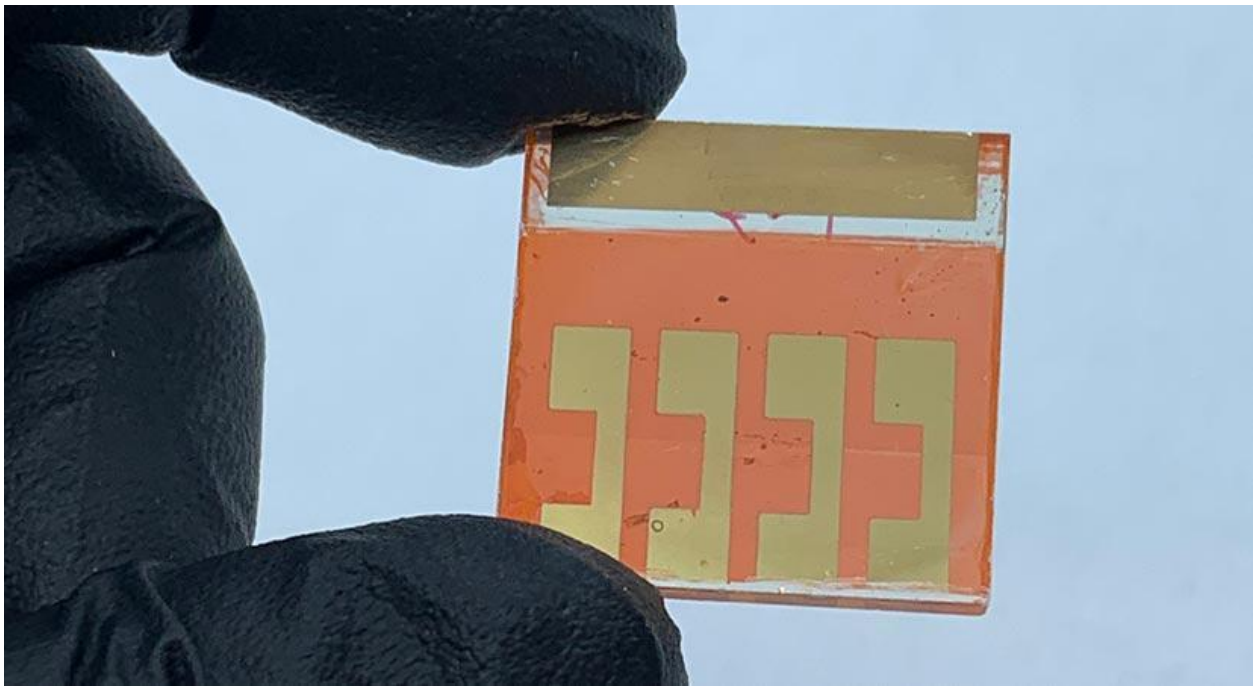
How Carbon Taxes Induce and Accelerate Clean Innovation



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Citizens' Climate Lobby

How Carbon Taxes Induce and Accelerate Clean Innovation

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Summary

- Innovation in clean technology will be essential for rapidly and affordably decarbonizing the global economy and slowing the pace of climate disruption.
- Carbon taxes provide powerful incentives to enhance clean innovation, a benefit that is often overlooked in discussions and economic models of climate policy.
- Policies that support innovation directly, such as R&D subsidies, are a useful complement to carbon pricing, but no substitute for getting prices right.

Introduction

Economists overwhelmingly agree that "carbon taxes"—levies on the sale of climate-polluting fossil fuels such as oil, natural gas, and coal—offer "the most cost-effective lever to reduce carbon emissions at the scale and speed that is necessary" to address the global climate emergency.[1] The logic of making polluters pay is simple: individuals and enterprises, acting out of self-interest, will shift toward lower-carbon alternatives as prices rise for fossil fuels. Real-world evidence supports that logic; for example, a modest carbon tax in Great Britain slashed the use of coal in electricity generation from more than 40 percent in 2013 to a mere 3 percent just six years later.[2]

Sometimes overlooked in discussions of carbon taxes is the similarly strong consensus among economists that "a consistently rising carbon price" will also "encourage technological innovation" to support cost-effective substitutes for fossil fuels.[3] New technology offers the welcome promise of weaning the world off dirty fuels much faster and less expensively than many forecasts assume. By inducing the development of cleaner new technology, as well as favoring immediate adoption of currently available low-carbon technology, carbon taxes provide two critically important paths toward climate mitigation.

