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Education and Innovation

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12.1 Introduction

A vast body of research shows that educational investments yield long-run benefits for students (e.g., Chetty et al. 2014; Deming and Walters 2017; Jackson, Johnson, and Persico 2016). Less is known, however, about the role of education in encouraging entrepreneurship and innovation.

In this chapter, we review the existing literature and attempt to understand the linkages between education and innovation. We first provide a brief review of relevant theoretical frameworks. We then explore the possible impacts of three different types of educational interventions that might have an impact on downstream innovation. We also outline possible avenues for future research.

We draw three main conclusions. First, increasing investment in basic skills would help ensure that all potential future innovators are able to reach

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the knowledge frontier and take advantage of their natural talents. Second, since research universities play such an important role in knowledge creation and innovation, democratizing access to them as well as increasing public investment in them would likely yield big benefits in terms of innovation. Third, while technology alone is not a panacea, there is much potential for technology to lower the cost of providing extremely effective personalized education. Software can be used to replace the essential role that a tutor plays in diagnosing specific deficits and meeting learners where they are. Educational innovations, such as computer-assisted learning (CAL), can provide personalized support and feedback at a fraction of the price of a tutor, helping future innovators succeed in the early years of school and widening the talent pipeline.

12.2 Education and Innovation: Theory

The importance of human capital and education for innovation and growth is theoretically grounded in models of endogenous growth, such as Romer (1986, 1990, 1994). Two ingredients of this class of models are critical. First, human capital is factor-augmenting in the production of knowledge (or ideas). Second, ideas are nonrival, implying that they can be used by others who have not developed them, creating positive externalities that fuel growth. The combination of these two ingredients suggests that investments in education, which "create" human capital, not only benefit their original recipients but also encourage growth for the entire economy. A corollary is that, since private individuals do not internalize the social benefits of education, private investments in education are likely to be too low from a social perspective, which calls for public investments in education.

12.3 Defining Human Capital

The concept of human capital is at the core of this class of models. But what exactly is "human capital"? Early research (e.g., Romer 1990) measured differences in human capital by years of education. Subsequent work has tried to better characterize the types of investments that produce valuable knowledge and contribute to innovation and growth. Focusing on the production of knowledge, Scotchmer (1991) argued that the production of innovation is cumulative and that new knowledge builds on existing knowledge. Baumol (2005) emphasized the importance of scientific knowledge for innovation and growth. More recently, macroeconomic models, such as Lucas (2015), Lucas and Moll (2014), and Akcigit et al. (2018), have argued that social learning and interactions play a key role in encouraging growth, while Bell et al. (2019) stressed the importance of mentorship for producing innovators.

How can education produce the type of knowledge that generates innovation and growth? Altonji, Blom, and Meghir (2012) showed substantial differences in the labor market returns to different college majors, which suggests that the content of education matters. In an attempt to create a mapping between higher education, research, and innovation, Biasi and Ma (2020) link the content of college and university courses with that of academic publications and patents and show large differences among and within schools in the extent to which course content is "keeping pace" with the knowledge frontier. Deming and Noray (2018) find that the economic return to technology-intensive jobs and college majors declines with work experience, and they connect this decline to obsolescence of older-vintage skills learned in school. Taken together, this literature suggests that educational institutions foster innovation by teaching skills that keep workers near the technology frontier.

12.4 Growth Accounting

Empirical support for endogenous growth theory comes from exercises of growth accounting, which have shown that differences in human capital can explain differences in rates of growth. Mankiw, Romer, and Weill (1992), Benhabib and Spiegel (1994), Bils and Klenow (2000) as well as Manuelli and Seshadri (2014) use cross-country evidence to establish a link between human capital and growth. Hendricks and Schoellmann (2018) investigate wage gains and wage convergence for immigrants to the US and find that differences in human capital levels in the sending country explain 60 percent of the observed difference in wage gains. Jones (2014) argues that standard growth accounting models estimate a lower bound for the importance of human capital for growth and demonstrates that an alternative method of aggregating human capital in models of endogenous growth can explain all observed cross-country income differences.

In an attempt to better capture human capital, Hanushek and Woessmann (2008) examine the relationship between growth and alternative measures of workers' cognitive skills. They find that countries that increase cognitive skills grow more quickly. Hanushek, Ruhose, and Woessmann (2017) further show that cross-state variation in the US in "knowledge capital" can explain 20–30 percent of state variations in per capita GDP. Relatedly, Schoellmann (2012) uses wage returns to schooling to measure differences in the quality of education across countries and finds that foreign workers from countries with better education experience larger wage gains on moving to the US.

Yet, despite the strong evidence that links human capital with economic growth, there is little direct evidence of a causal effect of human capital on innovation, with a few notable exceptions, such as Bianchi and Giorcelli (2019, discussed below).

12.5 Investing in Basic Skills

Are inventors born or made? Providing an answer to this question requires understanding the production function for innovation. Scotchmer (1991) modeled innovation as a cumulative process, whereby existing knowledge acts as an input in the production of new content. One of the prerequisites for producing high-quality innovative content is therefore the ability to reach the knowledge frontier. As technology progresses, however, this frontier shifts outward (Jones 2009), increasing the "burden of knowledge" on potential inventors.

What does it take to reach the knowledge frontier? Like innovation, education is a cumulative process, and access to higher-level knowledge relies on access to basic education and skills in the very first years of life. Einstein would hardly have been able to invent the theory of general relativity, had he not had access to primary and secondary education. Education alone probably cannot make someone a great innovator. However, a good education is necessary to get potential innovators to the knowledge frontier in the first place. A high-quality education builds cognitive and noncognitive skills, which increase the productivity of future innovators.

12.6 Schooling and Cognitive Abilities

Recent research has emphasized the importance of innate traits of successful inventors and entrepreneurs. Aghion et al. (2017), for example, argue that inventors tend to have higher IQs, which has been interpreted as a signal of high ability and talent. Emphasis on these "innate" traits might suggest that luck is a key factor for becoming a successful inventor.

A closer look at the empirical evidence, however, reveals that education can play an equally important role in determining whether innate traits lead to innovation. Time spent in school, for example, has a causal positive effect on children's cognitive abilities. Ritchie and Tucker-Drob (2018) use a regression-discontinuity design on school entry-age cutoffs to show that an additional year of schooling increases IQ by 1 to 5 points. Moreover, they find that effects persist across the life span. Similarly, Cornelissen and Dustmann (2019) use differences in school-entry rules across regions in England to show that schooling improves literacy and numeracy skills of children aged 5 to 7, as well as noncognitive skills for children aged 11.

The benefits of additional schooling, however, are not confined to the early years. Cascio and Lewis (2006) explore the effects of an additional year of high school on a person's score on the Armed Forces Qualifying Test, and they find large effects, especially for racial minorities. These findings suggest that late investments in schooling can help close racial and ethnic gaps in cognitive skills. Using data from Sweden and exploiting conditionally random variation in test-taking dates, Carlsson et al. (2015) estimate that 10 additional days of high school raise intelligence scores by 1 percent of a standard deviation. Adding to this evidence, Card and Giuliano (2016a,b) show that underrepresented minorities benefit from increased access to gifted and talented programs. Gaining access to these programs in fourth grade leads to a 0.7 standard deviation increase in math test scores for Black students, from 0.8 to 1.5 standard deviations.[1]

Given the relationship between cognitive skill and innovation, gifted and talented programs such as the one studied by Card and Giuliano (2016a,b) could directly create more innovators from underrepresented backgrounds. Comparing their estimates to the relationship between achievement scores and patenting found in Bell et al. (2019) suggests that universal gifted and talented screening might increase the share of inventors (defined as someone who has ever held a patent) from 0.1 to 0.7 per thousand for Black students.[2]

12.7 Schooling and Noncognitive Abilities

Cognitive abilities, however, are not the only innate trait associated with innovation and entrepreneurship. Levine and Rubinstein (2017) find that entrepreneurs have specific personality traits, which make them "smart and illicit." Compared with the unincorporated self-employed, the incorporated self-employed (as a proxy for entrepreneurs) tend to score higher on cognitive tests, show greater self-esteem, and are more likely to have engaged in illicit activities as teenagers. Education can keep "smart and illicit" individuals, especially those coming from less advantaged backgrounds, from falling through the cracks.

Despite these advances, the predictive power of individual traits is fairly low, and there are enormous potential returns to democratizing access to education and to supporting everyone to reach the knowledge frontier.

12.8 Improving the Type and Quality of Education

Beyond simply expanding access to education, improving the type and quality of education might have large effects on innovation, entrepreneurship, and growth. As mentioned earlier, expanding the scale of targeted gifted and talented programs in K–12 schools could greatly widen the pipeline of future innovators (Card and Giuliano 2016a,b). Additionally, certain types of education programs seem to be particularly beneficial for innovation. Bianchi and Giorcelli (2019), for example, show that increased and "democratized" access to STEM (science, technology, engineering, and mathematics) education, through the opening of vocational and technical programs in 1960 Italy, led to increases in patenting. Similarly, Toivanen and

1. See Card and Giuliano (2016a), table 3.
2. Bell et al. (2019), figure IV(B).

Vaananen (2016) find large, positive causal effects on patenting of expanding access to Engineering MSc programs in Finland.

Yet despite a possible "democratizing" role of higher education for invention, Bell et al. (2019) show that US inventors (measured through inclusion as patentees) come from a small set of top US schools, which admit very few low-income students. These findings cast doubt on the idea that the current US education system is effective in providing access to the type of innovation that is needed for broad-based and "democratic" invention.

12.9 Universities as a Source of Entrepreneurship and Innovation

If education is important for producing future innovators, what is the role of universities in this process? To answer this question, we first review the existing evidence on linkages between universities, entrepreneurship, and innovation.

Today, universities such as Stanford and the Massachusetts Institute of Technology (MIT) in the US or the Technion in Israel, serve as catalysts for entrepreneurship and innovation. But can entrepreneurship be taught? Many university professors believe that yes, entrepreneurship is a skill that can be trained through exposure and experience. Israel's Technion was one of the first universities to offer a course in entrepreneurship, when Nobel Laureate Dan Shechtman, world renowned for his work in chemistry and material science, set up a course on technological entrepreneurship.[3] Shechtman has been running this course successfully for more than 30 years, and the Technion now pushes to deepen its commitment to teaching entrepreneurship. Ezri Tarazi, a professor of industrial design who is in charge of Technion's program, argues that entrepreneurship can in fact be taught and "talent can be developed."

Focusing on MIT, a major technology-based university, Hsu, Roberts, and Eesley (2007) examine trends in entrepreneurship among MIT alumni since the 1930s to investigate who enters entrepreneurship and how this has changed over time. One of their most striking findings is that rates of company formation by MIT alumni have increased dramatically since the 1930s, suggesting that MIT may have become "better" at encouraging entrepreneurship. Notably, they find that rates of entrepreneurship are generally higher among MIT alumni who are foreign citizens (who might be positively selected) and that women alumnae lag behind their male colleagues in the rate at which they become entrepreneurs. Both these findings suggest that expanding access to university education can encourage entrepreneurship and innovation, especially if they are combined with programs targeting underrepresented minorities and female entrepreneurs.

