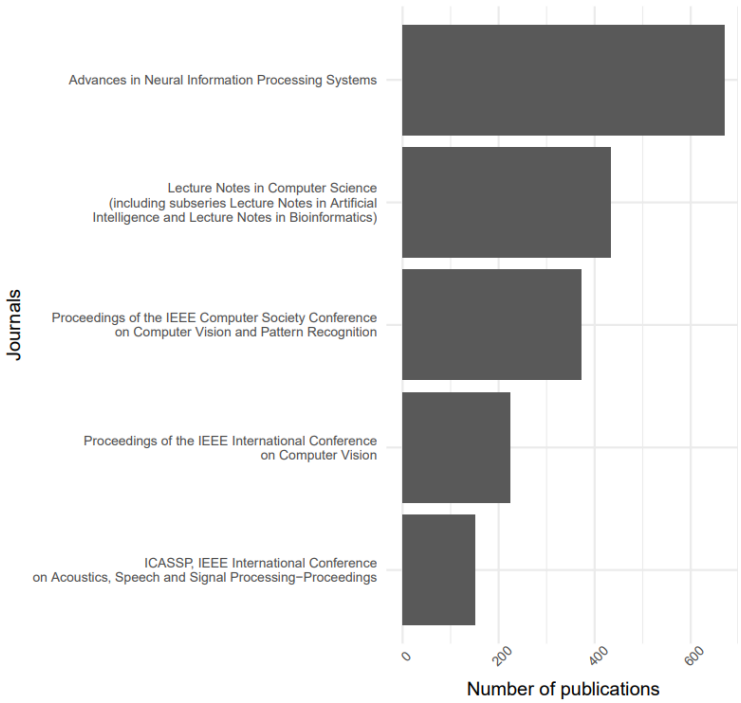

Figure 4 - Top 5 Journals for Big Tech publications

a) Amazon

Amazon's core business is retail through e-commerce, while at the same time committing itself to technological development as part of its investment strategy (Berryman, 2014). The company's scientific ventures remain something to be discussed and studied, or for that matter the network potential of Amazon Web Services, a cloud computing service that has a global reach (Mathew and Varia, 2014).

The total Amazon's co-authored publications on our database from 2000 (year the first publications with DOI appear in our dataset) to 2021 was of 483 publications. The general growth path is upwards, showing a continuous increase in the time studied with occasional decreases like in 2008 or 2016 (figure (5)). Displaying few publications in the early 2000s and less than twenty per year by 2010, from 2017 onwards the production level rise steeply reaching the seventy publications per year in 2021. The two publications' categories: articles and conference proceedings show a similar growth trail with small increases from 2000 to 2015 and a great surge onwards.

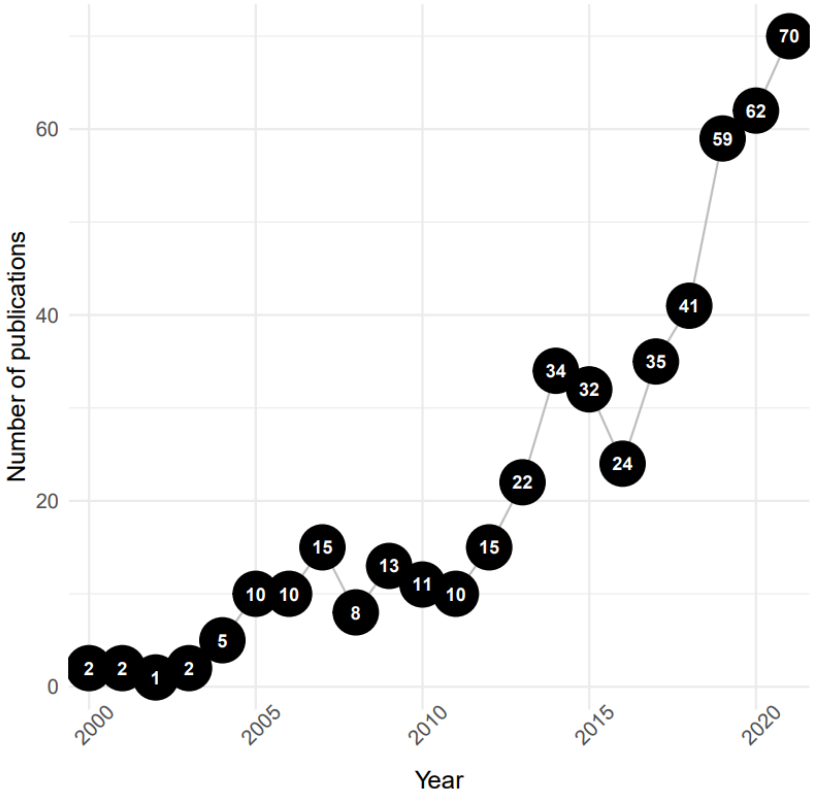

Figure 5 - Publications co-authored by Amazon

Looking to the list of journals were Amazon co-authored publications feature the most, the common themes are "Computer Science" ones: signal-processing, software or human-computer interaction (table (1)). Additionally, "Business, Management and Accounting" or "Engineering" are other major subject areas covered by Amazon published research.

Journal	**Subject Areas and Categories (Scimago)**
Proceedings of the Annual Conference of the International Speech Communication Association, INTERSPEECH	Computer Science: computer science (miscellaneous), human-computer interaction, signal processing, software
Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	Computer Science: computer science (miscellaneous) Mathematics: theoretical computer science
ICASSP, IEEE International Conference on Acoustics, Speech and Signal Processing – Proceedings	Computer Science: signal processing, software Engineering: electrical and electronic engineering
International Conference on Information and Knowledge Management, Proceedings	Business, Management and Accountings: miscellaneous
ACM International Conference Proceeding Series	Computer Science: artificial intelligence, computer networks and communications, computer vision and pattern recognition, human-computer interaction software

Table 1 - Top 5 Journals for Amazon publications

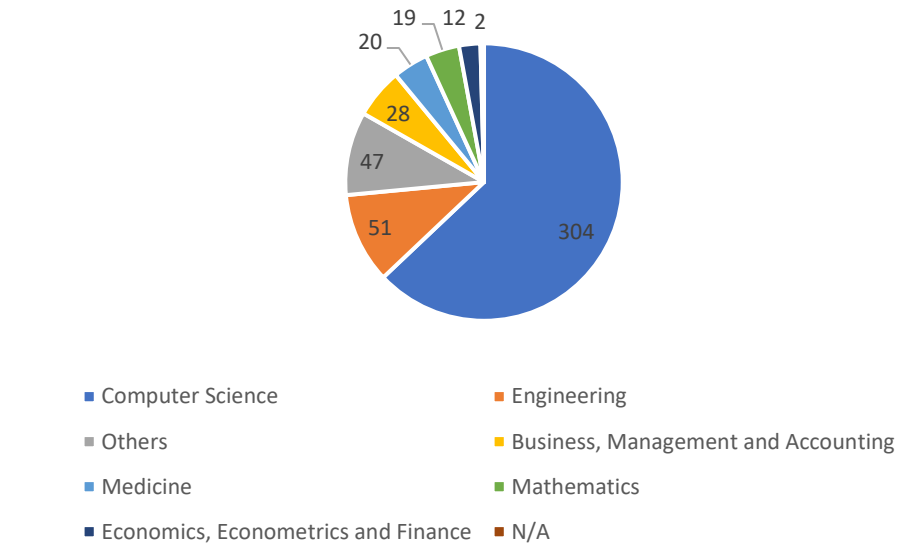

Figure 6 - Amazon Publications by Journal Subject Area

Amazon does not present a high partnership intensity on publications' co-authorship, for although showing some collaborations with universities, most of the output appears to be produced mainly by Amazon. Endorsing this are the affiliations' nationality, the U.S. dominate (more than 450 affiliations, almost 80% of total), other nations show residual values with China coming a distant second (29 publications, less than 5% of total).

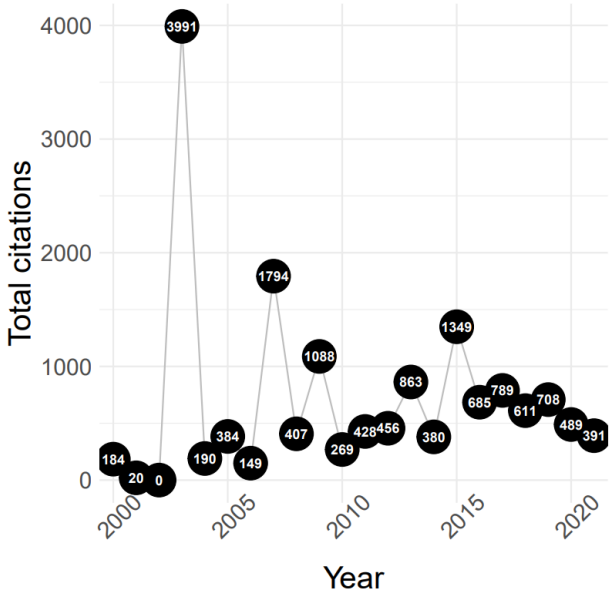

Figure 7 - Citations received by Amazon's publications

Totalizing 15625 citations in the analyzed period 2000-2021, Amazon has an average of 32 citations per publication and of 710 citations per year. Citations have different patterns concerning their growth behavior when compared to publications' one. The few publications issued in the early 2000s have a great number of citations, reaching the impressive statistics of 3991 citations in the year 2003 or 1794 ones in 2007, contrasting with the later period of the dataset in which the number of publications skyrocketed, but on which citations tend to decrease (1349 in 2015 to 391 in 2021). Therefore, those first Amazon authored publications

have a great scientific value to the community, something that latter publications were not able to achieve.

b) Apple

Apple or "Apple, Inc." like the other Big Tech companies is a digital platform, but whose main business is within the technology industry (software and hardware) (Zhang, 2017). As such, the innovation driven Apple relies, from an early stage, on research and development to create products and technologies (Johnson et al., 2012) that answer the public needs and that challenge the technological standard. However, this research can take different forms from patents to publications, the latter of which (the concern of this work) is yet to be analyzed.

Apple publications' levels have two stages of growth, as observed in figure (8). The first, that starts in the mid-1980s, shows an increasing number of publications only to be interrupted in the mid-1990s. Then, a decrease to minimum levels at the turn of the century until 2016, always displaying a constant but small number of publications. From 2016 onwards, a rise is reached, with the maximum of 40 publications in 2021 being the apex of this second growth period. are Although conference papers and articles share similar growth trends, conference papers have a much stronger showing during the recent upsurge, hence being the main contributor to it.

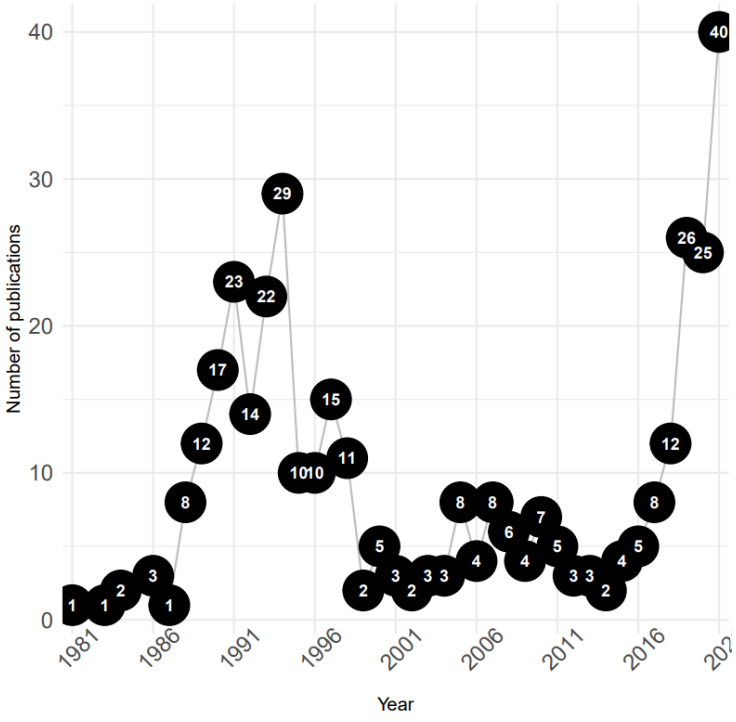

Figure 8 - Publications co-authored by Apple

As Apple is a computer and consumer electronics firm, there is no surprise in the categories of the journals where it publishes more often being "Computer Science" (particularly software, and computer graphics), as well as "Engineering" (table(2)).

