STUDY OF INNOVATION AND TECHNOLOGY IN CHINA

POLICY BRIEF

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Measuring the U.S.-China Innovation Gap: Initial Findings of the UCSD-Tsinghua Innovation Metrics Survey Project

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Benoît Godin, writing in 2002, commented that "the relative absence of innovation surveys in the United States [...] is probably a consequence of [its] uncontested superiority in innovation."[1] The superiority of the United States in innovation, however, is no longer unchallenged. Today it competes closely with foreign economies for innovation dominance in a range of products and services. The United States still maintains a global lead in many technologies, but its ability to stay at top appears fragile as other countries catch up in innovation capacity. This is increasingly the case in the U.S.-China innovation relationship.

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In this research brief, we report a new methodology to measure innovation between industries in the United States and China. Using an expert opinion survey targeted to specific high-tech industries, we seek to answer two questions: 1) What is the gap in innovation between the United States and China? 2) At what rate is Chinese innovation catching up to the United States? Results from the first industry survey in integrated circuit (IC) design are presented.

THE NEED FOR A NEW METRIC

The need to improve innovation measurement receives wide acknowledgement in what has been described as "the most important practical inquiry of our times."[2] Most of the dialogue comparing cross-country innovation, however, continues to rely on traditional metrics. In comparing U.S.-China innovation capacities, the most commonly cited figures are research and development (R&D) expenditures, patent output, numbers of science, technology, engineering and mathematics (STEM) graduates, and journal citations. As inputs or intermediate outputs into the innovation process, these metrics highlight potential innovation but fail to capture actual innovation performance.[3]

Actual innovation involves translating inputs into outputs and requires viewing innovation inputs in the context of their innovation environment. This journey to commercialization was first characterized in the 1967 Charpie Report as "a hazardous venture, replete with obstacles and substantial risks."[4] These obstacles and risks differ between industries and across countries. In our survey, we aim to illuminate these differences and to construct an eventual time series of data to explore the changing nature in innovation between the United States and China through comparative innovation levels, the relevant innovation environment, and developments over time.[5]

METHODOLOGY

Survey design of the U.S.-China Innovation Survey of Expert Opinion centers around three components:

1. Industry-specific
2. Leading-edge firms
3. Expert-based

Selecting Appropriate Industries

Innovation performance varies across industries. To account for this, we measure innovation at the country-industry level, using a separate survey for each industry to obtain disaggregated results.

Innovation differences also exist within industries, requiring that selected industries be narrow enough to avoid over-aggregating innovation measurement but general enough to have policy relevance. For example, in the semiconductor industry, innovation performance differs between IC design, manufacturing, and test and packaging subsectors. Within IC design, however, differences also exist (i.e., automotive, consumer electronics, wireless) but narrowing further would limit policy application. We therefore use IC design as one survey target.

Providing a Common Reference Point Through Leading-edge Firms

Firms within a specific industry experience varying levels of innovation based on many factors, including their specific value network and domain.[6] Often these subgroups are difficult to identify. To allow for easy interpretation, we ask questions in context of "leading-edge" firms. Targeting the survey to leading-edge firms also gives the benefit of capturing "crest of the wave" innovation to understand at what point the forefront of Chinese innovation will reach U.S. levels.

Constructing a Sample of Experts

We adopt the broad definition of an expert as an individual "in a more or less favorable position to know the facts."[7] In practice, this includes senior executives, scientists, engineers, and academics working in the target industry.

An expert opinion survey has multiple advantages. First, experts incorporate their personal knowledge and experience when responding to survey questions, thus providing more information than would be obtained from a direct measure of innovation outputs. Second, views of innovation may differ between experts within a firm. Traditional innovation surveys use the firm as the unit of analysis, but using a sample of experts allows for wider survey coverage, including experts working outside of firms in academic and government institutions.

No complete listing of an industry's expert population exists. To assemble our survey sample, we compiled a list of organizations—including firms, universities, and institutes—that work or research in the target industry. Individual experts were then identified, primarily by their job title.[8] As a check on respondents' eligibility, respondents self-rate their level of industry expertise on a five-point scale prior to taking the survey. Respondents who self-identify as "unfamiliar" or "casually acquainted" are not included in survey results.

