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TESTIMONY
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HEARING ON BUILDING A RESILIENT ECONOMY: SHORING UP SUPPLY
SENATE COMMITTEE ON BANKING, HOUSING, AND URBAN AFFAIRS
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Thank you Chairman Brown, Ranking Member Toomey, and Members of the Committee for the opportunity to talk with you today about the strategic capabilities our country needs to build a resilient economy. I am a Professor in the Department of Engineering and Public Policy in the College of Engineering at Carnegie Mellon University, and a Research Associate with the National Bureau of Economic Research. My research focuses on the development, commercialization and global manufacturing of emerging technology, and national policy in that context. My "research laboratory" is often the factory floor of manufacturing firms across the U.S. and around the world.

From World War II to the present day, U.S. national security and economic prosperity in an increasingly global economy has rested, to a significant extent, on American leadership in technology, and through that technology, production. The Allied victory in World War II (1939-1945) was attributed to American (and Soviet) ability to turn out military aircraft, tanks, and other weapons systems in unprecedented quantities thanks to the technology advancements behind the American System of Mass Production (Hounshell 1985). In the 1990 Defense Authorization Act (PL 101–189), Congress defined "critical technologies" as "essential for the United States to develop to further the long-term national security or economic prosperity of the United States." The COVID-19 pandemic highlighted the criticality of technological leadership -- such as in mRNA and proline stabilization techniques for vaccines (the latter which have helped U.S. vaccines have better immunogenic responses to COVID as the virus mutates) -- not only for security and prosperity, but also for social well-being, in particular, human health . Perhaps most significantly, the COVID-19 pandemic underscored that *access* to certain final products and their intermediate inputs can likewise be critical to national security, economic prosperity (including jobs), and social well-being. For example, early on in the pandemic, limited access to latex-free elastic for mask ear loops held certain companies up from manufacturing masks entirely. In one company's case, they finally identified a supply of elastic, but it was only available on a spool that didn't work with the automated mask manufacturing equipment. With the textile industry having moved manufacturing overseas decades earlier, the company was unable to identify an automated de-spooler, and so was stuck for a period of time having to have a worker hand-unspooling elastic, with the expected productivity slow-down (Fuchs Testimony 2020).

When discussing critical technologies, we wouldn't ordinarily think of elastic; yet during those early months of the most intense supply shortages (roughly January through May 2020) were hospital workers were left with garbage bags and home-sewn cloth masks, that lack of elastic cost our country millions of masks *a week* (alone out of just one company -- with the total losses surely much more).

A similar story could be told in how the current shortage in semiconductors for applications requiring high robustness and safety is stopping cars from being produced and leading to job losses in Michigan. The solution to these problems are not as simple as just stockpiling masks or reshoring manufacturing of elastic or semiconductors. It can be challenging to stockpile for an uncertain future (we don't know the most effective protection for the next pandemic) and concentrated or single-source manufacturing can also reduce the resiliency of supply (electric grid power-outages in Texas caused semiconductor plants clustered around Austin to go down, helping contribute to the current shortages). As such, stockpiling and reshoring are just two (important) tools in a broader suite of tools we need in our arsenal: Other tools include leveraging and enhancing firms' and the economy's capability to pivot, building design platforms that reduce dependency on single-source suppliers, and innovating to change the rules of the game and the supply chain dependencies themselves.

For example, in the case of the mask producer facing global shortages in elastic, the lesson of the story is *not* that the U.S. needs to reshore or stockpile elastic. What's needed is for that firm and the U.S. economy to have the capability to rapidly pivot -- diversify the suppliers internationally, adapt the equipment, change the elastic, create a mask that does not require elastic, adapt regulations… or some combination of these actions. To build an economy capable of rapidly pivoting during crises, we need timely situational awareness, a robust manufacturing ecosystem, tools in place that value common cross-mission interests between social well-being (here health) and defense, and a government pre-prepared for adaptive response during crises.