Journal	Subject Areas and Categories (Scimago)
ICASSP, IEEE International Conference on Acoustics, Speech and Signal Processing – Proceedings	Computer Science: signal processing, software Engineering: electrical and electronic engineering
Conference on Human Factors in Computing Systems – Proceedings	Computer Science: computer graphics and computer-aided design, human-computer interaction, software
Proceedings of SPIE – The International Society for Optical Engineering	Computer Science: computer science applications Engineering: electrical and electronic engineering Materials Science: electronic, optical and magnetic materials
Proceedings of the Annual Conference of the International Speech Communication Association, INTERSPEECH	Computer Science: computer science (miscellaneous), human-computer interaction, signal processing, software
ACM SIGPLAN Notices	Computer Science: computer science (miscellaneous)

Table 2 - Top 5 Journals for Apple publications

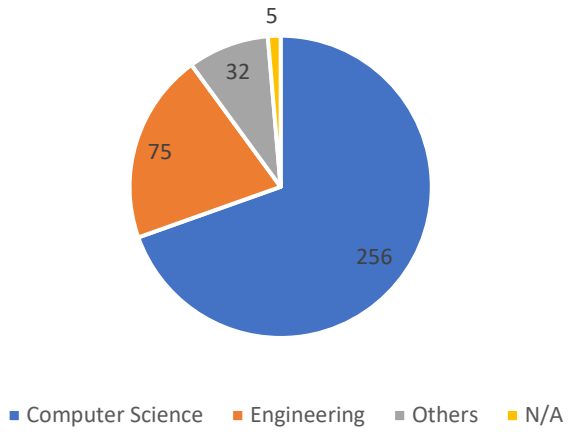

Figure 9 - Apple Publications by Journal Subject Area

Regarding the authors' affiliations, a very small part is associated to entities outside Apple's platform brand ("Apple Computer", "Apple", "University and Apple Inc."), specifically American companies ("Wyatt Software Services Inc."). Additionally, no author external to an U.S. affiliation was found. Therefore, the bulk of knowledge produced is solely by American researchers affiliated to Apple, with sporadic partnerships with other U.S. companies.

Citations mimic the two growth periods of the publications, as shown in figure (10). Although highly irregular, in the first growth phase some values achieved surpass the one thousand citations per year threshold, as well as in the second growth phase. Like publications, the mid-1980s to mid-1990s' period and the one after 2016 are the ones with higher volume of citations. When accounting all citations during the forty-one-year period (1981-2021), a total of 10318 citations is attained, making an average of more than 250 citations per year highly misleading when values close to zero and higher to one thousand are recorded. Nevertheless, considering the total of 368 publications by Apple in our database, the total amount of citations is twenty-eight times higher.

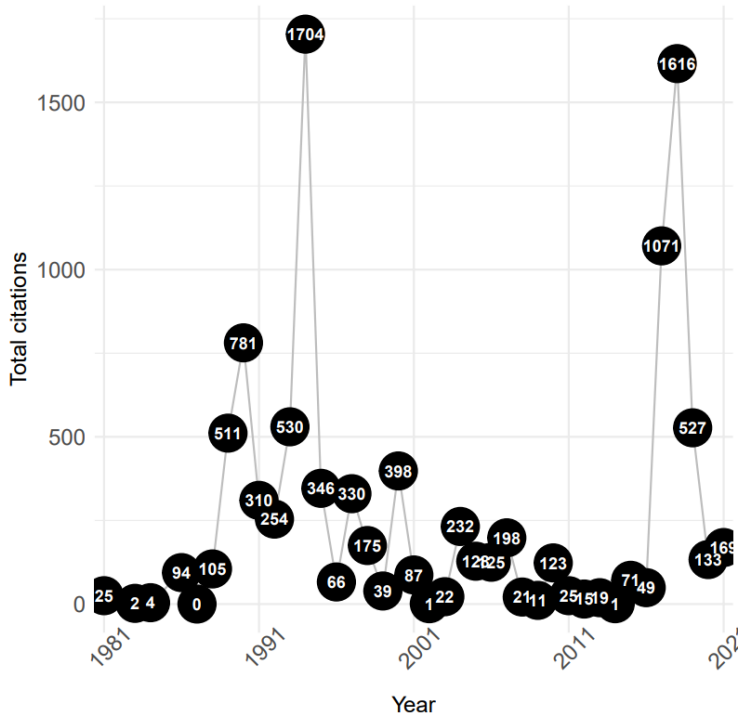

Figure 10 - Citations received by Apple's publications

c) Facebook

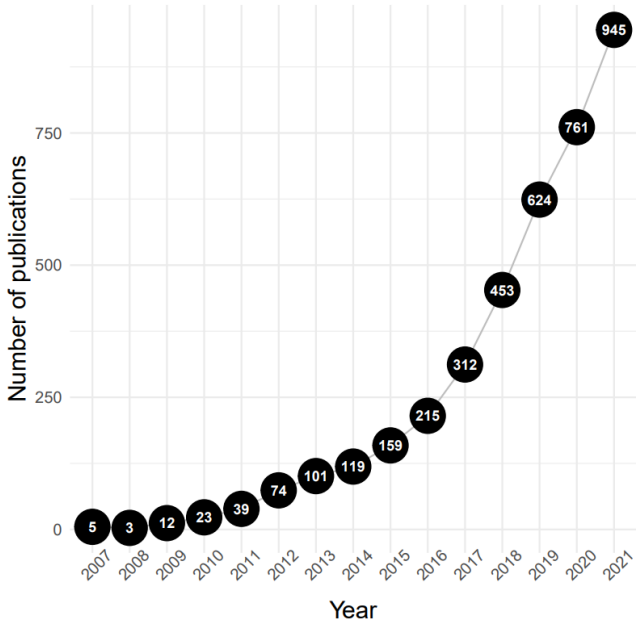

Figure 11 - Publications co-authored by Facebook

As a platform and social network with immense economic power, Facebook can support scientific activity namely in knowledge creation, development, dissemination and institutionally wise (Nentwich and Konig, 2014), but its key differentiator is the ability to connect people. As a social network, Facebook can help potentiate collaborations between scientists in an effective fashion (Schleyer et al., 2008). Some studies have been conducted on how Facebook, the social medium, can be used to academic purposes like research (Niu, 2009; González et al., 2016), but

very few on Facebook itself as a knowledge producer (Gupta et al., 2015; Coursaris and Van Osch, 2014; Basak and Calisir, 2015).

Facebook displays an uninterrupted growth in number of publications from 2007 ((year the first publications with DOI appear in our dataset) to 2021, going from a residual five publications to more than nine hundred, respectively, as seen in figure (11). The two categories: articles and conference papers share an identical growth path, lining up perfectly with the general trend previously described (uninterrupted growth).

The scientific journals with more Facebook affiliated research published are predominantly Computer Science themed ones, some also covering the fields of Social Sciences and Engineering (figure (12)). Note that the top three journals: "Advances in Neural Information Processing Systems", "Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition" and "Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)" have more than 150 publications authored by Facebook (see appendix C).

Journal	**Subject Areas and Categories (Scimago)**
Advances in Neural Information Processing Systems	Computer Science: computer networks and communications, information systems, signal processing
Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition	Computer Science: computer vision and pattern recognition, software
Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	Computer Science: computer science (miscellaneous)
Proceedings of the IEEE International Conference on Computer Vision	Computer Science: computer vision and pattern recognition, software
ICASSP, IEEE International Conference on Acoustics, Speech and Signal Processing − Proceedings	Computer Science: signal processing, software

Table 3 - Top 5 Journals for Facebook publications

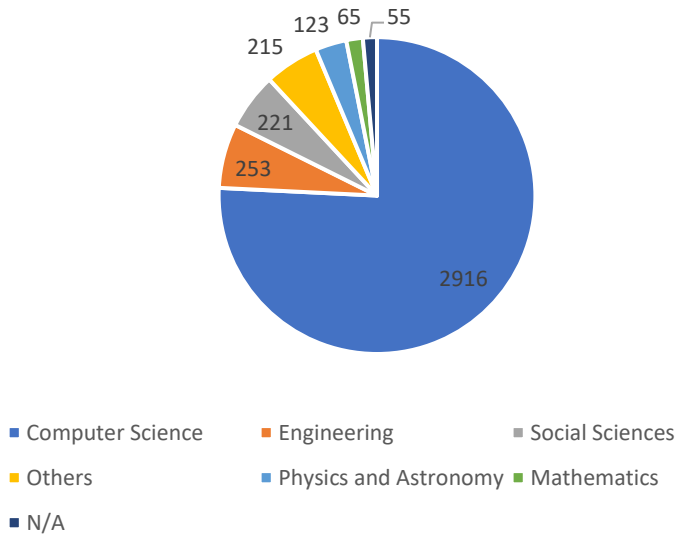

Figure 12 - Facebook Publications by Journal Subject Area

Almost all research was produced indoors with “Facebook, Inc.” (or “Meta Platforms, Inc.”) and “Facebook Research” (or “Meta Research”) authoring most publications, just a very small fraction going to American universities. Naturally, all the researcher’s affiliation’s nationality are American.

Citations show a different trend than the one of publications, increasing until 2017, reaching a whopping number of 98259 citations. From 2018 onwards, a downward turn follows, never attaining prior levels in a continuous fall until 2021, as seen in figure (13). From a total count of 3845 Facebook publications, they receive an aggregate of 305158 citations, with an average of 20343 citations per year and 79 citations per publication.

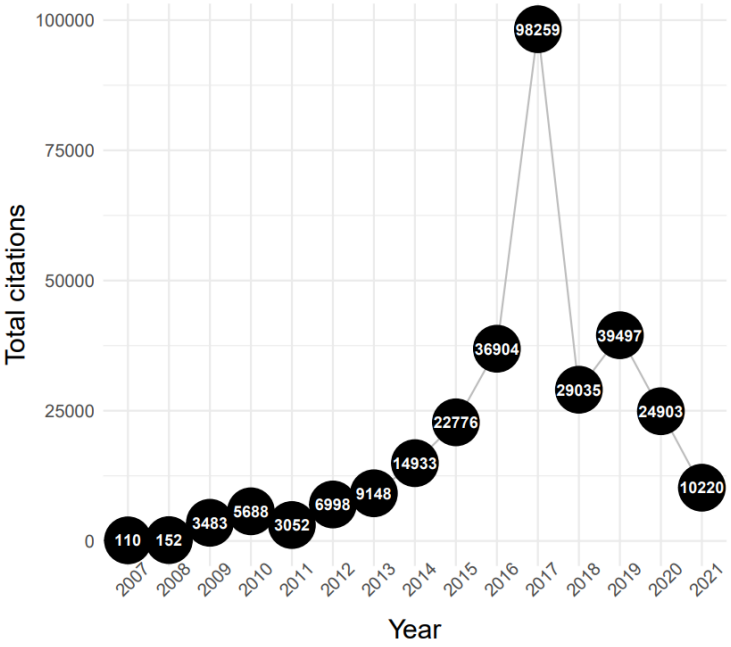

Figure 13 - Citations received by Facebook's publications

d) Google

A digital platform, Google is perhaps the Big Tech company with the greatest business diversity, being present in search engine, e-commerce, A.I., social media (YouTube) and other technological fields. Furthermore, regarding the topic under discussion in this paper - research, Google was one of the first to compile scholarly knowledge (Jacsó, 2005), while providing bibliographic information, with Google Scholar. Nonetheless, the study of Google researchers' published output is yet to be conducted.