Innovation Definition

We adopt the OECD definition of innovation: "Innovation is the implementation of a new or significantly improved product (good or service), process, new marketing method, or a new organizational method." Innovation does not have to be occurring at the global frontier to count as innovation, as long as it signifies an improvement to the firm, national market, regional market, or global market.[9]

Measurement at Country-Industry Level

Expert groups from the United States and China likely approach the term "innovation" from heterogeneous base points, making a comparison between the two groups difficult. To correct for this bias, respondents are asked in the survey to rate the level of innovative activity of two hypothetical IC design teams in addition to rating their own country. These answers are used to adjust the respondents' self-responses and ensure comparability across countries.[10]

RESULTS

Response Rate

The IC design survey was administered using a web-based survey from May to June 2013 and included four email reminders. Additionally, the China survey collected responses from IC design industry conferences in October 2013. The U.S. sample received 68 complete responses and the China sample received 83 responses, resulting in an approximate 4 percent response rate.[11] This low response rate was not unexpected, but there is serious concern that nonrespondents may differ from respondents on survey answers. To measure one aspect of the bias, we test differences between the composition of respondents' and nonrespondents' job titles. With the exception of CEOs, which were six percent less likely to respond than other job categories, these differences are minimal and not significantly different. Measures will be taken in future surveys to increase response rates.[12]

Demographics

Responses to demographic questions reveal interesting differences between the U.S. and China samples. For example, the U.S. sample, on average, has more years of experience in IC design than the China sample—21.8 years versus 10.9 years, respectively. This reflects the overall younger IC design industry in China, but also likely results from a lower proportion of self-rated "experts" in the China sample—59 percent in China compared to 91 percent in the United States.[13] Both samples are comprised mostly of individuals from the private sector, with the next largest representation coming from universities.

Among IC design end-user applications, the U.S. sample is widely diversified, with more than 60 percent of respondents working each in computing, consumer electronics, and telecommunications/wireless applications and over 20 percent of respondents each specializing in automotive, industrial, medical, and military applications. The China sample, by contrast, has over 58 percent and 42 percent of respondents working in consumer electronics and telecommunications/wireless, respectively, but no other end-user application receives more than 20 percent of respondents. U.S. respondents additionally are much more likely to work in multiple applications.

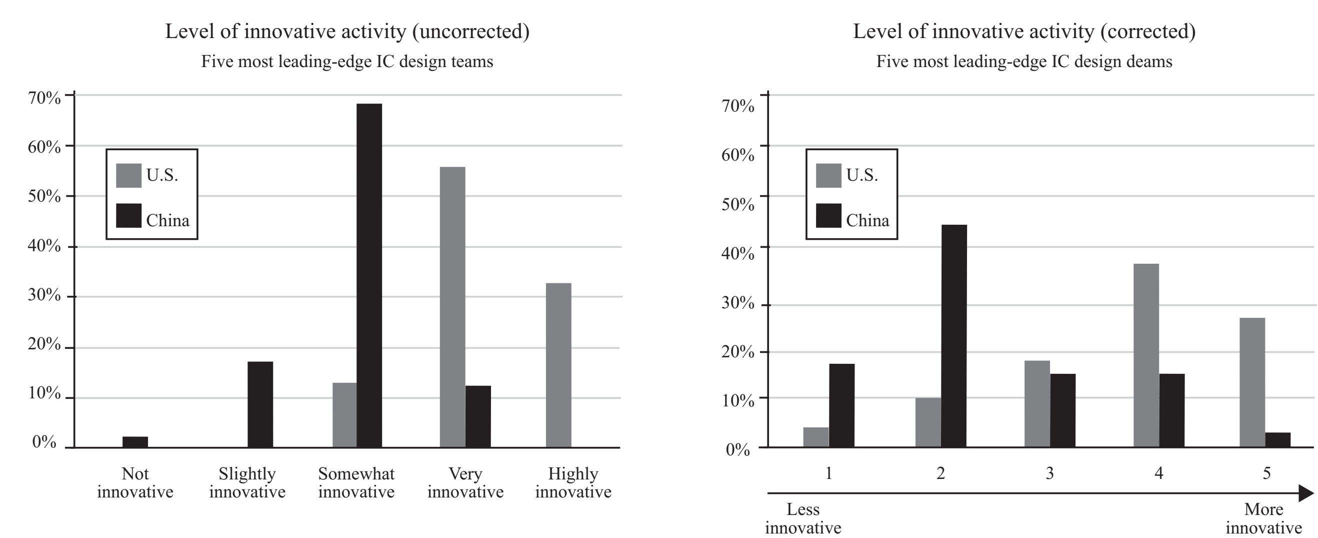
This same pattern presents itself in IC design categories, which includes design, mixed-signal, and analog. In the U.S. sample, 67 percent of respondents engage in more than one category, while only 19 percent of respondents in the China sample design in more than one category. The China sample is also less diverse, with only 14 percent using analog compared to 51 percent in the United States.[14]

