Issue Brief

Quad AI

Assessing AI-related Collaboration between the United States, Australia, India, and Japan

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Executive Summary

The Quadrilateral Security Dialogue, commonly known as the Quad, is a semi-formal but strategically significant grouping of four countries—the United States, Australia, India, and Japan. Cooperation on critical and emerging technologies is a key element of the Quad's agenda, and all four nations have a particular interest in strengthening cooperation on responsible development of artificial intelligence (AI).[1] Their desire to collaborate stems not only from recognizing AI's transformative economic, societal, and national security potential, but also the importance of ensuring that technological innovation is shaped by their shared democratic values and respect for human rights.[2] The Quad could offer an alternative to China's techno-authoritarian model of technology development and use, setting the standard for a multilateral approach to countering the malicious use of AI for surveillance, censorship, and misinformation.[3] The group, however, faces non-negligible barriers to effective technology cooperation, including different approaches to data governance, varying economic and technological capabilities, and divergent geopolitical priorities.

This report assesses the state of AI collaboration among the Quad members, focusing specifically on trends in joint AI-related research publications and investment flows into AI companies over the past decade. It also evaluates the AI-related research and investment ties between each of the Quad countries and China during this period. Our main findings are as follows:

AI Research:

- **All four Quad countries are among the top 10 AI research producers in the world, both by number of research publications and citations**. Researchers in the Quad countries collectively generated nearly 650,000 AI-related research papers between 2010 and 2020, more than the total authored by European Union and Association of Southeast Asian Nations (ASEAN) researchers combined.

- **Each Quad country has AI-related research strengths that could be leveraged for joint research opportunities**. Japan stands out in simulation and human-computer interaction (HCI), India in data mining and data science, Australia in linguistics and theoretical computer science, and the United States in machine learning and natural language processing.

- **While the United States collaborates extensively with Australia, India, and Japan on AI-related research, the latter three Indo-Pacific states collaborate little with one another**. The United States is the leading research partner for Australia, India, and Japan, and AI researchers from these three Indo-Pacific countries collaborated with U.S. peers on at least 19 percent of their internationally co-authored research papers. In contrast, collaboration rates between Australian, Indian, and Japanese researchers never exceeded 4 percent of each country's respective internationally co-authored AI research output.

- **China is the top research partner for the United States and is the second-leading partner for the rest of the Quad members**. Not only does research cooperation between the United States and China outweigh U.S. research collaboration with the rest of its Quad partners taken together, but Australia, India, and Japan each have more research partnerships with China than they do with one another.

AI Investments:

- **Between 2010 and 2021, the majority of investment transactions in AI companies located in the United States, Australia, India, and Japan included domestic investors.** The United States, however, is the largest foreign investor in Australian, Indian, and Japanese AI companies, both in terms of the number of investment transactions and overall transaction value.

- **While the United States has robust AI investment ties with Australia, India, and Japan, there is relatively little investment activity between the latter three Indo-Pacific countries.** Although there was more AI investment activity between Japan and India than between India and Australia or Australia and Japan, it was largely one-sided, with Japanese investors targeting Indian AI companies while Indian investors seem more reluctant to pursue opportunities in Japan.

- **There is far more AI investment activity between the United States and China than the United States and each of the remaining Quad countries.** While the number of Chinese investment transactions in the U.S.-based AI companies has declined since their peak in 2017, U.S. investments in China's AI companies increased in 2021.

- **Australia, India, and Japan each have more AI investment activity with China than they do with one another.** Similar to the trends observed in the Quad countries' AI research collaboration, AI investment activity between China and each of three Indo-Pacific members of the Quad exceeds the limited investment flows between these three countries, both in terms of the number of investment transactions and overall transaction value.

The Quad offers a forum to build trust, identify opportunities for joint research ventures, and gather AI entrepreneurs, investors, and strategic industry partners to increase and diversify technology collaboration. But the prospects for its success depend largely on building stronger ties among U.S. allies beyond their bilateral linkages to the United States. Patterns of AI-related research collaboration and investment across the Quad highlight that the group's three Indo-Pacific members are less closely intertwined with one another than they are with the United States. Moreover, each of the Quad states has varying but fruitful AI research and investment relationships with China. To capitalize on the Quad's potential, fuel innovation, and decrease dependency on Chinese technology and markets, the group needs to strengthen and expand AI research collaboration and investment among Australia, India, and Japan.

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Introduction

The origins of the Quadrilateral Security Dialogue, commonly known as the Quad, trace back to 2004, when the United States, Australia, India, and Japan came together to coordinate a multilateral response to the Indian Ocean earthquake and tsunami. The grouping fell apart in 2008, largely due to economic pressure from China and wavering commitment from its members. The four nations resumed the dialogue in late 2017 in light of increasing strategic competition with China, and momentum has grown since 2019, when the group's meetings were upgraded to the ministerial level.

Technology cooperation is a core element of the Quad agenda. The Quad Critical and Emerging Technology Working Group, for example, was established in March 2021 to coordinate efforts in pursuit of an "open, accessible, and secure technology ecosystem."[4] Quad leaders met again in September 2021, issuing a joint statement of principles for technology design, development, governance, and use, rooted in their shared democratic values and expressed respect for human rights.[5] They also announced new efforts, including standing up technical standards contact groups on advanced communications and AI, launching a semiconductor supply chain initiative, and establishing fellowships for leading STEM graduate students.[6] Another notable effort is the Track 1.5 industry dialogue on Open RAN deployment and adoption for secure, open, and transparent 5G and beyond-5G networks.[7]

These initiatives reflect individual state priorities for developing emerging technologies broadly and AI more specifically as an instrument of national power, alongside a shared desire to ensure "a free, open, inclusive, and resilient Indo-Pacific."[8] All four Quad members have released national AI strategies in the last five years, acknowledging the technology's value for economic growth, societal development, and military power.[9] Having recognized AI's important role in their future prosperity and security, Quad members appear intent on using the forum to advance their technological ambitions through collaboration.

The efforts by the United States, Australia, India, and Japan to collaborate on AI and other technology development through the Quad forum hold promise for several reasons. For one, the grouping sets a flexible, overarching structure atop a strong foundation of bilateral and multilateral diplomatic, economic, technological, and military ties. Without a permanent secretariat, the semi-formal arrangement of ad-hoc working groups allows for experimentation and agility in collective efforts. In one combination or another, the four countries are also members of other international fora around AI development, and the Quad arrangement can serve to further reinforce those linkages and efforts.[10] Although the non-binding nature of the Quad allows for some ambiguity

and can pose coordination challenges, its members see the grouping as an opportunity to use multilateral means to achieve their AI development ambitions.

Much of the Quad's promise also stems from the fact that it brings together four nations with unique and compatible technological strengths. Technology collaboration generally permits partners to take advantage of one another's relative strengths and maximize the advantage of scale, averting duplicated efforts and developing regulatory approaches that foster innovation.[11] In the Quad context, each state could potentially leverage its unique advantages to boost the group's collective strength. India has a massive tech talent pool, while Australia has a robust, high-skilled workforce and a highly developed digital economy. Japan is a global leader in robotics, automation, and commercialization of tech breakthroughs. The United States is investing heavily in AI across the board—from AI workforce and education initiatives to greater resources for research and development to bolstering domestic AI chips production. With the amassed specialized knowledge, equipment, and resources of its members, the Quad could serve as a natural incubator for cutting-edge innovation on a regional and global scale.

Finally, as the four leading democracies in the Indo-Pacific, the United States, Australia, India, and Japan see the Quad as a collective effort to curb China's disruptive regional behavior.[12] From its development and export of surveillance technologies that facilitate repression to its economically coercive measures to suppress competition, China's digital authoritarianism challenges regional democratic interests, and, in turn, fuels the Quad states' efforts to develop next-generation technologies in line with their national goals and shared values. Working together, the four Quad nations can be effective in rolling back China's technology market dominance. For instance, the Quad's commitment to secure an Open RAN system for 5G development created the prospect of competition for Huawei's telecommunications equipment monopoly by lowering market entry barriers for other vendors.[13] By articulating a shared vision for technological and AI leadership rooted in democratic values and principles, the Quad offers an alternative to China's techno-authoritarian model that has made headway in the region over the past decade.[14]

However, even with the advantages presented by the Quad and members' stated commitments to technology collaboration, the Quad states still face barriers to achieving their shared technology cooperation agenda, including in AI. Regulatory hurdles could slow the pace of collaboration. In particular, national data sharing laws and regulations could hamper the group's ability to capitalize on members' unique strengths. For example, in 2019, India rejected Japan's Osaka Track, a framework to promote data transfers in favor of expanding data localization.[15] In addition, Quad

members' economic entanglements with China could slow the pace of collective action. Despite individual and shared concerns about its increasingly assertive global and regional behavior, in 2020, China remained the largest trading partner for the United States, India, Australia, and Japan.[16] Close economic ties to China could therefore hinder the Quad's technological collaboration agenda.

Against this backdrop, this report analyzes the state of AI-related collaboration between the four Quad countries. The United States, Australia, India, and Japan differ a great deal with respect to the size, maturity, and dynamism of their respective AI ecosystems, as well as their science and technology sectors more broadly. Nonetheless, all four democracies increasingly view AI as important to their national security and prosperity and are interested in partnering to ensure AI progress is compatible with democratic principles. This report uses two indicators of AI development and activity—AI research publications and investment in AI companies—to evaluate the scope and patterns in AI collaboration between the Quad countries over the past decade. We assess data across these indicators to map out each country's AI ecosystem, their unique strengths and weaknesses, their relationships with one another, and, where appropriate, their linkages to China. Finally, we outline areas of future opportunity and possible pathways for expanding AI-related cooperation among all of the Quad's members.

AI Research across the Quad

Research related to artificial intelligence can fuel scientific and technological progress, propel innovation, and contribute to breakthroughs in a broad range of fields, including health care, transportation, agriculture, finance, smart cities, and national security.[17] Although their individual priorities and approaches may differ, the four Quad countries have repeatedly stressed their commitment to advancing AI research through investment in AI education, public and private funding to universities and research institutions engaged in work on AI, enhancements to data infrastructures, and continued expansion of the computing resources necessary for AI development. AI research has benefited immensely from a culture of openness, and all four Quad nations also see research collaboration as a path to progress in AI.