Google co-authored publications have an uninterrupted growth path in the period examined, totalizing 2909 publications (figure (14)). Presenting a steady growth until mid-2010s, Google publications rise steeply in the late 2010s with the maximum recorded being 751 publications in 2021. Most of the output is comprised of conference papers (about 2250), with articles presenting a much lower value of the total (more than 500). The conference papers growth path is identical to the general view one, attaining high values by the late 2010s.

Like other Big Tech companies, Google affiliated researchers tend to publish preferentially on "Computer Sciences" themed journals (table (4)), whose categories are "computer networks and communications", "information systems", "computer vision and pattern recognition" or "artificial intelligence".

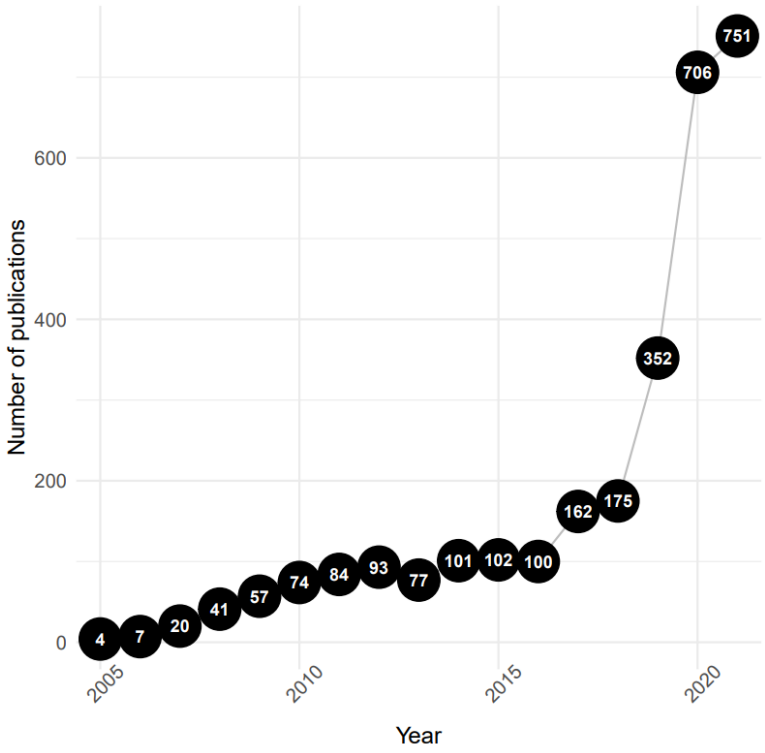

Figure 14 - Publications co-authored by Google

Journal	Subject Areas and Categories (Scimago)
Advances in Neural Information Processing Systems	Computer Science: computer networks and communications, information systems, signal processing

Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	Computer Science: computer science (miscellaneous) Mathematics: theoretical computer science
Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition	Computer Science: computer vision and pattern recognition, software
Proceedings of the IEEE International Conference on Computer Vision	Computer Science: computer vision and pattern recognition, software
37th International Conference on Machine Learning, ICML 2020	Computer Science: artificial intelligence

Table 4 - Top 5 Journals for Google publications

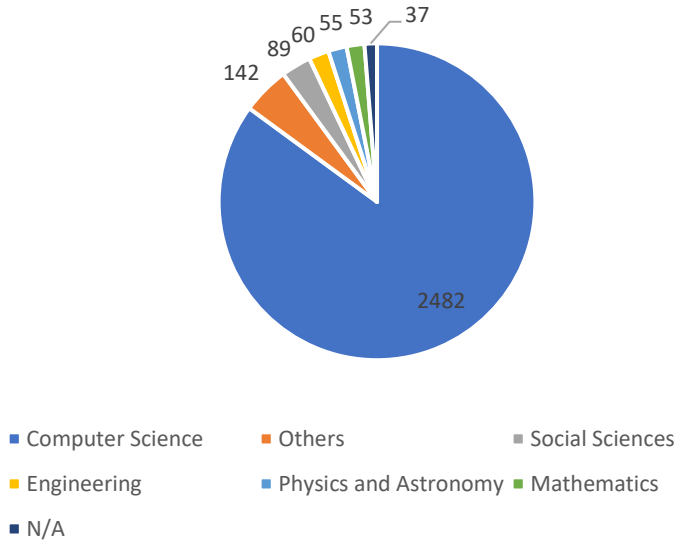

Figure 15 - Google Publications by Journal Subject Area

The majority of the publication's authorship affiliation is with Google itself, presenting some small recurring partnerships mainly with American universities ("University of California", "Massachusetts Institute of Technology – M.I.T.", "Carnegie Mellon University") (see appendix (D3)). As such, the authors' affiliation nationality reveals a clear U.S. hegemony (almost two thirds of total publications' output), with Israel, China and the United Kingdom being the nearer row of countries (see appendix (D4)).

The publications' citations are in line with the publications' growth distribution, having a steady growth until 2010, then booming to the highest values attained between 2015 and 2020, followed by a decline in the more recent year of our dataset (2021) (figure (8)). Totalizing 144131 citations in the period studied (2005-2021), this gives an average of 49 citations per publication and 6863 citations per year, still the citations' growth path clearly indicates that it is in the latter period that a more intense interest on the scientific output co-authored by Google researchers started to be perceived.

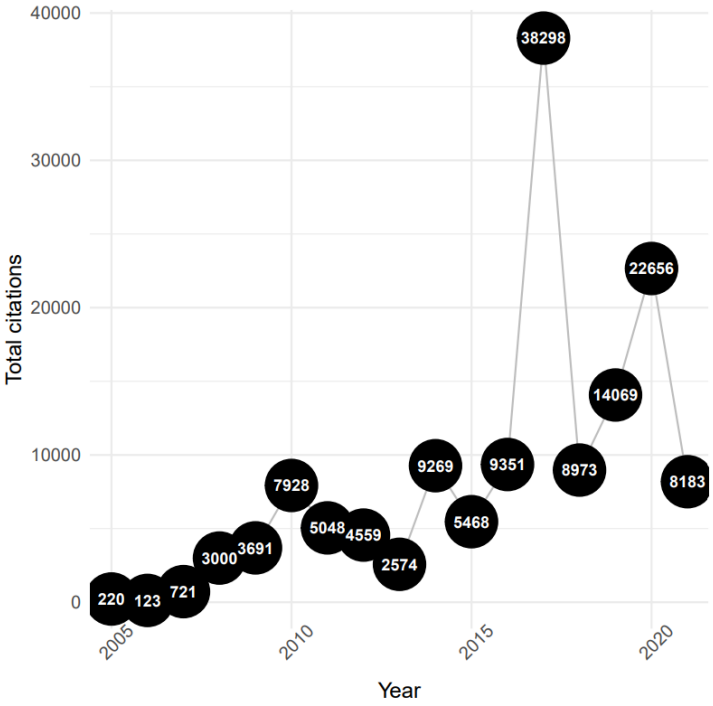

Figure 16 - Citations received by Google's publications

e) Netflix

Netflix has a fairly recent history when compared to some of the other Big Tech companies, its streaming service operations began in 2007, since then it quickly grew to become the major internet media and entertainment corporation (Snyman and Gilliard, 2019). The power of its platform is of such extent, that the effects of the pandemic induced financial crisis did not hurt its established customer network, as well as the company's enduring profitable state (Lozic, 2021).

Accounting a total of 237 publications since 2007, the scientific output co-authored by researchers affiliated to Netflix is marked by an upward trajectory, with 2017 being the apex quantitatively wise listing twenty-six publications as seen in figure (16)**.** Considering only the categories of articles and conference papers, we see a steady slow growth in number of articles, unlike conference papers that had a fast rise by 2014 onwards with some level inconsistencies proven for example in 2017 and the small downturn during the pandemic (see appendix (E2)).

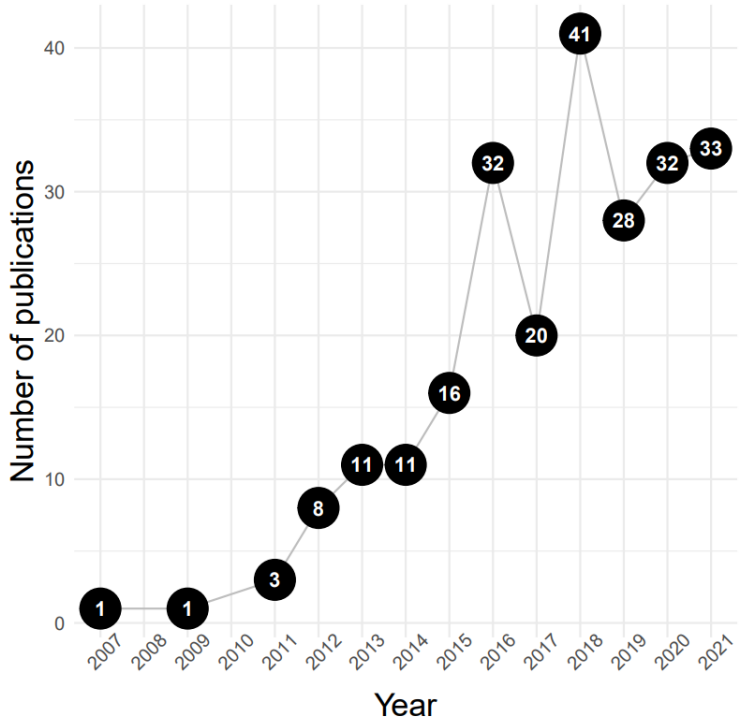

Figure 17 - Publications co-authored by Netflix

As for the most covered subjects by Netflix co-authored research, by looking at the top 5 journals where it publishes the most, again a common theme is identified: "Computer Science" (tab. (5)). All the journals are part of the benchmark in this area, encompassing different categories on the computer science's whole: software, applications, information systems, among others.

Journal	**Subject Areas and Categories (Scimago)**
IEEE Transactions on Image Processing	Computer Science: computer graphics and computer-aided design, software
Advances in Neural Information Processing Systems	Computer Science: computer networks and communications, information systems, signal processing
Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	Computer Science: computer science (miscellaneous) Mathematics: theoretical computer science
Proceedings of the ACM SIGKDD International Conference on Knowledge Discovery and Data Mining	Computer Science: information systems, software
Proceedings of SPIE - The International Society for Optical Engineering	Computer Science: computer science applications Engineering: electrical and electronic engineering Physics and Astronomy: condensed matter physics

Table 5 - Top 5 Journals for Netflix publications

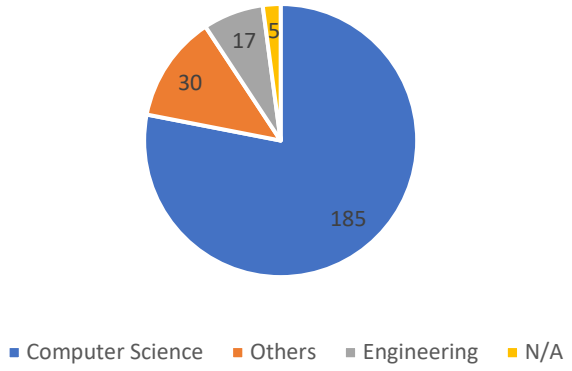

Figure 28 - Netflix Publications by Journal Subject Area

Concerning the authors' affiliations, only a very small part of publications by Netflix researchers are co-authored with external entities mainly universities ("Stanford University", "Universite McGill"). Therefore, Netflix has not yet productive partnerships established in research and its scientific output is still largely made on its own or in sparse collaborations. Substantiating this stance is the publications authors' nationality, almost all of them are from the United States.

