Popp, David

Article

Energy and environmental technology

NBER Reporter

Provided in Cooperation with:
National Bureau of Economic Research (NBER), Cambridge, Mass.

Suggested Citation: Popp, David (2015) : Energy and environmental technology, NBER Reporter, National Bureau of Economic Research (NBER), Cambridge, MA, Iss. 4, pp. 13-16

This Version is available at:
https://hdl.handle.net/10419/178716

1999, pp. 22–46, E. Talvi and C. Vegh, "Tax Base Variability and Procyclicality of Fiscal Policy," NBER Working Paper No. 7499, January 2000, and Journal of Development Economics*, 78(1), 2005, pp. 156–90, and A. Alesina and G. Tabellini, "Why is Fiscal Policy Often Procyclical?" NBER Working Paper No. 11600, September 2005, and* Journal of the European Economic Association*, 6(5), 2008, pp. 1006–36.*
Return to text

5 *J. Frankel, C. Vegh, and G. Vuletin, "On Graduation from Fiscal Procyclicality," NBER Working Paper No. 17619, November 2011, and* Journal of Development Economics*, 100(1), 2013, pp. 32–47.*
Return to text

6 *While 2000 is certainly an arbitrary point to break the sample, minor variations do not make a difference.*
Return to text

7 *For a detailed discussion of the Chilean case, see J. Frankel, "A Solution to Fiscal Procyclicality: The Structural Budget Institutions Pioneered by Chile," NBER Working Paper No. 16945, April 2011, and* Journal Economia Chilena*, Central Bank of Chile, 14(2), 2011, pp. 39–78.*
Return to text

8 *J. Frankel, C. Vegh, and G. Vuletin, "On Graduation from Fiscal Procyclicality," NBER Working Paper No. 17619, November 2011, and* Journal of Development Economics*, 100(1), 2013, pp. 32–47.*
Return to text

9 *E. Ilzetzki, E. Mendoza, and C. Vegh, "How Big (Small?) Are Fiscal Multipliers?" NBER Working Paper No. 16479, October 2010, and* Journal of Monetary Economics*, 60(2), 2013, pp. 239–54.*
Return to text

10 *A. Auerbach and Y. Gorodnichenko, "Fiscal Multipliers in Recession and Expansion," NBER Working Paper No. 17447, September 2011, and in A. Alesina and F. Giavazzi, eds.,* Fiscal Policy after the Financial Crisis*, Chicago, Illinois: University of Chicago Press, 2013, pp. 63–98,*
Return to text

11 *D. Riera-Crichton, C. Vegh, and G. Vuletin, "Procyclical and Countercyclical Fiscal Multipliers: Evidence from OECD Countries," NBER Working Paper No. 20533, September 2014, and* Journal of International Money and Finance*, Vol. 52(C), 2015, pp. 15–31.*
Return to text

12 *C. Vegh and G. Vuletin, "The Road to Redemption: Policy Response to Crises in Latin America," NBER Working Paper No. 20675, November 2014, and* IMF Economic Review*, Vol. 62(4), 2014, pp. 526–68.*
Return to text

13 *Recall from Figure 1 that, historically, Greece and Portugal have been the only two industrial countries with procyclical government spending. Further, Figure 2 shows these two countries as "still in school."*
Return to text

14 *C. Vegh and G. Vuletin, "Overcoming the Fear of Free Falling: Monetary Policy Graduation in Emerging Markets," NBER Working Paper no. 18175, June 2012, and in D. Evanoff, C. Holthausen, G. C. Kaufman, and M. Kremer, eds.,* The Role of Central Banks in Financial Stability: How Has It Changed? *World Scientific Studies in International Economics, Book 30, Singapore: World Scientific Publishing, 2013).*
Return to text

Energy and Environmental Technology

David Popp

Developing new and improved clean-energy technologies is an important part of any strategy to combat global climate change. For example, generation of electricity and heat is the largest source of carbon emissions, accounting for 42 percent of carbon emissions worldwide in 2012.[1] Meeting the climate policy goals currently under consideration, such as European Union discussions to reduce emissions by 40 percent below 1990 levels by 2030 or the U.S. Clean Power Plan goal of reducing emissions from the electricity sector by 32 percent by 2030, will not be possible without replacing much of the current fossil fuels-based electric generating capacity with alternative, carbon-free energy sources.