3. "Technion Fosters Entrepreneurship within Ivory Towers as Startup Nation Calls." *Times of Israel*, December 25, 2019. Available at https://www.timesofisrael.com/technion-fosters-entrepreneurship-within-ivory-towers-as-startup-nation-calls/.

The origins of MIT and other technology-based universities like Cornell and Iowa State can be traced back to the land-grant universities established by the Morrill Acts of 1862 and 1890. Funded initially by granting federally controlled land to colleges, the mission of these colleges was purposefully practical (in stark contrast to the liberal arts curriculum), focusing on agriculture, science, military science, and engineering.

Research on the land grant college system suggests that it played a particularly important role in encouraging local entrepreneurship and innovation. Kantor and Whalley (2019) show that agricultural extension centers that were connected to the US land grant system created important productivity spillovers to the local economy. A working paper by Maloney and Caicedo (2020) shows that the land grant universities, which trained engineers, encouraged county-level economic growth. In addition, research by Andrews (2019) and Valero and Van Reenen (2019) has shown that the establishment of universities increased local invention. Andrews (2019) examines the effects of land grant colleges on agricultural patenting and productivity by exploiting cases in which the location (county) in a state that received a land grant college was chosen through an "as good as random" process and compares outcomes for these 29 universities with runner-up counties that were not chosen. Andrews find that agricultural innovation (both in terms of patents and new crop varieties) increased in these counties relative to the control.

Rosenberg (1994) argued that reliance on local funding has created strong incentives to focus on applied research that has helped create local clusters of innovation. Land grant colleges in particular were good at securing social returns from publicly funded research, and perhaps even superior to the current US system focused on patenting, licensing, and technology transfer (Mowery et al. 2004).

The available evidence suggests that funding plays a major role in determining the rate and direction of technical change. Hvide and Jones (2018), for example, show that a change in funding rules in Norway created dramatic effects on both entrepreneurship and patenting. Until 2003, Norwegian professors benefited from the "professor's privilege," granting full rights to new business ventures and intellectual property. In that year, however, Norway switched to a system of shared rights, similar to the system established by the Bay-Dole Act of 1980, which grants just one-third of these rights to the professor, with two-thirds going to the university (e.g., Lach and Schankerman 2008). Using comprehensive data on Norwegian workers, firms, and patents, Hvide and Jones document a 50 percent decline in entrepreneurship and innovation in response to this change. In earlier research, using alumni presentations on Congressional appropriations committees as an instrument for research funding, Payne and Siow (2003) had shown that an increase of $1 million in federal research funding (in 1996 USD) results in 10 additional articles and 0.2 additional patents.

Analyses of university patenting have shown that the relationship between universities and innovations that surround them is in flux and may be weakening over time (Henderson, Jaffe, and Trajtenberg 2006). Yet the available evidence may underestimate the real benefits of universities for entrepreneurship and innovation if universities develop methods rather than creating specific startups and firms. Cohen, Nelson, and Walsh (2002) find that actual products from academic research are less important than research techniques and tools. Wright (2012) further shows that the way of doing agricultural research that was developed in the land grant system encouraged agricultural innovation that formed the foundation of the Green Revolution. More recently, examining drug development during 1988–2005, Sampat and Lichtenberg (2011) find that public sector labs account directly for about 10 percent of drugs, but may enable two-thirds of marketed drugs. Taken together, these findings suggest that spillovers from universities to the private sectors are difficult to quantify and easy to underestimate.

Another channel by which education can encourage innovation is by improving access to mentors and potential collaborators. Jones, Wuchty, and Uzzi (2008), Wuchty, Jones, and Uzzi (2007), Jones (2009), Deming (2017), and Jaravel, Petkova, and Bell (2018) all show that innovation often happens in teams. Universities and other types of educational institutions may provide the settings in which these teams are formed.

Spillovers in teams and among highly skilled individuals more generally appear to be particularly important in STEM. Azoulay, Graff Zivin, and Wang (2010), for example, document that the death of a superstar in science reduces the productivity of their collaborators. Bell et al. (2019) use tax data linked with patent records to show that mentors matter greatly for invention. Moser, Voena, and Waldinger (2014) show that the arrival of prominent German Jewish émigré chemists resulted in a substantial increase in patenting in the fields of the émigrés. Moser and San (2020) further show that restrictions on immigration in the 1920s, which reduced the number of eastern and southern European-born scientists who were active in the US, caused a persistent decline in invention by US-born inventors. Taken together, this literature suggests that educational institutions are an important source of innovation.

12.10 Effects of Innovation on Education

Our discussion to this point has focused on the potential benefits that improvements in access and in the quality of education can have for innovation, entrepreneurship, and ultimately, growth. Innovation, however, can also directly affect education, for example by reducing costs and improving quality and efficiency.

In recent years, the education sector has adopted new technologies at a much slower rate compared with other sectors (Chatterji 2018). In 2019, only 2.5 percent of the federal Department of Education's budget was earmarked

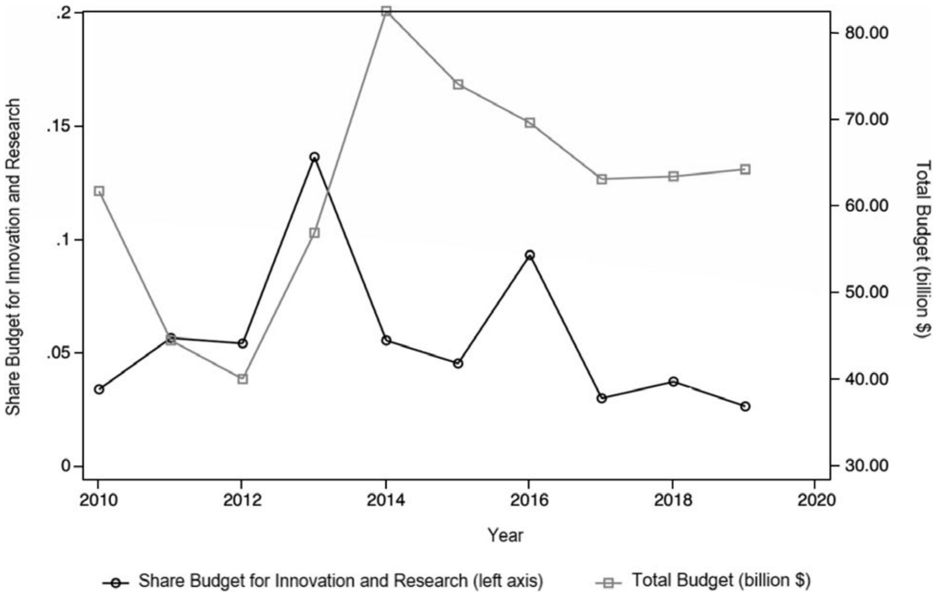

Fig. 12.1 Department of Education's total budget and share earmarked for innovation

Note: The black line shows the total budget of the federal Department of Education. The gray line shows the share of the budget earmarked for *Innovation and Improvement* and for the activities of the *Institute of Education Sciences.* Budget data from https://www2.ed.gov/about/overview/budget/tables.html?src=rt, accessed May 17, 2020.

for research and innovation; this share has been declining from 8.2 percent in 2016 to 3.8 percent in 2019 (figure 12.1). Since 1995, the education sector has been experiencing slow productivity growth (Cutler 2011). A possible reason for this slow growth is that the private benefits from technology adoption are smaller in education than in other sectors due to the structure of the market (Chatterji and Jones 2012). Alternatively, management challenges, which are typical of large organizations in the education sector, may have hindered the adoption of new technologies due to a bias in favor of the status quo and distorted incentives.

One strand of research has used experiments to evaluate the effect of the adoption of new technologies in the classroom on student achievement. In the US, technology adoption has proceeded at a reasonable pace. The ratio of students to computers for 15-year-olds is close to 1 (Bulman and Fairlie 2016), and nearly all students have access to the Internet (Fairlie, Beltran, and Das 2010; Golsbee and Guryan 2006). Barrow, Markman, and Rouse (2009) argue that technology adoption in schools could be beneficial, because it allows for better personalization of the learning experience.

Chatterji (2018) explains:

> However, despite the ubiquity of technology in the classroom and various proposed mechanisms of action, rigorous evaluations of the impact of technology on student performance are rare and results are mixed (Bulman and Fairlie 2016). Goolsbee and Guryan (2006) find that while E-Rate increased investments in education technology between 1996–2000 in California public schools, it produced no statistical impact on student performance. This finding is consistent with other studies from the United States and around the world, which find little or no impact of technology on student outcomes (e.g., Angrist and Lavy 2002; Rouse and Krueger 2004). However, some studies have found a positive impact of technology on student performance (Ragosta 1983; Banerjee et al. 2007; Machin et al. 2007; Barrow, Markman and Rouse 2009; Cheung and Slavin 2013). As discussed in Barrow et al. (2009), these benefits must be weighed against the costs of program adoption and ongoing implementation.

There is little evidence that the mere existence of technology in the classroom produces benefits. Teachers and students might not use technology even when it is available (e.g., Cuban, Kirkpatrick, and Peck 2001) or use it in suboptimal ways (Wenglinsky 1998). For example, recent high-profile technology interventions, such as a $1 billion tablet initiative in the Los Angeles Unified School District, have been roundly criticized by journalists and education policy experts due to implementation challenges. In the Los Angeles Unified School District, for example, many students were unable to access the required curriculum due to serious technical issues.

However, one promising way that technology has been applied to enhance learning is through computer-assisted learning (CAL) software. CAL software automatically adapts content and difficulty level based on diagnostic assessment and students' previous responses. This software essentially creates a personalized learning environment for each student that exactly meets his or her needs. Several recent studies have found large benefits of personalized learning through CAL. Muralidharan, Singh, and Ganimian (2019) find that middle-school students in India who randomly receive access to CAL software score 0.37 standard deviations higher in math and 0.23 standard deviations higher in Hindi over only a 4.5 month period. Importantly, they find larger gains for students with lower baseline achievement. CAL essentially replicates the successes of many other interventions that use personalized tutoring and mentoring to teach students "at the right level." We know this approach works, but it is expensive. Thus, one way that innovation might increase productivity in education is by lowering the cost of personalization.

12.11 Conclusion

The research that we have reviewed in this chapter indicates that improvements in access and in the quality of education have immense potential for encouraging entrepreneurship and innovation. Education provides the tools that creative individuals need to succeed as inventors and entrepreneurs. Some of these tools can be measured quantitatively, through improvements in IQ scores, which have been linked to innovation. But many others are intangible, including tools taught in entrepreneurship programs around the world.