Research publications are a commonly used indicator to assess organizational or national competitiveness, highlight areas of strength, and illuminate barriers to productivity that may be hindering broader technological progress. Many factors influence research productivity, including the quality of academic research institutions, access to public and commercial research funding, and the ability to attract, cultivate, and retain talent. Additionally, broader systemic issues such as institutional culture, bureaucracy, corruption, a country's level of educational attainment and economic development, and openness to scientific and technological exchanges also play an important role.[18] Although there are important differences between the AI ecosystems of the United States, Australia, India, and Japan, a comparison of their AI research production, areas of research focus, and patterns of research collaboration offers a useful perspective into their individual and collective accomplishments as well as gaps that require additional investment and attention.

This section explores the scope and nature of AI research across the four Quad countries, their patterns of collaboration with one another as well as with China between 2010 and 2020. Our analysis uses English-language AI publication data from the CSET merged corpus of scholarly literature from Digital Science's Dimensions, Clarivate's Web of Science, Microsoft Academic Graph, China National Knowledge Infrastructure, arXiv, and Papers with Code.[19] The publications data for this analysis of scholarly literature was pulled from the broader corpus in October 2021.[20] It is to be expected that analyses conducted at different points in time, using different methods to classify AI papers, and drawing on a different combination of bibliometric data sources will yield slightly different results. Appendix 1 offers a detailed discussion of our research methodology, including our approach to identifying and classifying research publications related to the development and application of AI.

AI Research Output and Key Research Subfields

Over the last decade, scholars from the United States, Australia, India, and Japan have authored a combined total of 642,813 AI papers, accounting for nearly 28 percent of the global AI research output.[21] When taken together as a group, the Quad countries have published more AI papers than all of the EU and ASEAN countries combined (532,802 papers).[22]

All four of the Quad countries are in the top 10 of AI research producers in the world, based on the number of published AI papers linked to institutions and authors from these countries. As Table 1 shows, between 2010 and 2020, the United States was the second largest producer of AI research, accounting for 17 percent of the world's total. India and Japan, ranked third and fifth, respectively, each accounting for around 5 percent of the global total, while Australia placed eighth, with roughly 3 percent of the global production of AI research.[23]

Table 1: Top 10 Countries by Production of AI-relevant Scholarly Papers, 2010–2020.

Country	No. of AI publications	Global share
China	603,467	26.2%
United States	395,464	17.2%
India	116,319	5.0%
United Kingdom	111,879	4.9%
Japan	104,716	4.5%
Germany	101,541	4.4%
France	78,214	3.4%
Australia	66,106	2.9%
Canada	64,929	2.8%
Italy	60,429	2.6%

Source: CSET merged corpus.

Research volume is not necessarily indicative of research quality or impact. Yet the AI-related research authored by scientists from the four Quad countries is also highly cited, appearing to have had notable influence on progress in AI-related research fields, at least as indicated by citation counts (see Table A, Appendix 2). AI research papers published by scientists and scholars from the United States have generated upward of 10 million citations over the past decade, well over the number of citations credited to AI papers originating from China—and this is despite the fact that Chinese researchers have published more papers than U.S.-based researchers have over this period of time. Australia's AI citation counts are over 26 times higher than the country's publication output. Meanwhile, India and Japan are also among the top 10 countries producing the most highly cited AI research.

In addition to overall research output and quality indicators, it is also useful to examine the specific areas of focus AI researchers from the United States, Australia, India, and Japan are exploring in their publications. In our dataset, we identified 289 AI-related research subfields where authors from at least one of the Quad countries have published at least one AI-related paper. Looking at the distribution of AI research papers by subfield for each country provides insights, however limited, into particular areas of research strengths, as well as helping to offset some of the challenges in comparing countries with vast differences in research volume.

Table 2: Quad Countries' AI Research by Fields of Study, 2010–2020.

PUBLICATION COUNT AND SHARE OF A COUNTRY'S TOTAL AI PUBLICATIONS

AI Fields	United States		Australia		India		Japan	
Pattern recognition	47,263	12%	9,751	15%	30,630	26%	11,898	11%
Computer vision	29,430	7%	4,907	7%	11,707	10%	16,053	15%
Algorithm	25,666	6%	4,247	6%	4,976	4%	5,335	5%
Machine learning	33,832	9%	6,146	9%	9,322	8%	4,456	4%
Data mining	12,413	3%	2,759	4%	6,153	5%	2,485	2%
Control theory	9,384	2%	1,410	2%	2,443	2%	6,916	7%
Natural language processing	17,825	5%	2,186	3%	5,944	5%	4,389	4%
Human–computer interaction	16,487	4%	2,619	4%	2,808	2%	6,854	7%
Theoretical computer science	10,403	3%	1,773	3%	1,101	1%	1,218	1%
Linguistics	8,413	2%	1,521	2%	502	0%	1,263	1%
Data science	9,109	2%	1,583	2%	2,409	2%	819	1%
Simulation	3,333	1%	403	1%	534	0%	3,867	4%

Note: This list displays the top seven AI research subfields for each of the Quad countries by volume of production. The remaining five fields in the table can be seen as areas of strength for at least one of the Quad countries, i.e., where their individual production is uniquely high so that it is worth highlighting from a substantive perspective.
Source: CSET merged corpus.

As Table 2 shows, pattern recognition, machine learning, and computer vision are among the top AI fields therein researchers from the Quad countries tend to publish, which reflects global publication trends (see Table C, Appendix 2). Below, we look more closely into the AI subfield-specific publication patterns of each of the Quad countries to identify their respective AI-related research strengths.

Australia: Australia's top AI research fields by paper count—pattern recognition, machine learning, and computer vision—generally reflect global trends and distributions. That said, about 9 percent of AI papers published by Australia focus on machine learning, which is nearly double the global rate of 5 percent. It is also worth

drawing attention to Australia's research in theoretical computer science and linguistics, where in absolute terms, the country's publication output outnumbers that of Japan and India despite the fact that the latter two have a much higher AI paper count overall.

For context, theoretical computer science focuses on the mathematical aspects of computer science and provides us ways to investigate some deeper philosophical questions. Linguistics involves modeling of the basic linguistic processes (comprehension, production, and learning of language) and includes working on crucial AI problems (perception, communication, knowledge, planning, and reasoning and learning). Research in linguistics is closely linked to the field of natural language processing, which is one of the major fields of AI.

India: India's top three AI research subfields include pattern recognition, computer vision, and machine learning. Although this distribution largely mirrors global patterns, 26 percent of India's AI-related research pertains to pattern recognition, while globally, that number stands at about 14 percent. Data mining is India's fourth largest AI field, and Indian scholars have written 6,153 papers on it in the past decade. From a comparative standpoint, while over the past decade India and Japan have published a relatively similar number of AI research papers overall (116,319 vs. 104,716), Indian research production in data mining is roughly three times more than that of Japan. Data mining or knowledge discovery in databases involves the nontrivial extraction of implicit, previously unknown and potentially useful information from data. Given India's massive population and increasing internet and smartphone penetration, there are immense opportunities for data collection. AI researchers in India are therefore well positioned to study data systems and processes; indeed, data science is one of the fastest growing AI-related research fields in India in the past 10 years.[24]

Japan: Computer vision is the most popular field of AI research in Japan, representing 15 percent of the country's overall AI publications, and exceeding the global figure of 8 percent. Japan's AI research also stands out in two additional fields—control theory and human-computer interaction. Japanese paper production in each of these fields is roughly three times that of Australia and India, respectively. Control theory pertains to the use of feedback to influence the behavior of a system for a desired goal, while research on human-computer interaction broadly deals with interfaces between people and computer systems. Both fields have linkages to robotics research and development, and the relatively high number of publications in these areas may be interlinked with Japan's accomplishments in robotics. Finally, although simulation research accounts only for 4 percent of Japan's overall AI-related publication output over the past decade,

Japanese researchers have published more papers in this field than even the United States, making Japan a global leader in AI-related simulation research.

United States: While the United States lags behind China in overall AI-related research output, it is far ahead of its Quad allies. The United States is a global leader in AI subfields such as machine learning, data science, human-computer interactions, and theoretical computer science (where it outperforms even China) and is ahead of Australia, Japan, and India in the remainder of the AI-related subfields presented in Table 2, except simulation where it comes second to Japan. Even when we contrast U.S. paper counts with all of Australia, India, and Japan's paper production taken together, the United States still leads in several key areas including natural language processing and linguistics.

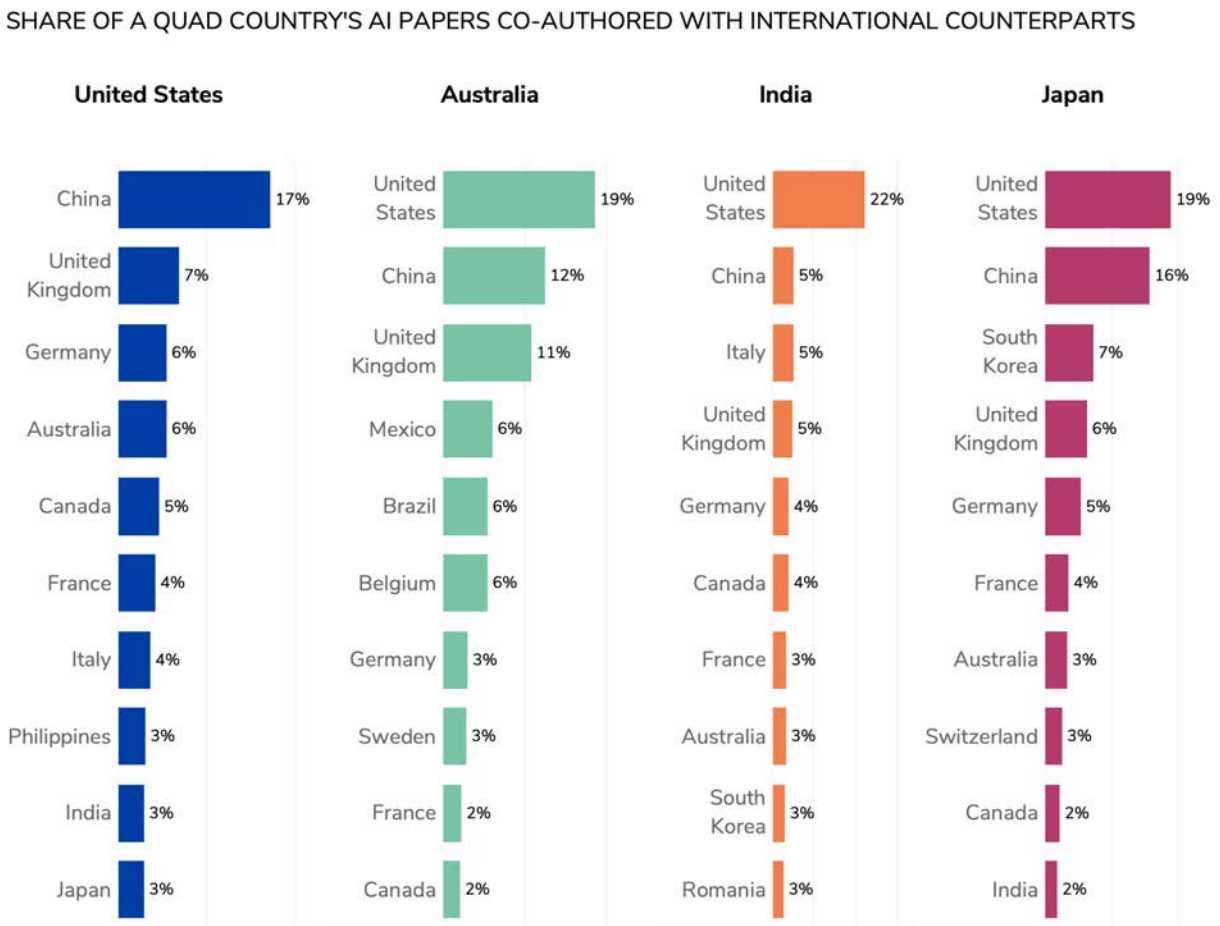
Patterns of Research Collaboration between the Quad Countries