In the case of shortages of safe, robust semiconductor chips for a range of defense, transportation (including automotive and aerospace), medical, and power electronic applications, cross-sector data sharing in public-private partnerships and funding of common design platforms will be essential. Innovations in hardware and software can facilitate common design platforms across these sectors, and thereby enhance their market power and their ability to switch production to alternative manufacturing facilities during supply chain crises. Identifying the right path will require sophisticated understanding of the technical implications of defense and commercial interests, as well as understanding and valuing the systemic implications of semiconductor shortages across the economy for businesses (including start-ups pushing the technical and possibility frontier), economic prosperity, and jobs.

The stakes for creating effective policy in critical technologies, supply chains, and infrastructure could not be higher or more challenging. As illustrated above, critical technologies, supply chains, and infrastructure are deeply interdependent, such that capabilities (and policy) in one affects the other. In addition, their impact cuts across all national missions: national security, economic prosperity (including jobs), and societal well-being (including health, equity, and the environment). When there were medical supply shortages, small hospitals, rural doctors, essential workers, minorities, and those in the lowest income classes were hardest hit. Energy outages and environmental damage to infrastructure have significant costs for national security and private companies (for example the February 17, 2021 electric grid power outages in Texas which led major semiconductor plants clustered around Austin both to have to shut down and throw out months of ruined products), and at the same time often disproportionately affect minorities and those in lower income brackets. The current semiconductor shortage is not only a threat to national security, but also to jobs and economic prosperity, for example in Michigan where fewer cars are being produced and layoffs are happening as a result.

Key to the U.S. overcoming these challenges will be finding a way to quantify the value of investments across multiple missions, and to identify solutions that offer win-wins where the sum is greater than the individual parts. Fortunately, while not simple, with today's modern data and analytic tools, charting a path to a resilient economy and supply that affords win-wins across missions and sectors is attainable. Building this capability, however, is going to require Congress creating a new institution capable of being strategic and forward-looking, receiving work from all agencies including multiple agencies on a single topic, and leveraging leading technical expertise in engineering and the physical sciences, matched with leading expertise in modern analytics (machine learning, operations research, natural language processing) and the social sciences (economics, political science, sociology, history).

In my remarks today I want to highlight three critical steps toward building a resilient economy, and the nature of the cross-mission critical technology analytics capability our country needs to successfully implement these steps:

<u>First</u>, the U.S. must build timely situational awareness, otherwise we are flying blind.

Inadequate data and analytic capability is weakening government decision-making regarding critical technologies and critical supply chains. U.S. Defense agencies and policymakers lack mechanisms to assess their strategic weaknesses and opportunities versus other nations in technologies critical to national security. The U.S. government also lacks timely, easy-to-navigate, product-level data on the long chain of intermediate suppliers supporting the production of final goods. Without knowing the U.S.'s global standing in technology and production, it is difficult to make policy -- whether the importance of secrecy about technological capabilities or where to enhance domestic manufacturing capabilities and where to create alliances.

These challenges were underscored by COVID-19: While existing surveys such as the Annual Survey of Manufactures and the Economic Census provide snapshots of U.S. capabilities, these data do not capture the rapidly evolving supply status during a crisis such as the COVID-19 pandemic. (The US Census collects data on all domestic businesses once every five years. At the time of the pandemic outbreak, the last data collected on all domestic manufacturers was 2017). Real-time information is essential to guide decisions to coordinate and mobilize additional capacity during crises, whether a pandemic, other natural disasters, or war. Fortunately, timely situational awareness is attainable: Leveraging automated text analysis of public data, we were able to gain real-time situational awareness of U.S. domestic manufacturers entering, pivoting into, and scaling up in response to the COVID-19 crisis, particularly small and medium sized businesses. Within two weeks we revealed significantly greater domestic mask and respirator manufacturing capacity than was known by the government at that time. (Fuchs, Karplus, Kalathil, Morgan 2020)

