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E-BRIEF

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ENERGY AND NATURAL RESOURCES POLICY

A Blueprint for Going Green: The Best Policy Mix for Promoting Low-Emission Technology

by
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- Governments across Canada are examining policies to promote low greenhouse gas emissions technology. How should governments design these policies to get the most out of the billions of public dollars they plan to spend?
- Supporting technology development requires more than just government investment in new clean technologies. Consumers must also demand them throughout the economy. Emissions pricing is the best way to create that demand.
- Governments should supplement emission pricing with modest and targeted subsidies for risky research and development into technologies furthest from the market. However, given the importance of worldwide markets, policies prioritizing domestic end-use of low-emissions technology will be less cost-effective in Canada.

Canadian policymakers are now expressing a greater interest in low-emission technology. Ontario's Climate Change Action Plan includes up to $375 million of research and development (R&D) support for low-carbon technologies, and billions more for subsidies to encourage consumers and businesses to use low-emission technology. Alberta's government is proposing a carbon tax, with some revenues devoted to supporting low-emission technology. The federal government's policies include a $2 billion Low Carbon Economy Trust to support projects that reduce carbon emissions.

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New and improved low-emission energy technologies are vital to meet Canada's pledge to reduce greenhouse gas emissions by 30 percent compared to 2005 levels by 2030. The ultimate objective of climate policy is to reduce greenhouse gas emissions, but large reductions in emissions will not be possible unless more alternative carbon-free energy sources are developed.

How should governments design their technology support policies to get the most bang for these public bucks? Research on the effectiveness of policies to promote low-emission energy technologies such as wind and solar energy suggests three lessons in particular for Canada as it promotes low-emission technology.

- Incentives matter. Supporting technology development means not only investing in new technologies but also creating demand for clean technologies in the broader economy. Without policies that reflect the social cost of damages caused by pollution, newly developed low-emission technologies will not diffuse through the marketplace.
- Governments should implement broad-based policies that create markets for low-emission technology today and offer research support for emerging technologies not yet cost-competitive. They should direct their own research and development to non-commercial research rather than crowding out applied research that private companies might do.
- Canada cannot go it alone. Just as Canadian oil producers sell to a global market, so alternative energy producers must also pay attention to global markets. Access to foreign markets will be essential to create sufficient demand for Canadian low-emission energy technologies.

The Role of Government Policy

Understanding the role of environmental policy on technological change involves the study of what economists have termed "market failures." These failures mean that market forces alone will not lead to optimal allocation of resources, justifying government intervention. Two market failures are particularly relevant to energy and environmental technology.

The Economics of Pollution: Because pollution is not priced by the market, firms and consumers have little 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.

The Economics of Knowledge: At the same time, the "public good" 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. Science policy to support research performed in both the private and the public sectors helps bridge this gap. Such policies may include direct government funding of research projects and indirect support such as tax credits for private-sector R&D.

Research and Development Subsidies and Emissions Pricing

Evidence suggests that, although science policy plays a supporting role, 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 low-emission technologies. A study of various policy instruments for promoting both innovation and diffusion of renewable energy technologies in the US electricity sector ranks their effectiveness as follows:

1) a carbon tax based on the emissions from fossil fuels;
2) tradable emission permits, such as the European Union Emissions Trading Scheme;
3) renewable energy portfolio standards requiring that a specific percentage of electricity be generated by renewable sources;
4) a production subsidy for renewable energy; and
5) an R&D subsidy.[1]

However, an optimal portfolio of policies, including both emissions pricing and support for R&D, achieves emission reductions at significantly lower cost than any single policy.

Fisher et al. (2013) provide an updated assessment for the electricity sector, including a broader array of policy options. Although they do not offer an explicit ranking of policies, the main results still hold: when combined with emissions pricing, direct subsidies to more expensive technologies such as solar energy should be modest.

At the macroeconomic level, the long-term welfare gains from an optimally designed carbon tax[2] are much larger than from optimally designed R&D subsidies[3] (Popp 2006). 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. Renewable energy usage is much lower when using only the R&D subsidy because such subsidies address market failures in the invention of new technologies but do not provide incentives to adopt new technologies.