Level of Innovative Activity

To take advantage of respondents' familiarity with their domestic industry, all results presented show respondents rating their own country, with Chinese respondents rating China and U.S. respondents rating the United States. Additionally, as explained above, all answers are in relation to leading-edge IC design teams, which are left undefined for respondents. On the level of innovative activity, respondents provide ratings on a five-point scale from "not innovative" to "highly innovative." (See Figure 1.)

In the U.S. sample, a combined 87 percent of respondents rate leading-edge IC design teams in the United States in the top two categories "highly innovative" or "very innovative." Chinese respondents consistently

Figure 1. Level of innovative activity in leading-edge IC design teams



rate Chinese IC design teams lower, with 85 percent rating them in the next two lower categories "slightly innovative" or "somewhat innovative." To correct for possible bias in how the two different samples approach the term "innovation," however, we correct these answers using responses to two questions in which respondents rate hypothetical IC design teams.

Upon correction, a wider gap emerges between the innovative level of U.S. and Chinese leading-edge IC design teams. Most notably, now 65 percent of Chinese respondents rate China in the bottom two levels of innovative activity. U.S. responses are also distributed more downward, showing that, comparatively, many respondents overstated the level of innovative activity in their country. Overall, the corrected responses reveal a larger gap between the United States and China than originally stated by the industry experts.

Innovation Gap

To quantify this "innovation gap," respondents are asked the time needed for leading-edge IC design teams in their country to catch up to the global technological frontier. The global technological frontier is defined as "the most advanced technology being used globally by IC design teams." This is measured in two ways—as the number of months required for leading-edge IC design teams to reach the current global technological frontier and as the number of months required to reach the advancing global technological frontier.

Among U.S. respondents, 95 percent indicated the United States is currently at the global technological frontier, while 98 percent of Chinese respondents ranked China as behind the frontier. According to Chinese respondents, an average of 40 months is needed for Chinese leading-edge IC design teams to catch up to the current frontier.[15] To catch up to the advancing frontier, an average of 55 months is required. This is illustrated in Figure 2, with the size of the bubbles representing the percent of respondents providing a certain answer.

These results show a larger gap than was commonly believed exists between China and the current frontier. General consensus usually puts China as two years behind the United States in semiconductor technology.[16] Taking the average of responses, we find that the expert consensus is closer to four years. This is a conservative estimate, since it does not include the 21 percent of Chinese respondents that state that China will never catch up to the global technological frontier.

Innovation Environment

While our survey does not encompass all elements of the innovation environment, we target many factors known to influence high-tech development. Our survey shows that within leading-edge IC design teams in the United States, the largest obstacles to innovation are lack of finance from venture capital, shortage of qualified talent, and foreign competition. In China, the largest obstacles include lack of high-quality intellectual property, weak intellectual property protection, shortage of qualified talent.[17] As seen in Figure 3, the impact magnitude of the obstacles on Chinese innovation is viewed as considerably larger than that on the United States.

Based on these responses, both countries would benefit from an increase in qualified IC design talent pools. This is reinforced by answers to a later question, where 74 percent state that international talent is difficult to hire, while only 4 percent state that it is easy to hire. U.S. respondents give similar answers for both domestic and international talent acquisition, with the average showing that talent is neither easy nor difficult to hire.