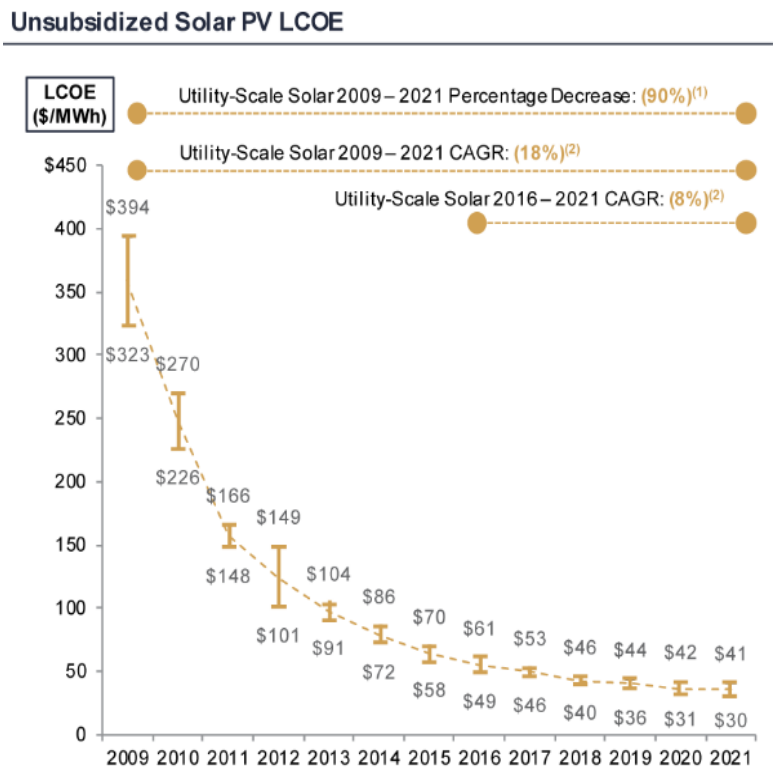
Why Innovation Matters

Modern civilization is built on fossil fuels, which provide most of the energy to run our factories, power our cars, and heat our homes. Eliminating them over the next thirty years will require more than regulations or taxes. It will necessitate rapid discovery of lower-cost forms

of clean energy and their speedy deployment throughout industry, agriculture, transportation, power generation, and buildings.

Global emissions of CO_2 have remained at unsustainably high levels in the absence of stronger tax or regulatory policies to phase out the burning of fossil fuels.[4] However, energy experts hold out hope that future technology advances can help mitigate the impending climate crisis. A 2006 study by Pacific Northwest National Laboratory concluded that "accelerated technology development offers the potential to dramatically reduce the costs of [climate] stabilization . . . over the century, compared to the Baseline Cases, by 50% or more, leading to economic benefits of hundreds of billions to trillions of dollars globally."[5]

Progress in the clean energy sector since then has been dramatic. Over a decade, the unsubsidized cost of wind energy fell 70 percent, and the cost of utility-scale solar plummeted 89 percent.[6] A report by the Department of Energy (DOE) in 2017 concluded that aggressive "stretch" national technology policies could, with some luck, reduce CO_2 emissions by nearly 30 percent between 2017 and 2040, enough at least to slow current warming trends. The DOE report also concluded that a very modest carbon tax of $20 per ton, increasing 5 percent annually, would cut emissions about 20 percent. Together, they could slash emissions as much as 45 percent by 2040.[7]



Lazard, "Levelized Cost of Energy," 2021

On an even more hopeful note, a team of researchers at the University of Oxford used probabilistic cost forecasting models tested on more than 50 technologies to conclude in 2021 that "a rapid green energy transition will likely result in overall net savings of many trillions of dollars—even without accounting for climate damages or co-benefits of climate policy. . . . [If] solar photovoltaics, wind, batteries and hydrogen electrolyzers continue to follow their current exponentially increasing deployment trends for another decade, we achieve a near-net-zero emissions energy system within twenty-five years."[8]