These programs encourage innovation at two important margins. First, they help people who would have been innovators anyway to become more successful, either in terms of increased invention or by creating new businesses that are more profitable. Second, they allow creative individuals who would otherwise not have become inventors or entrepreneurs to reach their potential, widening the talent pipeline. Based on the research in this survey, we conclude that this second mechanism is particularly important for encouraging innovation through education.

Many big questions remain, however. For example, to better guide education policy, we need better estimates of the marginal returns to investments in skills for different types of people (such as men vs. women, majority students vs. underrepresented minorities). Moreover, there is a great need for additional research on the stage of life at which investments in education are most effective in encouraging creativity and innovation (e.g., early childhood education vs. universities). Also, no real consensus has been reached on the type of education that is most successful in encouraging innovation (e.g., training in math and science vs. soft skills).

Different approaches to these issues imply radically different policies, ranging from focused investments in the "best and brightest" to concerted efforts at expanding and maintaining a broad pipeline of innovation. Putting aside considerations of inequality for the moment, the approach we take to "access" helps determine the level and the quality of innovation. These considerations heighten the urgency of the issue for education policy.

Technology will become a more important source of educational innovation in the near future, for two reasons. First, advances in machine learning and artificial intelligence tools will lower the cost of personalized instruction, particularly in subjects like math, where learning gaps can be more easily identified and addressed. As these techniques improve, they will become more widespread. Second, growing cost pressures in the education sector will make technological improvements more urgent and necessary. Education is a "people" business, so as people become relatively more expensive, technology becomes a more appealing substitute for some aspects of in-person instruction.

References

Aghion, Philippe, Ufuk Akcigit, Ari Hyytinen, and Otto Toivanenet. 2017. "The Social Origins of Inventors." NBER Working Paper No. 24110. Cambridge, MA: National Bureau of Economic Research.

Akcigit, Ufuk, Santiago Caicedo, Ernest Miguelez, Stefanie Stantcheva, and Vale-

rio Sterziet. 2018. "Dancing with the Stars: Innovation through Interactions." NBER Working Paper No. 24466. Cambridge, MA: National Bureau of Economic Research.
Altonji, Joseph G., Erica Blom, and Costas Meghir. 2012. "Heterogeneity in Human Capital Investments: High School Curriculum, College Major, and Careers." *Annual Review of Economics* 4(1): 185–223.
Andrews, Michael J. 2019. "Local Effects of Land Grant Colleges on Agricultural Innovation and Output." NBER Working Paper No. 26235. Cambridge, MA: National Bureau of Economic Research.
Angrist, Joshua, and Victor Lavy. 2002. "New Evidence on Classroom Computers and Pupil Learning." *Economic Journal* 112(482): 735–65.
Azoulay, Pierre, Joshua S. Graff Zivin, and Jialan Wang. 2010. "Superstar Extinction." *Quarterly Journal of Economics* 125(2): 549–89.
Banerjee, Abhijit V., Shawn Cole, Esther Duflo, and Leigh Linden. 2007. "Remedying Education: Evidence from Two Randomized Experiments in India." *Quarterly Journal of Economics* 122(3): 1235–64.
Barrow, Lisa, Lisa Markman, and Cecilia Elena Rouse. 2009. "Technology's Edge: The Educational Benefits of Computer-Aided Instruction." *American Economic Journal: Economic Policy* 1(1): 52–74.
Baumol, William J. 2005. "Education for Innovation: Entrepreneurial Breakthroughs Versus Corporate Incremental Improvements." *Innovation Policy and the Economy* 5: 33–56.
Bell, Alex, Raj Chetty, Xavier Jaravel, Neviana Petkova, and John Van Reenenet. 2019. "Who Becomes an Inventor in America? The Importance of Exposure to Innovation." *Quarterly Journal of Economics* 134(2): 647–713.
Benhabib, Jess, and Mark M. Spiegel. 1994. "The Role of Human Capital in Economic Development: Evidence from Aggregate Cross-Country Data." *Journal of Monetary Economics* 34(2): 143–73.
Bianchi, Nicola, and Michela Giorcelli. 2019. "Scientific Education and Innovation: From Technical Diplomas to University STEM Degrees." NBER Working Paper No. 25928. Cambridge, MA: National Bureau of Economic Research,
Biasi, Barbara, and Song Ma. 2020. "The Education-Innovation Gap." Working paper. New Haven, CT: Yale University.
Bils, Mark, and Peter J. Klenow. 2000. "Does Schooling Cause Growth?" *American Economic Review* 90(5): 1160–83.
Bulman, George, and Robert W. Fairlie. 2016. "Technology and Education: Computers, Software, and the Internet." *Handbook of the Economics of Education* 5: 239–80.
Card, David, and Laura Giuliano. 2016a. "Can Tracking Raise the Test Scores of High-Ability Minority Students?" *American Economic Review* 106(10): 2783–2816.
———. 2016b. "Universal Screening Increases the Representation of Low-Income and Minority Students in Gifted Education." *Proceedings of the National Academy of Sciences* 113(48): 13678–83.
Carlsson, Magnus, Gordon B. Dahl, Björn Öckert, and Dan-Olof Roothet. 2015. "The Effect of Schooling on Cognitive Skills." *Review of Economics and Statistics* 97(3): 533–47.
Cascio, Elizabeth U., and Ethan G. Lewis. 2006. "Schooling and the Armed Forces Qualifying Test: Evidence from School-Entry Laws." *Journal of Human Resources* 41(2): 294–318.
Chatterji, Aaron K. 2018. "Innovation and American K–12 Education." *Innovation Policy and the Economy* 18: 27–51.
Chatterji, Aaron K., and Benjamin Jones. 2012. "Harnessing Technology to Improve

K–12 Education." Discussion Paper 2012-05. The Hamilton Project. Washington, DC: Brookings Institution.
Chetty, Raj, Nathaniel Hendren, Patrick Kline, and Emmanuel Saez. 2014. "Where Is the Land of Opportunity? The Geography of Intergenerational Mobility in the United States." *Quarterly Journal of Economics* 129(4): 1553–1623.
Cheung, Alan C. K., and Robert E. Slavin. 2013. "The Effectiveness of Educational Technology Applications for Enhancing Mathematics Achievement in K–12 Classrooms: A Meta-analysis." *Educational Research Review* 9: 88–113.
Cohen, Wesley M., Richard R. Nelson, and John P. Walsh. 2002. "Links and Impacts: The Influence of Public Research on Industrial R&D." *Management Science* 48(1): 1–23.
Cornelissen, Thomas, and Christian Dustmann. 2019. "Early School Exposure, Test Scores, and Noncognitive Outcomes." *American Economic Journal: Economic Policy* 11(2): 35–63.
Cuban, Larry, Heather Kirkpatrick, and Craig Peck. 2001. "High Access and Low Use of Technologies in High School Classrooms: Explaining an Apparent Paradox." *American Educational Research Journal* 38(4): 813–34.
Cutler, David M. 2011. "Where Are the Health Care Entrepreneurs? The Failure of Organizational Innovation in Health Care." *Innovation Policy and the Economy* 11: 1–28.
Deming, David J. 2017. "The Growing Importance of Social Skills in the Labor Market." *Quarterly Journal of Economics* 132(4): 1593–1640.
Deming, David J., and Kadeem L. Noray. 2018. "Stem Careers and the Changing Skill Requirements of Work." NBER Working Paper No. 25065. Cambridge, MA: National Bureau of Economic Research.
Deming, David J., and Christopher R. Walters. 2017. "The Impact of Price Caps and Spending Cuts on US Postsecondary Attainment." NBER Working Paper No. 23736. Cambridge, MA: National Bureau of Economic Research.
Fairlie, Robert W., Daniel O. Beltran, and Kuntal K. Das. 2010. "Home Computers and Educational Outcomes: Evidence from the NLSY97 and CPS." *Economic Inquiry* 48(3): 771–792.
Goolsbee, Austan, and Jonathan Guryan. 2006. "The Impact of Internet Subsidies in Public Schools." *Review of Economics and Statistics* 88(2): 336–47.
Hanushek, Eric A., and Ludger Woessmann. 2008."The Role of Cognitive Skills in Economic Development." *Journal of Economic Literature* 46(3): 607–68.
Hanushek, Eric A., Jens Ruhose, and Ludger Woessmann. 2017. "Knowledge Capital and Aggregate Income Differences: Development Accounting for US States." *American Economic Journal: Macroeconomics* 9(4): 184–224.
Henderson, Rebecca, Adam B. Jaffe, and Manuel Trajtenberg. 2006. "Universities as a Source of Commercial Technology: A Detailed Analysis of University Patenting, 1965–1988." *Review of Economics and Statistics* 80(1): 119–27.
Hendricks, Lutz, and Todd Schoellman. 2018. "Human Capital and Development Accounting: New Evidence from Wage Gains at Migration." *Quarterly Journal of Economics* 133(2): 665–700.
Hsu, David H., Edward B. Roberts, and Charles E. Eesley. 2007. "Entrepreneurs from Technology-Based Universities: Evidence from MIT." *Research Policy* 36(2): 768–88.
Hvide, Hans K., and Benjamin F. Jones. 2018. "University Innovation and the Professor's Privilege." *American Economic Review* 108(7): 1860–98.
Jackson, C. Kirabo, Rucker C. Johnson, and Claudia Persico. 2016. "The Effects of School Spending on Educational and Economic Outcomes: Evidence from School Finance Reforms." *Quarterly Journal of Economics* 131(1): 157–218.