My research focuses on the role of technology for both reducing energy consumption and providing clean energy. This work includes three main themes: empirical studies of the relationship between environmental policy and innovation, policy simulations and empirical work on ways environmental and science policies may promote energy innovation, and empirical studies of environmental technology transfer. Much of my research uses patent data to track energy innovation, thereby building on the pioneering efforts of NBER researchers such as Adam Jaffe and Bronwyn Hall, whose early forays into patent data made these data accessible to a new generation of researchers.[2]

Empirical Studies of Induced Innovation

My empirical work on policy-induced technological change seeks to understand how policy affects the development of new environmentally-friendly technologies. I use patent data to track changes in environmental technologies, such as pollution control devices, alternative energy sources, and technologies designed to improve energy efficiency. With this research, I aim to better inform researchers who simulate the effects of long-term policies such as climate change policy and to contribute to the broader discussion of environmental policy design.

Early work on energy innovation focused on the link between energy prices and innovation. In a 2002 paper, I use patent data to identify innovation on 11 different alternative energy and energy efficiency technologies.[3] In the long run, a 10 percent increase in energy prices leads to a 3.5 percent rise in the number of energy patents. Most of the response occurs quickly after a change in energy prices, with a mean lag response time between energy prices and patenting activity of 3.71 years. My estimates controlled for the quality of knowledge available to an inventor as well as other factors influencing R&D, such as government support for energy research and technology-specific demand shifters.

Subsequent work turned attention to the incentives offered by various policy instruments, showing that the types of incentives matter. In a 2003 paper, I combine plant-level data on flue gas desulfurization (FGD) units installed at U.S. coal-fired power plants with patents pertaining to FGD devices to assess the impact of innovation before and after the 1990 Clean Air Act (CAA),[4] which instituted permit trading for sulfur dioxide (SO_2). Before this act, new plants were required to install flue gas desulfurization capacity capable of removing 90 percent of SO_2. As a result, the innovations that occurred before the 1990 CAA focused on reducing the cost of FGD units, rather than on improving their environmental performance. After passage of the act, the focus of innovation became improving the ability of FGD units to remove SO_2 from a plant's emissions.

While economists often favor using

David Popp is a research associate in the NBER's Programs on Environmental and Energy Economics and Productivity, Innovation, and Entrepreneurship. He is professor of public administration and international affairs at the Maxwell School of Syracuse University, where he is also a senior research associate in the Center for Policy Research.

Popp studies the links between environmental policy and innovation, with a particular focus on how environmental and energy policies shape the development of new technologies for combating climate change. His research often makes use of patent data to trace development of green technologies, exploring how policy and prices shape innovation. Other recent work considers the potential of technology for climate adaptation by studying how innovation responds to natural disasters.

Popp is a co-editor for two journals, the *Journal of the Association of Environmental and Resource Economists* and *Environmental and Resource Economics*. He currently serves on the advisory committee of the Green Growth Knowledge Platform. Popp received a B.A. in political economy from Williams College in 1992, and a Ph.D. in economics from Yale University in 1997. He lives in Manlius, NY with his wife, Deirdre, and two teenage children. He enjoys baseball, hiking, snowshoeing, and attending his children's many musical and theater performances.

broad-based policies, such as a carbon tax or tradable permits, to address externalities, policy makers often use more narrowly focused options. In renewable energy, popular options include feed-in tariffs, in which governments guarantee a fixed price above prevailing market prices for energy from renewable sources, and renewable portfolio standards that require a minimum percentage of electricity be generated using renewable sources. While renewable portfolio standards leave it to market forces to decide which renewable sources are used to meet the target, feed-in tariffs may target specific energy sources. For example, at their peak, feed-in tariffs for solar energy in Germany were over seven times higher than the feed-in tariffs for wind energy.[5]

In a 2010 publication, Nick Johnstone, Ivan Haščič, and I collect data on renewable energy policies and patents across countries to assess the effect of various renewable energy policies on innovation.[6] Figure 1 shows that patenting activity has increased rapidly over the past decade as these policies have become more prevalent.[7] Moreover, different instruments end up promoting innovation on different types of renewable energy. Quantity-based policies, such as renewable portfolio standards, favor development of wind energy. Of the various alternative energy technologies, wind has the lowest cost and is closest to being competitive with traditional energy sources. As such, when faced with a mandate to provide alternative energy, firms focus their innovative efforts on the technology that is closest to market. In contrast, direct investment incentives are effective in supporting innovation in solar and waste-to-energy technologies, which are further from being competitive with traditional energy technologies and thus need the guaranteed revenue from a feed-in tariff to be competitive.