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The key word in that assessment is "if." Some techno-optimists maintain that American ingenuity will drive down the cost of clean energy with minimal government involvement, lowering emissions without raising costs to consumers. Innovation is the closest thing to a "free lunch" in economics, but even it isn't really free. Researching and developing new and better ways of doing things at commercial scale takes significant resources. It requires the pull of demand and the push of costs to motivate long-term investment of those resources. Most experts, therefore, argue that technology advances much more quickly if policies and prices are right.[9] "Technological change may be the most important determinant of the long-run cost of emissions abatement," observe two leading students of green innovation. "Consequently, the ability of an environmental policy to influence technological change is perhaps one of the most important criteria on which to judge its success."[10]

The discovery of knowledge is highly creative, widely dispersed, and hard to predict. Nonetheless, most economists believe, as a matter of both logic and empirical study, that innovators respond to opportunities to profit from technology invention and adoption. Carbon taxes shift those opportunities from fossil fuels to clean energy.[11] They help break the "lock-in" of entrenched older technologies based on fossil fuels that discourages industries from changing their processes to favor cleaner methods.

As former Princeton economist and Federal Reserve Vice Chairman Alan Blinder wrote, "Once America's entrepreneurs and corporate executives see lucrative opportunities from carbon-saving devices and technologies, they will start investing right away — and in ways that make the most economic sense. . . . I can hardly wait to witness the outpouring of ideas [a carbon tax] would unleash."[12] Glenn Hubbard, former chairman of the Council of Economic Advisors in the George W. Bush administration, similarly observed, "business people don't innovate because it feels good; they innovate because there's a return to that innovation. If you want a return to that innovation . . . you will need to put a price on carbon."[13]

In the same spirit, Nobel Prize-winning climate economist William Nordhaus declared,

> The country may have the best climate scientists . . . it might have the best materials scientists . . . it might have the best financial wizards developing new financial derivatives to fund all these investments. But if the carbon price is zero, then projects to develop promising but costly low-carbon technologies will die before they get to the boardroom of a profit-oriented company.[14]

Many entrepreneurs agree. Two major clean energy investors, one a Republican and one a Democrat, wrote in *Politico*, "Putting a market price on carbon would provide clear price signals to investors like us. Then, the U.S. innovation engine — our most valuable asset — would be turned loose, and capital and U.S. jobs would follow."[15] A survey of 35 large U.S.

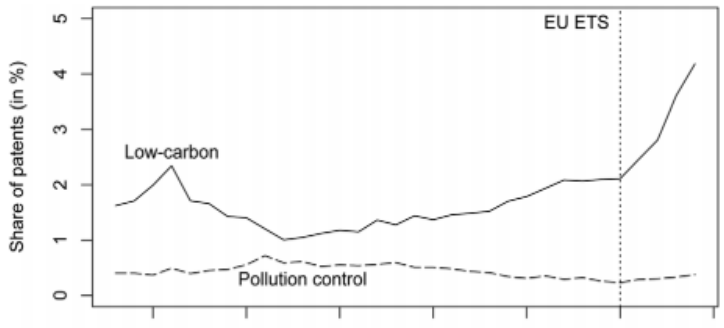
companies found that among nine policy tools under consideration, "putting a price on carbon was by far the most important action that respondents think the U.S. government could take to advance low-carbon innovation."[16] Former Microsoft CEO Bill Gates, founder of the Breakthrough Energy Coalition, said, "Without a carbon tax, there's no incentive for innovators or plant buyers to switch" to clean energy.[17]

The next best thing to a carbon tax is the credible looming specter of a price on carbon. "Almost 1,400 companies are betting it will be the tool of choice for policymakers around the world and they aren't waiting for governments to see what happens," observes Dimitri de Vreeze, a member of the board of Dutch multinational Royal DSM. "CEOs today are creating financial schemes within their own companies – setting a theoretical carbon price, say €40 per ton, and then conducting business as if that price was real. . . . Whether companies set carbon prices themselves or governments do it for them, it creates a stronger business incentive to invest in low-carbon technology and innovation for an eco-friendly future."[18]