Jaravel, Xavier, Neviana Petkova, and Alex Bell. 2018. "Team-Specific Capital and Innovation." *American Economic Review* 108(4–5): 1034–73.
Jones, Benjamin F. 2009. "The Burden of Knowledge and the 'Death of the Renaissance Man': Is Innovation Getting Harder?" *Review of Economic Studies* 76(1): 283–317.
———. 2014. "The Human Capital Stock: A Generalized Approach." *American Economic Review* 104(11): 3752–77.
Jones, Benjamin F., Stefan Wuchty, and Brian Uzzi. 2008. "Multi-University Research Teams: Shifting Impact, Geography, and Stratification in Science." *Science* 322(5905): 1259–62.
Kantor, Shawn, and Alexander Whalley. 2019. "Research Proximity and Productivity: Long-Term Evidence from Agriculture." *Journal of Political Economy* 127(2). DOI: 10.1086/701035.
Lach, Saul, and Mark Schankerman. 2008. "Incentives and Invention in Universities." *RAND Journal of Economics* 39(2): 403–33.
Levine, Ross, and Yona Rubinstein. 2017. "Smart and Illicit: Who Becomes an Entrepreneur and Do They Earn More?" *Quarterly Journal of Economics* 132(2): 963–1018.
Lucas, Robert E., Jr. 2015. "Human Capital and Growth." *American Economic Review* 105(5): 85–88.
Lucas, Robert E., Jr., and Benjamin Moll. 2014. "Knowledge Growth and the Allocation of Time." *Journal of Political Economy* 122(1): 1–51.
Machin, Stephen, Sandra McNally, and Olmo Silva. 2007. "New Technology in Schools: Is There a Payoff?" *Economic Journal* 117(522): 1145–67.
Maloney, William F., and Felipe Valencia Caicedo. 2020. "Engineering Growth." CEPR Discussion Paper No. DP15144. London: Centre for Economic Policy Research.
Mankiw, N. Gregory, David Romer, and David N. Weil. 1992. "A Contribution to the Empirics of Economic Growth." *Quarterly Journal of Economics* 107(2): 407–37.
Manuelli, Rodolfo E., and Ananth Seshadri. 2014. "Human Capital and the Wealth of Nations." *American Economic Review* 104(9): 2736–62.
Moser, Petra, and Shmuel San. 2020. "Immigration, Science, and Invention. Evidence from the Quota Acts." Working paper. New York University, New York.
Moser, Petra, Alessandra Voena, and Fabian Waldinger. 2014. "German Jewish Émigrés and US Invention." *American Economic Review* 104(10): 3222–55.
Mowery, David C., Richard R. Nelson, Bhaven N. Sampat, and Arvids A. Ziedonis. 2004. *Ivory Tower and Industrial Innovation: University-Industry Technology Transfer before and after the Bayh-Dole Act*. Stanford, CA: Stanford University Press.
Muralidharan, Karthik, Abhijeet Singh, and Alejandro J. Ganimian. 2019. "Disrupting Education? Experimental Evidence on Technology-Aided Instruction in India." *American Economic Review* 109(4): 1426–60.
Payne, Abigail, and Aloysius Siow. 2003. "Does Federal Research Funding Increase University Research Output?" *B.E. Journal of Economic Analysis & Policy* 3(1): 1–24.
Ragosta, Marjorie. 1983. "Computer-Assisted Instruction and Compensatory Education: A Longitudinal Analysis." *Machine-Mediated Learning* 1(1): 97–127.
Ritchie, Stuart J., and Elliot M. Tucker-Drob. 2018. "How Much Does Education Improve Intelligence? A Meta-Analysis." *Psychological Science* 29(8): 1358–69.
Romer, Paul M. 1986. "Increasing Returns and Long-Run Growth." *Journal of Political Economy* 94(5): 1002–37.
———. 1990. "Endogenous Technological Change." *Journal of Political Economy* 98(5, part 2): S71–S102.

———. 1994. "The Origins of Endogenous Growth." *Journal of Economic Perspectives* 8(1): 3–22.
Rosenberg, Nathan, and Richard N. Nelson. 1994. "American Universities and Technical Advance in Industry." University of Illinois at Urbana-Champaign's Academy for Entrepreneurial Leadership Historical Research Reference in Entrepreneurship. https://ssrn.com/abstract=1506333.
Rouse, Cecilia Elena, and Alan B. Krueger. 2004. "Putting Computerized Instruction to the Test: A Randomized Evaluation of a 'Scientifically Based' Reading Program." *Economics of Education Review* 23(4): 323–38.
Sampat, Bhaven N., and Frank R. Lichtenberg. 2011. "What Are the Respective Roles of the Public and Private Sectors in Pharmaceutical Innovation?" *Health Affairs* 30(2): 332–39.
Schoellman, Todd. 2012. "Education Quality and Development Accounting." *Review of Economic Studies* 79(1): 388–417.
Scotchmer, Suzanne. 1991. "Standing on the Shoulders of Giants: Cumulative Research and the Patent Law." *Journal of Economic Perspectives* 5(1): 29–41.
Toivanen, Otto, and Lotta Vaananen. 2016. "Education and Invention." *Review of Economics and Statistics* 98(2): 382–96.
Valero, Anna, and John Van Reenen. 2019. "The Economic Impact of Universities: Evidence from Across the Globe." *Economics of Education Review* 68: 53–67.
Wenglinsky, Harold. 1998. "Does It Compute? The Relationship between Educational Technology and Student Achievement in Mathematics." ETS Policy Information Center Report, Educational Testing Service, Princeton, NJ.
Wright, Brian D. 2012. "Grand Missions of Agricultural Innovation." *Research Policy* 41(10): 1716–28.
Wuchty, Stefan, Benjamin F. Jones, and Brian Uzzi. 2007. "The Increasing Dominance of Teams in Production of Knowledge." *Science* 316(5827): 1036–39.

Comment Eleanor Wiske Dillon

Many conditions must come together for someone to develop a successful innovation. She, or he, must understand the current base of knowledge in her area to build on it; she must have the spark of a new idea; and she must have the inclination and security to take a risk in developing her idea. Both the content and the structure of educational institutions can be designed to foster these conditions.

In chapter 12, Biasi, Deming, and Moser focus largely on the role of education in providing for the first condition: a base of knowledge from which to innovate. In particular, they emphasize that incomplete and unequal access to quality education leaves some potential entrepreneurs without the base of knowledge they need to develop new ideas. Providing this base of knowledge

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is undoubtedly the most important role of education in supporting innovation. Failure to provide quality education to all young people will lead to missed opportunities and will lower the overall pace of innovation in the economy. In education systems like that of the US, where access to education varies systematically with parents' income and with race, this failure also reinforces existing inequalities by shutting down a path for economic mobility.

Democratizing access to general education, while valuable for many reasons, is a broad policy and may have limited direct effects on the rates of invention. I focus my discussion on whether the existing economic literature can suggest more targeted interventions that would particularly spark innovation. I follow the authors on focusing mainly on the US context. Universities with strong track records of producing successful innovators share a focus on building mentor relationships, exposing students to real-world open questions, and training in STEM (Science, Technology, Engineering, and Math) fields. Providing curricula with these themes in high school, which nearly all young people now complete in the US, could be another powerful policy for increasing both the representativeness and total level of innovative entrepreneurship.

Access to Training for Innovation

Attendees of a small set of US colleges account for an outsized share of US patents (Bell et al. 2019). Not all innovations generate patents, and not all patents are innovative, but this tight concentration of patenting suggests some colleges and universities are creating environments that nurture invention, beyond simply catching students up to the frontier of knowledge. Biasi, Deming, and Moser emphasize that these most innovative colleges are often small and private (Cal Tech and MIT top the rankings by rates of patenting)[1] and admit relatively few low-income students. Increasing access to these colleges could create more equitable opportunities and reduce the strong relationship between parental income and future innovation in the US.

However, these current centers of innovation make up a tiny fraction of college seats in the United States. Democratizing access to these schools will do little to increase overall innovation unless capacity is simultaneously increased without affecting the quality of instruction. In Bell et al.'s sample, the 10 colleges with the highest rates of patenting among their students produce 90 patent holders per 1,000 attendees, in contrast to 7 per 1,000 in the remaining sample. These 10 colleges had a combined enrollment of

1. As part of a larger project using Census data, Bell et al. (2019) match US citizens born between 1980 and 1984 to the college they attended for the longest time and also to US patent records. They then report the share of attendees matched to each college who hold at least one patent.

just over 30,000 undergraduate students in 2018—about the same size as Purdue University.[2]

Policymakers and educators could do more to spur innovation by bringing successful elements of entrepreneurial instruction into more colleges and high schools, reaching a wider audience. Pinpointing what these institutions do to promote invention is difficult to do using observational data, and I have not found any economic studies that attempt it, but profiles of programs like those at Stanford (Read 2019) and Technion (Solomon 2019) suggest a few common practices. Both programs put students in contact with successful entrepreneurs, creating mentorship opportunities. Both also set students to work on current open problems suggested by businesses through class projects and hackathons. Finally, both programs place a specific emphasis on training in STEM fields.

Ingredients of Education for Innovation

Each of these ingredients in training for innovation has at least suggestive support in existing economic studies of innovation and entrepreneurship. Bell et al. (2019) find that young people who grow up in a neighborhood with more inventors are more likely to later become inventors themselves, and they are more likely to innovate in the same fields represented by inventors in their early neighborhoods. Girls are more likely to go on to innovate in the same fields as female inventors in their neighborhoods, but not more likely to follow in the fields of local male inventors. Bell et al. interpret these findings as evidence that neighbors are not just affecting general human capital accumulation (through, for example, higher quality schools), but also sharing specific knowledge and mentorship. Lerner and Malmendier (2013) find that Harvard Business School graduates who interacted with more former entrepreneurs during school were more likely to succeed if they started businesses in the future, providing further support for the importance of learning some soft skills directly from active entrepreneurs.

There is also outside evidence on the importance of exposure to open questions. Chatterji (2009) and many others document that past experience in incumbent firms in the same industry improves entrepreneurial success. While industry experience provides specific skills, helping would-be innovators reach the current frontier of knowledge, it may also surface the kinds of open questions that successful innovations can answer. Koning, Samila, and Ferguson (2020) find that female medical researchers are significantly more likely than male researchers to patent innovative treatments for female diseases and conditions, which may reflect different priorities but

2. Top colleges are from the data that Bell et al. (2019) released with their paper. Counts are full-time undergraduate enrollment in Fall 2018, from the Integrated Postsecondary Education Data System (US Department of Education, National Center for Education Statistics 2018).

again reinforces that innovators must identify an open problem before they can solve it.

As the authors discuss in their chapter, several studies find persuasive evidence that increases in STEM training, such as increased vocational and technical secondary education in Italy (Bianchi and Giorcelli 2020) and expanded engineering training in Finland (Toivanen and Väänänen 2016), generate increases in patenting. The current patent system is better designed to protect innovations in the sciences than in, for example, business operations. These studies may therefore partially capture a transfer of talent and energy from fields where innovations are not captured by patents to fields where they are. However, these are also fields where computerization has rapidly expanded the frontier of what is possible and created entire new fields, with well-documented increases in the demand for workers trained in these areas by incumbent firms. It is reasonable to believe that this training is also particularly valuable for entrepreneurs in this era.

A Role for Vocational Training

Bringing curricula that develop entrepreneurial skills to more colleges, and particularly to secondary schools, would do at least as much to capture more would-be innovators as improving equitable access to the elite, but small, institutions that already target these skills. Technical and vocational curricula, which have declined recently in the US but remain common in many European countries, would seem to be a good environment for this training. Most US high school students follow an academic curriculum, which emphasizes abstract thinking and general knowledge, such as mathematics and writing in preparation for college course work. In contrast, vocational tracks teach applied and often technical skills, providing applied, subject-specific knowledge that is otherwise not available until post-secondary schooling (figure 12.C.1). Increasingly, European vocational tracks emphasize apprenticeships and direct links with active businesses (Hampf and Woessmann 2016). These kinds of curricula could provide all three ingredients for innovation: a focus on technical STEM subjects, mentorship from innovators, and exposure to open questions.