International research collaboration can enhance research output, quality and impact.[25] Collaborations allow researchers to share resources, costs, and infrastructure, cultivate ideas and skills, and work together to address regional, transnational or global problems. Recent studies indicate that the percentage of worldwide science and engineering articles produced with international collaboration has increased from 18 percent to 23 percent from 2010 to 2020.[26] That said, countries demonstrate different rates of international research collaboration depending on factors such as national science and technology policies, higher education infrastructure, and others.[27]

The Quad countries differ significantly in their propensity for international collaboration in AI-related research, as proxied by internationally co-authored publication counts. Over the past decade, 69 percent of all AI research papers published by Australian researchers were co-authored with at least one non-Australian author. That figure stands at 48 percent for the United States and at 30 percent for Japan. India has the lowest international collaboration rate among the Quad nations, with only 20 percent of all of its AI research papers co-authored with counterparts from outside of the country. All four countries have seen their share of internationally co-authored AI-related papers increase significantly over this period of time, mirroring global trends.[28]

When looking at the top research partners for each of the Quad countries, it is immediately evident that AI researchers from Australia, India, and Japan most often collaborate with their counterparts from the United States.

Figure 1: Quad Countries and Their Top 10 AI Research Partners, 2010–2020.



Source: CSET merged corpus.

As Figure 1 shows, 22 percent of all of India's international AI co-authorships are with the United States, such that Indian AI scholars collaborate at least four times more with U.S.-based AI scholars than researchers from any other country in the world. Nineteen percent of Australia's and Japan's internationally co-authored AI papers each are with U.S.-affiliated researchers. Comparatively, the collaboration rates between AI researchers from Australia, India, and Japan are much lower—never exceeding 4 percent of each country's respective co-authored AI publications.

For Australia, India and Japan do not even rank in the top 10 of research partners. This is particularly notable considering Australia's high research collaboration rate. For India, research collaborations with Australia account only for 3 percent of the country's internationally co-authored publications, whereas Japan does not make it to the top 10 of India's research partners. Finally, when looking at Japan, research papers co-authored with colleagues from Australia represent 3 percent of the country's

internationally co-authored publications, while publications authored jointly with researchers from India represent 2 percent of Japan's international co-authorships.

There are a number of explanations for why Australia, India, and Japan have close AI-related research ties to the United States but not to one another. Most basically, researchers from around the world have professional and personal incentives to seek out collaboration with colleagues from the United States. U.S. universities, research institutions, and individual researchers enjoy a global reputation for excellence and prestige, are often relatively well-funded, and have the advanced equipment to conduct technologically-sophisticated research. A mixture of these considerations as well as other historical, cultural, geographic, and strategic factors shape research collaboration ties between the Quad countries as well.

The United States and Australia, for example, share extensive research ties across STEM and other fields, reinforced by a shared language, cultural affinity, and close economic and security ties. The United States and Japan also have a long standing and robust alliance and the two countries have worked together on science and technology research and development since the mid-1960s, with AI increasingly becoming a top priority for cooperation.[29] Research collaboration between the United States and India has also benefited from bilateral initiatives such as the Indo-U.S. Science and Technology Forum (IUSSTF) launched in 2000 to promote long-term scientific collaborations. Evidence from survey research also suggests that the majority of Indian faculty members living and working in U.S. universities in science and engineering fields report having collaborations with researchers in India.[30]

On the other hand, Australia, India, and Japan have traditionally not been important research partners for one another. While it is difficult to ascertain the specific factors that are hindering collaboration between researchers from these three countries, geography, language barriers, funding constraints, and bureaucratic impediments all play a role.[31]

The massive research output produced by the Quad countries makes them global leaders in AI research. Each country's performance stands out in key AI-research fields—Australia in theoretical computer science and linguistics, India in data mining and data science, Japan in simulation, HCI, and control theory, and the United States in machine learning and natural language processing, among several others. However, there are crucial differences in the rates of international collaboration amongst the four Quad members. While Australia, India, and Japan all have close research ties to the United States, they tend to collaborate much less frequently with one another. As the

Quad members continue working toward greater technology cooperation, there is certainly space to enhance AI research ties between the three Indo-Pacific nations.

Patterns of Research Collaboration between the Quad Countries and China

China is a global leader in AI research. As Table 1 shows, the country surpassed the United States in the number of AI papers produced between 2010 and 2020 and is far ahead of India, Japan, and Australia. China comes second only to the United States when looking at citation counts, a common measure of research quality, and once again significantly ahead of Australia, India, and Japan.

Previous CSET research shows that while the United States, Australia, and the European Union have all grown more collaborative over the past 20 years, China's level of collaboration has remained relatively flat.[32] China has a relatively low international collaboration rate in research on science and engineering in general, as well as in AI more specifically, where according to our data over the past decade, only about 20 percent of the country's overall AI publications listed co-authors outside of China.[33] China's international collaboration rate in AI research is then more akin to that of India, but lower than that of Japan (30 percent), the United States (48 percent), or Australia (69 percent).[34]

Despite China's comparatively low international collaboration rate in AI-related research, the scale of its production still makes it a critical research partner for the United States, Australia, Japan, and to a lesser extent, India (see Table B, Appendix 2). U.S. AI researchers collaborate with their Chinese counterparts more than they do with colleagues from any other country–indeed, nearly 17 percent (56,194 papers) of America's internationally co-authored AI papers are with Chinese counterparts. Collaboration with Chinese scholars also account for 16 percent (7,850) of Japan's internationally co-authored AI papers and over 12 percent (12,169 papers) of Australia's internationally co-authored AI papers.

Although India has a lower international collaboration rate than its Quad allies, China is India's second largest collaborator after the United States, accounting for 5 percent of India's internationally co-authored AI papers. India and China have co-authored only 2,184 AI papers over the past decade, which is a lower output than that of research collaborations between China and the United States, China and Australia, and China and Japan.

As previously noted, China is the global leader in AI research publications, and even when taking its relatively low overall international collaboration rate into account,

remains a key research partner for all of the Quad countries. It is however possible that we will begin seeing changes in these patterns over the next several years as the Quad nations introduce new or expand existing regulations on joint research with China.[35] Some such measures are already underway—several tackling the issue of research security more broadly while others dealing with China more specifically. The Congressionally mandated National Security Commission on Artificial Intelligence, for instance, has urged U.S. universities to limit their collaboration with entities and individuals affiliated with the Chinese military.[36] Australia, meanwhile, has introduced measures for increased vetting of government-funded projects undertaken at the country's universities.[37] India has instructed its universities to not enter into academic cooperation agreements with Chinese institutions without approval.[38] Japan has reportedly initiated a system for Japanese and foreign researchers to seek government approval before they access dual-use research and technologies.[39] While there is merit in responsible and open AI-related research collaboration with Chinese counterparts that fuels scientific and technological progress, the Quad nations may be reconsidering some research partnerships involving China, particularly in areas pertinent to national security. Such shifts present an opportunity for enhancing research collaboration activities between Australia, India, and Japan based on their individual and complementary research strengths.

AI Investment Activity across the Quad

Investments in AI companies are growing more rapidly and becoming more global with funding coming from every corner of the market and every part of the world.[40] Both domestic and foreign investors are increasingly seeing financial returns on their investments in AI companies.[41] Cross-border investments can be mutually beneficial to foreign investors and target companies, allowing foreign investors to profit from the technological innovation developed by target companies, which in turn, rely on the funding to develop innovative products and grow commercially.[42] In keeping with these global trends, investors and AI companies from each of the Quad countries are ramping up their funding as well as competing to attract investments.

This section proceeds in three parts. First, we offer an overview of the AI investment ecosystem within each of the Quad countries. Second, we analyze the investment activities between these four nations to better understand the extent to which their respective AI ecosystems are interlinked. Finally, we assess the AI investment ties each of the Quad countries maintains with China.

To measure investment flows between investors and AI companies located across the United States, Australia, Japan, and India (as well as China), we rely on financial data from Crunchbase. No financial database covers the entire investment market perfectly, and therefore our analysis is limited only to the AI companies listed by Crunchbase and to observations where the investor's country of origin is available. Appendix 1 offers a detailed discussion of our research methodology.

There are two additional limitations to keep in mind. First, the investment community is increasingly globalized, meaning that when an AI company is able to attract funding, such capital often comes from investors located in more than one country. As such, our assessments of the number and the size of investment transactions coming from the United States and targeting Japan's AI companies, for example, are not mutually exclusive from our estimates of how much and how frequently Chinese investors are investing in Japanese AI companies because these investors often find themselves involved in the same funding rounds.