Importantly, data collection of any form is costly, whether by government, public-private partnership, or automated algorithm. For this reason, it makes sense to focus on supply chains of products that are sufficiently critical to national missions -- whether national security, economic security, or human health -- for the benefits (such as lives saved) of the full supply chain being tracked to outweigh the costs. Similarly, not all products or sectors or situations warrant data collection at the same frequency. For example, early on during the pandemic the number of mask and respirator manufacturers was changing by the week; in contrast, while manufacturing capabilities can change from year to year, it takes five years to build a semiconductor fabrication facility. Further, with modern data analytics, publicly scrapable data is increasingly valuable, but in many cases, and particularly during crises, the ability to rapidly spin-up public-private partnerships around data may also be needed. For example, during COVID-19 it became essential to understand personal protective equipment and COVID-19 testing supply chains in great depth, but it may not be necessary to collect detailed or the same data on these supply chains all the time. Similarly, in the current semiconductor shortage for safe, robust chips on mature process nodes, a public-private partnership may be able to focus on data-sharing to identify design commonalities and design paths toward less heterogeneous or production-line-specific chips, and that same data may have less value once new design platforms are in place.

Going forward, data collection and public private partnership infrastructure should be built proactively, rather than reactively.[1] To figure out which products and supply

[1] Given the cost-benefit trade-offs in data collection, in our white paper, "A New Approach to Coordinate U.S. Critical Supply Chains in Crisis," (2021) Professor Valerie Karplus and I recommend taking a strategic (and analytic) approach to data collection: The U.S. government should only regularly track and model domestic and international supply chains of *select* products critical to national missions. For these select products, the Department of Commerce should create a "critical product" tracker at the U.S. Census that would revitalize and revamp the U.S. Census's capability to update with greater depth and frequency its relevant business establishments and production capacity data in select critical end products. Aspects of such industry studies at the Economic Census were historically paid for by the Defense Logistics Agency, but discontinued a few years back. This mutual interest by the Department of Defense and Department of Commerce may also serve as an early indicator of strategic win-wins. Given that such tracking is costly, the Department of Commerce should through a national critical technology analytics program conduct cost-benefit analysis to quantify the value of tracking different products and their intermediate inputs and with what frequency. Such analyses should be conducted by a cross-mission critical technology analytics program in conjunction with relevant agencies (e.g. FEMA, HHS, CDC) and include the value (in terms of lives saved and improved) of various products during crises (starting with the current,

chains have sufficient national value to be tracked will require cross-mission valuation that aggregates across defense, health, labor, equity, and commercial interests. Such cross-mission critical technology and supply chain analytics must leverage technical expertise relevant to these sectors alongside the latest data and analytic tools. As part of such an effort, the U.S. government should accelerate its investment and research in automated tools that dynamically advance our capabilities to have real-time situational awareness of global technology, human capital, and production capabilities and the U.S.'s standing therein. The technical frontier in these capabilities are being advanced in the U.S. by large companies, start-ups, and academics; but do not yet exist throughout government. A critical technology analytics program will need to address what timely situational awareness is needed in different sectors, what strategic information is in the public domain (and therefore harvest-able by automated algorithms), and how the relevance of information in the public domain may vary by sector. A critical technology analytics program will also need to address the relative strengths and weaknesses of automated algorithms versus public private partnerships sharing government and industry-confidential data, versus groups of individual experts at assessing the U.S. global standing in technologies and supply chains. Finally, a critical technology analytics program should also reflect on how -- given its high relevance across missions, but the distinctly different goals of those missions -- to advance the algorithmic capabilities to build timely situational awareness as a strategic capability in the U.S. As goes without saying, as these capabilities become more advanced, they should actively be integrated into agencies and departments across government.

Second, the U.S. must create the supply chains of tomorrow, not fix the supply chains of yesterday.

Timely situational awareness of the U.S. position globally in critical technologies and supply chains is necessary, but by itself insufficient. The U.S. must focus on and invest in innovation to transform supply chains and our competitive position therein.