Vocational training lost popularity in the US partially from a perception that multiple tracks would tend to segregate low-income, non-white, and lower-performing students into applied curricula without strong earning prospects while preserving the path to affluence through academic training and college for more privileged students. However, there is growing interest among policymakers, academics, and the public for thoughtfully designed, high-quality technical training in secondary school.[3] Renewal of these pro-

3. See Jacob (2017) for a survey of recent academic work, and a cry for more attention, or Belkin's (2018) *Wall Street Journal* article for an example of public interest.

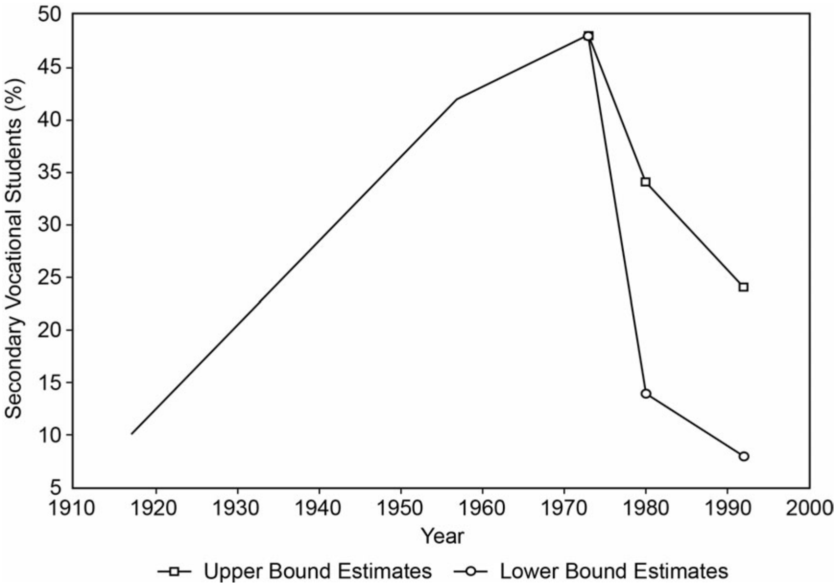

Fig. 12.C.1 Share of US secondary school students in vocational tracks
Source: Alon (2018) "Earning More by Doing Less: Human Capital Specialization and the College Wage Premium." Lower and upper bounds indicate more or less restrictive definitions of vocational curriculums.

grams could include opportunities to switch tracks, commitment to high-quality training, and an awareness of the potential of these programs to reinforce inequalities rather than mitigating them.

I know of no research that estimates the effects of vocational secondary school curricula on business starts or innovation, but several papers find generally positive effects on labor market outcomes (Jacob 2017). In one recent example, Bertrand, Mogstad, and Mountjoy (2019) study a reform in Norway that improved that country's vocational secondary school track, including adding apprenticeships, and led to increased enrollment. They estimate that entering vocational training generates a noticeable increase in post-school earnings, particularly for men, who were more likely to choose the more technical fields of that training. One aspect of the reform allowed students to convert from a vocational track to an academic one, which enabled them to go on to college, but the earnings gains are not a result of men taking this opportunity. This result suggests that vocational training teaches skills that are distinct from those learned in college but still valuable in the labor market.

Bertrand, Mogstad, and Mountjoy (2019) also find that enrollment in Norway's vocational secondary school track reduced criminal charges during students' teenage years, presumably because they were more occupied with school, and modestly increased secondary school completion. Creating strong vocational secondary school options appears to engage students who are otherwise on the margin of dropping out or engaging in illegal activities that would hamper future work. Potential innovators may particularly benefit from these alternative paths through secondary school. Levine and Rubinstein (2017) find that the most successful entrepreneurs have both high cognitive skills and a higher likelihood of having engaged in petty criminal behaviors (i.e., vandalism) in high school. Providing opportunities for creative thinking and applied problem solving early could generate the extra benefit of catching outside-the-box thinkers before they drift out of the system. Exploring the potential for well-designed vocational training to increase innovation would be a valuable area for future research.

References

Alon, Titan. 2018. "Earning More by Doing Less: Human Capital Specialization and the College Wage Premium." Unpublished manuscript.

Belkin, Douglas. 2018. "Why an Honors Student Wants to Skip College and Go to Trade School." *Wall Street Journal*, March 5. https://www.wsj.com/articles/college-or-trade-school-its-a-tough-call-for-many-teens-1520245800.

Bell, Alex, Raj Chetty, Xavier Jaravel, Neviana Petkova, and John Van Reenen. 2019. "Who Becomes an Inventor in America? The Importance of Exposure to Innovation." *Quarterly Journal of Economics* 134(2): 647–713.

Bertrand, Marianne, Magne Mogstad, and Jack Mountjoy. 2019. "Improving Educational Pathways to Social Mobility: Evidence from Norway's 'Reform 94.'" NBER Working Paper No. 25679. Cambridge, MA: National Bureau of Economic Research.

Bianchi, Nicola, and Michela Giorcelli. 2020. "Scientific Education and Innovation: From Technical Diplomas to University STEM Degrees." *Journal of the European Economic Association* 18(5): 2608–46.

Chatterji, Aaron K. 2009. "Spawned with a Silver Spoon? Entrepreneurial Performance and Innovation in the Medical Device Industry." *Strategic Management Journal* 30(2): 185–206.

Hampf, Franziska, and Ludger Woessmann. 2016. "Vocational vs. General Education and Employment over the Life-Cycle: New Evidence from PIAAC." CESifo Working Paper Series No. 6116. Munich: CESifo.

Jacob, Brian. 2017. "What We Know about Career and Technical Education in High School." Technical Report. Washington, DC: Brookings Institution.

Koning, Rembrand, Sampsa Samila, and John-Paul Ferguson. 2020. "Inventor Gender and the Direction of Invention." *AEA Papers and Proceedings* 110: 250–54.

Lerner, Josh, and Ulrike Malmendier. 2013. "With a Little Help from My (Random) Friends: Success and Failure in Post-Business School Entrepreneurship." *Review of Financial Studies* 26(10): 2411–52.

Levine, Ross, and Yona Rubinstein. 2017. "Smart and Illicit: Who Becomes an Entrepreneur and Do They Earn More?" *Quarterly Journal of Economics* 132(2): 963–1018.

Read, Max. 2019. "How to Major in Unicorn." *New York Magazine*, September 4. https://nymag.com/intelligencer/2019/09/how-to-network-through-stanford-university.html.

Solomon, Shoshanna. 2019. "Technion Fosters Entrepreneurship within Ivory Towers as Startup Nation Calls." *Times of Israel*, December 25. https://www.timesofisrael.com/technion-fosters-entrepreneurship-within-ivory-towers-as-startup-nation-calls/.
Toivanen, Otto, and Lotta Väänänen. 2016. "Education and Invention." *Review of Economics and Statistics* 98(2): 382–96.
US Department of Education, National Center for Education Statistics. 2018. Integrated Postsecondary Education Data System (IPEDS). Four-Year Institutions. Accessed June 12, 2020. https://nces.ed.gov/ipeds/.

Panel Remarks
Creating "Smart" Policy to Promote Entrepreneurship and Innovation

Karen G. Mills and Annie V. Dang

Introduction

In 2011, as the US was emerging from the Great Recession, a group of experienced entrepreneurs started a new company seeking to solve the pain points small businesses faced in accessing capital, barriers only exacerbated during the crisis as traditional bank lenders tightened credit to smaller firms. The company, named Kabbage, went on to become one of the most valuable financial technology or "fintech" companies, originating almost $8 billion in loans and attaining unicorn status with a $1.2 billion valuation by the end of 2019. Initially launched as a single loan product for eBay sellers, Kabbage expanded to offer fully automated online financing to small businesses, including a purchasing card, payment-processing solution, and cash flow management tool. Using artificial intelligence, machine learning, and Big Data to power internal loan underwriting algorithms, Kabbage successfully targeted a market segment that had been ill served by the traditional banking industry, while using innovative techniques to speed the lending process, manage risk, and hone the accuracy of its predictive models.

Kabbage's meteoric success story is every entrepreneur's dream, but it

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is not representative of a typical business owner's experience in the US. About half of small businesses fail within 5 years of starting (US Small Business Administration Office of Advocacy 2019). Moreover, the past several decades have witnessed a concerning decrease in startup rates and a general fear that entrepreneurship in America is not what it once was, with the share of US employment accounted for by young firms decreasing by 30 percent over the past 30 years (Decker et al. 2014). Numerous academics, economists, and policymakers have attempted to pinpoint the causes of this unsettling trend, but no definitive answer yet exists.

Why are the numbers so concerning? Research identifies entrepreneurship as key to unlocking innovation and fostering regional and national economic productivity (Acemoglu et al. 2013; Decker et al. 2014; Lerner 2020; Van Praag and Versloot 2007). Although scholars may disagree on the most accurate measures (inputs vs. outputs) of innovation (e.g., proportion of budget spent on research and development vs. patent citations or the introduction of new and meaningful products and technologies), there is general agreement that entrepreneurship has a positive effect on employment, productivity, and growth at the national and local levels.

Extensive studies demonstrate that small and young firms contribute to innovation and employment growth (Almeida and Kogut 1997; Fritsch and Mueller 2004; Haltiwanger, Jarmin, and Miranda 2013; Henrekson and Johansson 2010). The question is: Which businesses are responsible for what kind of contribution? In the US, small businesses form an important part of the national economy, comprising a significant portion of total firms (31.7 million businesses, equaling 99.9 percent of all firms), markedly contributing to employment (47.1 percent of private sector employees), and representing two out of every three net new jobs (US Small Business Administration Office of Advocacy 2020). However, behind these numbers lies a great deal of heterogeneity. As defined by the US Small Business Administration (SBA), a small business is any independent business with fewer than 500 employees. Of the 30 million small businesses, 24.8 million or 81 percent are sole proprietorships—businesses without any employees. Efforts examining the remaining "employer" small businesses underscore the massive variation among small firms in the US (Chatterji 2018; Guzman and Stern 2019; Mills 2019), particularly highlighting the difference between local firms and the fledgling innovative startups that will grow to become the next technology behemoths.