Empirical studies

History supports the view that energy prices strongly influence the pace of clean technology development and adoption. In the 1960s, for example, when energy prices were falling, the efficiency of air conditioners actually declined. That trend reversed sharply after the oil price shocks of the 1970s, with energy prices accounting for up to half the subsequent efficiency gains in these home appliances.[19] A global study published in 2013 found that over the period 1990 to 2009, a $20 increase in oil prices on average induced a 13 percent increase in solar and wind technology patents over the following year.[20]

FIGURE 1.—SHARE OF LOW-CARBON PATENTS, 1978–2009



Source. Note that "pollution control technologies" are a control group that do not relate to greenhouse gases.

A 2016 study by two economists at the London School of Economics examined 3,428 firms covered by the European Union's Emissions Trading System (EU-ETS) and determined that they filed 36 percent more low-carbon patents than similar unregulated firms.[21] A follow-up study of British firms covered by the EU's carbon market found that they "increased their low-carbon patenting and R&D spending by roughly 20–30 percent" relative to similar firms that did not face added costs for their greenhouse gas emissions.[22] Remarkably, both of these latter studies pertained to the early years of the EU-ETS, when carbon prices averaged well under 20 Euros per metric ton of CO_2 and thus had limited bite.[23]

Many studies also indicate that fuel taxes and carbon taxes stimulate green innovation in the transportation sector. As one 2015 study of European policies concluded, "Fuel price is one of the main drivers of technological efforts on green automotive technologies."[24] A 2010 paper on the impacts of the oil price shocks of the 1980s found that "the price of oil is strongly associated with a positive, statistically significant and nontrivial effect on energy-efficient automotive innovation" as measured by fuel-efficiency patents.[25] A 2016 study based on data from 80 countries estimated that a 10 percent increase in tax-inclusive gasoline prices stimulated a 10 percent increase in green vehicle technology patents.[26] A 2022 paper on the impact of Sweden's carbon tax concluded that it boosted the number of clean transportation patents by 71 percent from 1990 to 1999, more than would be expected by the price effect on fossil fuels alone. The "salience" or visibility of the carbon tax evidently had a strong, independent effect, suggesting that it may be an especially powerful driver of innovation.[27]

Similar evidence of strong links between energy (or carbon) prices and clean technology innovation was documented in a massive synthesis published in 2021 of more than 200 studies. The authors of that literature review also reported heartening evidence of a "reinforcing tendency of successful, expanding technology-industries to foster institutions and coalitions that sustain progress." They concluded, "Given the unambiguous finding that market-wide prices do generally influence patents, the case for carbon pricing is enhanced further, in light of the push it may give to low carbon innovation."[28]

Despite such evidence, few economists have undertaken the complex task of fully accounting for technology improvements in their forecasts of the effect of carbon taxes on greenhouse gas emissions. As one detailed assessment of several leading models cautioned, "these models generally do not represent induced research and development spending and the associated spillovers" and thus "may understate the environmental effectiveness of the policies."[29] One recent study estimates that carbon taxes could induce energy efficiency innovations sufficient to cut energy usage 30 percent more than traditional models assume over the course of a century.[30]

How to Promote Innovation

To be most effective at motivating clean innovation and reducing climate-polluting emissions, carbon taxes must be predictable, politically popular enough to last, and sufficiently high for people to notice.[31] The good news is that several carbon tax bills pending in Congress satisfy these criteria. With a substantial fraction of revenue returned as a dividend to every American, any of these would likely build a lasting base of political support.[32] With provisions for a border carbon adjustment, it should discourage opposition from major industry sectors.[33] By starting with a relatively low fee but then rising each year at a meaningful rate, its trajectory would not disrupt consumers or businesses in the near term,

but would exert a powerful influence on business investment and R&D spending based on future cost projections.[34]

