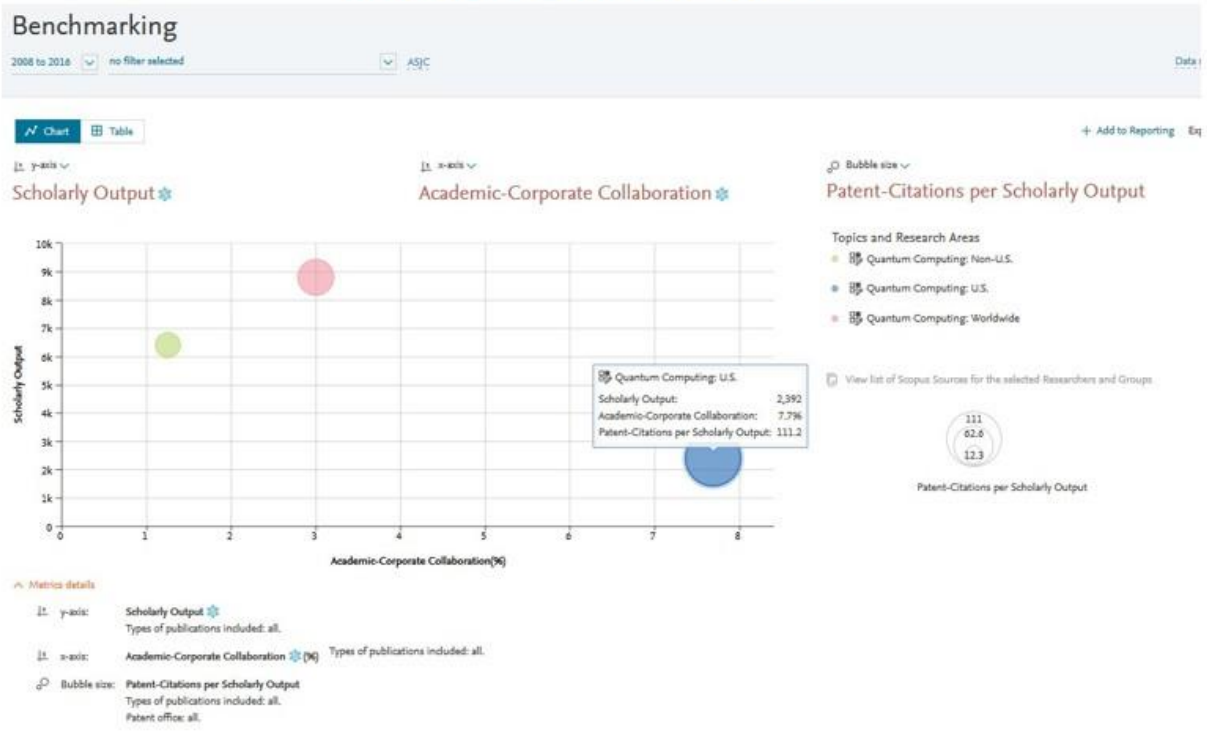
and major U.S. corporations than the level of academic-corporate collaboration found globally. Quantum computing is a competitive field, with high-impact research being done globally with significant financial resources being dedicated to researching the field.

The graph below shows total scholarly output from 2012-2017 in quantum computing, totaling about 10,000 papers (including conference proceedings) globally with around 2,700 papers from the U.S. The x-axis represents the percentage of university-industry collaboration: 7.7% for the U.S., only 1.2% for the rest of the world. The size of the bubble indicates how often these papers were cited in worldwide patenting activity—111 papers per thousand in the U.S., or over 11% of all papers and conference proceedings written, vs. 21 papers per thousand for the rest of the world—a ratio of over 5:1. When measured by overall field-weighted citation impacts, the U.S. also stands out from the rest of the world in quality terms, with around 30% of U.S. papers among the top 10% cited worldwide, versus 15% for non-U.S. papers (top 10% among all fields and all papers published).

Major U.S. corporations, including Google, Microsoft, IBM, and Intel, are deeply embedded in the research network for quantum computing technologies in a way that other global firms are not. Over ninety percent (90%) of all papers Google co-authors and over eighty percent (80%) of papers that IBM and Microsoft author have at least one academic co-author. These papers are often very highly cited. In addition, national laboratories and U.S. funding agencies are an important contributor to overall output.

Quantum Computing: Academic-Corporate Collaboration and Patent Citations per Scholarly Output, US vs. Non-US



Papers are credited to the headquarters location for each corporation in the model, regardless of the sponsoring R&D location. Actual academic co-authors for major U.S. firms are overwhelmingly U.S. institutions. The top fifteen collaborators for Google, for example, are all U.S. institutions. Only one non-U.S. university, ETH Zurich, is among the top twenty. Competing firms, including Google, IBM, and Microsoft, are frequent co-authors (among the top 20 collaborators for each company). In the geomap

below, the color intensity represents the level of academic-corporate collaboration, with the size of the bubble being the number of QC publications. The dark red dots represent U.S. tech companies. U.S. universities also have far higher levels of academic-corporate collaboration than the others. Europe and Asia are pale in comparison, but one or two Japanese firms also have a fairly high level of collaboration.

The analysis demonstrates that the U.S. quantum computing landscape differs in fundamental ways from the remainder of the world leading to strong and potentially positive implications for U.S. primacy in quantum computing and quantum technologies. The integrated combination of corporations, universities, national labs, and funding agencies in the U.S. may allow for the simultaneous pursuit of productive fundamental research of the highest quality, while working on solving practical problems in Pasteur's quadrant and bringing promising technologies to market.

Given the implications for cryptography and national security in quantum computing, and its potential importance to innovations of a wide variety, the U.S. government should evaluate being more deeply involved in support for quantum computing than is usual for new technologies, along the lines of the SEMATECH collaboration. The NSF, Department of Energy (DOE), and others may be able to function effectively as a broker between the fundamental and applied research being done in the academic community with the commercial needs and uses of the corporate community, perhaps using existing programs and vehicles to help different kinds of entities to connect.

As a significant contributor to federal R&D, the Department of Defense (DOD) is vitally important to funding support for certain aspects of these technologies. Any increased level of involvement by the DOD and other US funding agencies will need to be balanced with the need to preserve an open research environment internationally, share findings, accelerate quantum computing research, and transform research findings into new technologies, products, and services of benefit to all.