Second, the amount of money coming from individual investors to target AI companies is also difficult to assess accurately, as investors are not likely to reveal this information. Crunchbase, like other financial data providers, only offers information on the total amount raised (where available) by a target company in a particular investment stage and does not disclose the contributions made by individual investors. For example, the U.S.-based Enlitic, a healthcare sector company specializing in deep learning, raised

$25 million in a Series B round in 2019 from six investors, four of which are headquartered in Australia, one in Japan, and another in the United States. While Crunchbase data shows that Enlitic was able to attract $25 million from these investors during this specific funding round, we cannot know for certain the exact amount of money each investor invested in this company.

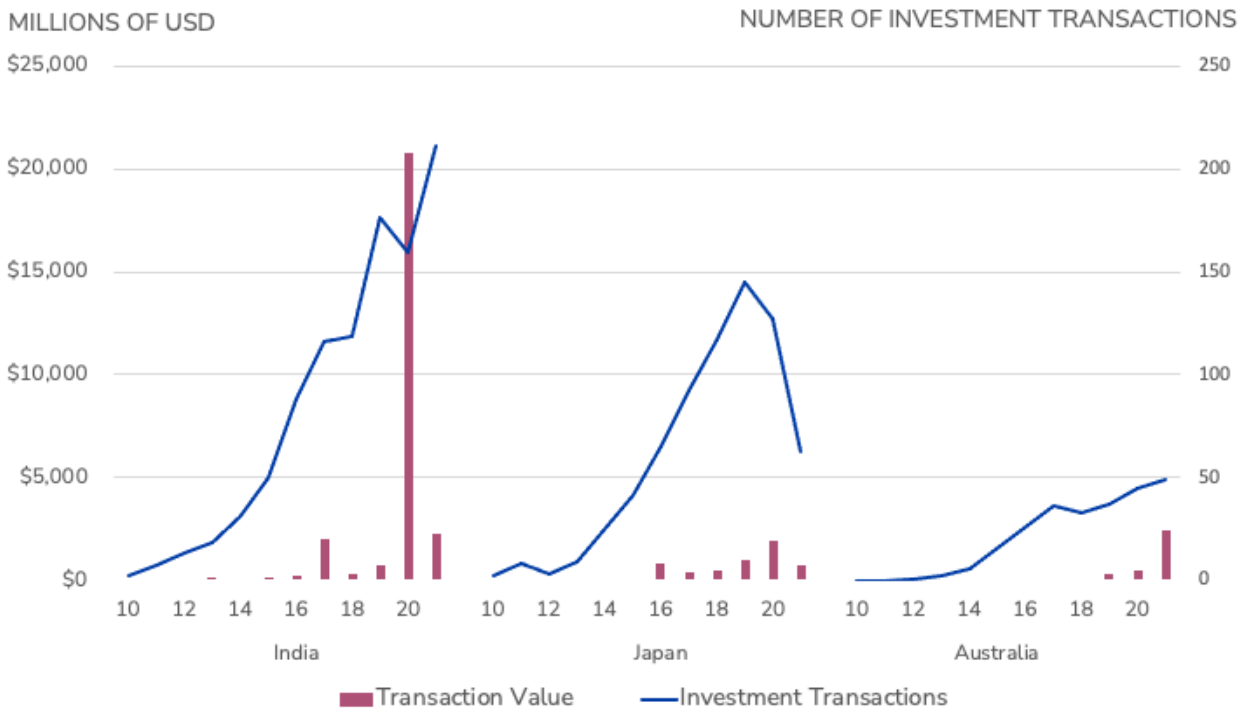
Despite these limitations, the discussion below offers a useful overview of AI investment activity involving the four Quad countries as well as China between 2010 and 2021. Ultimately, the findings mirror the patterns observed throughout the analysis of research collaboration trends, namely that while all three Indo-Pacific countries have extensive AI investment linkages to the United States, they are currently not leveraging the opportunities presented in one another's AI investment market. Moreover, based on both the frequency and value of AI-related investment transactions, all four nations, but particularly the United States, retain close AI investment ties with China.

Overview of the Quad Countries' AI Investment Ecosystems

The AI investment ecosystems of the Quad countries differ in size, scale, and vitality. The United States has the world's largest AI market with 11,772 active AI companies. Between 2010 and 2021, U.S.-based AI companies have received 13,793 investment transactions and raised over $525 billion. Despite the COVID-19 pandemic, 2020 was a phenomenal year for the U.S. AI market, with $77 billion raised across 1,866 deals.

With 1,900 active AI companies, India has the second largest AI market among the Quad countries and the third largest startup ecosystem in the world.[43] As Figure 2 below demonstrates, investment in India's AI companies has grown significantly over the past decade, and investors' enthusiasm for the country's tech unicorns is unlikely to dwindle soon.[44] Between 2010 and 2021, Indian AI companies raised $26.9 billion across 990 investment transactions. Notably, however, $10.2 billion of that overall value came from two investment transactions, when in 2020 Reliance Jio—a subsidiary of the Indian conglomerate Reliance Industries focused on developing AI-enabled technologies—raised $5.7 billion from Meta and $4.5 billion from Google in two separate corporate rounds.[45] Aside from this, India has an active early-stage market in which investors finance companies frequently, but with small amounts of capital. Early-stage financing rounds—such as pre-seed, seed, angel, and series A and B—account for 75 percent of observed investment transactions in which Indian AI companies participated but make up only 5 percent of observed transaction value.

Figure 2: Investment Flows into Indian, Japanese, and Australian AI Companies, 2010–2021.



Source: CSET analysis of Crunchbase.

Japan has the third most active AI market among the Quad countries, with 747 AI companies. But as evident from Figure 2 above, the country's AI investment activity is declining. Between 2010 and 2021, Japanese AI companies received $5.5 billion across 697 investment transactions. Investment in Japanese AI companies peaked in 2019 with 145 investment transactions but began to slow down in 2020. By 2021, the number of investment transactions fell to 63, having declined by 56 percent since the peak period, in part due to the economic impact of the COVID-19 pandemic.[46] Early-stage financing rounds account for 51 percent of observed AI transactions but comprise about 22 percent of the observed transaction value. Japan's AI market sees a relatively high number of transactions albeit with a lower value attached to each, with a median size deal of $7.9 million.

Australia has 475 AI companies, and while its AI investment market is less active than those of the other three Quad countries, investors are beginning to show more enthusiasm for the country's AI companies. As Figure 2 above shows, Australian AI companies received the lowest amount of transaction value and investment transactions among the Quad nations, raising $3.4 billion across 251 deals between 2010 and 2021. However, Australian AI companies appear to be attracting more

investment transactions, and the overall value of transactions is also on the rise. 2021 was a particularly successful year for Australian AI companies which attracted nearly $2.4 billion across 49 transactions, including one notable deal where the Australian e-commerce giant Woolworths acquired Quantium, a local AI company focused on data analytics, for $173.2 million.

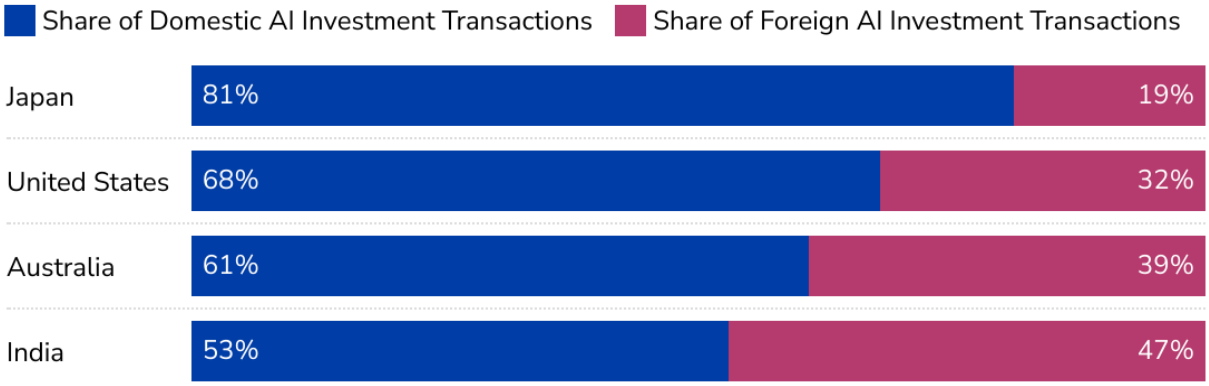
AI Investment Trends across the Quad Countries

In examining Quad AI investment trends, we first look closely at the four countries' investments into their respective domestic AI companies and second, assess the cross-border AI investment ties between the four nations by counting the number of investment transactions and overall transaction value involving each dyad within the Quad.

Assessing Quad Countries' Investments in Domestic AI Companies

Over the past decade, domestic investors were involved in the majority of investment transactions targeting AI companies located in each one of the Quad countries. As Figure 3 illustrates, between 2010 and 2021, domestic investors were involved in 81 percent of Japan's AI investments (657 investment transactions), 68 percent of U.S. AI investments (12,191 investment transactions), 61 percent of Australia's AI investments (189 investment transactions), and 53 percent of India's AI investment (735 investment transactions).

Figure 3: Share of Domestic and Foreign AI Investment Transactions in the Quad Countries, 2010–2021.



Source: CSET analysis of Crunchbase.

There are a number of reasons that investors may prefer their domestic AI markets to foreign investment opportunities, including favorable regulations, lower costs of doing

business, greater prospects for profit, local network for information and deal sourcing, and other incentives set by governments to retain homegrown capital for a range of economic and strategic reasons.[47] That said, a healthy, vibrant AI investment ecosystem is one that is able to attract foreign as well as domestic capital. The next section discusses the AI investment ties between the four Quad countries.

Assessing AI Investment Ties between the Quad Countries

Based on our data, the United States is the top foreign investor in Indian, Australian, and Japanese AI companies. As Figure 4 shows, U.S.-based investors took part in 23 percent of the observed investment transactions in Indian AI companies (316 investment transactions/$20.5 billion), 19 percent of investments in Australian AI companies (59 investment transactions/$869 million), and 11 percent of investments in Japanese AI companies (91 investment transactions/$904 million).

Figure 4: Top 10 Foreign Investors in Indian, Japanese, and Australian AI Companies, by Share of AI Investment Transactions, 2010–2021.