In respondents' answers to the impact of government on innovation in leading-edge IC design teams, two

Figure 2. Innovation gap in leading-edge IC design teams in China

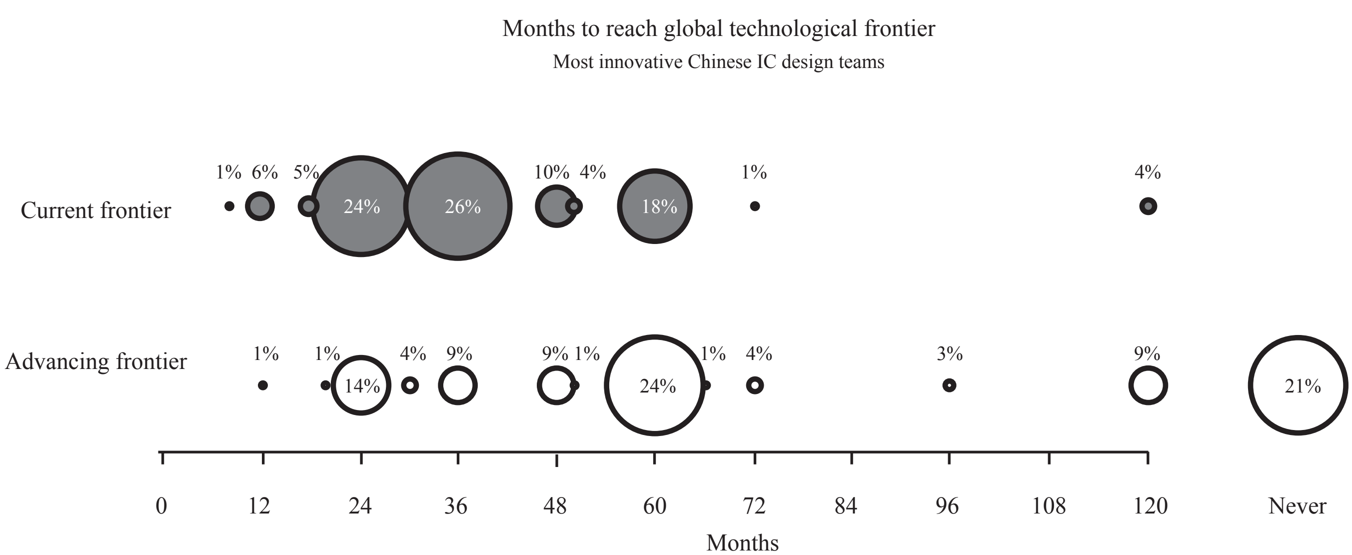


Figure 3. Obstacles to innovation in leading-edge IC design teams

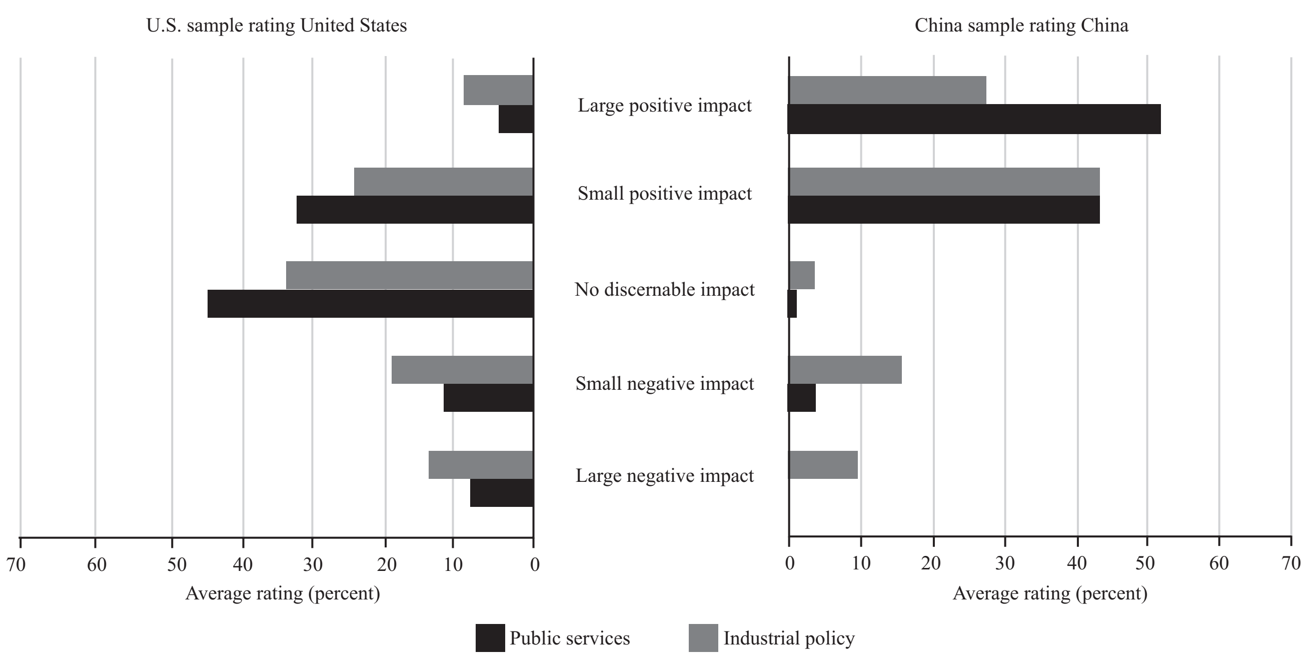
interesting patterns emerge. First, the views of respondents from the United States are fairly evenly dispersed for both public services and industrial policy.[18] Among Chinese respondents, however, the 95 percent felt that the impact of industrial policy on innovation in leading-edge IC design teams is positive, with 52 percent stating it is highly positive (Figure 4).