Finally, as observed in figure (19), the citations received by the Netflix's publications indicate a high level of acceptance and interest, reaching over one thousand citations in 2015. Totalizing 8283 citations over the fifteen years period studied, this gives an average of 552 citations received per year, but just of 34 citations per publication.

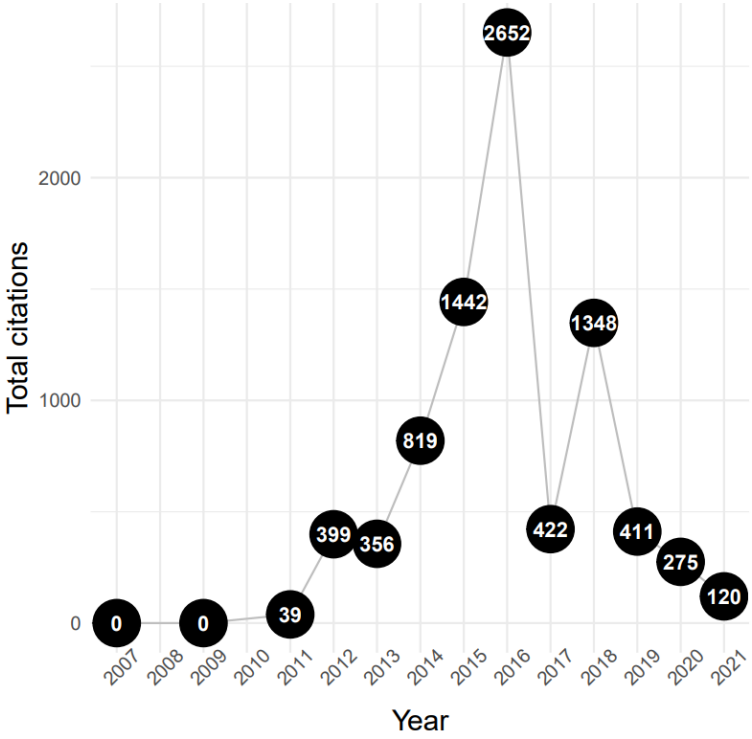

Figure 19 - Citations received by Netflix's publications

5. Discussion

The results obtained show a steady growth of scientific production by researchers affiliated to Big Tech companies, with all of them showing upwards trajectories for most of the respective dataset periods. Facebook and Google are the clear frontrunner in publication volume, with the other three companies behind. Therefore, there is a clear indicator of Big Tech as private companies that value the production of publications (Behrens and Gray, 2001).

Conference papers play a large role in Big Tech's published output, accounting for more than two thirds of the total number publications in all of them, except in Amazon's case in which articles outnumber slightly the number of conference papers. However, articles also have a representative share, usually reporting one third of the total. In most cases, the growth paths of conferences papers and articles matches the general one, a steady growth with occasional small declines followed by a burst typically after 2015.

The participation in conferences requires a considerable financial assurance (Rowe, 2018), hence their financial strength, as digital platforms, improves their cases. Conferences are also linked to a higher likelihood to publish in a top-tier scientific journal (Gorodnichenko, 2021), and when considering each Big Tech company's top 5 of journals where it publishes the most the majority are of high-quality. "Computer Sciences" themed journals dominate said top 5s, with "Mathematics" and "Engineering" also appearing, this comes as no surprise for Big Tech are digital-driven business models relying on their technological apparatus to differentiate themselves from competition and consolidate their market dominance.

Regarding the authors' affiliations, there does not seem to be a great openness to outdoors collaboration by any of these giant corporations. Much of the output is authored by the companies themselves with sporadic collaborations, hence we fail to identify major partnerships. Furthermore, most of the affiliations observed outside Big Tech tend to be of American universities, conveying the argument of the established bond of powerful corporations with universities like in the past (Freeman and Louçã, 2001). Reinforcing these assertions is the U.S. dominance in the affiliations' nationalities, with other countries presenting small values in comparison. Such circumstance contradicts the case for conferences (that Big Tech make a point of attend) as international partnerships' incubators (Jefferson et al., 2018).

Finally, citations are used to study the perceived quality of Big Tech's publications. Facebook takes the lead, followed by Google. Considering the publications' numbers, one can conclude that Facebook's output is the one more esteemed and useful to the scientific community, with averages of 79 citations per publication and 20343 citations per year, with Google having averages of 49 citations per publication and 6863 citations per year. Hence, these two companies are the ones with a stronger case for knowledge hubs with a scientific absorption agenda (Santesteban and Longpre, 2020). However, no platform presented a linear growth path in the respective timespans, with many inconsistencies surfacing, not allowing to understand how publications are being held by the scientific community.

6. Conclusion

In this paper a scientometric analysis of scientific publications authored by Big Tech companies' researchers was conducted, aiming to understand the basic key indicators of their research, with an analysis of the level of publications and citations, as well as the authors' affiliations.

All companies showed a steady growth on number of publications, achieving a surge in the latter periods of their respective datasets. Hence, we can conclude that there is a greater focus on publications as scientific research products by Big Tech and not just patents. Individually, Google and Facebook had the higher volumes, followed from a distance by the remaining three companies.

The growing path by publications is not fully evident in citations' analysis. Big Tech publications' citations do not show a clear trajectory, with the only common pattern being a great rise by the mid-2010s. Nevertheless, it is an indicator of the reception by scientific community of Big Tech's co-authored publications, with Facebook having the better performance of the lot, only matched, tier wise, by Google.

Concerning the themes covered by the publications, "Computer Sciences" is the journals' subject area most common across all Big Tech's output, specifically on the themes of software, computer networks and communications, artificial intelligence, computer vision and pattern recognition, and software. Other relevant subject area, common to all Big Tech is "Engineering". As for the research profile, Google, Facebook and Amazon present the most diversified portfolio, having publications in areas such as "Social Sciences", "Mathematics" or "Medicine", especially Amazon considering it has a smaller output volume when compared to Google or Facebook.

Finally, regarding affiliations, Big Tech do not present frequent partnerships with any particular entities, in fact the overwhelming majority of authors' affiliations are to Big Tech themselves. A small number of collaborations with universities are observed, primarily American ones, expressing a lack of international co-authorship of publications. These conclusions are intrinsically linked to our decision to consider only considered articles and conference papers.