These results suggest particular challenges to policy makers who wish to encourage long-run innovation for technologies that have yet to near market competitiveness. Economists generally recommend using broad-based environmental policies, such as emission fees, and letting the market "pick winners." This leads to lower compliance costs in the short-run, as firms choose the most effective short-term strategy. But because firms will focus on those technologies closest to market, broad-based market policy incentives do not provide as much incentive for research on longer-term needs. There may be a complementary role for policies such as direct R&D subsidies to promote development of clean technologies further from the market.

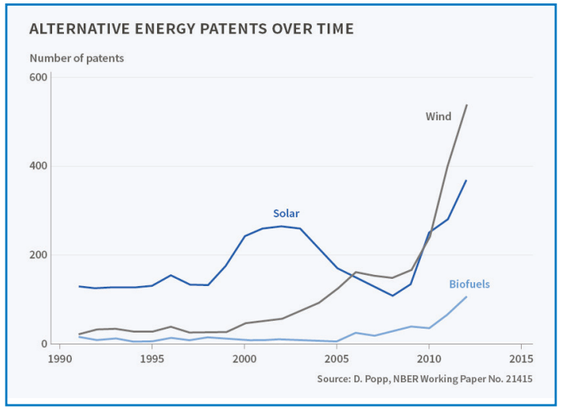

Figure 1

The Roles of Environmental and Science Policy

Understanding the role of environmental policy on technological change involves the study of two market failures. Because pollution is not priced by the market, firms and consumers have no incentive to reduce emissions without policy intervention. Thus, the market for technologies that reduce emissions will be limited without policy interventions that alter these incentives. At the same time, the public goods nature of knowledge leads to spillovers that benefit the public as a whole, but not the innovator. As a result, potentially innovative private firms and individuals may not have incentives to provide the socially optimal level of research activity.

The evidence suggests that science policy plays a supporting role, but that environmental policies are most important for promoting new green technologies. Policies must be in place not only to encourage the development of cleaner technologies, but also to encourage the adoption of existing clean technologies. In a 2006 paper using ENTICE, a model of the global economy that links economic activity to carbon emissions and allows research in the energy sector to respond to policy changes,[8] I compare long-run welfare gains from both an optimally-designed carbon tax (one equating the marginal benefits of carbon reductions with the marginal costs of such reductions) and optimally designed R&D subsidies.[9] While combining both policies yields the largest welfare gain, a policy using only the carbon tax achieves 95 percent of the welfare gains of the combined policy. In contrast, a policy using only the optimal R&D subsidy attains just 11 percent of the welfare gains of the combined policy. This finding is confirmed by other researchers simulating U.S. and global energy policies, showing that policies directly targeting environmental damages from electricity generation better promote both emissions reductions and innovation.[10] However, carbon prices and R&D subsidies can complement each other if clean technologies are less developed than existing dirty technologies. In such a case, initial R&D subsidies can close the gap between clean and dirty technologies, reducing the level of carbon taxes needed in future years to reduce greenhouse gas emissions.[11]

To better understand the potential for future public energy R&D spending, in recent work, I use scientific publications to evaluate the effectiveness of public energy R&D expenditures.[12] Combining data on scientific publications for alternative energy technologies with data on government R&D support helps isolate the effect of public R&D and sheds light on the process through which public R&D helps develop scientific knowledge. Interestingly, unlike work on private sector innovation, other factors such as energy prices and policy have little effect on alternative energy publications. Thus, current government energy R&D efforts appear to support novel research, rather than crowding out work that would otherwise be done. I find little evidence for diminishing returns to energy R&D at current funding levels. However, patience is important for evaluating public investment in energy R&D. The ultimate goal of government energy R&D funding is not a publication, but rather a new technology. Thus I use citations these articles receive from future patents to assess the impact of basic science on new technologies. Figure 2 traces the time path of the increased citation probability for publications generated from an additional $1 million in R&D funding being cited by a patent. It may take up to a decade to realize the full effect of public energy R&D funding on publications, and even longer until these publications are cited in new energy patents. Because of the lags between initial funding and publication, there is little increase in the cumulative probability of a citation resulting from new R&D funding until approximately six years after the funding, with the effect not leveling out until almost 18 years afterwards. Allowing for a five year window for processing patents, this suggests that new patent applications citing these publications begin appearing about one year after funding and continue for 13 years.