Taxing pollution isn't the only way to promote innovation in non-polluting technologies, of course. Regulations, such as building efficiency standards, can also promote valuable innovation, but their narrow coverage makes them no substitute for economy-wide carbon pricing.[35] Broad carbon pricing also "encourages innovation without requiring accurate predictions regarding which technologies will be most cost-effective at reducing emissions," observed three climate policy experts in a whitepaper for the World Resources Institute. "This is a major advantage because breakthroughs could emerge from any number of sources . . . A carbon price encourages all clean-energy technologies simultaneously, thus eliminating the possibility of regulations diverting scarce resources to promote the 'wrong' technologies."[36]

Direct government subsidies and tax incentives for research and development also promote new technology. Indeed, virtually every introductory economics textbook makes the case for such subsidies.[37] The logic is that private firms, left to their own devices, underinvest in R&D from a *social* perspective, because they do not capture the full benefits that "spill over" to other firms, and consumers, from the broader adoption of their innovations. In addition, aversion to risk and uncertainty leads most firms to underinvest in the sorts of basic research that produce revolutionary technological breakthroughs (atomic energy, the Internet, etc.).[38] All that said, studies repeatedly find that *public support for R&D, while highly desirable and complementary, is no substitute for carbon taxes when it comes to curbing greenhouse gas emissions*, or even promoting faster progress in clean technology.[39]

Conclusion

Transitioning to a low-carbon world will not be painless, but new technology can significantly ease the way if given an economy-wide boost. As Nobel Prize-winning economist Paul Krugman notes, "Even modest incentives for expanded use of renewable energy led to a spectacular fall in prices over the past decade."[40] The key, of course, is getting the right incentives to unlock the full creative potential of humanity. Rising carbon taxes are "the most cost-effective lever to reduce carbon emissions at the scale and speed that is necessary," not least because they will powerfully promote new innovations and accelerate their adoption.

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Notes

[1] Climate Leadership Council, "Economists' Statement on Carbon Dividends: The Largest Public Statement of Economists in History ."

[2] University College London, "British carbon tax leads to 93% drop in coal-fired electricity," January 27, 2020. For other evidence, see Jonathan Marshall, "Carbon Taxes Can Do the Job," April 2019.

[3] "Economists' Statement on Carbon Dividends." A team of economists associated with Resources for the Future expressed the profession's consensus that "Establishing a price on CO_2 emissions is the single most important policy for encouraging the innovation that might bring about advanced technology development." Joseph E. Aldy et al., "Designing Climate Mitigation Policy," *Journal of Economic Literature*, 48:4 (2010), 903-934. For another bullish assessment, see Andrea Baranzini, et al., "Carbon pricing in climate policy: seven reasons, complementary instruments, and political economy considerations," *Climate Change* 8 *(*March 2017).

[4] Hannah Ritchie and Max Roser, "CO2 and Greenhouse Gas Emissions," December 2019. Emissions from richer nations have fallen slightly over the past decade, "thanks to the expanding role of renewable sources (mainly wind and solar PV), fuel switching from coal to natural gas, and higher nuclear power output," but not nearly fast enough to slow the pace of warming in a meaningful way. International Energy Agency, "Global CO2 Emissions in 2019," February 11, 2020.

[5] Leon Clarke, et al., *Climate Change Mitigation: An Analysis of Advanced Technology Scenarios* (Richland, Wash.: Pacific Northwest National Laboratory, 2006).

[6] Lazard, "Levelized Cost of Energy and Levelized Cost of Storage 2019," November 7, 2019.

[7] U. S. Department of Energy, "Energy CO_2 Emissions: Impacts of Clean Energy Technology Innovation and Policy," January 2017.

[8] Rupert Way, et al., "Empirically grounded technology forecasts and the energy transition," INET Oxford Working Paper 2021-01, September 2021.

[9] Dana Nuccitelli, "Policy Incentives Needed to Boost Clean Tech Efforts," Yale Climate Connections, January 8, 2019.

[10] Raphael Calel and Antoine Dechezleprêtre, "Environmental Policy and Directed Technological Change: Evidence from the European Carbon Market," *The Review of Economics and Statistics*, 98:1 (2016), 173–191.

[11] Joe Kennedy, "How Induced Innovation Lowers the Cost of a Carbon Tax," Information Technology & Innovation Foundation, June 2018. Kennedy is former chief economist at the Commerce Dept.