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8. Appendices

Appendix A – Graphs on Amazon

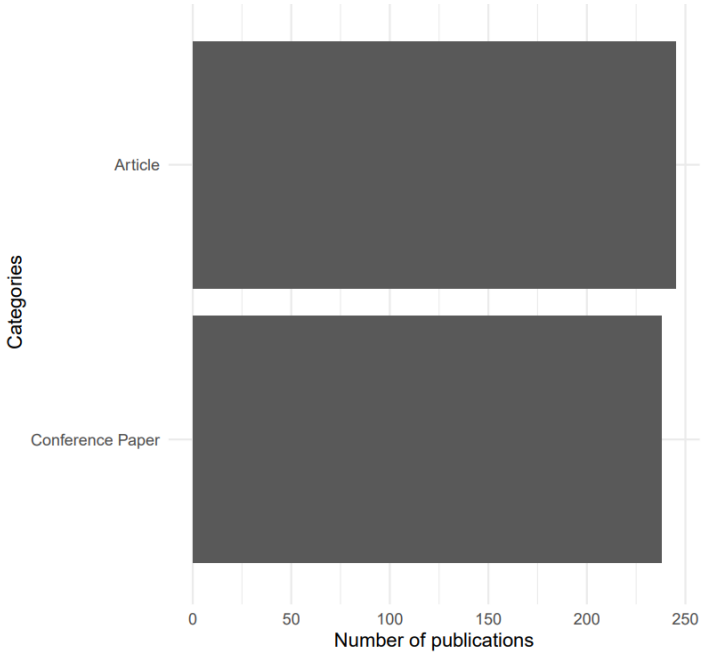

Figure A1 - Amazon publications by category

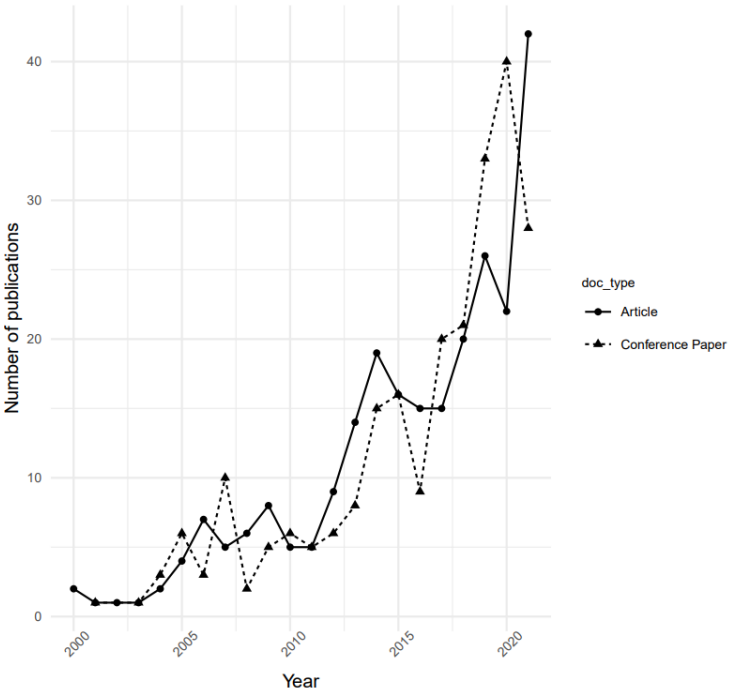

Figure A2 - Conference Papers and Articles by Amazon overtime

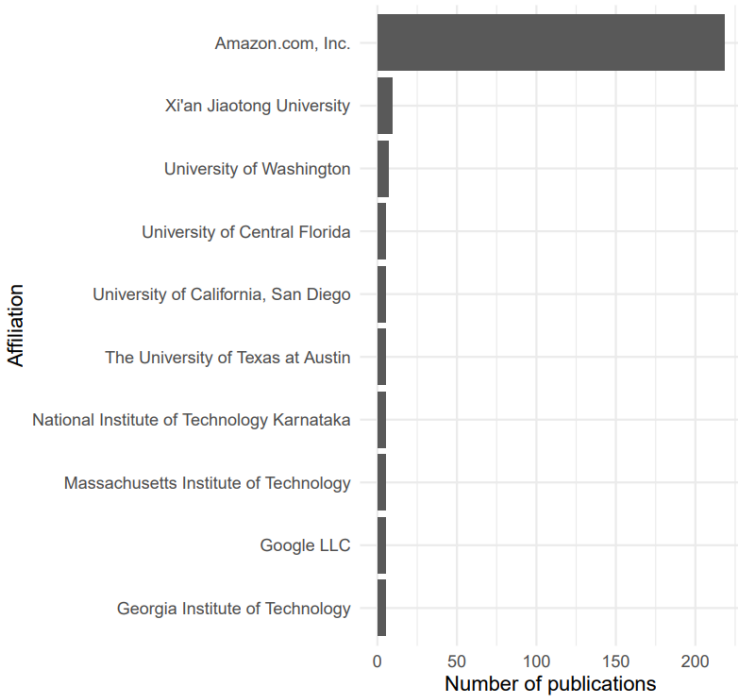

Figure A3 - Amazon publications authors' affiliations

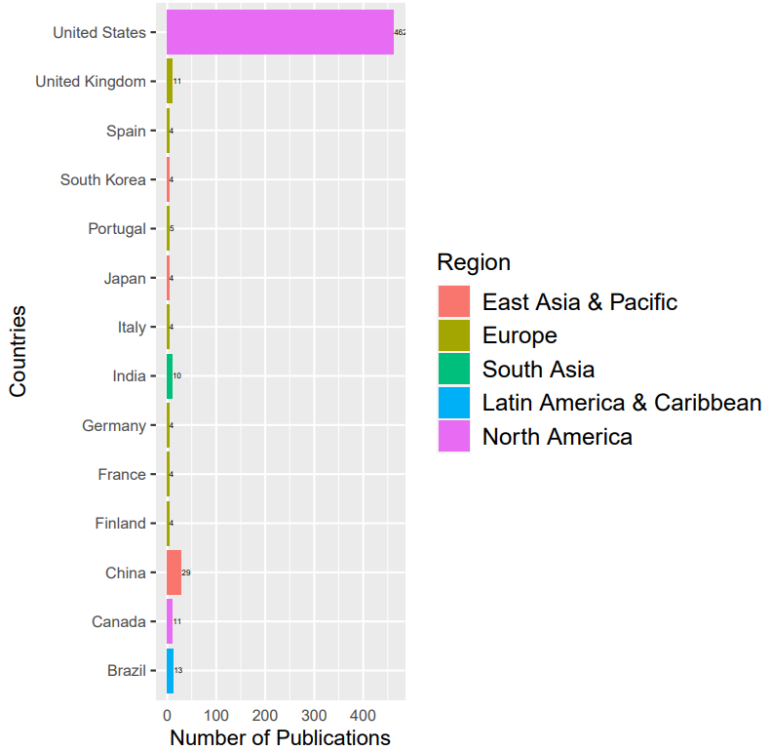

Figure A4 - Amazon publications authors' affiliation nationality

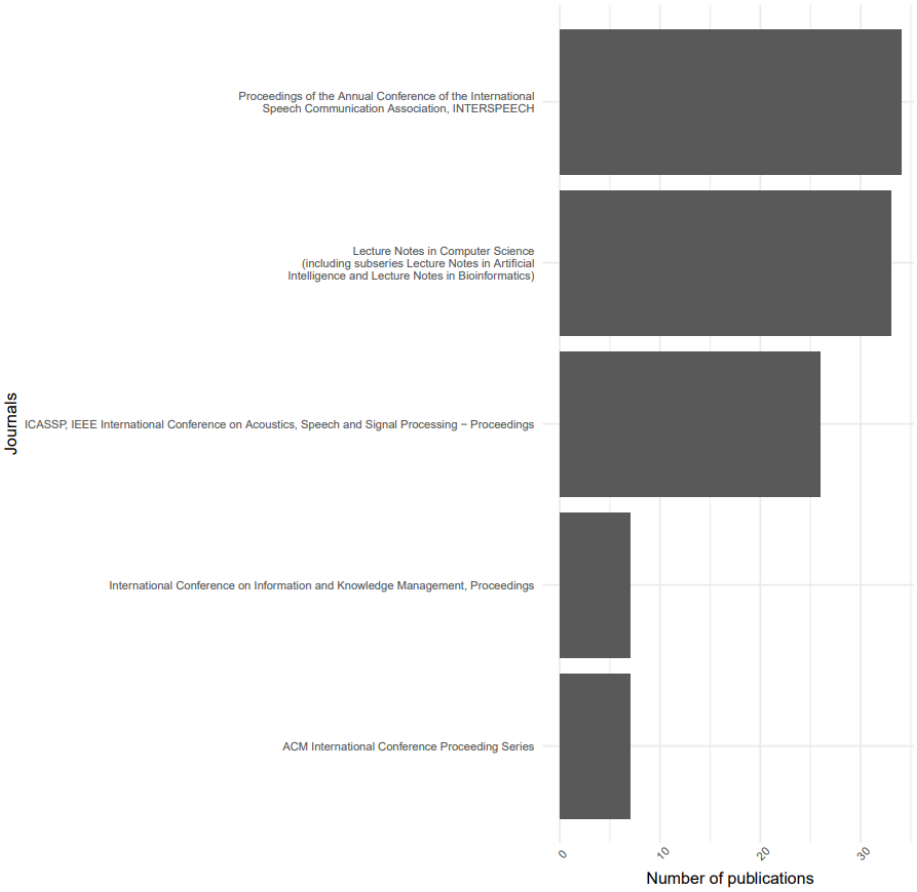

Figure A5 - Top 5 Journals for Amazon publications

Appendix B – Graphs on Apple

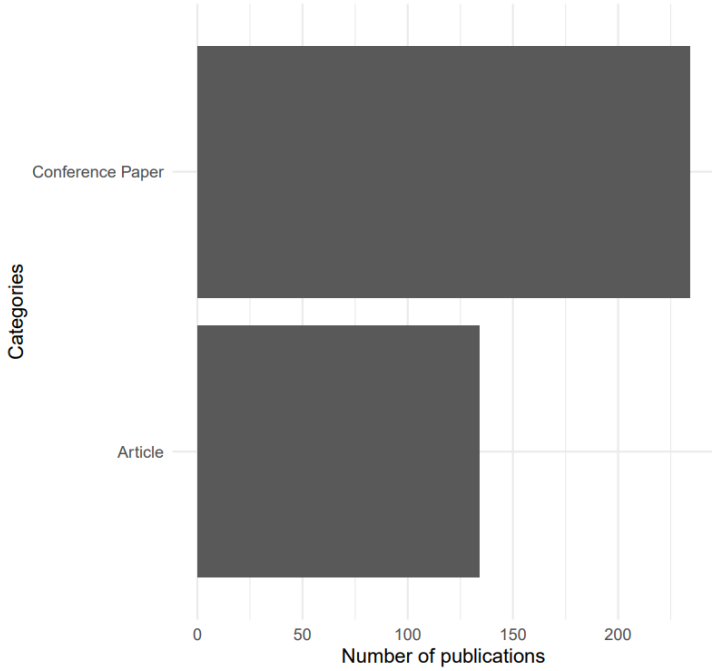