A recent categorization (Delgado and Mills 2020; Mills 2019; see figure P.1) shows that of the 6 million US small businesses with employees, approximately 4 million operate in the local business-to-consumer (B2C) economy, firms conventionally labeled as "Main Street" businesses. These are the restaurants, coffee shops, dry cleaners, and other local businesses that make up the fabric of our communities. Another 1.1 million are supplier businesses, those that operate in the supply chain and traditionally sell

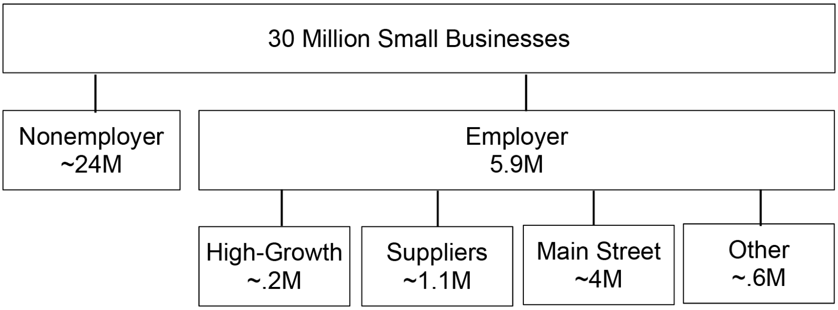

Fig. P.1 Types of small businesses
Source: Mills (2019). Reproduced with permission of Palgrave Macmillan.

to other businesses (B2B) or to the government. Only a small proportion of America's 30 million small businesses—an estimated 200,000—are high-growth startups like Kabbage, generally viewed as the entrepreneurial source of transformative innovation.

The heterogeneity of America's small businesses has led to some confusion and missteps in policy circles regarding the best strategies to promote entrepreneurship and innovation. Many policies that create ideal conditions for large businesses to innovate (such as R&D tax credits) are often less effective for smaller firms. And it has become increasingly evident that small business policies for local Main Street businesses require a different template from actions that support the much smaller number of high-growth innovative firms, such as those that flourish in Silicon Valley and other technology ecosystems. This sliver of high-potential firms requires specially designed, nuanced policies that fuel high-growth entrepreneurship and target innovation (Aulet and Murray 2013).

Policy Playbook for High-Growth Entrepreneurship

In the face of declining startup rates and fears of sinking economic dynamism in the US, both federal and local governments have increased their focus on encouraging entrepreneurship. Some locales have centered their economic development strategies on luring large innovative corporations by offering millions of dollars in tax breaks and other incentives, as seen by Amazon's well publicized and much debated search for a second headquarters (Mills and Rivkin 2018). The hope is that these anchor companies will create an innovation center of gravity and spur other companies to move to or start up in the area. Over the past several decades, state and local governments have pledged significant resources to target these large incumbent firms, with some estimates putting the total amount of incentives at $45 billion annually, tripling in size from 1990 to 2015 (Bartik 2018).

	High-Growth Firms	Main Street Businesses
Access to Capital	• Angel and R&D Tax Credits • Regional VC Support (SBIC) • SBIR/STTR • Scale-Up Capital • Grants/Business Plan Competitions	• Bank Loan Guarantees (SBA) • Fintech/Challenger Banks • Tax Policy
Advice/Education	• Entrepreneurship, education, and mentorship programs • Startup academies	• Small Business Development Centers/SCORE Advisors
Ecosystems	• Accelerators/Incubators • Clusters	• Main Street Associations • Small Business Saturday

Fig. P.2 Policy options to promote different types of entrepreneurship
Source: Examples from authors' analysis.

In recent years, however, this strategy, sometimes called "elephant hunting," has been replaced or supplemented by a series of policies designed to boost innovation and job creation through the direct encouragement of entrepreneurship. These various government policy efforts tend to fall into three main categories: improving access to capital, delivering entrepreneurship advice and education, and creating entrepreneurial ecosystems (see figure P.2). For each category, the policy options differ significantly depending on the type of small business targeted. The majority of efforts to spur innovation are directed at the smaller segment of high-growth firms, which are expected to deliver the most productivity growth.

Access to Capital

Financing is a key determinant of small business growth and success. Entrepreneurs in new and young firms need capital to build their businesses and pay their employees, purchase inventory and startup equipment, and obtain other resources. Depending on the type of small business, access to capital can come from a host of different sources. Traditional Main Street businesses commonly access financing through banks, ranging from large financial institutions—like Bank of America and JPMorgan Chase—to regional banks, community development financial institutions, and community banks. In contrast, high-growth startups seek financing from entirely different capital markets, looking to venture capital and private equity firms for funding.

Venture capital (VC) is structured as high-risk capital that pursues early-stage entrepreneurial opportunities with high potential for dynamic growth and market disruption. The success rate of investments is low for nearly all VC firms, with only one or two out of every ten portfolio companies accounting for the majority of the returns to a particular fund (Kerr, Nanda, and Rhodes-Kropf 2014; Nicholas 2019; Sahlman 2010). Because expertise and relationships are required to access and evaluate VC deals, funding has historically been unevenly distributed, geographically and demographically. In 2020, 85 percent of VC funding in the US went to companies in just three states—California, Massachusetts, and New York (National Venture Capital Association 2019). Similarly, in 2021, only 15.6 percent of venture money went to fund businesses co-founded by women, with an even smaller 2 percent going to businesses founded solely by women (Pitchbook 2019). From 2013 to 2017, only about 23 percent of VC funding went to minority founders (RateMyInvestor 2019). Recently, some VC firms have sought to remedy such disparities and improve their access to this untapped pool of talent and opportunity by funding larger numbers of diverse founders and increasing diversity among their own investors. Other actors, such as academic institutions, private foundations, and pension funds, are also taking steps to increase their investments in women- and minority-owned funds while diversifying their own investment teams.

Several governments have crafted policy initiatives to address market gaps by growing the amount of and points of access to VC. One approach encourages new risk capital formation by stage, such as through angel capital tax credits[1] (Lerner et al. 2015) and R&D tax credits (Becker 2015) in the US and scale-up capital schemes in the United Kingdom.[2] Other policies have focused on geography, such as the SBA’s Small Business Investment Company program. This initiative funds over 300 small venture and private equity capital providers in geographies where there is less risk capital available for high-growth firms. Federal set-asides from research budgets fund substantial research and innovation grants to small companies through the Small Business Innovation Research and the Small Business Technology Transfer programs. These activities support new entrepreneurs across multiple industries in their discovery and growth phases. Significant opportunity still exists, however, for additional policies that expand access to risk capital for a larger and more diverse set of investors and entrepreneurs.

1. Section 1202 of the US Internal Revenue Code details an exclusion for both angel investors and entrepreneurs, providing 100 percent of tax-free gains up to $10 million. This angel capital tax credit is designed to incentivize investors to finance promising startups as well as to stimulate entrepreneurship by providing an additional viable source of capital.

2. The UK government provides similar tax credits to promote entrepreneurship and investment, including the Enterprise Investment Scheme and the Seed Enterprise Investment Scheme, both of which seek to incentivize the funding of innovative startups through 30 and 50 percent tax breaks, respectively, and up to a capped amount. In addition, Innovate UK, part of UK Research and Innovation, provides funding to innovative businesses (about 2.5 billion pounds since 2007, matched by industry funding).

Advice and Entrepreneurship Education

The second critical area of support for entrepreneurship is the construction of advising networks that help entrepreneurs navigate the highly uncertain world of starting a business. Entrepreneurship education has come to the fore at numerous universities, business schools, and even high schools and continuing adult education programs. There is an insatiable appetite for counseling and advice, particularly from low-cost or free venues, such as Small Business Development Centers or the SCORE counselor network, both of which are supported by the SBA. The SBA also provides resources to underserved and underrepresented entrepreneurs who may face increased barriers to achieving their business goals, through specially targeted Women's Business Centers and Veterans Business Outreach Centers.

Here again, however, high-growth innovative startups tend to seek counsel via distinct tracks, such as specialized boot camps and startup academies geared toward high-tech and innovation-driven entrepreneurs and teams. Founders of high-growth firms can access tailored advice from VC and private equity partners with intimate knowledge of the particular sector they inhabit. They can also reach out to industry peers and build networks of likeminded entrepreneurs and funders in advance of officially launching their product or service, gaining intangible benefits and lessons in management skills, crisis leadership, and goal setting (Chatterji et al. 2018).

Ecosystems

Entrepreneurs learn from one another, as well as from suppliers, customers, universities, and support organizations in their sector or cluster. Just as in other policy areas, ecosystems conducive to helping innovative high-growth entrepreneurs look quite different from communities designed for businesses on Main Street. For the local mom and pop shops in the town square, Main Street business associations and other types of neighborhood commercial alliances provide a valuable source of business counseling and referrals, and they often serve as conduits to the local and regional governments, with an eye toward the advancement of business owner interests.

For high-growth businesses, innovation ecosystems—clusters, incubators, and accelerators—have gained momentum in recent years. Prior studies show the importance of industry clusters in entrepreneurship and economic performance and growth (Delgado, Porter, and Stern 2010, 2016; Porter 1998; Saxenian 1994). Well-known examples of clusters in the US include information technology in Silicon Valley and biopharmaceuticals and medical devices in Boston. By co-locating with similarly focused companies in a particular field, young firms stand to gain agglomeration benefits and externalities, sharing in the technology, skills, knowledge, and innovations facilitated by both their collaborators and competitors (Chinitz 1961; Delgado, Porter, and Stern 2010; Glaeser and Kerr 2009). Clusters also tend to draw large pools of specialized talent, which is especially important as new innovative service businesses require an increasing number of employees in the fields of science, technology, engineering, and math (Delgado and Mills 2020).

The proven efficacy of industry clusters has not been limited to the traditional coastal cities. For example, strong "fintech" clusters have emerged outside the conventional financial hubs of New York City and San Francisco. Kabbage, highlighted earlier, is headquartered in Atlanta, Georgia, which also serves as home to major American credit reporting agency Equifax, bitcoin payment service BitPay, and international payments giant Global Payments, Inc. The wider Atlanta metropolitan area also boasts a major location for financial systems provider Fiserv and an engineering office for payments processor Square.

Entrepreneurs and early-stage companies also gain significant knowledge and value by participating in mentorship programs designed specifically for high-growth startups. Accelerators and incubators, established by both private and public actors, provide young firms with access to mentorship and potential seed funding to test their business models and refine their innovations. These ecosystems also fuel environments where startups can collaborate with other members of their cohort to gain advice from peers and a broader network of investors and mentors. Research has shown the various beneficial effects of accelerators and incubators on regional entrepreneurship and innovation (Gonzales-Uribe and Leatherbee 2017; Hochberg 2016), leading to many levels of government employing them as tools to promote innovation and economic productivity (e.g., MassChallenge in Boston, LAUNCH accelerator by NASA, USAID, and the Department of State).

Conclusion

Kabbage's journey to success has by no means been a completely smooth ride. Although the long-term effects of COVID-19 and the economic downturn remain to be seen, it is clear that companies like Kabbage are not immune to the shocks created by the pandemic. Soon after the US declared a state of emergency due to coronavirus in mid-March of 2020, Kabbage announced it would furlough a significant number of its employees in America and shut down its Bangalore outpost completely. However, Kabbage reorganized and funneled its resources to help small businesses in a different way, setting up a website where customers could purchase gift cards to support their local businesses. It also repurposed its technology to facilitate loans to small businesses through the Paycheck Protection Program authorized by the CARES Act, ultimately becoming the program's second-largest lender by application volume and approving nearly $7 billion in loans through

August 2020. Kabbage was officially acquired by American Express several months later, in October 2020 (de León 2020; Kabbage Newsroom 2020). As illustrated by the nimble actions of Kabbage and many other financial technology companies responding to the coronavirus pandemic, innovation in times of crisis is a hallmark of entrepreneurship, with benefits that are widely distributed.