However, carbon prices and R&D subsidies can complement each other if low-emission technologies are less developed than existing fossil-fuel technologies.[4] In such a case, initial R&D subsidies can close the gap between the costs of clean and dirty technologies, reducing the level of carbon taxes needed in future years to reduce greenhouse gas emissions (Acemoglu et al., forthcoming). Indeed, recent research uses patent citation data to evaluate the value of energy patents (Dechezleprêtre et al. 2013). Clean patents generate larger knowledge spillovers than the fossil-fuel technologies they replace, suggesting that an optimal policy over time would begin with high initial energy R&D subsidies, followed by a gradually increasing carbon tax to create demand for clean technologies while the R&D subsidies are gradually phased out.[5] Moreover, because early R&D efforts lower the

1 This ranking is from Fisher and Newell (2008). The above list excludes one policy, a tax on electricity, not currently debated in policy circles.

2 An optimal carbon price equates the marginal benefits of carbon reductions with the marginal costs of such reductions.

3 An optimal R&D subsidy equates the social marginal benefits of research, including the aforementioned knowledge spillovers, to the marginal costs of performing research.

4 The distinction between clean and fossil-fuel technologies varies across the studies cited in this policy brief. In general, the distinction is among technologies that burn fossil fuels as a source of energy, whereas clean technologies use alternative energy sources with little or no pollution.

5 The clean technologies studied include renewable electricity generation and electric and hybrid vehicles, while the fossil-fuel technologies studied include fossil-fuel electricity generation and internal combustion engines.

cost of low-emission energy, the resulting carbon tax is lower than it otherwise would be if R&D subsidies were not part of the policy mix.

Government Research and Development

Scientific publications can help us evaluate the effectiveness of public energy R&D expenditures and the process through which public R&D helps develop scientific knowledge (Popp 2016). Interestingly, unlike work on private-sector innovation, other factors such as energy prices and policy have little effect on alternative energy publications.[6] Thus, current government energy R&D efforts appear to support novel research rather than crowding out work that would otherwise be done. However, earlier studies do find instances where government energy R&D crowds out private R&D efforts, particularly when government funding targets applied research topics (Popp 2002). Government R&D will continue to be most effective if it focuses on breakthrough technologies that are not yet close to market.

In addition to correcting for underinvestment by private firms, government R&D projects often aim to improve the commercialization of new technologies. What remains important is that government involvement complements rather than replaces private-sector activities. For example, Small Business Innovation Research grants from the US Department of Energy help small firms bring new technologies to market by funding technology prototyping (Howell 2016). Such one-time grants to small young firms that would otherwise have difficulty financing the fixed costs of commercialization are an example of government investment complementing that of the private sector.

Popp (2016) also shows that there is room to expand energy R&D budgets. There is little evidence for diminishing returns to energy R&D at current funding levels across OECD countries. However, patience is important for evaluating public investment in energy R&D. The ultimate goal of energy R&D funding by governments is not publications but new commercially successful technologies. The citations these articles receive from future patents are a measure of the impact of basic science on new technologies (Popp 2016).[7] Because of the time necessary both to complete research and to see it published, it may take up to a decade to realize the full effect of public energy R&D funding on publications, and even longer before these publications are cited in new energy patents.

New patent applications citing publicly funded research begin appearing about one year after funding and continue at an increasing rate for up to 13 years. Although ideally government-funded R&D should focus on riskier projects less likely to be performed in the private sector, the long lags between funding and success from such projects may make it difficult to sustain political support for research on these drawn-out projects. For this reason, funding some low-risk projects likely to have relatively quick returns may help build support for a continuous, steady stream of public energy R&D funding.

6 In this study, energy prices are technology specific. For example, biofuels research is expected to respond to changes in oil and gas prices, while wind and solar research is expected to respond to electricity prices.

7 Patents offer several advantages for measuring technological progress. Unlike R&D data, patents are available in highly disaggregated formats, allowing researchers to study the development of specific technologies across both space and time. Moreover, researchers have found that patents, sorted by their date of application, provide a good indicator of R&D activity, as patent applications are usually filed early in the research process (see, for example, Griliches 1990). Nonetheless, individual patents have a wide range of value, and not all inventions are patented. Thus, patent counts are most useful for providing evidence of changing technological trends.