CONCLUSION AND STEPS FORWARD

In our survey, we uncover a fair consensus that China is four to five years behind the United States in leading-edge IC design. There is a substantial view, however, that China will never catch up to the global technological frontier. According to Chinese respondents, the largest obstacle preventing innovation in IC design in China is intellectual property protection—indicating a needed shift in resources. Moreover, the rate at which China is catching up to the United States in IC design is expected to be rapid.

Current plans are to complete three to four surveys each year for different industries, with the next two

Figure 4. Government impact on innovation in leading-edge IC design teams



target industries being biopharmaceuticals and electric vehicles. In doing so, it is crucial to ensure comparability of responses not only within each industry but also across industries. Survey response rates require careful attention, and future surveys will increase efforts to elicit responses through mailed pre-invitations and follow-up phone reminders and interviews in addition to the current web administration. In-depth follow-up interviews will also provide additional insight into survey responses and dynamics within each industry's innovation environment.

In total, the U.S.-China Innovation Survey of Expert Opinion makes a contribution to innovation measurement and to understanding the relationship among innovation capacities in the United States and China. The use of industry-specific and expert-based surveys allow insights into innovation difficult to gain through general firm population innovation surveys or through conventional metrics reported by firms or governments.

Our survey should not be taken as a stand-alone measure, however. In targeting only the leading edge of industry, survey results stay silent on the remaining industry, which may exhibit different paces of growth and encounter different influences from the innovation environment. Disruptive or unexpected innovations that may occur in the future are also unlikely to be included in experts' views. We try our best to account for all influences possible, but in the end there will be unforeseeable events that impact innovation.