[12] Alan S. Blinder, "The Carbon Tax Miracle Cure," *Wall Street Journal*, January 31, 2011.

[13] "Hubbard Argues for a Carbon Tax," *Wall Street Journal Environmental Capital blog*, June 28, 2007.

[14] William Nordhaus, *The Spirit of Green* (Princeton, NJ: Princeton University Press, 2021), 224. For pithy observations on carbon taxes and innovation from another Nobel laureate, see Paul Romer, "Conditional Optimism," October 8, 2018: "The main reason to put a tax on greenhouse gasses is not the one from the textbook. This is a tax that we want people to avoid. We want innovators to discover all kinds of clever new ways to let people have the things that they want without paying this tax. . . The lesson . . . is that small incentives can generate lots of innovation."

[15] Martin Lagod and Jason Scott, "Put a Price on Carbon," *Politico*, July 26, 2010. See also the powerful statement in support of carbon fee and dividend by Utah technology executives, "Want cleaner air? Unleash American Ingenuity," *Deseret News*, March 30, 2022.

[16] Pew Center on Global Climate Change, "A Survey of Company Perspectives on Low Carbon Business Innovation 3," (2011).

[17] Quoted in James Bennet, "We Need an Energy Miracle," *Atlantic*, November 2015.

[18] Dimitri de Vreeze, "How carbon pricing accelerates innovation," World Economic Forum, October 26, 2017.

[19] Richard Newell, et al., "The Induced Innovation Hypothesis and Energy-Saving Technological Change," *Quarterly Journal of Economics* 114:3 (1990), 941-975. Government efficiency standards and unexplained factors accounted for the rest of the observed efficiency gains. Other case studies of price-induced innovation may be found in OECD, *Taxation, Innovation and the Environment* (2010).

[20] Patrick Bayer, et al. "Global patterns of renewable energy innovation, 1990-2009," *Energy for Sustainable Development,* 17 (2013), 288–95.

[21] Raphael Calel and Antoine Dechezleprêtre, "Environmental Policy and Directed Technological Change: Evidence from the European Carbon Market," op. cit.

[22] Raphael Calel, "Adopt or Innovate: Understanding Technological Responses to Cap-and-Trade," *American Economic Journal: Economic Policy*, 12:3 (2020), 170-201.

[23] Several economists have pointed to low carbon prices as an explanation for conflicting empirical findings on the impact of European carbon markets on technology innovation. See, for example, Lars Gulbrandsen and Christian Stenqvist, "The limited effect of EU emissions trading on corporate climate strategies: Comparison of a Swedish and a Norwegian pulp and paper company," *Energy Policy*, 56 (2013), 516-525; Tobias Schmidt, et al., "The effects of climate policy on the rate and direction of innovation: A survey of the EU ETS and the electricity sector," *Environmental Innovation and Societal Transitions*, 2 (2012), 23-48; and Eugénie Joltreau and Katrin Sommerfeld, "Why Does Emissions Trading under the EU ETS Not Affect Firms' Competitiveness? Empirical Findings from the Literature," IZA Institute of Labor Economics, December 2017.

[24] Nicolò Barbieri, "Investigating the impacts of technological position and European environmental regulation on green automotive patent activity", *Ecological Economics*, 117 (September 2015), 140-152. See also Nicolò Barbieri, "Fuel prices and the invention crowding out effect: Releasing the automotive industry from its dependence on fossil fuel, *Technological Forecasting and Social Change*, 111 (October 2016), 222-234.

[25] Joseph Crabb and Daniel Johnson, "Fueling Innovation: The Impact of Oil Prices and CAFE Standards on Energy-Efficient Automotive Technology," *The Energy Journal*, 31:1 (2010).

[26] Philippe Aghion, et. al. "Carbon Taxes, Path Dependency, and Directed Technical Change: Evidence from the Auto Industry," *Journal of Political Economy,* 124:1 (2016), 1–52.

[27] Nils aus dem Moore et al., "Driving Innovation? Carbon Tax Effects in the Swedish Transport Sector," Leibniz Institute for Economic Research, USAEE Working Paper No. 21, January 2022.