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past, and various future scenarios of pandemic), the value of data on final products and one or more of their intermediate inputs (not all may have high value in being tracked), and the value of how frequently the data is collected (which will vary widely by sector). Finally, the Department of Commerce should develop mechanisms for the U.S. Census to share business data with action-oriented arms of government during crises. (Fuchs and Karplus 2021)

In parallel to these standing data collection activities, the U.S. government should create the public-private infrastructure necessary to spin-up during crises near-real-time situational awareness, assessment of potential capacity domestically and internationally, and response. To do so, the U.S. government should invest in an integrated, secure, near-real-time data architecture for supply chains considered "critical" and into which multiple government and industry data sources would feed; and maintain the necessary connections to mobilize nonpartisan domestic stakeholder teams by product with technical competency and visibility into evolving production conditions. These public-private teams would commit now to being tasked during a future crisis with providing data and options to federal and state decision makers, developing appropriate and situationally-relevant metrics for progress, and working to achieve an equitable nationwide response. (Fuchs and Karplus 2021)

Energy storage solutions, particularly lithium-ion batteries for electrified transportation, are growing geometrically in terms of market size and material needs. And yet, the global supply chain for lithium ion batteries is constrained in several ways that could be catastrophically disruptive as demand rises. In this context, novel battery materials that represent very little (or no) supply chain risk in terms of cost, transport, working conditions, and/or geopolitical strife; and novel methods for producing materials that are both free of cobalt as well as able to be produced using materials that can be sourced from within the US (Burke and Whitacre 2020; Sovacool et al 2020) could be transformative in terms of security and geopolitical dependencies. Likewise, synthetic processes for these materials that can be scaled with low cost and using well understood and common production methods could be revolutionary in terms of circumventing risky supply chain situations in favor of locally sourced materials, recycled materials, and cost-optimizing processes (Ciez and Whitacre 2019).

Similarly, national leadership in next-generation (e.g. beyond-CMOS) computing device design and processing capabilities as well as the innovations such devices will require across the stack is destined to determine national leadership in computing, AI, and beyond (Khan, Hounshell, and Fuchs 2018), and create entirely new industries and innovation ecosystems. This revolution in the devices that drive computing capabilities will draw on entirely new supply chains.

Both of these hardware innovations hold potential for new entrepreneurial opportunities and fundamentally change the existing industry, today's supply chain dependencies, and the U.S. 's standing therein. Excitingly, our research also suggests that these innovations in advanced materials and processes are likely to also likely to have more and more rewarding jobs for U.S. based high-school educated operators and technicians (Combemale and Fuchs 2020; Combemale, Ales, Whitefoot, Fuchs 2021; Cotterman, Fuchs, Small and Whitefoot 2022).

While innovation is often a middle or long-run game, hardware and software innovations that transform supply chain dependencies can also be short-term solutions. Take, for example, the current shortage in semiconductor chips for industrial applications requiring higher safety and robustness but lower performance. In the semiconductor industry, given the high capital costs and long lead times in building new fabrication facilities, it can be easier to redesign chips for existing production facilities than the other way around. The DoD has a long history of redesigning chips from legacy systems to be produced on available fabrication facilities. Analogously, many companies facing shortages are currently redesigning some of their chips to circumvent supply constraints.

Going forward there is an even greater opportunity to leverage innovation and chip redesign to address semiconductor shortages in applications requiring high safety and robustness but lower performance. Production in the global semiconductor industry has in recent years increasingly been concentrated in a small set of geographic locations and suppliers. Further reducing supply resiliency, semiconductor chips have been increasingly customized for unique production lines and facilities, creating high switching costs, and temporary monopoly power for suppliers during shortages. Industrial applications like aerospace, automobiles, medical devices, power electronics, and defense systems have different needs (e.g. robust to vibrations and heat but lower performance), and are small percentages (less than 25%) of the total semiconductor market. Application needs within this 25% are highly heterogeneous, and the robust but lower performance chips are produced by semiconductor suppliers with lower profit margins. As a consequence, these companies and sectors have low market power, which becomes particularly relevant during shortages.