Endnotes

1. Benoît Godin, "The Rise of Innovation Surveys: Measuring a Fuzzy Concept," Project on the History and Sociology of STI Statistics, Working Paper No. 16, 2002. Beginning in 2008, the National Science Foundation's annual Business R&D and Innovation Survey, designed according to the OECD's Oslo Manual framework, leads the way in measuring national end-product innovation in the United States.
2. The Advisory Committee on Measuring Innovation in the Twenty-First Century Economy, "Innovation Measurement: Tracking the State of Innovation in the American Economy," 2008, xi.
3. This issue was highlighted as early as 1967 in the "Charpie Report" delivered to the U.S. Department of Commerce, which criticizes the sole availability of R&D as statistical evidence on the innovative process, acknowledging that "they are not reliable indications of *innovative* performance." Because of this, the panel emphasizes their inability to provide solid recommendations. "We wish to make clear that our analysis could not be based upon empirical data on the innovative process. Rather, we have had to rely on personal experience and knowledge and, where appropriate, data concerning R&D." (see U.S. Department of Commerce, *Technological Innovation: Its Environment and Management* (Washington, DC: Government Printing Office, 1967), 8).
4. U.S. Department of Commerce, *Technological Innovation*, 8.
5. It should be noted that one metric will never be sufficient to explain all innovation. The 2008 report *Innovation Measurement: Tracking the State of Innovation in the American Economy* states that "the very nature of innovation suggests that it will never yield to a tidy and static measure" (xi). Others have compared innovation metrics to baseball statistics—"unlikely that one single statistic tells the whole story" (Litan et al., "Improving Measures of Science, Technology, and Innovation: Interim Report," 12)—and to the search for the Holy Grail—"what you should look for are multiple metrics with offsetting weaknesses" (National Science Foundation, "Advancing Measures of Innovation: Knowledge Flows, Business Metrics, and Measurement Strategies," 2006).
6. Clayton Christensen, *The Innovator's Dilemma* (Boston: Harvard Business School, 1997), 49.
7. Charles F. Turner and Elizabeth Martin, eds., *Surveying Subjective Phenomena: Volume 1* (New York: Russell Sage Foundation, 1984), 9. In more concrete terms, an expert for our surveys is an individual who is familiar with the innovation environment of their industry, knowledgeable of their country's domestic industry and of their country's technology advancement in relation to the global frontier, and able to identify leading-edge teams in their industry and informed on the advancements being made within these firms/teams.
8. The IC design organization list was created from organizations participating in industry conferences and with memberships in industry associations. This was supplemented by online searches for IC design organizations. Individuals from within these organizations were identified through company websites and use of online contact databases Lead411 and the Leadership Library.
9. The full definition was adopted upon recommendation of Stephanie Shipp and other participant feedback at IGCC's "Dialogue on Comparing U.S.-China STI Policy Decision-making Processes," UC San Diego, August 1–2, 2013. The IC design survey uses an abbreviated definition of technological innovation that includes only products and processes. Subsequent surveys will use the full OECD definition.
10. The methodology used to construct these scenarios and perform correction is known as anchoring vignettes. See Gary King, Christopher J. L. Murray, Joshua A. Salomon, and Ajay Tandon, "Enhancing the Validity and Cross-Cultural Comparability of Measurement in Survey Research," *American Political Science Review* 98 (2004): 191–207.
11. In the United States, of the initial 1,475 emails sent, more than 500 bounced back, some received "out of office" replies, and a few received "moved company" automatic replies. Of the 966 remaining emails, 96 individuals opened the survey link and 68 completed the survey. Using AAPOR response rate calculations,

$$\text{RRI} = \frac{I}{(I+P)+(R+NC+O)+(UH+UO)}$$

our most conservative estimate of the U.S. response rate is 4.6 percent. Of the 596 emails sent in China, 59 bounced back, 83 opened the survey link and 23 completed the survey, giving a response rate of about 3.9 percent.

12. Measures being considered include sending a paper pre-invitation letter to respondents and expanding the survey mode to include phone interviews/reminders. The large size of the sample makes it difficult to develop personal contacts with each respondent, but follow-up interviews with a subset of respondents are being planned to better understand answers provided in the survey.
13. We define self-rated experts as individuals who marked “expert” or “knowledgeable” when rating their knowledge of their country’s domestic IC design industry.
14. This is consistent with a recent analysis that identified only two significant foreign-owned analog design teams in China (one multinational corporation and one hybrid corporation). This lack of analog multinational presence in China is sure to influence wholly-owned Chinese design teams as well. An additional contributing factor to the low number of analog design participants in China could be due to analog design teams tending to be much smaller than digital design teams (see Douglas B. Fuller, “Chip Design in China and India: Multinationals, Industry Structure, and Development Outcomes in the Integrated Circuit Industry,” *Technological Forecasting and Social Change*, forthcoming (2013): 8).
15. This question contained one excluded outlier of 240 months. With the outlier included, the mean number of months for leading-edge Chinese IC design teams to catch up to the current GTF is 57.4 months (st. dev. = 42.1).
16. This is based on assumptions that China is on average about one generation behind the United States in semiconductor technology, which equates to about two years. This partly results from the 1994 Wassenaar Arrangement that aimed to deny China access to leading-edge semiconductor manufacturing technology.
17. Respondents rated each obstacle on a four-point scale ranging from “not a problem” to “large impact.” The weighting calculation for Figure 3 is (*small impact* × 1) + (*medium impact* × 2) + (*large impact* × 3)/total responses.
18. Public services include, among others, tax and business administration, customs services, immigration processing, and public infrastructure.