India		Japan		Australia	
United States	22.8%	United States	11.3%	United States	19.3%
Singapore	6.5%	Singapore	1.5%	United Kingdom	4.6%
United Kingdom	4.5%	China	1.0%	Singapore	3.9%
China	2.4%	United Kingdom	0.9%	China	3.3%
Japan	1.9%	Taiwan	0.7%	Japan	1.3%
United Arab Emirates	1.4%	South Korea	0.7%	South Africa	0.7%
Mauritius	0.8%	Iceland	0.6%	Philippines	0.7%
Germany	0.8%	France	0.5%	Switzerland	0.7%
Taiwan	0.7%	Germany	0.3%	Canda	0.7%
Australia	0.7%	Costa Rica	0.3%	India	0.3%
Netherlands	0.6%	United Arab Emirates	0.3%	Turkey	0.3%
Switzerland	0.5%	India	0.1%	Malaysia	0.3%

Note: Highlighted rows are Quad country investors.
Source: CSET analysis of Crunchbase.

Australia, India, and Japan are among the top 10 investors in American AI companies. That said, given the massive size of the U.S. AI investment market, their individual shares of the overall investment into U.S. AI companies are relatively small, as Table 3 below illustrates.

Table 3: AI Investment Activity between the United States and Each of Its Three Quad Partners, 2010–2021.

Countries	Number of AI investment transactions	Share of target country's AI investment transactions	AI transaction value involving investor country (million USD)	Share of transaction value involving investor country
🇺🇸 → 🇮🇳	316	23%	$20,562	61%
🇮🇳 → 🇺🇸	250	1%	$4,407	1%
🇺🇸 → 🇯🇵	91	11%	$904	14%
🇯🇵 → 🇺🇸	331	2%	$14,565	2%
🇺🇸 → 🇦🇺	59	19%	$869	22%
🇦🇺 → 🇺🇸	162	1%	$5,685	1%

Note: Arrows indicate the direction of investment from the investor country to the target country.
Source: CSET analysis of Crunchbase.

When looking closely at the investment transactions and transaction value involving the United States and its Quad partners, there are interesting differences between U.S.-Japan and U.S.-India AI activity. Japan is the fifth largest investor in American AI companies, and as Table 3 shows, Japanese investors are particularly active in the U.S. AI investment market, having been involved in as many as 331 investment transactions totaling $14.5 billion between 2010 and 2021. U.S. AI investment in Japan is far smaller by comparison, with U.S.-based investors taking part in about 91 investment transactions totaling $904 million.

The U.S.-India investment relationship, on the other hand, exhibits the opposite trends. Indian AI companies are big recipients of funding from the United States, with U.S. investors involved in as many as 316 transactions, totaling approximately $20.5 billion. Indian investors, meanwhile, have taken part in 250 investment transactions which

amounted to $4.4 billion reaching U.S. AI companies. Taken together, Japanese investors seem more enthusiastic about opportunities in the U.S. AI investment market than American investors looking at Japan's AI market, while Indian AI companies are managing to attract more U.S. investment than American AI companies drawing in capital from Indian investors.

Australia, meanwhile, is the tenth largest investor in U.S.-based AI companies, and between 2010 and 2021, Australian investors were involved in about 1 percent of observed transactions into U.S.-based AI companies (162 investments transactions/$5.6 billion); U.S. investors play a relatively significant role in the nascent Australian AI market.

Mirroring the trends highlighted in the AI research collaboration section, the investment data also indicates that while Australia, Japan, and India individually have close AI investment ties with the United States, they partake in little AI investment activity with one another. Among these three Indo-Pacific countries, there is some notable AI investment activity between Japan and India, but the relationship is largely one sided, with Japanese investors targeting Indian AI companies much more frequently than Indian investors pursuing opportunities in Japan (see Table 4 below). Japan is the fifth largest investor in Indian AI companies, with investors in Japan taking part in nearly two percent of observed Indian AI investment transactions between 2010 and 2021 (26 investment transactions). Yet in this period, only one Japanese AI company—Cinnamon AI—raised $15 million from multiple investors, one of which was the India-based SBI's Fintech Business Innovations. The 2018 Japan-India Digital Partnership agreement which set off to encourage Japanese investment in Indian startups can help explain some of this imbalance.[48]

Table 4: AI Investment Activity between India and Japan, Australia and India, and Japan and Australia, 2010–2021.

Countries	Number of AI investment transactions	Share of target country's AI investment transactions	AI transaction value involving investor country (million USD)	Share of transaction value involving investor country
🇮🇳 → 🇯🇵	1	0.1%	$15	0.2%
🇯🇵 → 🇮🇳	26	1.9%	$197.9	0.6%
🇦🇺 → 🇮🇳	10	0.7%	$11.9	0.0%
🇮🇳 → 🇦🇺	1	0.3%	$28	0.7%
🇯🇵 → 🇦🇺	4	1.3%	$78.8	2.0%
🇦🇺 → 🇯🇵	0	0.0%	0	0.0%

Note: Arrows indicate the direction of investment from the investor country to the target country.
Source: CSET analysis of Crunchbase.

Over the past decade, there has been relatively little investment activity between India and Australia, and in fact, Crunchbase lists only one investment transaction involving Indian investors targeting an Australian AI company. In 2020, the Indian company, Sonata Software, acquired Australia's GAPbusters Limited (GBW), an analytics company developing AI capabilities. Although the value of the transaction was not disclosed, our estimates suggest it was approximately $28 million (see Appendix 1). According to the company, Sonata Software's acquisition will strategically leverage GBW's AI technologies and strengthen its presence in Australia as well as Southeast Asia and Europe, where GBW is prevalent.[49]

Although Australia is among the top 10 investors in Indian AI companies, Australian investors have taken part in less than 1 percent of the total investments into Indian AI companies between 2010 and 2021 (10 investment transactions/$11.9 million). In 2021, Australia announced that it will set up a consulate in India to promote investment and innovation partnerships on emerging technologies.[50] This move could indicate Australia's interest in boosting investment in Indian AI companies.

As Table 4 illustrates, there is little bilateral AI investment between Japan and Australia. While Japan is the fifth largest investor in Australian AI companies, transactions that involve Japanese investors make up a little over one percent of observed investment transactions in Australian AI companies (four investment transactions/$78.8 million). At the same time, according to Crunchbase data, there is no observed capital flow from Australian investors to Japanese AI companies. As previously mentioned, domestic players dominate investment in the Japanese AI market, with foreign investors participating only in 19 percent of the observed investment transactions. That said, weak AI investment ties between Australia and Japan are another example of both the currently limited AI-investment linkages between all three of the Indo-Pacific Quad countries and the opportunities for closer alignment in the future.

AI Investment Ties between the Quad Countries and China

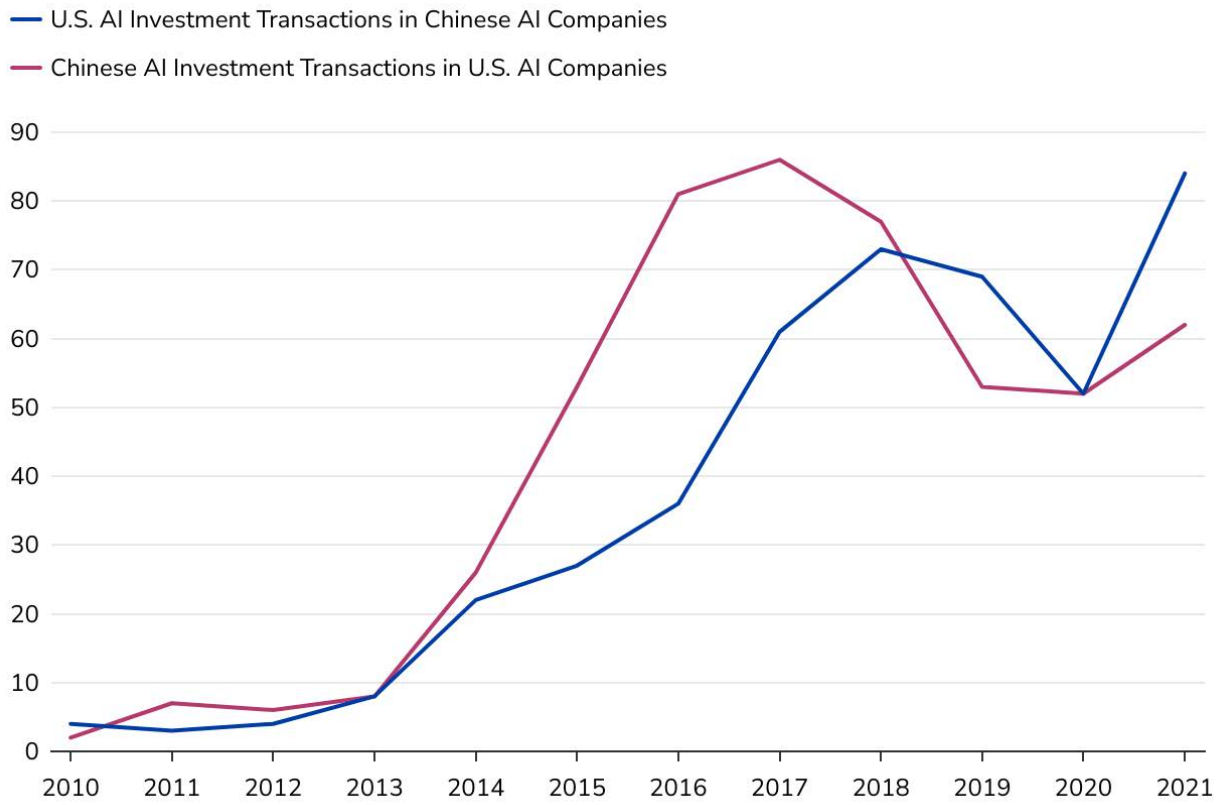
Between 2010 and 2011, Chinese AI companies raised nearly $114 billion dollars across 2,480 investment transactions, making the country's AI market larger than that of India, Japan, and Australia yet smaller than that of the United States. The United States is by far the largest foreign investor in Chinese AI companies, with U.S. investors taking part in 443 investment transactions amounting to $42.7 billion between 2010 and 2021. Earlier analysis shows that the United States is also the top investor in the three Indo-Pacific countries but invests less frequently and with smaller transaction value in Indian, Japanese, and Australian AI companies than in Chinese AI firms.