While not using the most advanced chips can limit options (older nodes also have lower profit margins), it can also be an opportunity. Government funding of common design platforms and design rules hold promise to increase both the aggregate market power as well as the supply chain resilience of these sectors critical to national security, economic prosperity, and domestic jobs. Common design platforms hold promise to increase the resiliency of supply chains by moving designs away from being tailored to specific production facilities, and making them more "fab-agnostic," thus reducing the cost of switching the manufacturing facility manufacturing the chip during global shortages. The Department of Defense has similar needs to commercial sectors like aerospace and automobiles in terms of prioritizing safety and reliability over high performance, and similar to what is needed by aerospace and automobiles, Department of Defense trusted fabrication facilities likewise do not operate at the most advanced semiconductor nodes. As such, the Departments of Commerce, Defense, and Energy have common interests in funding the development of common design platforms in both hardware (such as was done historically in RISC-5) and software (such as was done historically in the S-MOSIS program) that enhance commonality where sectors have common interests, and still leave room for differentiation where interests differ. (Blanton et al 2021)

As these examples show, it is essential that a cross-mission critical technology analytics program leverage experts at the technical frontier to ensure that the U.S. is incentivizing innovation to change the playing field, and incentivizing design platforms where there are win-win gains across national missions of defense and economic prosperity.

<u>Third,</u> to have a supply base resilient to demand shocks and to reap the benefits of innovation domestically, the U.S. must invest in a vibrant manufacturing base.

To make sure that the domestic economy can rapidly pivot into manufacturing products experiencing global shortages during crises, the U.S. must have a vibrant domestic manufacturing ecosystem. Already before the current pandemic, my and other scholars' research showed that countries like China are more competitive than the U.S. in adaptively producing a wide diversity of products at low to medium volumes (Treado and Fuchs 2015), at refining production systems for new products (Fuchs and Kirchain 2010; Nahm and Steinfeld 2014), and at scaling up that production (Fuchs and Kirchain 2010, Nahm and Seinfeld 2014). The COVID-19 pandemic underscored the dilapidation of our domestic manufacturing ecosystem and the loss of human capital needed for that ecosystem to be highly adaptive, flexible, and resilient. In the context of mask and respirator (N95) production during the early days of COVID-19, small and medium sized companies struggled with access to capital, access to information on how to make medical-grade masks, access to machines which were predominantly manufactured in China, shipping delays for those same machines and the components required for their repair, high qualification and certification costs, and challenges breaking into mainstream hospital distributor markets. (Kalathil, Morgan, Fuchs 2022)

That said, while U.S. companies, particularly small and medium sized ones struggled to pivot into and ramp-up domestic production of masks, in my research with Nikhil Kalathil and Granger Morgan on companies that pivoted, I have been struck by how much what was left of our domestic manufacturing ecosystem was central to U.S. companies being able to pivot in the cases where they successfully did so. One large American manufacturer was able to leverage its intellectual property and aerospace sourcing and production expertise to establish and ramp-up domestic manufacturing of masks within just a few weeks. General Motors was similarly able to leverage its automotive sourcing and production expertise to rapidly ramp-up domestic manufacturing of masks and ventilators. In Indiana, America Meltblown and Filtration was able, with support from the Indiana government, to leverage its expertise in filtration materials and oil absorbent products to pivot first into making meltblown polymer for masks and later to create a subsidiary for also making N95 masks themselves. Another company leveraged their company founder's technical macgyver skills to pivot from past experience in waste management and construction into domestic mask manufacturing. (Kalathil, Morgan, Fuchs 2022.) These observations during COVID have strengthened my belief in the importance of domestic core competencies in critical technologies and a strong domestic manufacturing ecosystem to having a resilient supply base during crises. Some pivoting companies' previous experience in waste management, construction, and water or oil infrastructure products has also strengthened my belief that the greatest promise for rebuilding our manufacturing ecosystems may be equitable country-wide investments in building the infrastructure of the future.