* * *

America is fortunate to have a strong heritage in both innovation and entrepreneurship. It is part of the national spirit of independence and the belief in economic mobility and the American Dream. Over the past several decades, the US economy has been built on a bedrock of innovations that have dramatically transformed traditional industries, from communications to financial services to Big Tech. However, the preservation of these strengths is far from assured. A relatively small number of high-growth entrepreneurs have been crucial drivers of the nation's innovation and productivity. The continued health of this innovation engine requires supporting a larger and more diverse set of entrepreneurs and investing in targeted ecosystems and policies that close market gaps and give these entrepreneurs the tools they need to grow and prosper.

References

Acemoglu, D., U. Akcigit, H. Alp, N. Bloom, and W. R. Kerr. 2013. "Innovation, Reallocation and Growth." NBER Working Paper No. 18993, revised November 2017. Cambridge, MA: National Bureau of Economic Research.

Almeida, P., and B. Kogut. 1997. "The Exploration of Technological Diversity and the Geographic Localization of Innovation." *Small Business Economics* 9: 21–31.

Aulet, B., and F. Murray. 2013. "A Tale of Two Entrepreneurs: Understanding Differences in the Types of Entrepreneurship in the Economy." Kauffman Foundation Working Paper. Kansas City, MO: Kauffman Foundation.

Bartik, T. J. 2018. "Who Benefits from Economic Development Incentives? How Incentive Effects on Local Incomes and the Income Distribution Vary with Different Assumptions about Incentive Policy and the Local Economy." Upjohn Institute Technical Report No. 18-034. Kalamazoo, MI: Upjohn Institute.

Becker, B. 2015. "Public R&D Policies and Private R&D Investment: A Survey of the Empirical Evidence." *Journal of Economic Surveys* 29(5): 917–42.

Chatterji, A. K. 2018. *The Main Street Fund: Investing in an Entrepreneurial Economy*. Washington, DC: Brookings Institution, The Hamilton Project.

Chatterji, A. K., S. Delecourt, S. Hasan, and R. M. Koning. 2018. "When Does Advice Impact Startup Performance?" NBER Working Paper No. 24789. Cambridge, MA: National Bureau of Economics Research.

Chinitz, B. 1961. "Contrasts in Agglomeration: New York and Pittsburgh." *American Economic Review* 51(2): 279–89.

Decker, R., J. Haltiwanger, R. Jarmin, and J. Miranda. 2014. "The Role of Entrepreneurship in US Job Creation and Economic Dynamism." *Journal of Economic Perspectives* 28(3): 3–24.

de León, R. 2020. "American Express Acquiring Small Business lender Kabbage." CNBC. Accessed January 4, 2021. https://www.cnbc.com/2020/08/17/american-express-acquiring-small-business-lender-kabbage.html.

Delgado, M., and K. G. Mills. 2020. "The Supply Chain Economy: A New Industry Categorization for Understanding Innovation in Services." *Research Policy* 49(8): 104039.

Delgado, M., M. E. Porter, and S. Stern. 2010. "Clusters and Entrepreneurship." *Journal of Economic Geography* 10(4): 495–518.

———. 2016. "Defining Clusters of Related Industries." *Journal of Economic Geography* 16(1): 1–38.

Fritsch, M., and P. Mueller. 2004. "Effects of New Business Formation on Regional Development over Time." *Regional Studies* 38(8): 961–75.

Glaeser, E. L., and W. R. Kerr. 2009. "Local Industrial Conditions and Entrepreneurship: How Much of the Spatial Distribution Can We Explain?" *Journal of Economics & Management Strategy* 18(3): 623–63.

Gonzalez-Uribe, J., and M. Leatherbee 2018. "The Effects of Business Accelerators on Venture Performance: Evidence from Start-Up Chile." *Review of Financial Studies* 31(4): 1566–1603.

Guzman, J., and S. Stern. 2016. "The State of American Entrepreneurship: New Estimates of the Quality and Quantity of Entrepreneurship for 32 US States, 1988–2014." NBER Working Paper No. 22905, revised July 2019. Cambridge, MA: National Bureau of Economic Research.

Haltiwanger, J., R. S. Jarmin, and J. Miranda. 2013. "Who Creates Jobs? Small Versus Large Versus Young." *Review of Economics and Statistics* 95(2): 347–61.

Henrekson, M., and D. Johansson. 2010. "Gazelles as Job Creators: A Survey and Interpretation of the Evidence." *Small Business Economics* 35: 227–44.

Hochberg, Y. V. 2016. "Accelerating Entrepreneurs and Ecosystems: The Seed Accelerator Model." *Innovation Policy and the Economy* 16: 25–51.

Kabbage Newsroom. 2019. "Start Spreading the News: Kabbage Joins American Express." Accessed January 4, 2021. https://newsroom.kabbage.com/news/kabbage-to-join-american-express/.

Kerr, W. R., R. Nanda, and M. Rhodes-Kropf. 2014. "Entrepreneurship as Experimentation." *Journal of Economic Perspectives* 28(3): 25–48.

Lerner, J. 2020. "Government Incentives for Entrepreneurship." Forthcoming in *Innovation and Public Policy*, edited by A. Goolsbee and B. Jones. Chicago: University of Chicago Press.

Lerner, J., A. Schoar, S. Sokolinski, and K. Wilson. 2015. "The Globalization of Angel Investments: Evidence Across Countries." NBER Working Paper No. 21808. Cambridge, MA: National Bureau of Economic Research.

Mills, K. G. 2019. *Fintech, Small Business & the American Dream*. Cham, Switzerland: Palgrave Macmillan.

Mills, K. G., and J. Rivkin. 2018. Amazon's HQ2 (A). Harvard Business School Case 718-494. Revised August 2019. Boston: Harvard Business School.

National Venture Capital Association. 2021. *NVCA 2019 Yearbook*. Washington, DC: National Venture Capital Association.

Nicholas, T. 2019. *VC: An American History*. Cambridge, MA: Harvard University Press.

Pitchbook. 2021. "The VC Female Founders Dashboard." Accessed October 14, 2021. https://pitchbook.com/news/articles/the-vc-female-founders-dashboard.

Porter, M. E. 1998. "Clusters and Competition: New Agendas for Companies, Governments, and Institutions." In *On Competition*, edited by M. E. Porter, 197–299. Boston: Harvard Business School Publishing.
RateMyInvestor, DiversityVC. 2019. "Diversity in U.S. Startups." Accessed May 11, 2020. https://ratemyinvestor.com/DiversityVCReport_Final.pdf.
Sahlman, W. A. 2010. "Risk and Reward in Venture Capital." Background Note 811-036. Boston: Harvard Business School.
Saxenian, A. 1994. *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*. Cambridge, MA: Harvard University Press.
US Small Business Administration Office of Advocacy. 2019. Survival Rates and Firm Age. https://www.sba.gov/sites/default/files/SurvivalRatesAndFirmAge_ADA_0.pdf.
———. 2020. Frequently Asked Questions. https://cdn.advocacy.sba.gov/wp-content/uploads/2020/11/05122043/Small-Business-FAQ-2020.pdf.
Van Praag, M., and P. H. Versloot. 2007. "What Is the Value of Entrepreneurship? A Review of Recent Research." *Small Business Economics* 29: 351–82.

Panel Remarks
Measuring Business Innovation Using a Multidimensional Approach

Lucia Foster

Advancing the US Census Bureau's mission "to serve as the nation's leading provider of quality data about its people and economy" requires a robust and agile research and development (R&D) program working in close collaboration with external experts and Census Bureau programmatic staff. Even straightforward concepts, such as the use of industrial robotics in manufacturing, can require a multidimensional measurement approach. While the Census Bureau is known for its surveys, some of our most innovative work combines survey data with administrative data or combines multiple sources of administrative data.

Here I discuss the multidimensional R&D approach that the Center for Economic Studies (CES) at the Census Bureau takes in attempting to better understand business innovation.[1] Since it is not possible to provide details on these many interrelated efforts, I highlight our multidimensional approach by giving examples of research using administrative data, survey data, and

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1. Jarmin (2019) discusses enhancing and improving economic measurement at the Census Bureau.

indirect inference. A more complete view of CES research activities is provided in our annual reports and working paper series.[2]

Context

Census is one of 13 principal statistical agencies in the US. The missions of these other agencies are often complementary to the Census mission and hence one important activity of CES is outreach to other agencies to partner on topics of mutual interest. When the topic is innovation, we often partner with the National Center for Science and Engineering Statistics (NCSES), but we also partner with other federal agencies, state governments, and other institutions (such as universities). Further, we work with individuals, especially academic experts, to help us improve our measures of the US economy and its people. Many of these researchers conduct work through one of the 30 locations in the Federal Statistical Research Data Center (FSRDC) system.[3] Most of the examples given below are based on research conducted with academic experts.

In all this work, we support U.S.C. Title 13, which allows the use of microdata to provide a benefit to the Census Bureau with conditions to protect the confidentiality of our respondents. Operationally, this pledge of confidentiality may constrain the granularity of publicly available information. For research questions that cannot be answered using published data, researchers can apply to use the data through the FSRDC system.

Measuring Business Innovation Using Administrative Data

I start by describing two large R&D projects attempting to measure innovation using administrative data: the Business Dynamics Statistics for Patenting Firms (BDS-PF) and the Innovation Measurement Initiative (IMI). Together they represent the collection and use of administrative data from the federal government, state governments, and universities, and they demonstrate our collaborations with academic researchers.

The Business Dynamics Statistics (BDS) program provides annual information for the US non-farm economy on firm startups and shutdowns, establishment entry and exit, and job creation and destruction. Core data for the BDS come from the Census Bureau's business frame, which relies heavily on federal administrative data.[4] CES has embarked on a multi-year project to enhance the BDS to include a series of indicators enabling us to provide information on business dynamics by firm characteristics, including

2. See https://www.census.gov/programs-surveys/ces/research.html.
3. See https://www.census.gov/fsrdc.
4. Researchers at CES developed the Longitudinal Business Database from the business frame (Jarmin and Miranda 2002; Chow et al. 2021), and the BDS is the public product derived from the Longitudinal Business Database.

globalization (exporting, importing, and multinational), human capital (of workers and owners), and innovation (patents, trademarks, R&D expenditures, and other inputs or outcomes of innovative activities). This section focuses on the component of the innovation project identifying firms that patent (BDS-PF).[5]

Multiple research teams have linked patent data to Census business data. An early part of the BDS-PF included a collaboration between the Census Bureau and US Patent and Trademark Office (USPTO). This team improved on the existing linkage (previously done through linking assignee information from patent documents to the business register) by incorporating additional inventor information from the same patent documents linked to the Longitudinal Employer-Household Dynamics (LEHD) data. The LEHD data rely on administrative jobs data from state agencies, federal agencies, and the Quarterly Census of Employment and Wages provided by states (Abowd et al. 2009). The researchers triangulate these two independent sources of information (assignees and inventors) to link granted patents to their firm owners, allowing them to substantially improve match rates over earlier studies (Graham et al. 2018).