The robust AI-related investment ties between the United States and China are not particularly surprising given the size and vitality of the Chinese economy and its AI ecosystem in particular, both of which offer compelling opportunities for U.S.-based investors. There are, nonetheless, powerful diplomatic, security, and economic incentives to strengthen technological collaboration between the United States and its three Quad allies while reducing dependence on the Chinese market. It is therefore notable that the AI investment relationship between the United States and China, as proxied by both the number of transactions involving investors from these two countries and the value of these deals, is that much stronger than the linkages between the United States and its three Indo-Pacific Quad allies.

That said, investment flows between China and the United States, including those related to AI, have taken a hit over the past few years.[51] Figure 5 shows Chinese investments in U.S. AI companies started to dip in 2018, then fell further and plateaued over the next two years, followed by a slight uptick in 2021. These trends may be the results of growing tensions, sanctions, export controls, and trade disputes between the United States and China. Meanwhile, U.S. investments targeting Chinese AI companies

declined in 2019, dropping further in 2020, but then climbed back up and hit a record high of 62 investment transactions in 2021. As U.S. investments in Chinese companies begin to receive more scrutiny, this upward trajectory may not hold up.

Figure 5: AI Investment Transactions Involving the United States and China, 2010–2021.



Source: CSET analysis of Crunchbase.

Japan, India, and Australia also have important AI investment ties with China, both attracting capital from Chinese funders and investing in Chinese AI companies. Between 2010 and 2021, AI investments involving China and Japan amounted to over $16 billion across 23 investment transactions. Meanwhile, AI investment involving China and India totaled $1.14 billion across 41 investment transactions. Over the same period, AI investments involving China and Australia reached $1.2 billion with 26 investment transactions.

Table 5: AI Investment Ties Involving China and Each of the Quad Countries, 2010–2021.

Countries	Number of AI investment transactions	Share of target country's AI investment transactions	AI transaction value involving investor country (million USD)	Share of transaction value involving investor country
🇺🇸 → 🇨🇳	443	14.7%	$42,791	22.3%
🇨🇳 → 🇺🇸	513	2.9%	$15,737	2.3%
🇯🇵 → 🇨🇳	15	0.5%	$16,008	8.3%
🇨🇳 → 🇯🇵	8	1.0%	$27	0.4%
🇮🇳 → 🇨🇳	8	0.3%	$269	0.1%
🇨🇳 → 🇮🇳	33	2.4%	$874	2.6%
🇦🇺 → 🇨🇳	16	0.5%	$999	0.5%
🇨🇳 → 🇦🇺	10	3.3%	$201	5.1%

Note: Arrows indicate the direction of investment from the investor country to the target country.
Source: CSET analysis of Crunchbase.

Table 5 offers a closer look at China's AI investment ties with each of the four Quad countries, providing insight into each particular dyad, as well as a comparative perspective. Japanese investments in Chinese AI companies account for the majority of the AI-related investment activity between the two countries, with Chinese AI companies raising about $16 billion across 15 transactions that involved Japanese investors, including large investment firms such as SoftBank and ORIX Group, and the corporate investor, Toyota Motor. While China is the third largest investor in Japanese AI companies, Chinese investment activity accounts for only 1 percent of Japan's observed AI investment transactions (eight investment transactions/$27 million); this finding once again illustrates the prominent role that domestic as opposed to foreign investors play in Japan's AI ecosystem. As a whole, Japan's AI investment relationship with China seems to resemble the one with the United States—that is, Japanese investors are taking part in high value transactions targeting both Chinese and U.S. AI companies, while Japanese AI companies are securing relatively lower value

transactions in funding rounds that involve American and Chinese investors (see Table D, Appendix 2).

China-Australia AI investment ties mirror some of the trends in the China-Japan investment relationship—that is, Australia's investments in China's AI companies far exceed China's investments in Australia's significantly smaller AI ecosystem. Although Australia is the eighth largest investor in Chinese AI companies, Australian investors took part in 16 investment transactions that made up only half a percent of China's observed AI investment transactions. Chinese investors, meanwhile, were involved in only 10 investment transactions targeting Australian AI companies. But because the Australian AI market is relatively small, these investments made China the fourth largest investor in the country's AI companies, with slightly over a 3 percent share of Australia's observed AI investment transactions. Looking at the total transaction value in our data, the $999 million raised by Chinese AI companies in funding rounds involving Australian investors is nearly five times larger than the $201 million raised by Australian AI companies during funding rounds in which Chinese investors participated.

China-India AI investment ties, on the other hand, appear substantively different from China's relationship with Japanese and Australian AI markets, in that the Chinese investments in Indian AI companies account for the bulk of the investment activity between the two countries. Indian AI companies attracted 33 investment transactions that involved Chinese investors, making China the fourth largest investor in India's AI market. India, on the other hand, is only the eleventh largest investor in China's AI market, with Indian investors participating in eight investment transactions over the past decade. Indian AI companies raised $874 million in deals that involved Chinese investors, which is three times more than the $269 million that Chinese AI companies received during funding rounds in which Indian investors took part. Here, it is also worth noting that India's AI investment relationship with China is similar to the one with the United States, as Indian AI companies seem to be attracting a great deal of investment from American and Chinese investors, while Indian investors are less active in U.S. and Chinese AI markets (see Table D, Appendix 2).

As noted earlier, AI related investment activity among Australia, India, and Japan is relatively limited. This section further demonstrates that each of the three Indo-Pacific countries is closely interlinked with China, much more so than with their Quad allies, excluding the United States. These AI-related investment linkages are part of a broader set of economic and technological entanglements that bind China with the Quad countries. These linkages are predictable and sensible given the size of the Chinese economy and the myriad opportunities investors see in the Chinese AI market. That said, the governments of the United States, Australia, India, and Japan have all

acknowledged that Chinese investment also presents the risk of technology transfer and intellectual property theft.[52] Chinese venture capital investments in particular have been targeting industries with clear strategic significance and national security applications, such as AI, autonomous vehicles, virtual reality, robotics, and blockchain technology, raising concerns that cutting edge technologies developed in these countries can be used to strengthen China's military capabilities.[53] Another shared concern is China's use of AI and related technologies for surveillance and repression, both domestically and increasingly abroad.[54] Yet while the Quad countries have repeatedly voiced their commitment to ensuring that the development and use of AI is aligned with democratic principles and values, the close AI investment ties between the four Quad nations and China could complicate if not undermine the group's agenda in this space.

Ultimately, the data on trends in AI investment activity between the four Quad nations as well as their investment relationships with China highlight a complex reality where financial and economic transactions continue to operate on a largely separate plane than diplomatic initiatives and national security concerns. The implementation of the Quad agenda on technology cooperation, including on AI, will likely require policy change both at the individual state level and through multilateral coordination. While there are no easy solutions, an important step forward is to recognize this stark difference between the extensive AI investment ties each of the Quad countries has with China and the limited investment flows between Australia, India, and Japan. As the next section illustrates, these gaps in both AI-related research and AI investment nonetheless offer a number of opportunities for the Quad nations to capitalize on their respective strengths and coordinate policies to tackle shared problems related to emerging technologies.

Opportunities and Paths Forward

In its February 2022 Indo-Pacific strategy, the White House places an emphasis not only on strengthening U.S. alliances in the region, but on "encouraging our allies and partners to strengthen their ties with one another."[55] As a key regional grouping, the Quad has a powerful potential to advance cooperation on critical and emerging technologies, including AI. Right now, however, the ties that bind Australia, India, and Japan to each other are weaker than those that connect these three countries to the United States. Moreover, all four Quad members, to a varied extent, are interlinked with China's vast AI ecosystem–whether through joint research endeavors or through financial investment.

Delivering on the Quad's goal to advance technology cooperation will require deepening and expanding existing collaboration efforts as well as forging new pathways where few exist. For example, policy reports from Australia's National Security College's "Quad Tech Network" provide useful ideas for a Quad battery partnership, a techno-diplomacy strategy for telecommunications security in the Indo-Pacific region, and biotechnology research and standards collaboration.[56] While we refrain from proposing policy recommendations on the basis of findings related to only two dimensions of a multifaceted regional partnership, we offer the following list of potential opportunities that policymakers and other relevant stakeholders across the four countries should consider to expand cooperation.

Research

Expanding bilateral and multilateral AI-related research between the Quad countries, and particularly among Australia, India, and Japan, can strengthen the broader technology cooperation agenda. Government stakeholders, universities, research institutions, and private sector partners can facilitate AI-related research collaboration between Australia, India, and Japan in a variety of ways, including grants for joint research projects, scholarships and fellowships for visiting researchers and academic exchanges, competitions and prizes for jointly developed prototypes and solutions, conferences, workshops, and many more. Aligning incentives and creating opportunities for joint projects requires public and private funding, dedicated leadership, effective coordination, as well as time. Below, we therefore propose exploring opportunities for joint AI research that can help the Quad nations tackle urgent and shared challenges, as well as increasing collaboration in AI research areas where differences in data governance and regulatory approaches present fewer barriers to multinational cooperation.

Leveraging Individual AI Research Strengths for Collaboration on Collective Challenges

One way to increase research collaboration is to leverage areas of individual excellence for joint projects that tackle collective challenges the four Quad nations face. Climate change is one such collective challenge and a priority area for the Quad as all four nations are increasingly vulnerable to natural disasters such as hurricanes, earthquakes, and tsunamis. Focusing research collaboration on AI techniques that can improve the prediction, response, and mitigation of natural disasters—either at the Quad level or bilaterally, to strengthen research ties between Australia, India, and Japan—is a potentially promising path forward.

Some such efforts are already underway on a bilateral basis. For example, a recent U.S.-Japan research exchange on AI included disaster prediction, resilience, and recovery as one of its key focus areas.[57] This bilateral research exchange model can be replicated to promote similarly focused research partnerships between Japan and Australia, and Japan and India. As previously noted, Japan is a global leader in AI-related simulation research. Since the 2011 Great East Japan earthquake and tsunami, Japanese researchers have made significant progress in using AI-enabled modeling and simulation to improve real-time tsunami inundation forecasting methods to better estimate the regional impact of tsunamis and enhance disaster response. This technology can be applied to forecast other hydrological and coastal hazards, such as storm surges, and the information from the damage forecast can inform decision-making both prior to and in the aftermath of the event, to facilitate evacuation, relief, and recovery efforts.[58] Both Australia and India could benefit from pursuing a research partnership with Japan to explore the applications of these technologies to their respective environmental concerns and disaster management systems.