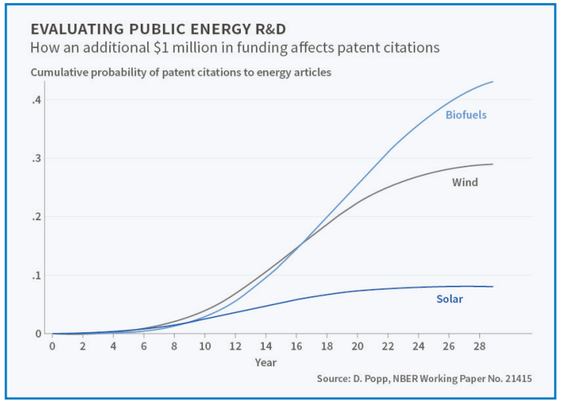

Figure 2

International Technology Transfer

A third stream of my research focuses on the international dimensions of environmental technological change. This work began with a 2006 study of air pollution control equipment in the United States, Japan, and Germany.[13] Whereas the United States was an early adopter of stringent sulfur dioxide (SO_2) standards, both Japan and Germany introduced stringent nitrogen oxide (NO_X) standards much earlier than the U.S. Using patent data from all three countries, I find that innovation responds to policy even in countries that adopt regulations late, suggesting that these countries do not simply take advantage of technologies "off the shelf" that have been developed elsewhere. Instead, late adopters often undertake adaptive R&D to fit previously developed technology to local markets. As evidence, I show that these later patents are more likely to cite earlier foreign rather than domestic inventions.

My more recent work on international environmental technological change explores how technology can help developing countries address environmental issues. As emerging and developing countries continue to grow, the environmental impact of their economies increases. Access to clean technologies may mitigate this impact. Mary Lovely and I flip the usual question of policy's effect on regulation around, asking instead how technology affects regulation.[14] Because most pollution control technologies are first developed in industrialized countries, and because environmental regulations are needed to provide incentives to adopt these technologies, we focus on the adoption of environmental regulation as the first step in the international diffusion of environmental technologies. Using a hazard model, we study the adoption of environmental regulations for coal-fired power plants in a set of 39 developed and developing countries. While the adoption of pollution control technologies within a country responds quickly to environmental regulation, we find that adoption of the regulations themselves follows the typical S-shaped pattern noted in studies of technology diffusion. Access to technology is an important factor influencing regulatory adoption. As pollution control technologies improve, the costs of abatement, and thus the costs of adopting environmental regulation, fall. Thus, countries adopt environmental regulation at lower levels of per capita income over time. Moreover, countries that are more open to international trade have better access to these technologies, and are thus more likely to adopt regulation. While openness to world markets may also work against passage of environmental regulation by increasing competition and making it harder for local firms to pass along cost increases to consumers, we find that the access to technology effect dominates once the level of abatement technology reaches a critical level, which in our sample occurs during the early 1990s.

International climate agreements also foster access to technology. The Clean Development Mechanism (CDM) enables entities in developed countries to sponsor emission-reducing projects in developing countries. A secondary goal of the CDM is to help developing countries achieve sustainable development through the transfer of climate-friendly technologies from developed countries. If the technologies transferred via CDM projects lead to subsequent diffusions within the country, it will reduce the future abatement costs of carbon emissions and drive technological change in the energy sector of the recipient country.[15] Tian Tang and I use data on wind turbine projects in China sponsored through the Clean Development Mechanism to ask whether these projects improve the technical capacity of wind projects in China.[16] Using a learning curve model allowing for spatially correlated errors, we find that project costs

decrease and project efficiency (measured by the capacity factor, which compares a wind farm's actual annual electricity generation to its potential annual output if the wind farm operates at its full capacity) increases with the previous experience of the project developer. The greatest efficiency gains come from repeated interactions between local project developers and foreign wind turbine manufacturers. That these improvements occur for the capacity factor as well as for cost reductions suggest that technology transfer occurs, and that the results are more than reduced transaction costs and lower contract prices for repeat customers.

Conclusion

While the papers cited here highlight the important connections between environmental policy and technological change, much work remains to fully understand the potential for technology to aid in both the mitigation of and adaptation to climate change. In addition to the research questions addressed here, the role of technology in climate change adaptation[17] and the behavioral influences of clean technology adoption,[18] are important areas for future work.