Figure B1 - Apple publications by category

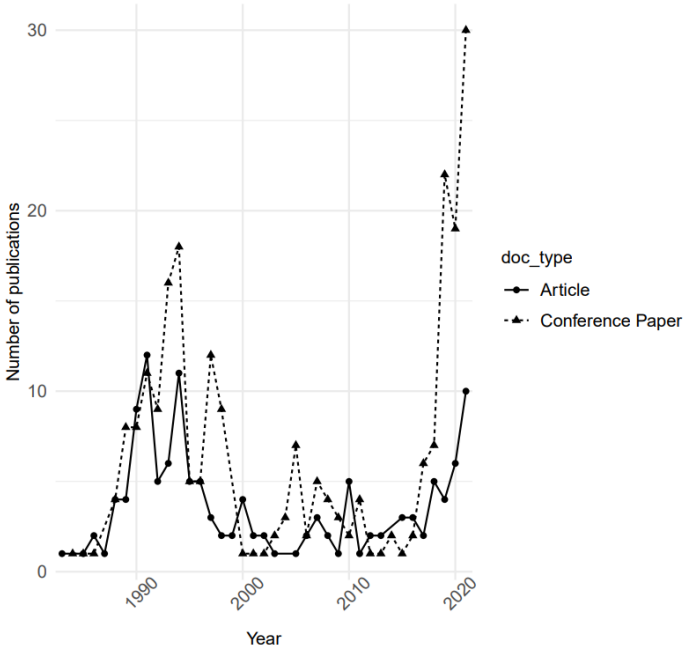

Figure B2 - Conference Papers and Articles by Apple overtime

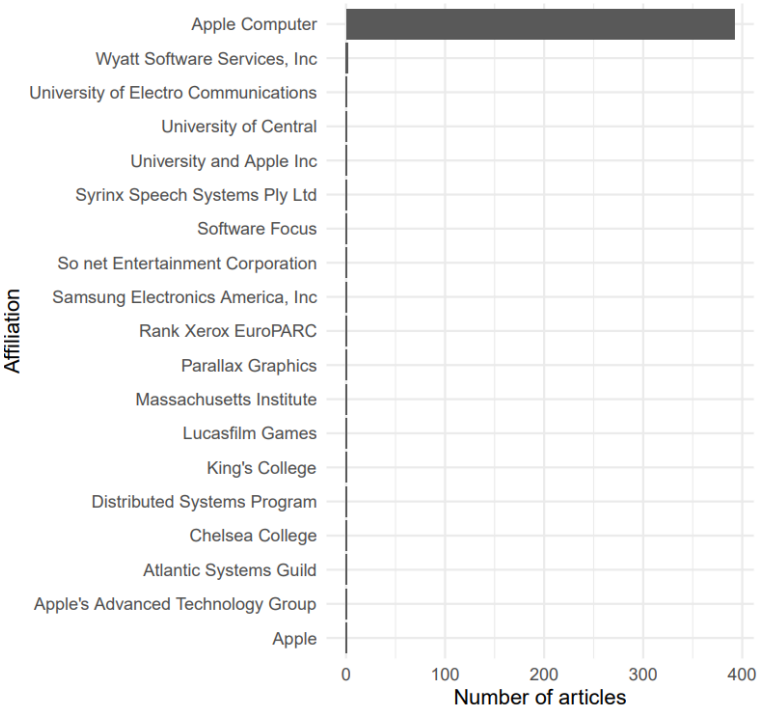

Figure B3 - Apple publications authors' affiliations

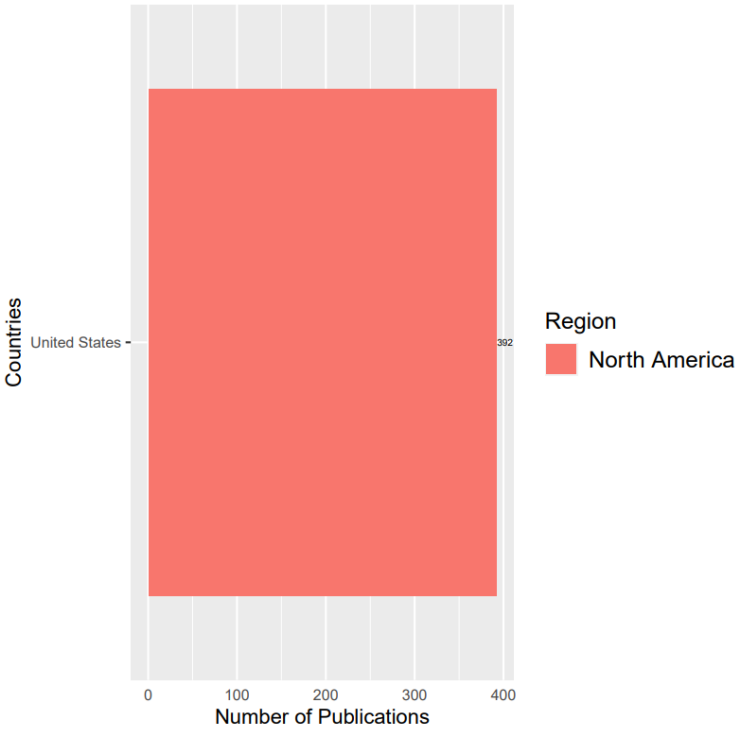

Figure B4 - Apple publications authors' affiliation nationality

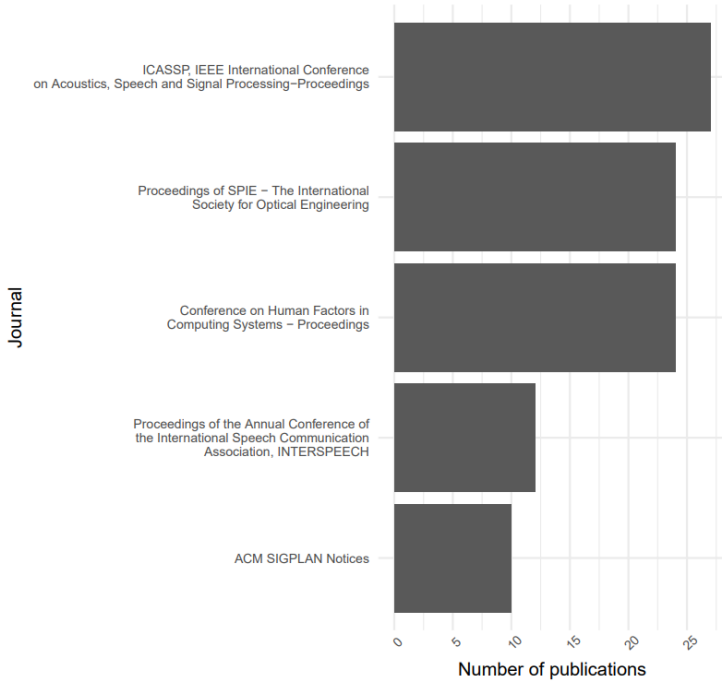

Figure B5 - Top 5 Journals for Apple publications

Appendix C – Graphs on Facebook

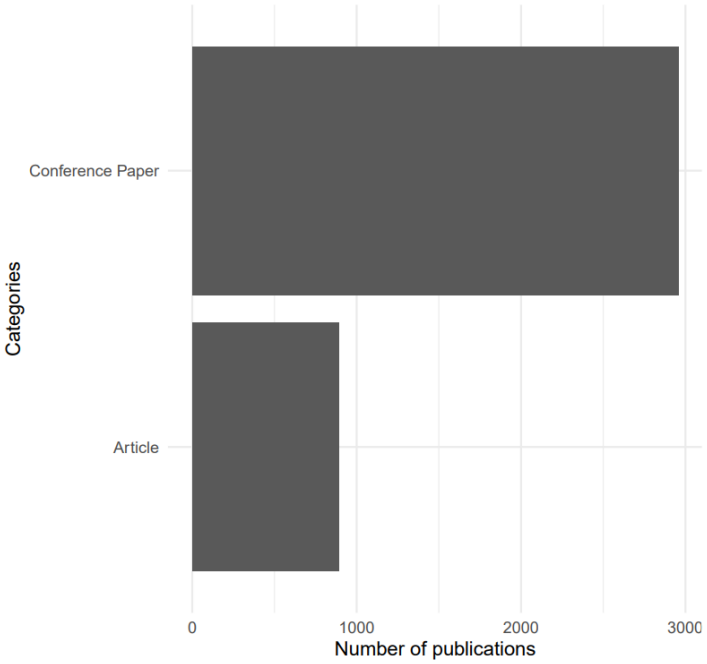

Figure C1 - Facebook publications by category

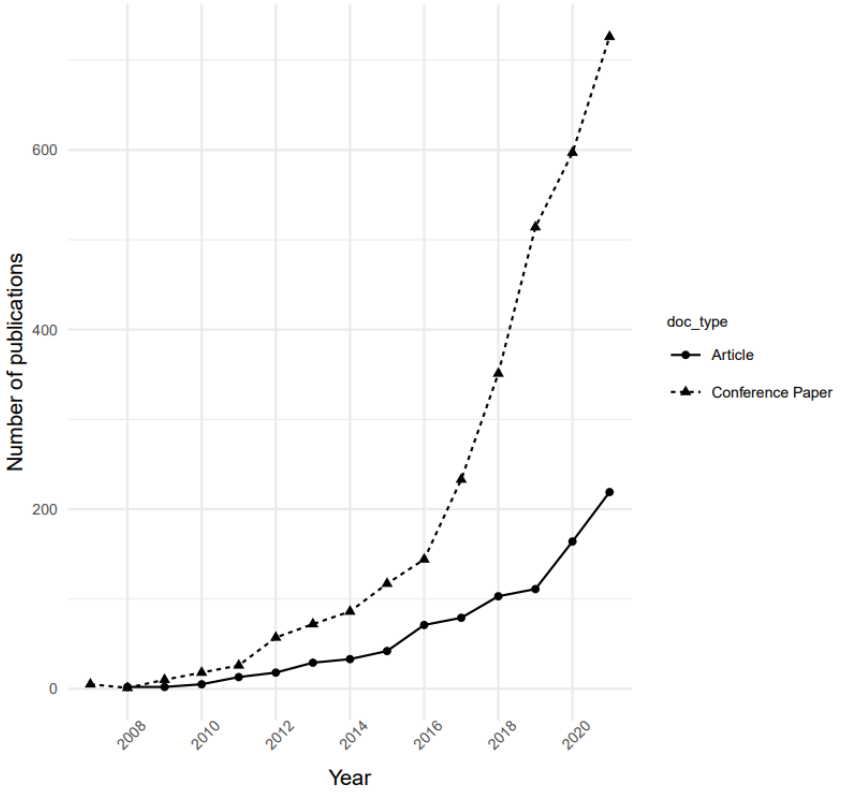

Figure C2- Conference Papers and Articles by Facebook overtime