Resiliency to crises and the capability to pivot are not the only reason to have a vibrant domestic manufacturing base. A vibrant manufacturing ecosystem is also important to keeping leadership in innovation domestically and creating well-paying U.S. jobs for hardworking high school graduates. To make sure the best science and technology advancements and the high-end operator and technician jobs that go with them happen domestically, in parallel to investing in science we need to rebuild our domestic physical and human capital across a broader swath of our country. Since co-location with manufacturing is in certain contexts, particularly materials and process innovations at the technical frontier, necessary for innovation, making sure the manufacturing processes happen domestically is likewise important to ensuring the capability to innovate and continue to lead at the technical frontier (c.f. Fuchs, 2014; Fuchs and Kirchain 2010). Excitingly, my research with Christophe Combemale and other colleagues shows that these game-changing products that leverage the technical frontier in advanced materials and processes also tend to have better jobs for high-school educated operators and technicians, whose back-and-forth with engineers on the production line is essential to bringing the new innovations successfully to market In these products, when inventors are U.S.-based (as they often are) and production processes for new products are still immature, the U.S. should have an initial advantage in keeping production domestic. However, unless the U.S. has invested in the prototyping facilities for scale-up of new products (particularly knowledge and capital intensive advanced materials and processes like those required in high-end next generation semiconductors) and the regional manufacturing ecosystems (including the highly-skilled high-school educated operators and technicians needed) to subsequently make those products at scale, investments in innovation will not stay domestically.

As I discussed in my 2020 testimony before the Ways and Means Subcommittee on Trade and in my 2021 testimony before the House Space, Science and Technology Subcommittee on Research and Technology, I have come to believe *strategic infrastructure investments hold the greatest promise to revitalizing U.S. worker skills and firm necessary for vibrant U.S. manufacturing ecosystems.*[2,3] By infrastructure I mean not just roads, bridges, transit networks, water systems, and dams; but also the energy, communications, manufacturing, and data infrastructure necessary for all of those.

Too often missing from national debates has been thinking about infrastructure investments as strategic investments in technology and knowledge capabilities, equity, national security, as well as platforms that enhance productivity and innovation. To realize this potential, our infrastructure investments need to be for *the infrastructure of the future*. Transportation, transit, and urban infrastructure should be designed to enable the safe and equitable introduction of driverless vehicles and smart city systems,

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[2] My focus on strategic infrastructure investments is due to the potential novelty of that approach. Manufacturing Extension Program and Manufacturing USA innovation institutes already play and will need to play an important role in reviving our manufacturing ecosystem. On the Manufacturing Extension Program's effectiveness in upgrading and the acquisition of competitive capabilities (c.f. Various pieces by Whitford, J.; Shapira; McEvily, B.). On the Manufacturing USA innovation institutes, their original goals, and evaluation thereof (c.f. Recent studies by GAO, NASEM).

[3] The U.S. generally lags behind other peer industrialized nations in infrastructure: The American Society of Civil Engineers (ASCE)'s 2017 report finds that the nation's infrastructure averages a "D," meaning that conditions are "mostly below standard," exhibiting "significant deterioration," with a "strong risk of failure." This lag which can largely be traced back to funding: On average, European countries spend the equivalent of 5 percent of GDP on building and maintaining their infrastructure, while the United States spends 2.4 percent. The United States also differs from most other industrialized countries in the extent to which it relies on local and state spending to meet its infrastructure needs -- only 25 percent of U.S. public infrastructure funding comes from the federal government.

and the matching large-scale interconnected data infrastructure for security, privacy, resilience and machine learning on that data (Anderson et al. 2016; Berges and Samaras 2019.) Electric grids should be restructured to ensure a clean and resilient power system that can accommodate a wide range of new designs and services (NASEM 2010, Lueken 2012, NASEM 2017).[4] (Fuchs Testimony 2020)

Investments such as those described above address national needs for resilience, energy and internet access, demand for products from cement to steel to semiconductors (particularly if inputs are sourced domestic manufacturing), *and* technology leadership (whether in cybersecurity, software for resilient distributed systems, semiconductors for communications, renewable energy sources, or batteries for energy storage). Infrastructure investments also build national capabilities for building things -- not just in the form of firms responding to the demand, but also in the form of operators and engineers. These workers will learn by doing. As we think about these investments strategically, it is critical to recognize the interconnectedness of knowledge and skills across these infrastructure domains. The physical and human capital relevant to deploying and managing sensors for sustainable and smart infrastructure -- from the concrete layer to forman to the engineer to the data infrastructure developer to the machine learning software -- have corollaries in resilient grid infrastructure, privacy-preserving health infrastructure, and intelligent manufacturing. In other words, to have the human capital and enterprises to manufacture the products of the future, we should build the infrastructure of the future. We should be strategic about these complementarities between infrastructure and critical technology and manufacturing capabilities, in where and how we invest, and in facilitating job and skill transitions across sectors through targeted training.[5,6] (Fuchs 2020 testimony)

Once again, a cross-mission critical technology analytics program holds the potential to identify and quantify the systemic implications of such investments and quantify paths to cross-mission win-wins.