Advancing Research Collaboration on Privacy-preserving AI Techniques

Different approaches to data governance and privacy concerns are a serious obstacle to international collaboration in AI-related research and technology development, given the high reliance of AI/ML methods on large scale datasets. There are, however, techniques in data analysis that allow multiple parties to perform operations on non-sensitive datasets without sharing or storing personally identifiable information.[59] These techniques, known as privacy-preserving machine learning (PPML), could make "new uses of AI possible without triggering privacy concerns…and/or reduce cybersecurity risks by protecting individual data while preserving its usefulness."[60]

A focus on PPML offers a path forward to increasing AI-related research collaboration between the United States, Australia, India, and Japan. For instance, it may be possible to establish a working group on PPML as part of the ongoing Quad efforts on Critical and Emerging Technologies cooperation. A similar effort is already underway as part of the EU-U.S. Technology and Trade Council, which has defined AI technologies designed to enhance privacy protections as a priority area for its next meeting, and can serve to inform parallel or future initiatives between the Quad nations. Bilateral collaboration is another option, such as recent efforts spearheaded by the Indo-U.S. Science and Technology Forum—a bilateral organization jointly funded by the United States and India—which has been discussing federated learning PPML techniques as a series of roundtables focused on trustworthy AI under its U.S.-India Artificial Intelligence Initiative.[61] The recently announced U.S.-UK prize on privacy-enhancing technologies is another model for bilateral research and development cooperation the Quad countries could also explore.[62] Adding research collaboration in PPML to the agenda of other multinational bodies that include most or all of the Quad countries, such as the OECD or GPAI that already articulated their commitments to international cooperation on AI that is transparent, trustworthy, and responsible, is another option.

A focus on PPML could also reduce barriers to more extensive AI-related defense research collaboration between all four or a subset of the Quad countries. The Joint Artificial Intelligence Center's Partnership for Defense, which includes representatives from the U.S., Australian and Japanese militaries, could be a viable forum for advancing collaboration on PPML.

Investment

There are important differences between the AI ecosystems of the Quad countries in terms of the size, scale, and vitality, all of which impact their respective ability to attract foreign investment. That said, increasing AI investment activities between the four nations could help advance their individual AI development and commercialization goals, strengthen the Quad as a regional body, and reduce dependence on Chinese technology, capital, and markets. Below we highlight a number of initiatives already working toward these goals and offer several additional considerations.

Incentivizing and Growing AI Investment Activity between Australia, India, and Japan

While Australia, India, and Japan each have close AI investment linkages to the United States, there is relatively little AI investment activity between these three countries. To change this, the three countries will likely need to introduce reforms that attract foreign

capital and reduce barriers to foreign investment in their respective technology sectors. There is also a need for more targeted efforts that specifically incentivize investors from these three countries to invest in each other's AI companies. Some efforts are already underway.

Japan's External Trade Organization (JETRO)—a government-affiliated organization that promotes mutual trade and investment between Japan and the rest of the world—has made progress in attracting foreign investors. In 2019, JETRO supported 943 foreign companies in expanding to Japan and attracted 36.2 percent of the overall investment from the Indo-Pacific region.[63] JETRO has been working with India's National Association of Software and Services Companies (NASSCOM) and other government and industry partners to facilitate contact between Indian startups and Japanese venture capitalists, companies, and other investors, and has seen some success in maturing Indian startups and bringing them to Japan's market.[64] Meanwhile, as part of its AI Action Plan, the Australian government has launched the Early Stage Venture Capital Limited Partnerships (ESVCLP) and Venture Capital Limited Partnerships (VCLP) initiatives to incentivize foreign investors to participate in Australia's AI market through tax concessions.[65]

It is too early to judge the success of these and other similar initiatives, but they demonstrate steps in the right direction.

Coordinating Investment Screening and Export Controls across the Quad

As discussed earlier, not only do AI investment linkages between the United States and China exceed U.S. AI investments with each of the other Quad countries, but Australia, India, and Japan each have stronger investment ties with China than they do with one another. China's state-led industrial policies aim to leverage technology obtained from foreign firms to strengthen the country's competitive advantage in emerging and critical technologies such as AI, and through its military-civil fusion strategy, to apply these technological advancements to gain an edge in the military-technological competition, especially over the United States and its allies. Although the four Quad countries have their own approaches to protecting domestic innovation and countering the transfer of dual-use and sensitive technologies, multilateral cooperation on export controls, investment screening mechanisms, and other technology-transfer policies can significantly increase the effectiveness of these measures.

Part of the challenge is that the existing four multilateral export control regimes are ill-prepared to tackle some of the issues laid out in this report, such as China's use of commercial technologies including AI to violate human rights, as well as its military-civil

fusion strategy that blurs the lines between the civilian and defense sectors, making it nearly impossible to determine the potential military end use of any given technology.[66] As such, some have called for the creation of a new fifth multilateral export control regime to facilitate information sharing, resource sharing, and coordination across like-minded allies and partners, and help close the gaps in individual nations' domestic export control systems, which often reflect the limitations exhibited by the previously mentioned existing multilateral regimes. Some efforts along this line of thinking are already underway; in December 2021, for example, the United States, Australia, Denmark, and Norway signed a joint statement, pledging to employ export control tools to prevent "the proliferation of software and other technologies used to enable serious human rights abuses."[67] The United States and Australia may consider incorporating India and Japan (as well as other like-minded nations) into this effort.

Beyond export controls, each of the Quad countries also has its own foreign investment screening mechanisms, some of which are meant to protect domestic innovation and competitiveness or prevent potentially hostile actors from investing in sectors of relevance to national security (see Table E, Appendix 2).[68] Over the past several years, each of the Quad countries has implemented changes to long-standing domestic authorities to better address evolving national security risks. But additional information sharing between likeminded countries such as the members of the Quad can make these efforts more effective and help nations learn from one another's experience dealing with investments that may be contrary to national interests without compromising the economic growth and innovation fueled by open foreign investment. One possible model for expanding cooperation in this space is the U.S.-EU Trade and Technology Council's investment screening working group.[69]

While foreign investment screening mechanisms are fairly well defined, the idea of an outbound investment screening regime is a relatively novel concept. Currently, Japan is the only Quad country that has some industry-specific outbound investment restrictions in place.[70] The topic has been a subject of debate in the United States since discussions surrounding the Foreign Investment Risk Review Modernization Act (FIRRMA) in 2017–2018; that said, as of May 2022, no concrete mechanisms have been adopted.[71]

Whether the path forward is through an outbound investment screening regime or alternative policy or regulatory measures, the AI-related investment linkages to China present a conundrum for the Quad countries and can be at odds with their stated consensus that "technology should not be misused or abused for malicious activities such as authoritarian surveillance and oppression."[72] Indeed, there have been incidents where investors and companies from the Quad countries have been linked to Chinese

companies that work with or supply the Chinese military or those complicit in human rights abuses.[73] For example, Qualcomm was an early investor in SenseTime, one of China's top facial recognition firms that in October 2019 was added to the U.S. Commerce Department's Entity List for enabling high-technology surveillance, mass arbitrary detention, and other human rights abuses in Xinjiang.[74]

The Quad countries will need to work together to mitigate some of the risks posed by their technology investment ties to China, including through exploring opportunities for multilateral coordination on export controls and investment screening mechanisms; initial engagements can focus on improving the understanding of their respective systems, identifying individual and shared risks and threats, and sharing best practices focused on dual-use and sensitive technologies.

Conclusion

The United States, Australia, India, and Japan are committed to fostering an open, accessible, and secure technology ecosystem, shaped by their shared democratic values and respect for human rights. While not a formal alliance, the Quad could become an important forum for cooperation on responsible development and use of AI, serving as a bulwark to China's use and export of digital authoritarianism in the region. To be successful, however, the Quad will have to navigate complex and often conflicting diplomatic, economic, and national security imperatives, divergent geopolitical priorities, and unique approaches to data governance, all the while reconciling a set of very different economic and technological capabilities.

This report assesses trends in AI-related research collaboration and investment flows into AI companies across the Quad to better understand the state of technology cooperation between these four nations, as well as their respective linkages to China along these same two dimensions. Our findings indicate that while over the past decade, Australia, India, and Japan have all deepened and expanded their AI-focused research partnerships and investment ties with the United States, these three Indo-Pacific countries have collaborated far less with one another. Despite recent tensions, China remains an important research partner for the United States, Australia, Japan, and to a lesser extent, India. And although Quad countries are well aware of the evolving threats related to certain foreign investments and have voiced concerns about China's malicious use of AI, all four nations have varied but significant investment ties to China's robust AI ecosystem.

For the Quad to reach its full potential in technology cooperation, Australia, India, and Japan will have to work together to strengthen their research partnerships and expand their commercial contacts with one another, beyond the bilateral relationships each of these countries already has with the United States. Doing so could bolster the Quad's status as a hub for technology innovation as well as reduce dependence on China's technology and markets.

Creating opportunities and securing funding for international AI-related research projects can be challenging. But initiatives that capitalize on areas of individual research excellence to tackle common challenges have real promise—for example, leveraging AI for disaster prediction to strengthen climate change resilience and mitigation efforts in the Indo-Pacific region. Privacy-preserving machine learning is another area that fits well for collaborative research, allowing researchers from different institutions and countries to work together on AI without concerns about sharing sensitive data. Increasing AI-related investment activity across the Quad, and in particular between

Australia, India, and Japan, will require targeted reforms to attract capital and reduce barriers to foreign investment in each other's technology sectors. Concurrently, the Quad nations should also coordinate more closely on export controls and investment screening measures to better protect their sensitive and dual-use technologies.

Authors

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Appendix 1: Methodology

Research: Our analysis uses publication data from CSET's merged corpus of scholarly literature which includes Digital Science's Dimensions, Clarivate Analytics' Web of Science, Microsoft Academic Graph, China National Knowledge Infrastructure, arXiv, and Papers with Code. To restrict our focus on research publications related to the development and application of AI, we applied the same classification method used in previous CSET publications.[75] Instead of developing keyword-based queries or explicit criteria for AI-relevant research, this method infers a functional definition from papers in the arXiv.org repository, training a model to predict the categories that authors and editors assign to the site's papers. Applying it to our broader corpus, we identified as AI-relevant the papers that would be likely to receive an AI-relevant categorization if uploaded to arXiv.org.[76] We pulled the dataset in October 2021; in order to avoid gaps in 2021 data, we only examined data through 2020. Papers are grouped by country based on authors' institutional (universities, companies, government, etc.) affiliation. While papers are not double-counted within a country, if a paper has authors from different countries, that paper is counted once for each unique country represented in its authors. Therefore, all papers linked with one country should not be seen as exclusive for that country alone.