Innovation and Incentives

R&D support must be combined with other environmental policies to create demand for low-emission technology. Although successful R&D support can lower the cost of low-emission technology, as long as traditional energy sources remain cheaper than low-emission technology, both consumers and firms have little incentive to move away from these dirtier energy sources. Empirical research on policy-induced technological change seeks to understand how different policy instruments affect the development of new environmentally friendly technologies. Many of these studies use patent data to track changes in environmental technologies, such as pollution control devices, alternative energy sources, and technologies designed to improve energy efficiency.

The Role of Energy Prices in Innovation

Early work on energy innovation focused on the link between energy prices and innovation, showing that innovation in both alternative energy sources and energy efficiency increases when energy prices rise. Over the long term, a 10 percent increase in energy prices leads to a 3.5 percent rise in the number of US patents in 11 different alternative energy and energy efficiency technologies (Popp 2002).[8] Most of the response occurs quickly after a change in energy prices, with an average lag between an energy price change and patenting activity of 3.71 years.[9] Similarly, when facing higher fuel prices, firms in the automotive industry tend to innovate more in cleaner technologies, such as electric and hybrid cars, and less in fossil-fuel technologies that improve internal combustion engines (Aghion et al. 2016). A 10 percent higher fuel price is associated with about 10 percent more low-emission energy patents and 7 percent fewer fossil-fuel patents.

While higher energy prices induce low-emission innovation, there is a distinction between price increases due to energy market forces and price increases that are induced by policy. Oil prices reached record highs during the early 21st century, peaking at just over US$145 in 2008. Because of Canada's rich natural resources, these high energy prices spurred innovation within Canada on both low-emission energy technologies (such as wind and solar technologies) and on methods designed to increase the extraction of fossil fuels (such as expanded efforts in the oil sands of Alberta; see Figure 1).

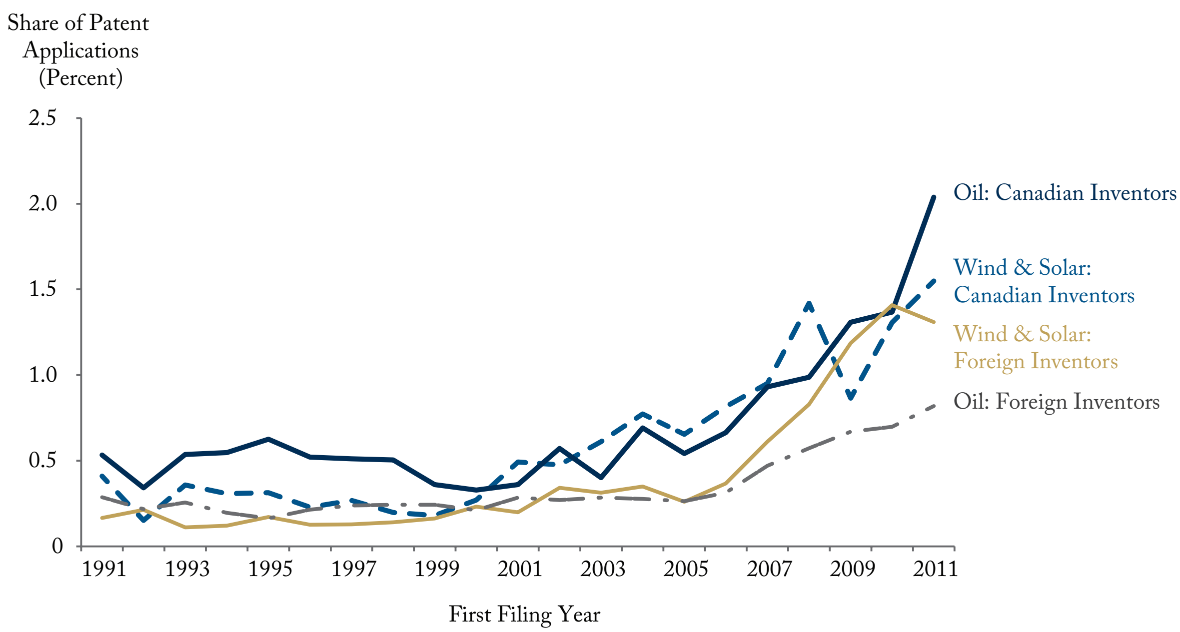
Ignoring the social costs of energy usage, renewable energy sources are generally more expensive than fossil fuels (Greenstone and Looney 2012). Similarly, high extraction costs mean that oil sands petroleum is profitable only when oil prices are high. Thus, higher energy prices encourage innovation not only on low-emission energy technologies but also on technologies that enhance recovery of traditional fossil fuels.[10]