---

1 *International Energy Agency (IEA) 2014, "CO_2 Emissions from Fuel Combustion: Highlights," Paris, France: OECD/IEA, 2014.*
Return to text

2 *B. H. Hall, A. B. Jaffe, and M. Trajtenberg, "The NBER Patent Citation Data File: Lessons, Insights and Methodological Tools," NBER Working Paper No. 8498, October 2001.*
Return to text

3 *D. Popp, "Induced Innovation and Energy Prices," NBER Working Paper No. 8284, May 2001, and the* American Economics Review, *92(1), 2002, pp. 160–80.*
Return to text

4 *D. Popp, "Pollution Control Innovations and the Clean Air Act of 1990," NBER Working Paper No. 8593, November 2001, and* Journal of Policy Analysis and Management, *22(4), 2003, pp. 641–60.*
Return to text

5 *D. Popp, "Using Scientific Publications to Evaluate Government R&D Spending: The Case of Energy," NBER Working Paper No. 21415, July 2015.*
Return to text

6 *OECD-EPAU, Renewable Energy Policy Dataset, version February 2013. Compiled by the OECD Environment Directorate's Empirical Policy Analysis Unit (N. Johnstone, I. Haščič, M. Cárdenas Rodríguez, T. Duclert) in collaboration with an ad hoc research consortium (A. de la Tour, G. Shrimali, M. Hervé-Mignucci, T. Grau, E. Reiter, W. Dong, I. Azevedo, N. Horner, J. Noailly, R. Smeets, K. Sahdev, S. Witthöft, Y. Yang, T. Dubbeling.)*
Return to text

7 *N. Johnstone, I. Haščič, and D. Popp, "Renewable Energy Policies and Technological Innovation: Evidence Based on Patent Counts," NBER Working Paper No. 13760, January 2008, and* Environmental and Resource Economics, *45(1), 2010, pp. 133–55.*
Return to text

8 *D. Popp, "ENTICE: Endogenous Technological Change in the DICE Model of Global Warming," NBER Working Paper No. 9762, June 2003, and* Journal of Environmental Economics and Management, *48(1), 2004, pp. 742–68; W. D. Nordhaus,* Managing the Global Commons: The Economics of the Greenhouse Effect, *Cambridge, MA: MIT Press, Cambridge, MA, 1994.*
Return to text

9 *D. Popp, "R&D Subsidies and Climate Policy: Is there a 'Free Lunch'?" NBER Working Paper No. 10880, November 2004, and* Climatic Change, *77(3–4), 2006, pp. 311–41.*
Return to text

10 *C. Fischer and R. G. Newell, "Environmental and Technology Policies for Climate Mitigation,"* Journal of Environmental Economics and Management, *55(2), 2008, pp. 142–62.*
Return to text

11 *D. Acemoglu, U. Akcigit, D. Hanley, W. Kerr, "Transition to Clean Technology," NBER Working Paper No. 20743, December 2014, and forthcoming in the* Journal of Political Economy.
Return to text

12 *D. Popp, "Using Scientific Publications to Evaluate Government R&D Spending: The Case of Energy," NBER Working Paper No. 21415, July 2015.*
Return to text

13 *D. Popp, "International Innovation and Diffusion of Air Pollution Control Technologies: The Effects of NO_X and SO_2 Regulation in the U.S., Japan, and Germany," NBER Working Paper No. 10643, July 2004 and the* Journal of Environmental Economics and Management, *61(1), 2011, pp. 16–35.*
Return to text

14 *M. Lovely and D. Popp, "Trade, Technology, and the Environment: Does Access to Technology Promote Environmental Regulation," NBER Working Paper No. 14286, August 2008, and the* Journal of Environmental Economics and Management, *51(1), 2006, pp. 46–71.*
Return to text

15 *D. Popp, "International Technology Transfer, Climate Change, and the Clean Development Mechanism,"* Review of Environmental Economics and Policy, *5(1), 2011, pp. 131–52.*
Return to text

16 *T. Tang and D. Popp, "The Learning Process and Technological Change in Wind Power: Evidence from China's CDM Wind Projects," NBER Working Paper No. 19921, February 2014, and forthcoming in the* Journal of Policy Analysis and Management.
Return to text