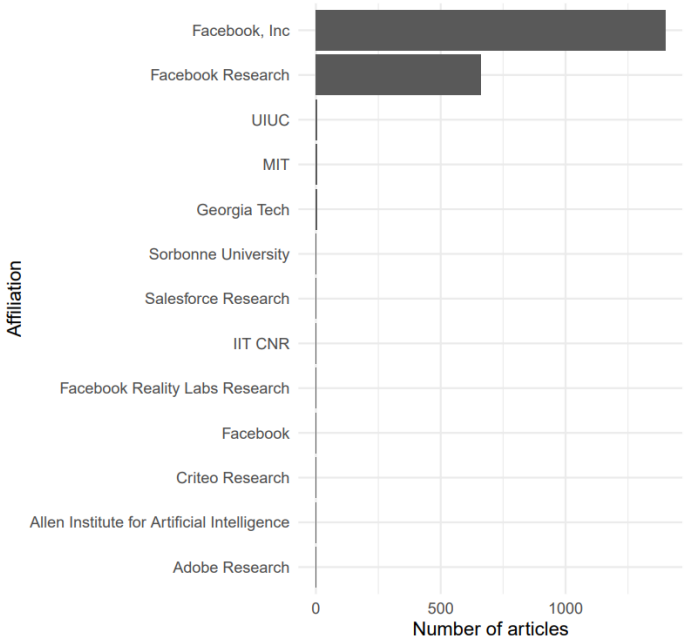

Figure C3- Facebook publications authors' affiliations

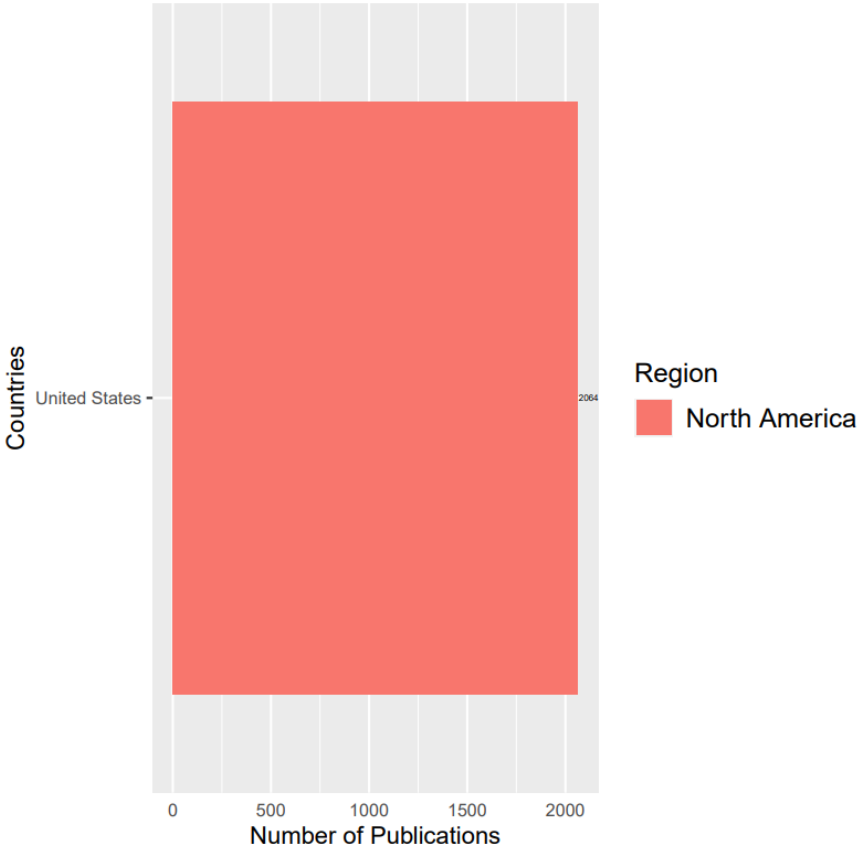

Figure C4 - Facebook publications authors' affiliation nationality

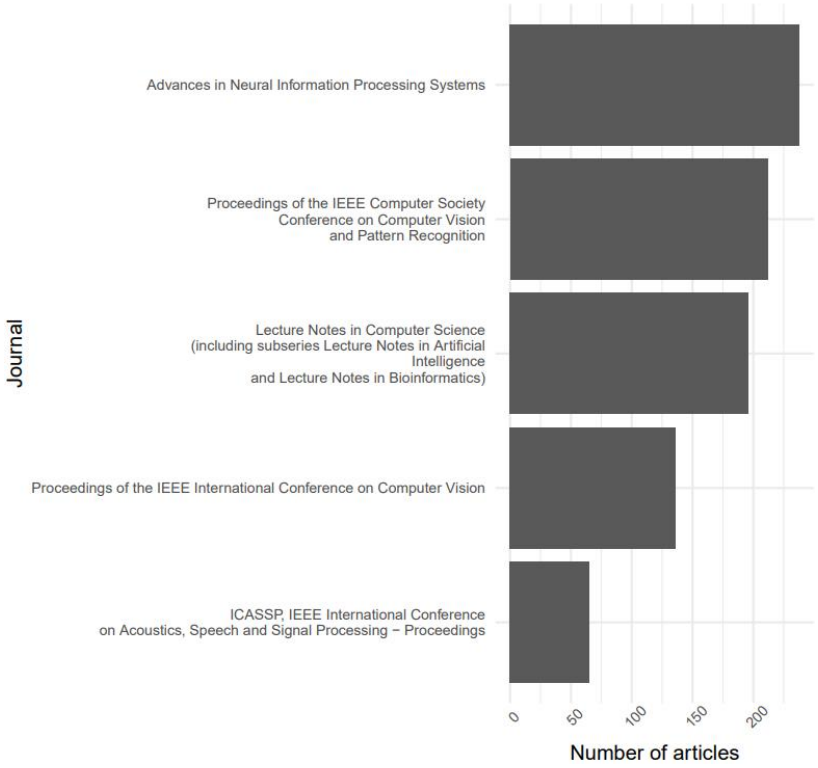

Figure C5 - Top 5 Journals for Facebook publications

Appendix D – Graphs on Google

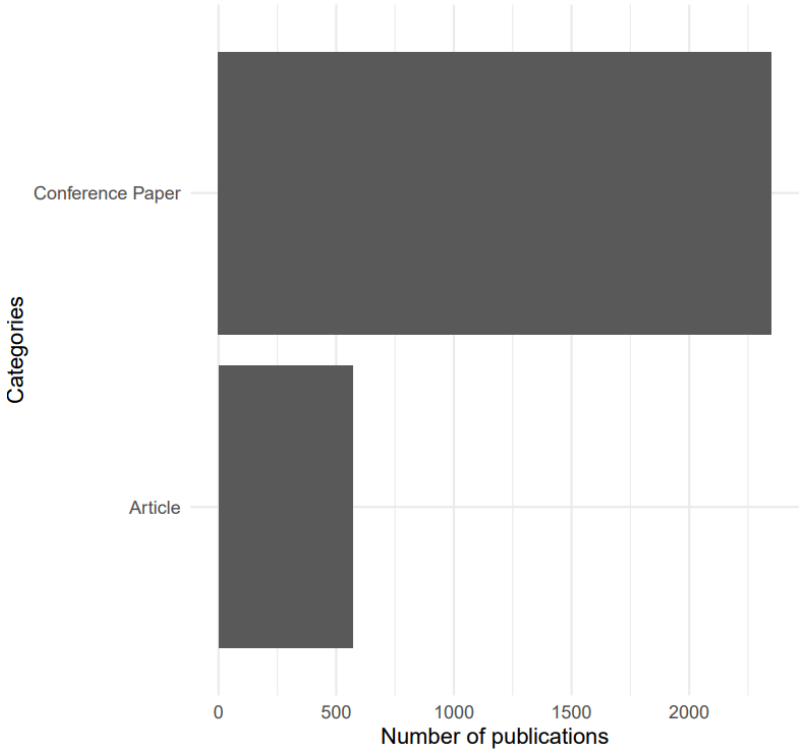

Figure D1 - Google publications by category

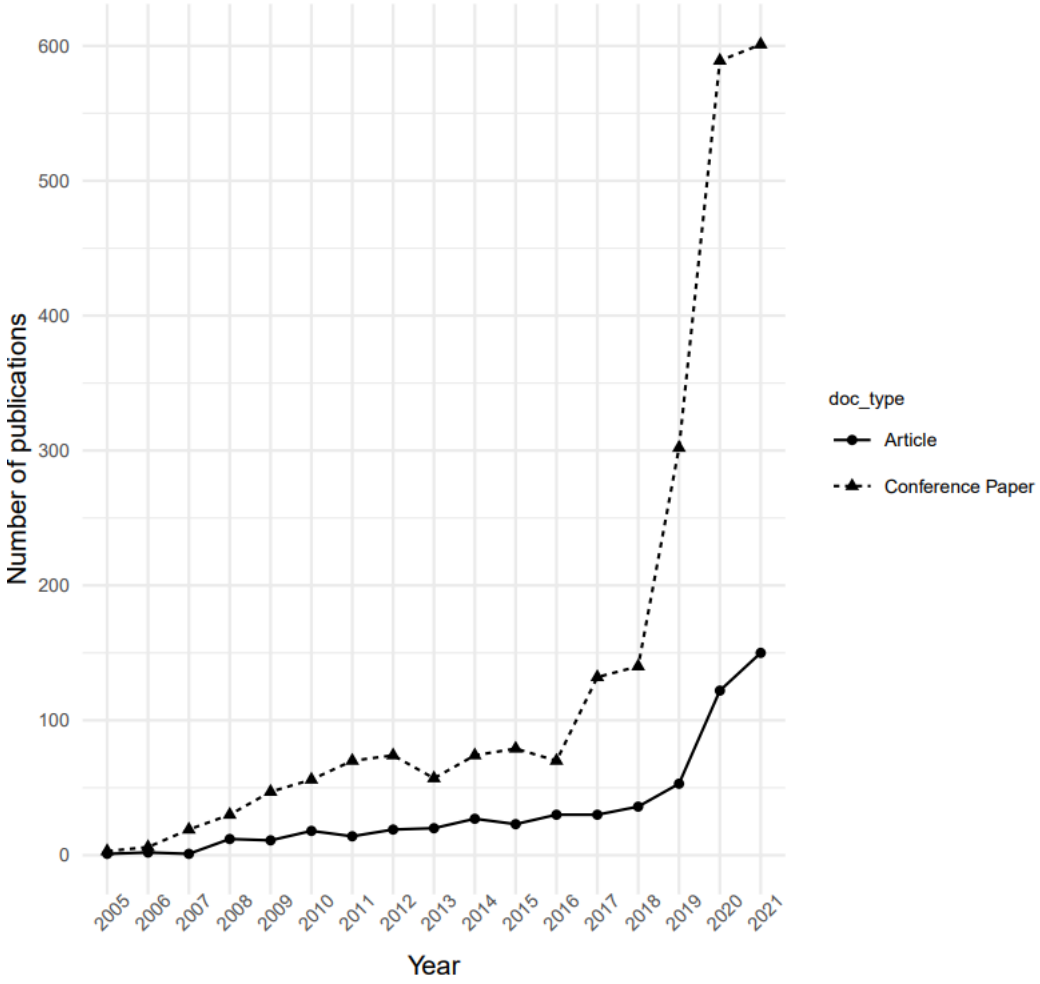

Figure D2- Conference Papers and Articles by Google overtime

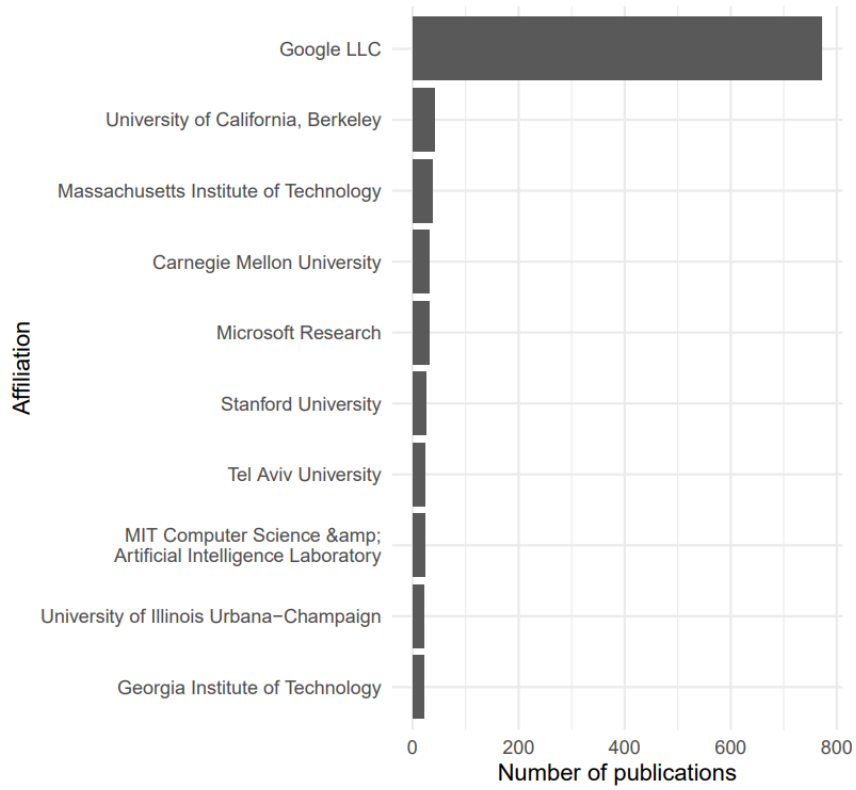

Figure D3- Google publications authors' affiliations

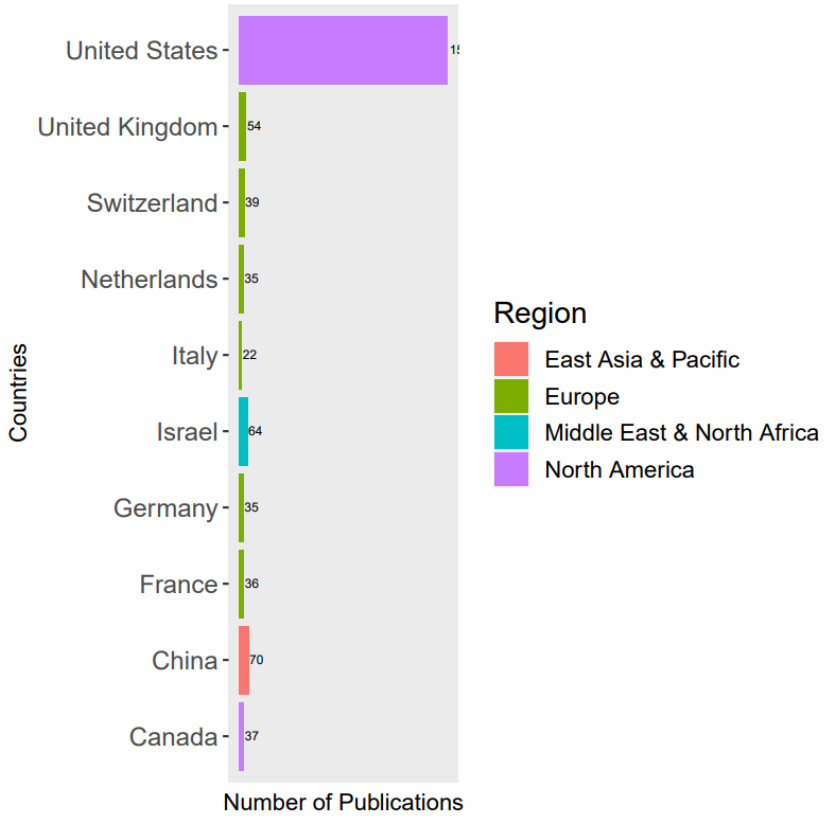