[28] Michael Grubb, et al., "Induced innovation in energy technologies and systems: a review of evidence and potential implications for CO_2 mitigation," *Environmental Research Letters,* 16:4 (2021). See also David Popp, "Environmental policy and innovation: a decade of research," *International Review of Environmental and Resource Economics,* 13 (2019), 265–337; Johan Lilliestam, et al., "The effect of carbon pricing on technological change for full energy decarbonization: A review of empirical ex-post evidence," *WIREs Climate Change*, 12:1 (September 2020); and Joeroen van den Bergh and Ivan Savin,

"Impact of Carbon Pricing on Low-Carbon Innovation and Deep Decarbonisation: Controversies and Path Forward," *Environmental and Resource Economics*, 80 (2021), 705–15.

[29] Alexander Barron, et al., "Policy Insights from the EMF 32 Study on U.S. Carbon Tax Scenarios," *Climate Change Economics* 9 (2018:1); see also Cristina Peñasco et al., "Underestimation of the Impacts of Decarbonisation Policies on Innovation to Create Domestic Growth Opportunities," October 2021, Cambridge University C-EENRG Working Papers, 2021-6. On the complexities of modeling induced technological change, see David Popp, et al., "Energy, the Environment, and Technological Change" (2009), NBER working paper 14832; reprinted in Bronwyn Hall, ed., *Handbook of Economics of Innovation* (2010), 873-937.

[30] Rong Wang et al., "Induced Energy-Saving Efficiency Improvements Amplify Effectiveness of Climate Change Mitigation," *Joule* (2019). A sophisticated estimate of how much clean innovation would be induced by a carbon tax is offered by a study published in 2018, based on evidence from the oil price shocks of the 1970s. Assuming only normal technological change, the study estimates that a $30 carbon tax would cut greenhouse gas emissions by a baseline 30 percent over 20 years. Taking into account the big boost to green innovation at the expense of R&D spending on fossil fuels would bring the total reduction in emissions to about 35 percent. S. Fried, "Climate Policy and Innovation: A Quantitative Macroeconomic Analysis," *American Economic Journal: Macroeconomics*, 10:1 (2018), 90–118. A Rhodium Group model estimates that a $50 carbon tax would cut CO_2 emissions by 39 percent relative to 2005 by 2030—but by 46 percent if the rate of innovation accelerates. Noah Kaufman and Kate Gordon, "The Energy, Economic, and Emissions Impacts of a Federal US Carbon Tax," July 2018.

[31] Carbon prices derived from markets for emissions permits rather than legislated tax rates may lack the predictability needed for optimal business investment; see, for example, Shi-Ling Hsu, *The Case for a Carbon Tax: Getting Past Our Hang-ups to Effective Climate Policy* (Island Press, 2011). Students of the early years of the European Union's carbon market observed that "the volatile price – and lack of clarity beyond 2020 - has undermined the potential of the EU ETS to drive the large, long-term investments that decarbonisation ultimately requires" (Tim Laing, et al., "Assessing the effectiveness of the EU Emissions Trading System," Centre for Climate Change Economics and Policy Working Paper 126, January 2013). On importance of policy commitment to firm investments in new technologies, see Steffen Brunner et al., "Credible commitment in carbon policy," *Climate Policy*, 12:2 (2012), 255-271 and Nicolò Barbieri, "Investigating the impacts of technological position and European environmental regulation on green automotive patent activity," *Ecological Economics*, 117 (September 2015), 140-152.

[32] Canada's national carbon tax, which includes a dividend, has withstood tough political challenges from the Conservative opposition. For a sampling of other discussions, see Goran Dominioni and Dirk Heine, "Behavioural Economics and Public Support for Carbon Pricing: A Revenue Recycling Scheme to Address the Political Economy of Carbon Taxation," *European Journal of Risk Regulation*, 10:3 (2019), 554–70; Timothy Rich and Kerby Gilstrap, "What if the US taxed fossil fuels and gave a check to every American? Turns out, most of the public is into that idea," TheHill.com, August 5, 2021.