17 *Q. Miao and D. Popp, "Necessity as the Mother of Invention: Innovative Responses to Natural Disasters," NBER Working Paper No. 19223, July 2013, and the* Journal of Environmental Economics and Management, *68(2), 2014, pp. 280–95.*
Return to text

18 *H. Allcott and M. Greenstone, "Is There an Energy Efficiency Gap?" NBER Working Paper No. 17766, January 2012, and* Journal of Economic Perspectives, *26(1), 2012, pp. 3–28; T. D. Gerarden, R. G. Newell, and R. N. Stavins, "Assessing the Energy-Efficiency Gap," NBER Working Paper No. 20904, January 2015.*
Return to text

Recessions and Retirement: How Stock Market and Labor Market Fluctuations Affect Older Workers

Courtney Coile and Phillip B. Levine

The sharp drop in equity values at the beginning of the recent financial crisis led to widespread concern about the effect of the crisis on retirement security. With defined contribution pension plans largely having replaced defined benefit plans for U.S. workers,[1] millions of individuals experienced deep declines in the value of their retirement savings. It was widely predicted that workers would delay retirement to make up for these losses, as newspaper headlines proclaimed "Economic Crisis Scrambles Retirement Math" and "Will You Retire? New Economic Realities Keep More Americans in the Workforce Longer."

The effect of the sharp rise in the unemployment rate on retirement was a less-publicized element of the crisis. Relative to earlier periods, workers who lost jobs experienced longer spells of unemployment and had a lower probability of finding new jobs.[2] Older workers who experienced job loss and difficulty finding work may have retired earlier than planned. Indeed, the Social Security Administration reported in 2009 that new retired worker benefit claims rose by 10 percent more than expected during 2008 and officials surmised that the weak economy was the cause.[3]

The potential effects of the crisis on retirement are more complex than suggested by the headlines. In a series of studies, we have investigated the effect of stock and labor market fluctuations on retirement decisions and retiree well-being in the United States. This summary reviews our exploration of whether retirement rates are higher when stock markets or labor markets are weak. We also describe our analyses of whether recessions have long-term impacts on retiree income and health.

Does the Stock Market Affect Retirement?

In order for stock market fluctuations to affect retirement decisions, several conditions must be met. First, since equity investors presumably expect a positive rate of return and understand that daily prices are volatile, there must be asset price movements representing larger- or smaller-than-expected returns. Second, workers must have enough stock assets that these price changes constitute meaningful wealth shocks. Third, retirement rates must be sensitive to fluctuations in wealth.

The stock market has experienced unusual equity returns over the past two decades, with two boom-bust cycles, culminating in the dot-com crash of 2000–2002 and the more recent financial crisis. Whether workers have substantial equity investments is a different matter. In one analysis, we report that 58 percent of U.S. households with a head aged 55 to 64 held stock assets in 2007, just before the recent crisis.[4] The most common form of ownership is through retirement accounts (50 percent of households), though some households own stocks directly (21 percent) or in mutual funds outside of retirement accounts (14 percent). Median stock assets are $78,000 among stockholders. Asset ownership and values are strongly correlated with education. Some 78 percent of households headed by a college graduate own stock, and the median holding is $125,000, while just 21 percent of households headed by high school dropouts hold stock, with a median holding of $10,000. Overall, nearly six in 10 of near-retirement-age households have less than $25,000 in stock assets and only one in eight have assets over $250,000.

Courtney Coile is a research associate in the NBER's Aging Program and editor of the NBER *Bulletin on Aging and Health*. She is a professor of economics at Wellesley College, where she directs the Knapp Social Science Center and has taught since 2000.

Much of Coile's research focuses on the economics of retirement. She is a long-time participant in the NBER's Social Security and Retirement Around the World project and is the co-author of *Reconsidering Retirement: How Losses and Layoffs Affect Older Workers*. She recently served on the National Academy of Sciences' Committee on the Long-Run Macro-Economic Effects of the Aging U.S. Population (Phase II) and is an editor for the *Journal of Pension Economics and Finance*.

Coile studied economics as an undergraduate at Harvard University and first worked at the NBER as a research assistant in those years. She earned her Ph.D. in economics from MIT in 1999.

Coile lives in the Boston suburbs with her husband and two school-age children. In her free time, she shares her love of baseball, music, and food with her family and is still working on getting her children to share her love of running and hiking.