Figure D4 - Google publications authors' affiliation nationality

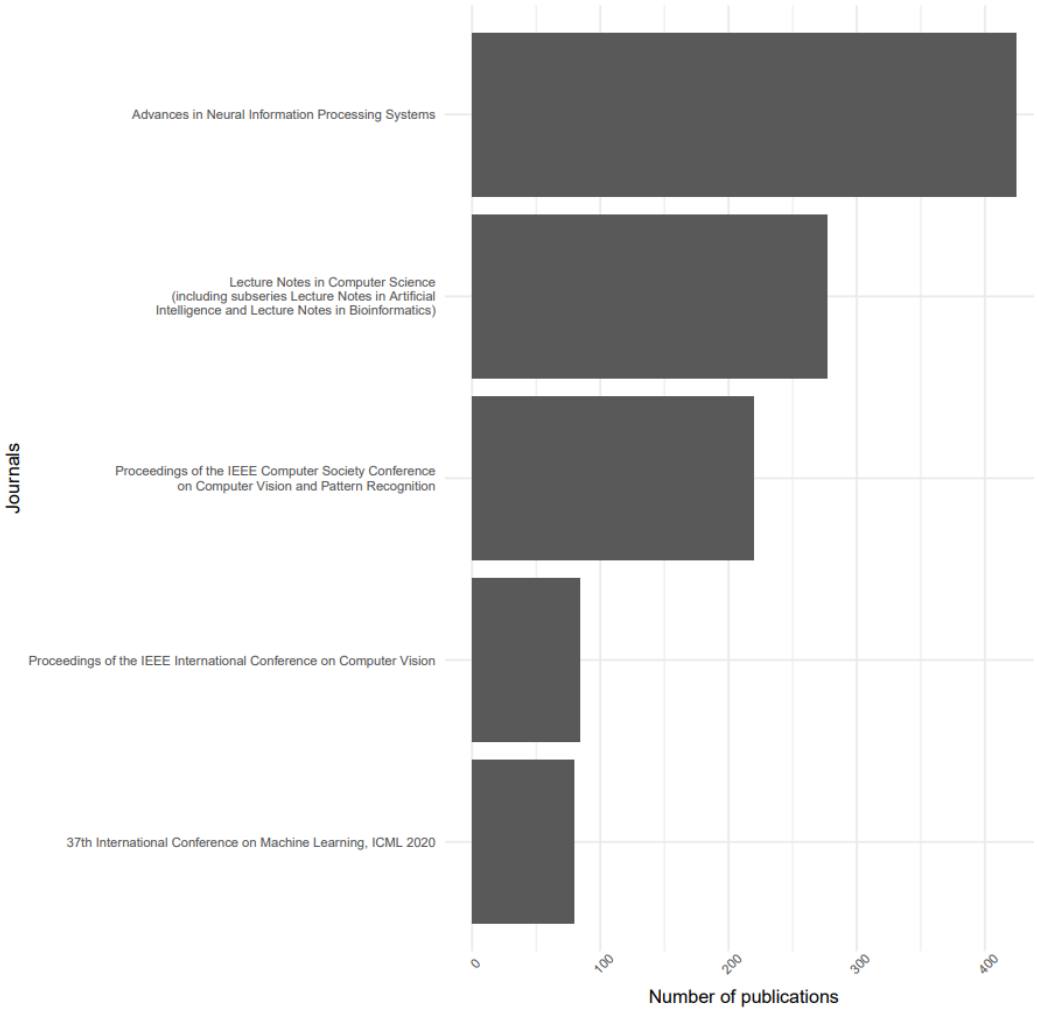

Figure E5 - Top 5 Journals for Google publications

Appendix E – Graphs on Netflix

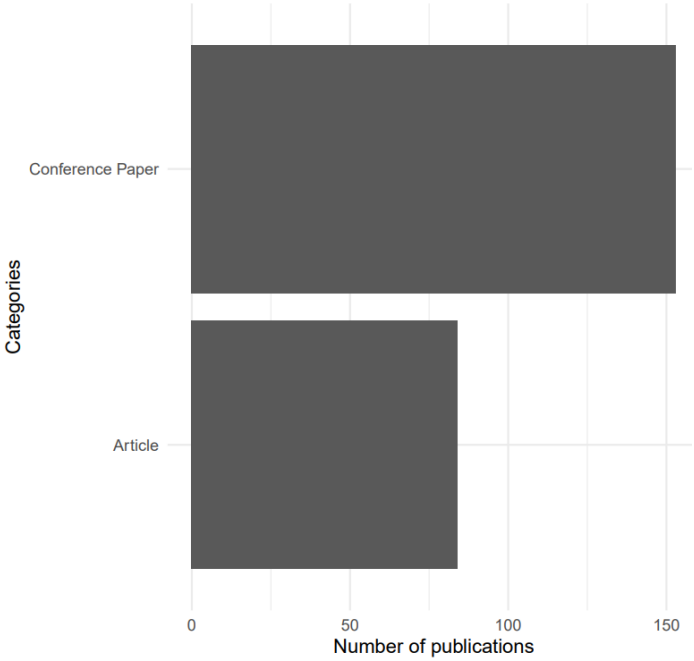

Figure E1- Netflix publications by category

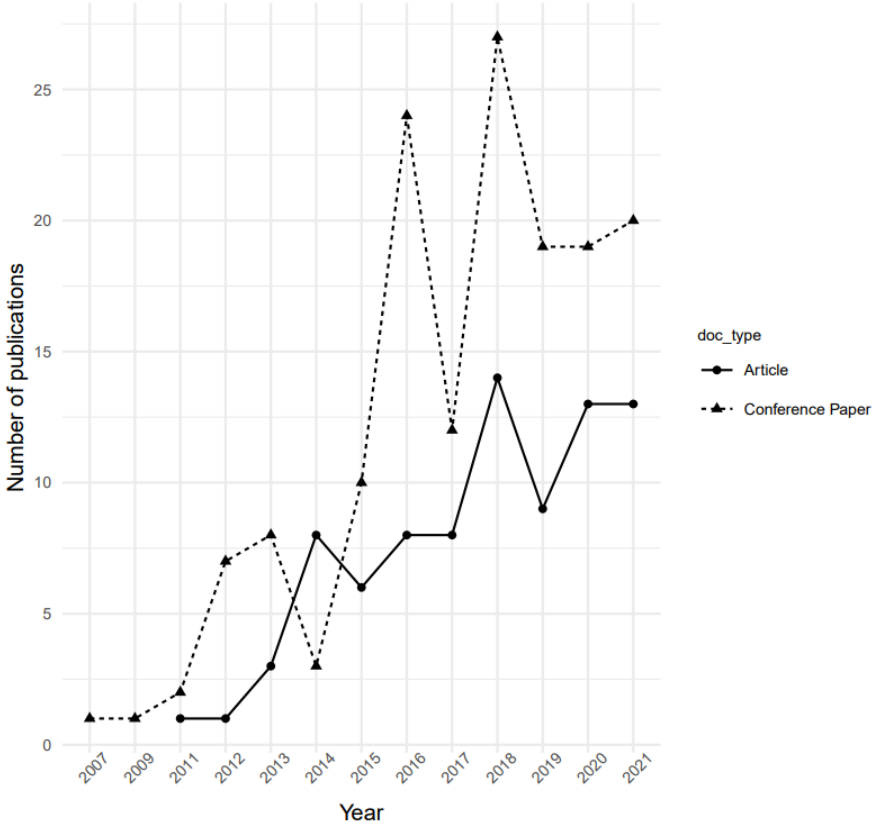

Figure E2- Conference Papers and Articles by Netflix overtime

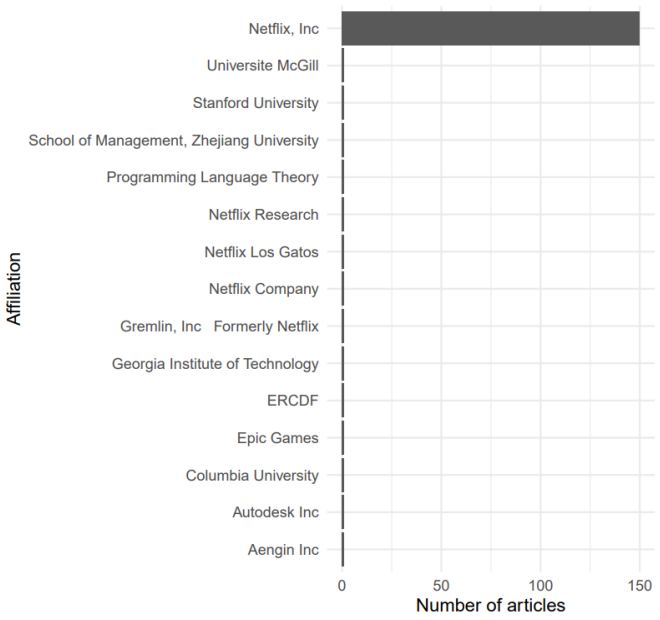

Figure E3- Netflix publications authors' affiliations

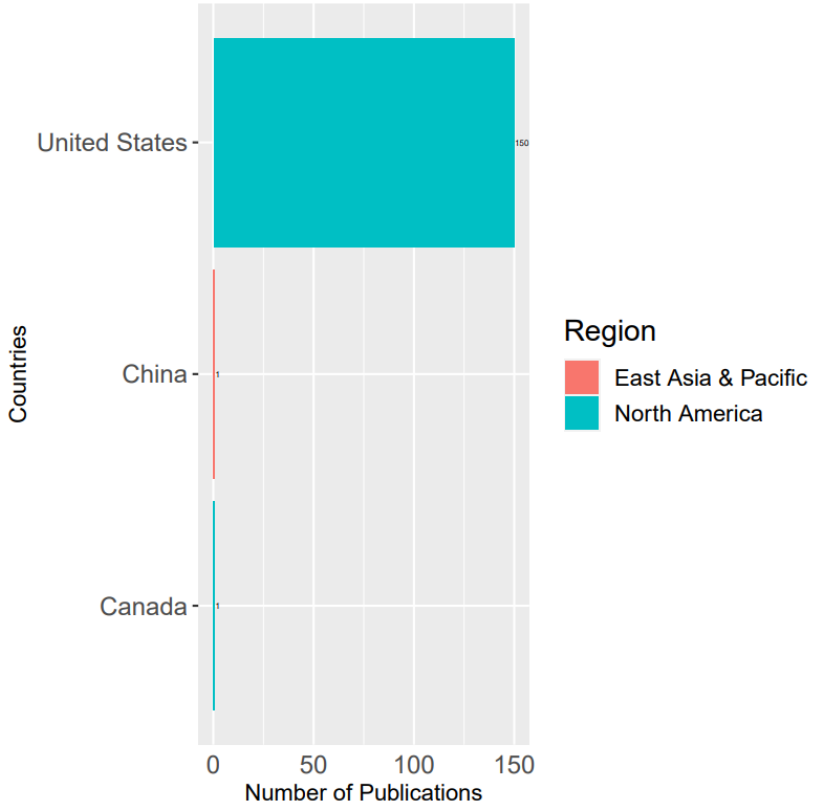

Figure E4 - Netflix publications authors' affiliation nationality

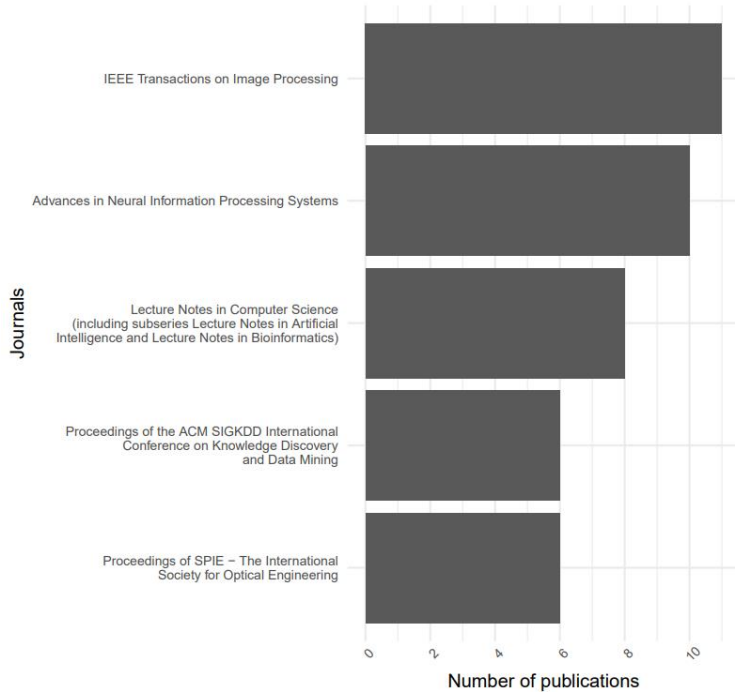

Figure E5 - Top 5 Journals for Netflix publications