8 These 11 technologies include both supply-side technologies (coal liquefaction, coal gasification, solar energy, batteries for storing solar energy, fuel cells, and using waste as fuel) and demand-side technologies that reduce energy consumption (recovery of waste heat, heat exchange, heat pumps, Stirling engines, and continuous casting of metal). For each technology, energy prices represent the price of energy related to that technology (e.g., the price of electricity for solar energy, the price of coal for coal liquefaction). The data span the years 1974–91.

9 These 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. Verdolini and Galeotti (2011) find similar results using a multi-country sample from 1975 to 2000.

10 Kim (2014) provides evidence that countries with large crude-oil reserves develop more oil extraction technologies, such as those used to obtain oil from the oil sands in Alberta. These countries also put less innovative effort into technologies that may reduce fuel consumption, such as electric and hybrid vehicles.

Figure 1: Selected Energy Patent Applications at the Canadian Intellectual Property Office, 1991–2011



Note: Figure 1 shows the share of patents related to wind and solar technologies or to enhanced oil recovery. As patents with Canadian inventors make up less than 15 percent of all patents filed at the CIPO, using shares provides a similar scale for both Canadian and foreign patents. Canadian patents are those with at least one Canadian inventor.

Source: Author's calculations from Canadian Intellectual Property Office (CIPO) data.

For comparison, although wind and solar energy patents from foreign inventors increased at similar rates to wind and solar patents from Canadian inventors, the increase in the share of oil recovery patents from foreign inventors is about half that of Canadian inventors. Thus, simply relying on uniformly higher energy prices to increase innovation in Canada provides incentives for both renewable energy and enhanced energy extraction research. In contrast, by reducing the price gap between low-emission energy sources and fossil fuels, policies such as a carbon tax spur additional low-emission energy research but do not promote additional investments in new oil recovery technology.

Policies and Innovation in the Electricity Sector

Understanding the incentive of various policy instruments is important. Although economists often favour using broad-based policies such as a carbon tax or tradable permits to reduce the price gap between low-emission energy and fossil fuels, policymakers 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 to be generated using renewable sources. Renewable portfolio standards leave it to market forces to decide which renewable sources are used to meet the target, but feed-in tariffs may target specific energy sources. For example, at their peak, feed-in tariffs for solar energy in Germany were more than seven times higher than the feed-in tariffs for wind energy (OECD-EPAU 2013).

The impact of such narrowly focused policies on innovation is policy specific. Policies such as renewable portfolio standards favour the development of wind energy (Johnstone et al. 2010). Of the various alternative energy technologies, wind has the lowest cost and is closest to being competitive with traditional energy sources. When faced with a mandate to provide alternative energy, firms focus their innovative efforts on the technology that is closest to market. Similarly, broad-based policies that increase energy prices, such as a carbon tax, will also increase demand for low-emission energy sources that are 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 require the guaranteed revenue from a feed-in tariff to be competitive.

These results suggest particular challenges to policymakers who wish to encourage long-term 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 approach leads to lower compliance costs in the short term, as firms choose the most effective short-term strategy. However, the policy choice to let the market decide also implicitly "picks a winner." Because firms will focus on those technologies closest to market, broad-based market policy incentives provide less incentive to develop technologies with longer-term needs, such as solar energy. Because no one technology will be fully able to meet all energy demands, complementary policies to promote the development of low-emission technologies further from the market are also needed. Here, R&D subsidies play a role by furthering the development of these low-emission technologies. While dedicated deployment subsidies such as feed-in tariffs are costlier for governments and likely less efficient on a broader scale, limited use of these policies may be justified to provide market experience with cutting-edge technologies.