AI related papers are classified into fields of study based on field score classifications inspired by MAG level 1 categories. MAG provides multiple topic scores for papers indicating their association with various fields. Each paper is counted only in one category based on the highest field score. When a paper lacks MAG classification but is closely linked to the "citation networks" of other papers, we impute its MAG field based on closely related papers. Papers where MAG fields are missing or cannot get imputed get assigned to an "unclassified" category.

Investment: Our analysis on equity investment includes private equity and venture capital investment as well as mergers and acquisition (M&A) deals to identify all relevant investment transactions between the Quad countries (as well as China, where appropriate) over the past decade (2010–2021). In this paper, M&A refers to investment transactions with 100 percent of the target company's equity sold, while private-market investments include venture capital and private equity funding rounds.

To identify AI companies, we ran a regular expression-based search query against business descriptions of the target companies.[77] Given that the company business description provided by Crunchbase appears limited in some cases, we supplement the AI company identification using the keyword-based method with Crunchbase AI tag. AI

companies in our analysis include companies that CSET or Crunchbase has identified as AI companies.

To account for transactions that only involve transfer of equity, we excluded transactions where the investment target is classified in Crunchbase as “debt financing,” “equity crowdfunding,” “grant,” “non-equity assistance,” “post IPO debt,” and “product crowdfunding.”[78] To analyze cross-country investment flows, we assigned the country location of target companies and investors by identifying their headquarters. Where people investors were identified, we located their primary company affiliation and assigned their country of origin based on the affiliated company’s headquarters. Where the investor's country of origin was not available, we excluded the related investment transaction. The missing data that we dropped accounts for five percent of the total transactions we analyzed. We performed a systematic review by spot-checking 10 percent of the missing data of each country in our analysis. The data is missing at random and does not impact the representativeness of the data included in our analysis.

Finally, we filled in transaction value gaps with estimated value. Financial data providers like Crunchbase only provide information on the total value that companies in a funding round raised where such information is disclosed. We produced the estimated totals using a multistage estimation process where we assigned each round the median amount for funding rounds of the same investment stage, target country, and year.[79] In addition, Crunchbase does not disclose the contributions made by individual investors, given that investors are unlikely to reveal this information. It is difficult to accurately assess the exact amount of money investors provided a company during a funding round, and our analysis does not necessarily call for this information. In this paper, we’re interested in looking at the presence of investors from investor countries in target countries of interest. Therefore, we believe that the discussion of investment transactions and value in which investors participated is a reasonable first step to identifying cross-country investment flows.

Appendix 2: Additional Figures and Tables

This appendix presents additional charts and tables of relevance to this topic.

Table A: Top 10 Countries by Citations on AI-relevant Scholarly Papers, 2010–2020.

Country	No. of citations	Global share
United States	10,719,032	23%
China	7,461,295	16%
United Kingdom	2,812,308	6%
Germany	2,042,789	4%
Canada	1,964,411	4%
Australia	1,733,406	4%
France	1,524,691	3%
Italy	1,096,455	2%
India	1,030,719	2%
Japan	973,227	2%

Source: CSET merged corpus.

Table B: Top 10 Countries by AI Research Collaborations with China, 2010–2020.

Co-author country	No. of AI publications
United States	56,194
United Kingdom	15,631
Australia	12,169
Canada	10,427
Japan	7,850
Singapore	7,579
France	5,199
Germany	4,468
Italy	4,346
South Korea	3,991

Source: CSET merged corpus.

Table C: Global AI Research by Fields of Study, 2010–2020.

Fields	No. of AI publications	Global share
Pattern recognition	311,499	13.5%
Computer vision	193,704	8.4%
Algorithm	130,002	5.6%
Machine learning	124,356	5.3%
Natural language processing	80,708	3.5%
Data mining	79,022	3.4%
Control theory	71,076	3.1%
Human-computer interaction	64,680	2.8%
Linguistics	53,040	2.3%
Theoretical computer science	34,399	1.4%
Data science	29,637	1.2%
Simulation	20,478	0.8%

Note: This list displays all AI research subfields as displayed for the Quad countries in Table 2, only ranked based on global AI paper production. The first nine fields in the list are also the top nine AI research subfields globally by volume of production. Theoretical computer science and data science rank fourteenth and fifteenth, and simulation ranks nineteenth in the world.
Source: CSET merged corpus.

Table D: AI Investment Activity between the United States and Each of Its Three Quad Partners and AI Investment Activity between China-Japan, China-India, and China-Australia, 2010–2021.

Countries	Number of AI investment transactions	AI transaction value involving investor country (million USD)	Average deal size (million USD)	Countries	Number of AI investment transactions	AI transaction value involving investor country (million USD)	Average deal size (million USD)
🇯🇵 → 🇺🇸	331	$14,565	$44	🇯🇵 → 🇨🇳	15	$16,008	$1,067
🇺🇸 → 🇯🇵	91	$904	$10	🇨🇳 → 🇯🇵	8	$27	$3
🇮🇳 → 🇺🇸	250	$4,407	$18	🇮🇳 → 🇨🇳	8	$269	$34
🇺🇸 → 🇮🇳	316	$20,562	$65	🇨🇳 → 🇮🇳	33	$874	$26
🇦🇺 → 🇺🇸	162	$5,685	$35	🇦🇺 → 🇨🇳	16	$999	$62
🇺🇸 → 🇦🇺	59	$869	$15	🇨🇳 → 🇦🇺	10	$201	$20

Source: CSET analysis of Crunchbase.

Table E: Overview of Foreign Investment Screening Policies across the Quad Countries.

Country	Authority	Purview
United States	Committee on Foreign Investment in the United States (CFIUS)	"Authorized to review transactions involving foreign investment in the U.S. (and certain real estate transactions by foreign persons) to determine the effect of such transactions on U.S. national security."
Japan	Foreign Exchange and Foreign Trade Act (FOREX Act)	"Enable proper expansion of foreign transactions and the maintenance of peace and security in Japan . . . through the minimum necessary control or coordination of foreign transactions . . . to ensure the equilibrium of the international balance of trade and stability of currency as well as to contribute to the sound development of the Japanese economy."
Australia	Foreign Acquisitions and Takeovers Act of 1975 (FATA)	"Empowers the Treasurer to examine proposals by foreign persons to acquire, increase a substantial shareholding in, or acquire a controlling interest in the assets of an Australian corporation (or in Australian urban land) in instances deemed to be contrary to national interest."
India	Foreign Exchange Management Act (FEMA) of 1999	"Consolidates and amends the law relating to foreign exchange by requiring all Indian persons (including Indian companies) looking to receive (or already have) foreign investment to comply with entry route norms, sectoral caps, investment limits, and pricing guidelines, as applicable. For instance, includes government approval for all investments by an entity of a country sharing land border with India."

Source: Various.[80]

Endnotes

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[5] Although the four countries share a democratic system of governance and express respect for human and civil rights, observers have raised concerns about democratic backsliding, discrimination, inequality, and other societal, economic, and political challenges each country continues to face.

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[7] The White House Briefing Room, "Fact Sheet: Quad Leaders' Summit."

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[9] For instance, in 2018, the Indian government released the "National Strategy for Artificial Intelligence discussion paper #AIForAll," which identified priority sectors for nurturing the country's AI ecosystem. The Japanese government first formulated its AI Technology Strategy in March 2017 to focus on incorporating data and AI in related industries, expanding public use of AI across industries, and creating an ecosystem connecting various industries. In 2019, Japan announced a new AI strategy. The Australian government launched an AI Roadmap in 2019, setting aside $22.2 million over four years to strengthen the country's AI capabilities, and an "AI Action Plan" to build the AI-enabled economy and lead in developing and adopting trusted, secure, and responsible AI. The United States has incorporated AI in a broad range of high-level plans. With the passage of the National AI Initiative Act of 2020, which

provides a framework for coordination of AI R&D across the federal government, and the formation of the National AI Research Resource Taskforce, the U.S. government is increasingly promoting AI innovation and treating it as central to U.S. economic prosperity and national security.

[10] All four of the Quad countries are founding members of Global Partnership on Artificial Intelligence (GPAI), an international initiative founded in 2020 to guide the responsible development and use of AI in line with human rights values and economic growth. In 2020, Japan and India proposed a cybersecurity pact to promote cooperation in research and development in AI and 5G among others. Similarly, in 2021 Australia and India created the Australia-India Cyber and Critical Technology Partnership, a grant program that enhances cooperation between the two countries in critical and emerging technologies, such as AI, IoT, quantum computing, synthetic biology, blockchain, big data, and 5G/6G. See: Innovation, Science and Economic Development Canada, *Joint Statement from founding members of the Global Partnership on Artificial Intelligence* (Ottawa: Government of Canada, June 15, 2020), https://www.canada.ca/en/innovation-science-economic-development/news/2020/06/joint-statement-from-founding-members-of-the-global-partnership-on-artificial-intelligence.html; Rezaul H Laskar, "India, Japan finalise key cyber-security deal to boost cooperation on 5G, AI," *Hindustan Times*, October 7, 2020, https://www.hindustantimes.com/india-news/india-japan-finalise-key-cyber-security-deal-to-boost-cooperation-on-5g-ai/story-WCMa9En3NFPkQMWCIGNFJI.html; Ministry of External Affairs, *13th India-Japan Foreign Ministers' Strategic Dialogue* (New Delhi: Government of India, October 7, 2020), https://www.mea.gov.in/press-releases.htm?dtl/33100/13th_IndiaJapan_Foreign_Ministers_Strategic_Dialogue; Australian High Commission New Delhi, *Australian-India Cyber and Critical Technology Partnership: Grant Round 2* (Canberra: Australian Government), https://india.highcommission.gov.au/ndli/AICCTP.html.

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[22] The sum of AI research papers produced over the past decade by the 27 EU countries is 451,842, and for the 10 ASEAN countries is 94,942. The combined value reflects the number of papers with at least one author with an affiliation to an institution located in a country member of either the EU or ASEAN.

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