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[4] Among other issues, much of our infrastructure was constructed for the climate of the 20th century, rather than for the climate of the 21st century (Chester et al. 2020). Rebuilding and reinvesting in our infrastructure to be resilient to extreme weather is essential for the safety of our communities and the resilience of our economy (Olsen et al., 2015).

[5] A recent OECD report has looked at current worker skills, how demand for those skills is expected to change with automation, and the training required to support “reasonable” transitions (OECD 2019). In our own research, we have been mapping skill requirements to jobs at a individual operator task level (Combemale, Ales, Whitefoot, Fuchs 2020a), and we are extending that task-level skill mapping now beyond the shop floor to technicians, engineers, and managers (Combemale, Whitefoot, Fuchs 2020). Whether at the OECD level or our own more granular one (or another method yet to emerge), we need to be mapping and broadcasting to training entities the skill transitions required to apply skills from one domain to the other across sectors.

[6] In facilitating these transitions, we should not underestimate the power of on-the-job learning and learning by doing (building). This is not to suggest that training isn’t necessary, rather that that training may not happen “out of work”, per se. Here, where large firms exist, industry in each sector should lead the training that is needed, where relevant in partnership with unions, with government facilitating assessment and dissemination of best practices and the mapping of the cross-sector transitions. Where small companies are involved, the government will play an essential role, in conjunction with larger companies, in mapping and funding necessary workforce transition training.

<u>As the above examples highlight,</u> the U.S. needs to build the capacity to identify and invest in solutions that offer win-wins across missions, charting paths where the sum across missions may be greater than the parts.

> "Unlike firms, nations have multiple objectives: national security, economic prosperity (including jobs), and social welfare (including health, environment, and equity). In the past the United States has pursued the technological component of each objective through science and technology agencies with singular missions, such as defense, energy, transportation, commerce, and labor. The National Research Council beautifully describes how this mix of missions helped create the revolution in computing: "By funding a mix of work in universities and industry, [the United States] was able to marry long-term objectives to real-world problems. And, by channeling its funding through a variety of federal agencies, it was able to ensure broad-based coverage of many technological approaches and to address a range of technical problems." Yet this excellent system has a hole: even if each agency (or program within an agency) perfectly fulfills its own narrowly specified mission, the country could still fail to fulfill the nation's overarching multi-objective goal." (Fuchs, *Boston Review* 2021)

I suspect part of why our country hasn't invested more in domestic manufacturing and infrastructure is failure to identify and quantify the value across missions (labor and equity, health, security, commerce) of these investments. Fortunately, with today's modern data and analytic tools it is possible to identify, quantify the value of, and incentivize technological solutions that are win-wins across multiple national objectives.

For example, our research shows that certain innovations in areas critical to national security (including high-end semiconductors for communications) also offer better jobs for hard working high school graduates (Combemale and Fuchs 2020; Combemale, Ales, Fuchs, Whitefoot 2021; Combemale, Ales, Fuchs, Whitefoot 2022).