[33] For a typical argument, see Michael Keen, et al., "Border Carbon Adjustments: Rationale, Design and Impact," IMF Working Paper, WP/21/239, September 2021.

[34] Regarding the magnitude of the tax and its impact on innovation, "what matters to the firm is not the effective price of carbon emissions today. Rather, it is the expected price of carbon emissions a decade or more in the future." David Popp, et al., "Energy, the Environment, and Technological Change," op. cit.

[35] Thus a 2010 OECD study observed, "Putting a price on pollution creates opportunities for a wide range of types of innovation. This gives taxation an advantage over more prescriptive environmental policy instruments which tend to encourage a focus on end-of-pipe innovations (i.e. innovations that reduce the emission of pollution but not the creation of it). . . . Such innovations are important, but are often less efficient than measures which reduce the creation of pollution in the first place. The wide range of actions that can be induced by taxation encourages a more balanced mix between innovations that result in a cleaner production process and end-of-pipe abatement measures." OECD, *Taxation, Innovation and the Environment* (2010). For contrary evidence that some regulations may be more effective than taxes at promoting radical innovation, see René Kemp and Serena Pontoglio, "The Innovation Effects of Environmental Policy Instruments — A Typical Case of the Blind Men and the Elephant?" *Ecological Economics* 72 (2011), 28-36.

[36] Noah Kaufman, et al., "Putting a Price on Carbon Emissions," World Resources Institute Issue Brief, January 2016.

[37] See, for example, Steven A. Greenlaw and David Shapiro, *Principles of Economics 2e* (OpenStax, 2017), 303, 308-309. The literature on these market failures is also discussed extensively in David Popp, et al., "Energy, the Environment, and Technological Change," op. cit. Such examples refute claims by some pundits that "innovation is not part of neoclassical economists' lexicon" as evidence that economists are naïve to put their faith in carbon taxes. See, for example, Matthew Stepp and Alex Trembath, "Innovation Before Carbon Pricing" (2013); Matt Hourihan and Robert Atkinson, "Inducing Innovation: What a Carbon Price Can and Can't Do," Information Technology & Innovation Foundation, March 2011.

[38] For a survey of empirical studies in this area, see David Popp, "Environmental Policy and Innovation: A Decade of Research," CESifo Working Paper No. 7544, March 2019.

[39] Stephen H. Schneider and Lawrence H. Goulder, "Achieving Low-cost Emissions Targets," *Nature*, 389 (September 4, 1997), 13-14; A. Jaffe, et al., "Environmental Policy and Technological Change," *Environmental and Resource Economics* 22 (2002), 41–69; Matthew Clancy and GianCarlo Moschini, "Pushing and Pulling Environmental Innovation: R&D Subsidies and Carbon Taxes," paper presented at the Agricultural & Applied Economics Association annual meeting, Boston, MA, July 31-August 2, 2016: "Our numerical simulations agree with much of the earlier literature. R&D subsidies on their own achieve only a fraction of the welfare gains attained by a carbon tax on its own, and adding R&D subsidies to a carbon tax leads to minor additional welfare gains." One widely cited study found that "combining both policies yields the largest welfare gain. However, a policy using only the carbon tax achieves 95% of the welfare gains of the combined policy, while a policy using only the optimal R&D subsidy attains just 11% of the welfare gains of the combined policy in his model." A major reason is that "While technology policy can help facilitate the creation of new environmentally-friendly technologies, it provides little incentive to adopt these technologies." David Popp, et al., "Energy, the Environment, and Technological Change" op. cit. An OECD report concluded, "the optimal approach is to have a strong environmental policy that combines taxes levied directly on environmentally harmful activities (and set at levels that reflect the costs of that environmental damage) with broad innovation policies that address the undersupply of innovation (including for the environment)." *Taxation, Innovation, and the Environment* (2010). See also Daron Acemoglu, et al., "The Environment and Directed Technical Change," *American Economic Review* 102 (2012:1), 131–166; and Her Majesty's Treasury of the UK Government, *The Economics of Climate Change: The Stern Review* (2006).

[40] Paul Krugman, "Greta Versus the Greedy Grifters," *New York Times*, February 27, 2020.