Importance of International Markets

The prospect of growing markets for low-emission technologies is essential for prospective investors in low-emission technology. For Canadian investors, this requirement often means that foreign markets play an important role. Because patent protection is country-specific, inventors must file a patent application in each country in which they desire protection. Inventors have one year after their initial filing to apply elsewhere. In most cases, they first seek protection in their home country, then apply elsewhere if they think the invention will be marketable abroad. However, Canadian inventors often seek protection in the United States first (see Table 1). A review of the top sources of solar and wind patents granted at the US Patent and Trademark Office shows that the majority of patents from other countries were filed at their home office (or in the European Patent Office in the case of European inventors). In contrast, nearly 80 percent of Canadian wind and solar patent applications were first filed in the United States, indicating that inventors perceive the US market as more important than the Canadian market.

Most studies of environmental innovation focus on national-level policies, but two recent studies on both foreign and domestic renewable energy policies demonstrate the importance of international markets for renewable energy. Domestic and foreign policies that increase the demand for solar energy stimulate innovation, with roughly equal-sized effects for both (Peters et al. 2012). For wind energy, the impact of policy changes in domestic markets is 12 times higher than similar-sized changes in foreign markets. Nonetheless, because

Table 1: First Filing Country, USPTO Patents from Top Patenting Sources

Wind	Number of Patents	Filed at Home *(Percent)*	Filed US *(Percent)*
United States	1,542	99.3	N/A
Germany	377	78.5	13.5
Japan	144	78.5	2.8
Denmark	137	54.7	7.3
Canada	*122*	*17.2*	*81.2*
Solar	**Number of Patents**	**Filed at Home *(Percent)***	**Filed US *(Percent)***
United States	4,556	99.6	N/A
Japan	1,105	96.3	1.7
Germany	422	91.9	2.8
France	148	93.2	3.4
Australia	121	86.8	12.4
Switzerland	86	67.4	8.1
Israel	99	49.5	48.5
Canada	*96*	*17.7*	*73.9*

Source: Author's calculations from data extracted from www.delphion.com.

foreign markets are, on average, 30 times larger than the domestic markets in most individual OECD countries, the overall effect of an increase in foreign demand is twice as large as an increase in domestic demand (Dechezleprêtre and Glachant 2014). Given Canada's close economic ties with the United States, policies that encourage the adoption of low-emission technologies in the United States will be important in creating larger markets for Canada's green innovators.

Although policies in other countries are beyond the control of Canadian policymakers, these findings offer a cautionary tale for those who hope to use energy policy in Canada to develop a Canadian low-emissions energy technology sector. The ability of energy and environmental policies to promote local industry will be greatest when the location of activity matters. For example, efforts to promote solar energy in Canada might create demand for local workers to install solar panels. But lower production costs in China mean that the panels themselves are still likely to be imported rather than produced in Canada. In short, the ability of Canadian firms to compete in global markets will be most important for developing a Canadian clean energy technology sector.

Conclusions

With plans for expanding alternative energy research budgets in the works, prudent planning is essential. Efforts to further the development of low-emission technologies require both additional research dollars and policy support to create demand for new technologies. Although broad-based policies such as carbon taxes or cap-and-trade promise the greatest short-term cost savings, modest targeted subsidies for specific technologies are justified for those technologies furthest from the market.

Specifically, government-funded R&D should focus on riskier projects less likely to be performed in the private sector. It may also make sense to fund some low-risk projects likely to have relatively quick returns to help build political support for a continuous, steady stream of publicly funded energy R&D. Most important of all, support for alternative energy R&D should be used to complement other energy policies, not to replace them.

Finally, Canada cannot go it alone. Just as Canadian oil producers sell to a global market, alternative energy producers must also pay attention to global markets. To develop these markets, Canada should not only promote policies to support renewable energy at home but be active in efforts to promote these policies worldwide, particularly in the United States.

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