Similarly, in the case of the current semiconductor shortage in safety-critical robust applications, government funding of design platforms that embrace commonalities (but leave room for differences) across the respective technological demands of the defense and commercial sectors can lead to a solution where the sum is greater than the parts for U.S. security, economic, labor, and equity interests. (Blanton et al 2021)

As a third example, if we just want to reduce carbon emissions, the best approach might be to scale up the use of electric vehicles as quickly as possible. However, if we expand the objective of that investment to also maximize national security, prosperity, and equity, we would need to find ways to invest in innovations that reduce our national reliance on concentrated supplies in geographic locations with higher probabilities of disruption; quantify the value (in terms of labor, supply resilience, and innovation) of domestic manufacturing of batteries; and predict which citizens would gain and lose jobs, and support those citizens in having jobs for the future of the industry moving to that region and being trained for those positions. (Fuchs *Boston Review* 2021)

As I have described, getting these investments right is non-trivial. In a mission-oriented government, how do we build the national analytic capacity in critical technologies and supply chains to identify, value, and act across missions? We need to create a program whose goal is strategically identifying opportunities across missions.

Today, the U.S. lacks real-time situational awareness of its strengths, weaknesses, opportunities and threats in various technologies and supply chains. The U.S. lacks ways of quantifying technology or product criticality, or the value of various policy responses (such as onshore manufacturing or secrecy) for technologies identified as critical. Perhaps most importantly, the U.S. lacks ways of analyzing the value of various policy responses across missions (e.g. national security, economic prosperity, and social well-being including health, equity, and the environment). To build a resilient economy and ensure that the nation's investments realize legislator's multiple objectives for them the U.S. must establish a national capability for critical technology analytics that will build the 21st century intellectual foundations, data infrastructure, and analytic tools needed to elucidate trade-offs and win-wins across national missions, including the dimensions by which to measure a technology's criticality, a proactive assessment of strengths weaknesses opportunities and threats in technologies and supply chains versus other nations and the ability to spin-up timely situational awareness thereon during crises, how innovation could potentially transform these situations, and the trade-offs across missions presented by different technology policy approaches.

A critical technology analytics program faces unique challenges in that the intellectual foundations for identifying critical technologies do not yet exist, the problems require talent not easily attracted by individual agencies, and the problems are uniquely cross-mission in nature, spanning multiple departments. In terms of talent, not only is frontier technical knowledge and sectoral depth needed on the problem-solving team, but also the latest in 21st century data and analytic capabilities (such as machine learning and natural language processing). Experts at the frontier of these types of knowledge typically sit across academia and industry. Given the overlaps between military and civilian demand for knowledge and products in "critical" areas, the organization would by definition be focused on problems at the nexus of academia, industry, and government.

Given these challenges, the ideal critical technology analytics program would be a highly flexible, distributed model capable of rapidly mobilizing and reconfiguring star private sector and academic talent, data, and resources. To ensure absorptive capacity of these new tools by government, individual government agencies would need to in parallel be developing internal competencies, and would be responsible for transitioning capabilities internally, and would have people on rotation in the critical technology analytics program serving as the bridge for that transition.

In summary, for a critical technology analytics program to identify cross-mission win-wins and thus have the greatest value for our nation, the program must be set up so as to

i) be strategic and forward-looking (not working on issues of the day or week or becoming a statistical agency focused on comprehensive data collection, rather with outputs involving analytics to inform strategic action,

ii) be able to receive work from all departments of government - including from multiple departments on a single subject, such that each department would still have their own analytic team but would seek to leverage the organization where it particularly needed star talent challenging to attract to individual agencies, and where select critical technology problems were particularly cross-mission in their nature;

iii) bring together to solve problems leading technical expertise in engineering and the physical sciences, matched with analytic (machine learning, operations research, natural language processing) and social science (economics, political science, sociology, history) expertise,

iv) be able to engage neutral third parties and have the capability to forge public-private partnerships that can serve as a neutral third party, and

v) conduct work internally but also be able to leverage expertise from academia and industry through contracts.

The U.S. has risen to the challenge of creating a star-studded entity to cut-across missions before. Founded in the aftermath of Sputnik with the goal of preventing technological surprises, DARPA was set up to cut through the rivalry between the military services (Fuchs 2010). To ensure future U.S. security, competitiveness, and access to critical supply, and to ensure the landmark science and infrastructure legislation proposed achieves legislator’s multiple objectives for it, the U.S. must establish, a cross-mission critical technology analytics program able to receive work across, collaborate with, and catalyze initiatives within the existing mission-driven agencies.

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