The latest research at Census for the BDS-PF focuses on patents related to artificial intelligence (AI) and uses natural language processing and machine learning to conduct this research. While the USPTO classifies the technologies embedded in patents according to preexisting classification systems with hundreds of classes and thousands of subclasses, Alderucci et al. (2019) argue that using these and/or keywords will miss much potential AI use, since AI is becoming a general-purpose technology. Alderucci et al. (2019) train a machine learning algorithm to identify 52,000 AI-related patents (or up to 140,000 patents using a looser definition), which, they note, is about 3 to 10 times the number of AI patents first identified by Cockburn, Henderson, and Stern (2019). The same methodology can potentially be applied across other technology fields.

An entirely different set of metrics comes from the joint IMI, which links Census data to the Institute for Research on Innovation and Science (IRIS) UMETRICS data from universities on federally sponsored research at the project level. The IRIS data include project-level financial transactions, such as payments to internal personnel, payments to outside vendors, and payments to contractors as part of sub-awards. As Lane et al. (2018) note in their overview of the IMI project, the IRIS builds on long-running efforts to demonstrate the innovation flowing from federally funded R&D.

IRIS currently includes over 30 universities with the goal of partnering with 150 universities (IRIS targets every university with at least $100 million in R&D). The data include 392,000 funded awards covering 643,000 research

5. Goldschlag and Perlman (2017) provide an overview of the larger project, Business Dynamics of Innovative Firms.

employees, $84 billon in award spending, and $61 billion in vendor and subcontract spending.[6] Dissemination of results from this project currently occurs in three ways: research papers, research datasets for qualified users on approved projects, and two quarterly reports (a vendor report and an employee report) at the campus level for participating universities. Additionally, Census and IRIS are developing other publicly available data products.

Researchers have combined the IMI data with Census datasets to examine such subjects as the gender gaps in science, technology, engineering, and mathematics (STEM) occupations (Buffington et al. 2016), outcomes of PhD recipients (Zolas et al. 2015), and the impact of workers' research experience on new firm outcomes. For the latter, Goldschlag et al. (2021) link the employee data with Census data on startups to look at the link between research experience and young firm outcomes, including survival, growth, and innovation. They find that workers' research experience is correlated with an "up-or-out" firm dynamic (negatively correlated with survival, but conditional on survival, and positively correlated with growth) and with innovative activities (as measured by patent and trademark filings).

Measuring Business Innovation Using Survey Data

To understand technology adoption and diffusion, we turn to survey data. The Annual Business Survey (ABS) is a relatively new survey (starting with reference year 2017) and represents a partnership between Census and NCSES. This firm-level survey covers all sectors of the non-agricultural economy.[7] The ABS 2018 was mailed to about 850,000 firms (about 560,000 firms responded) and includes sections on innovation (16 questions), technology (three questions), and intellectual property (four questions). My focus is on the three questions in the technology section.

These three questions concern the digital share of business activity (digitization), cloud service purchases, and advanced business technologies for reference year 2017. The digitization question asks firms for the extent to which certain information types (such as personnel or financial data) are stored in digital format. Similarly, the cloud services purchases question asks firms about which of their information technology functions in eight different areas (such as servers and data storage) are stored in the cloud. The third question asks directly about the testing or use of nine advanced business technologies (for example, machine learning, natural language processing, and robotics).

The survey results suggest that adoption of digitization is widespread, with the use of cloud computing being less so, and adoption of many of the advanced technologies still in their infancy (Zolas et al. 2020). We find nearly

6. For more information, see: https://iris.isr.umich.edu.

7. See also the Business Research and Development and Innovation Survey and the Annual Survey of Entrepreneurs.

70 percent of the firms have adopted some form of digitization (mainly for personnel and financial information), while more than 50 percent of firms report either no cloud purchases or that they are not necessary. Turning to advanced technologies, we find that 2.2 percent of respondents are using machine learning and less than 1 percent are testing its use.

Looking forward, the ABS 2019 has two sections especially relevant for innovation. The "Products and Processes" section has nine questions concerning new or improved goods, services, and business processes. Follow-up questions further distinguish between "new to the business" and "new to the market." The "Technology and Workforce" section has 32 questions about workforce composition and demand, and five advanced technologies (including AI, robotics, and specialized software). Researchers interested in innovation may find the question concerning factors prohibiting technology adoption and utilization in production especially interesting. At the time of this writing, the responses from the 300,000 firms surveyed have been collected and are being processed.

Applying Indirect Inference to Identify Innovative Activities

Given the challenges associated with measuring innovation directly, the last approach relies on indirect inference to identify areas in the economy with innovative activity. Using micro-level data on productivity growth and business entry and exit, Foster et al. (2021) identify patterns in these dynamics that are suggestive of innovative activity. We build on the stages of firm dynamics in response to innovation developed by Gort and Klepper (1982) which we summarize as: innovation leads to a burst of business entry, which is followed by experimentation and adoption, and ultimately a period in which businesses who have successfully responded to the innovation grow while those that have not, shrink and exit.

Foster et al. (2021) apply findings from the literature on the importance of reallocation for aggregate productivity growth to these stages of firm dynamics. Thus, following an innovation, we expect to see business entry, which leads to productivity dispersion as businesses experiment, then rising productivity growth as some businesses become more productive and resources reallocate toward successful businesses. Eventually, productivity dispersion compresses as the sector matures and settles down. Their analysis comparing outcomes of high-tech versus non-high-tech industries suggests that these patterns may be useful guides when looking for industries with innovation.

Conclusion

The Census microdata referenced here are available for qualified researchers on approved projects through the FSRDC system. The CES Working Paper Series and Technical Working Paper series include many papers documenting various Census surveys and research data sets. As these panel remarks have made clear, the Census Bureau leverages its partnership with academic experts to continually improve our measures of our nation's people and economy. Understanding innovation is a critical component in this work, and perhaps these panel remarks will inspire more researchers to utilize the FSRDC network to help us better understand business innovation.

References

Abowd, John M., Bryce E. Stephens, Lars Vilhuber, Fredrik Andersson, Kevin L. McKinney, Marc Roemer, and Simon D. Woodcock. 2009. "The LEHD Infrastructure Files and the Creation of the Quarterly Workforce Indicators." In *Producer Dynamics: New Evidence from Micro Data*, edited by Timothy Dunne, J. Bradford Jensen, and Mark J. Roberts, 149–230. Studies in Income and Wealth Vol. 68. Chicago: University of Chicago Press.

Alderucci, Dean, Lee Branstetter, Eduard Hovy, Andrew Runge, and Nikolas Zolas. 2019. "Quantifying the Impact of AI on Productivity and Labor Demand: Evidence from U.S. Census Microdata." Presented at Poster Session at 2019 NBER Summer Institute on IT and Digitization.

Buffington, Catherine, Benjamin Cerf, Christina Jones, and Bruce Weinberg. 2016. "STEM Training and Early Career Outcomes of Female and Male Graduate Students: Evidence from UMETRICS Data Linked to the 2010 Census." *American Economic Review: Papers and Proceedings* 106: 333–38.

Chow, Melissa, Teresa C. Fort, Christopher Goetz, Nathan Goldschlag, James Lawrence, Elisabeth Ruth Perlman, Martha Stinson, and T. Kirk White. (2021). "Redesigning the Longitudinal Business Database." Working Paper 21-08, Center for Economic Studies, US Census Bureau.

Cockburn, Iain, Rebecca Henderson, and Scott Stern. 2019. "The Impact of Artificial Intelligence on Innovation: An Exploratory Analysis." In *The Economics of Artificial Intelligence: An Agenda*, edited by Ajay Agrawal, Joshua Gans, and Avi Goldfarb, 115–46. Chicago: University of Chicago Press.

Foster, Lucia, Cheryl Grim, John Haltiwanger, and Zoltan Wolf. 2021. "Innovation, Productivity Dispersion, and Productivity Growth." In *Measuring and Accounting for Innovation in the Twenty-First Century*, edited by Carol Corrado, Jonathan Haskel, Javier Miranda, and Daniel Sichel, 103–36. Chicago: University of Chicago Press.

Goldschlag, Nathan, and Elisabeth Perlman. 2017. "Business Dynamics of Innovative Firms." Center for Economic Studies Working Papers 17–72. Washington, DC: US Census Bureau.

Goldschlag, Nathan, Ron Jarmin, Julia Lane, and Nikolas Zolas. 2021. "Research Experience as Human Capital in New Business Outcomes." In *Measuring and Accounting for Innovation in the Twenty-First Century*, edited by Carol Corrado, Jonathan Haskel, Javier Miranda, and Daniel Sichel, 229–54. Chicago: University of Chicago Press.

Gort, Michael, and Steven Klepper. 1982. "Time Paths in the Diffusion of Product Innovations." *Economic Journal* 92(367): 630–53.

Graham, Stuart J., Cheryl Grim, Tariqul Islam, Alan C. Marco, and Javier Miranda.

2018. "Business Dynamics of Innovating Firms: Linking US Patents with Administrative Data on Workers and Firms." *Journal of Economics and Management Strategy* 27(3): 372–402.

Jarmin, Ron S. 2019. "Evolving Measurement for Evolving Economy: Thoughts on 21st Century US Economic Statistics." *Journal of Economic Perspectives* 33(1): 165–84.

Jarmin, Ron, and Javier Miranda. 2002. "The Longitudinal Business Database." Center for Economic Studies, Working Paper 02-17. Washington, DC: US Census Bureau.

Lane, Julia, Jason-Owen Smith, Joseph Staudt, and Bruce Weinberg. 2018. "New Measurement of Innovation." In *Center for Economic Studies and Research Data Centers Research Report*: *2017*. Washington, DC: US Census Bureau.

Zolas, Nikolas, Nathan Goldschlag, Ron Jarmin, Paula Stephan, Jason Owen-Smith, Rebecca F. Rosen, Barbara McFadden Allen, Bruce A. Weinberg, and Julia I. Lane. 2015. "Wrapping It Up in a Person: Examining Employment and Earnings Outcomes for Ph.D. Recipients." *Science* 350(6266): 1367–1371.

Zolas, Nikolas, Zachary Kroff, Erik Brynjolfsson, Kristina McElheran, David Beede, Catherine Buffington, Nathan Goldschlag, Lucia Foster, and Emin Dinlersoz. 2020. "Advanced Technologies Adoption and Use by U.S. Firms: Evidence from the Annual Business Survey." Center for Economic Studies Working Paper 20-40, US Census Bureau.