

This PDF is a selection from a published volume from the National Bureau of Economic Research

Volume Title: The Role of Innovation and Entrepreneurship in Economic Growth

Volume Authors/Editors: Michael J. Andrews, Aaron Chatterji, Josh Lerner, and Scott Stern, editors

Volume Publisher: University of Chicago Press

Volume ISBNs: 978-0-226-81078-2 (cloth),
978-0-226-81064-5 (electronic)

Volume URL:

<https://www.nber.org/books-and-chapters/role-innovation-and-entrepreneurship-economic-growth>

Conference Date: January 7-8, 2020

Publication Date: February 2022

Chapter Title: Education and Innovation

Chapter Author(s): Barbara Biasi, David Deming, Petra Moser

Chapter URL:

<https://www.nber.org/books-and-chapters/role-innovation-and-entrepreneurship-economic-growth/education-and-innovation>

Chapter pages in book: p. 537 – 551

Education and Innovation

Barbara Biasi, David Deming, and Petra Moser

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

Barbara Biasi is an assistant professor of economics at Yale School of Management, and a faculty research fellow of the National Bureau of Economic Research.

David Deming is a professor of public policy at Harvard University, and a research associate of the National Bureau of Economic Research.

Petra Moser is a professor of economics and Jules I. Backman Faculty Fellow at New York University, and a research associate of the National Bureau of Economic Research.

This chapter was prepared for NBER Growth Conference “Beyond 140 Characters: The Role of Innovation and Entrepreneurship in Economic Growth.” We are grateful for valuable comments from Eleanor Dillon, as well as from conference participants and our editors Aaron Chatterji, Josh Lerner, Scott Stern, and Michael J. Andrews. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research. For acknowledgments, sources of research support, and disclosure of the author’s or authors’ material financial relationships, if any, please see <https://www.nber.org/books-and-chapters/role-innovation-and-entrepreneurship-economic-growth/education-and-innovation>.

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

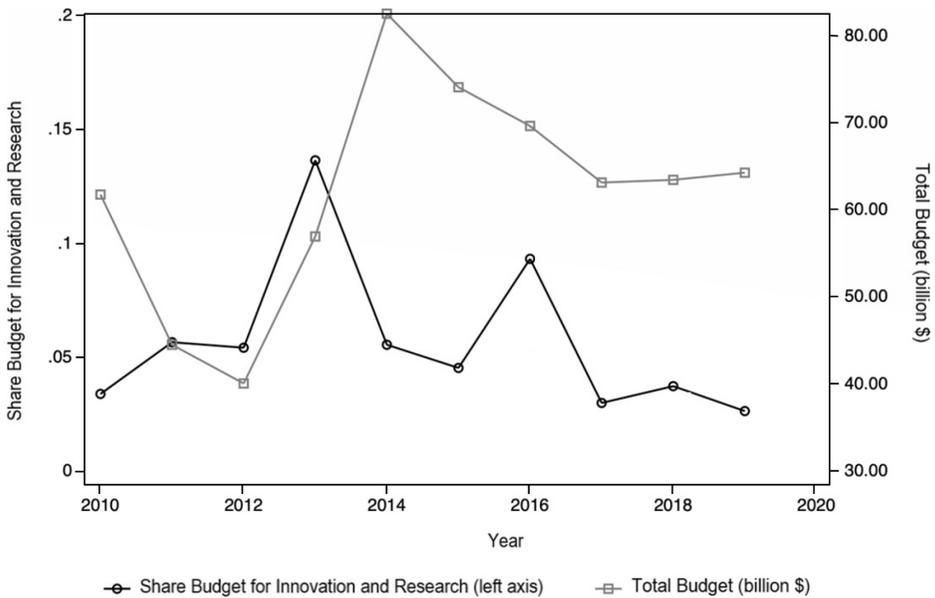


Fig. 12.1 Department of Education's total budget and share earmarked for innovation

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 Toivanen. 2017. “The Social Origins of Inventors.” NBER Working Paper No. 24110. Cambridge, MA: National Bureau of Economic Research.
- Akcigit, Ufuk, Santiago Caicedo, Ernest Migueluez, 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 Reenen. 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 Rootzet. 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. Easley. 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

Eleanor Wiske Dillon is a principal economist at Microsoft Research New England.

Thanks to the organizers Aaron Chatterji, Josh Lerner, Scott Stern, and Michael J. Andrews and the chapter authors Barbara Biasi, David Deming, and Petra Moser. For acknowledgments, sources of research support, and disclosure of the author’s material financial relationships, if any, please see <https://www.nber.org/books-and-chapters/role-innovation-and-entrepreneurship-economic-growth/comment-education-and-innovation-dillon>.