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Carbon Revenue: Recycling versus Technology Incentives

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Policy Summary

This paper addresses a number of issues about the disposition of the funds generated by the Alberta Specified Gas Emitters Regulation (SGER), focusing on the allocation of funds among three competing broad categories of expenditures: 1. revenue recycling via tax reductions, 2. support for developing new technologies, and 3. support for adoption of existing technologies.

1. Modeling studies of revenue recycling find that the impact of a price-based carbon policy can be significantly mitigated when tax revenues or sales of allowances get used to reduce corporate or income taxes. This avenue of disposition is easily designed to be transparent. If some of the revenues are used to reduce income taxes, the reductions can be focused on lower income households, where labour supply response is likely to be greatest.

2. An effective climate response requires a role for both developing and adopting new technologies. The returns to technology supports generally are *potentially* very large, but the empirical case for them is more nuanced.

3. The empirical evidence regarding the effectiveness of various measures aimed at either developing new technologies or adopting them is limited, and is far from universally supportive. By contrast, theoretical and simulation models tend to suggest that both avenues are useful. In many cases, however, the theoretical and simulation models abstract from three significant challenges:(a) picking winners, (b) free-riding, and, (c) lock-in.[1]

4. The easier it is to 'pick winners' the weaker may be the economic case for them. Technologies with the largest and broadest gains are most likely to be adopted given incentives from the price mechanism.

5. The picking winners problem is likely to be most costly if funds are focused on too small a subset of technologies. Losing technology diversity is a risk.

6. Public R&D expenditures are more likely to effectively promote invention if targeted on projects that yield significant social value but relatively small returns for private investors. (avoid crowding out).

[1] We are unaware of any simulation or theoretical study that considers more than one of these issues.

7. Even though there is a lot of evidence of ‘learning curves’ in new technologies including new energy technologies, empirical assessment of the effectiveness of adoption subsidies inspired by them is limited and suggests much lower cost-effectiveness than studies prepared by utilities.

8. Because of some of the uncertainties related to the effectiveness of technology-focused studies, education funding is another option. The endogenous growth literature argues that funding of education for scientists and engineers also plays a key role in technological development.

9. The importance of transparency, credibility, and time consistency in funding policies is emphasized in the literature for being crucial to shape actors’ long-term expectations. Investment in innovation requires maximization of certainty and predictability of environmental policy.

10. Capture by lobbying and vested interests must be avoided. Decisions should be made based on impartial assessment of potential for lowest cost emission reductions.

11. Even the appearance of partiality can undo the good of solid governance documents. The appearance of impartiality will be damaged to the extent that the funds paid into the CCEMF are returned to those who contributed them.

12. The emerging consensus is that technology support for either development or implementation of technologies should complement rather than replace carbon pricing.

1 Introduction

The purpose of this paper is to evaluate alternative uses of government revenues from carbon regulation and provide preliminary criteria for their assessment in the Alberta context. The Specified Gas Emitter Regulation (SGER) introduced by the provincial government in 2002 provides large emitters the option to acquire emission permits to meet their intensity based targets. In 2011, more than half of the total compliance burden was achieved through permit purchases, and as of March 2012, Alberta's Climate Change and Emissions Management Fund (CCEMF) held \$312M .

Multiple options for recycling such carbon-policy related revenues back into the economy exist and a growing body of literature debates their relative advantages. First, carbon revenues can be treated just like public funds from other sources and recycled through the general tax system, e.g. to cut personal income taxes and/or business taxes. This revenue recycling option is discussed in the context of an environmental tax reform (see for example (Ekins, Pollitt, Summerton, and Chewpreecha 2012)). Second, the generated funds can be used more specifically to further promote climate change mitigation through investment in low carbon technologies. Technology investment can either focus on the development of new technologies or the diffusion of existing clean technologies. There is broad agreement in the literature that achieving meaningful reductions in greenhouse gas (GHG) emissions involves a large-scale transformation of energy technologies that requires both improvement of existing technologies and creation of new technologies (Marangoni and Tavoni 2013). To date, Alberta's carbon revenues have been recycled via the CCEMF (option 2) and as such mainly supported projects using technologies in the later stages of the development process, demonstration and commercialization.

The remainder of the paper is structured as follows. Section 2 and section 3 provide a brief overview of Alberta's current climate regulation and the CCEMF. Section 4 identifies two types of investment in low carbon technologies at two distinct stages of technological change processes, namely the invention stage (technology development) and the innovation stage (technology diffusion). Research investigating the effectiveness of investment in invention and innovation are reviewed and compared to each other in the Alberta context. Section 5 discusses carbon revenue recycling choices in terms of governance and transparency issues. Section 6 concludes.

2 Alberta's Climate Policy

Alberta released its Climate Change Strategy in 2008, building on the province's previous Climate Action Plan from 2002. The Strategy establishes a emission reduction target of 50Mt below BAU in 2020, which corresponds to an increase of 18% above 2005 emission levels (NRTEE 2012). The interim commitment was to cut emissions by 20Mt below BAU by 2010. The long-term target is the reduction of 200Mt below BAU by 2050, of which the largest part is planned to be achieved through the employment of carbon capture and storage technologies (CCS) (139Mt), followed by reductions in carbon-intensity of the energy sector (37Mt) and greater energy efficiency (24Mt).

Alberta introduced the Specified Gas Emitter Regulation (SGER), an intensity-based climate regulation, in 2002 in the context of the Provinces' Climate Action Plan. The SGER entered into force as of July 1, 2007 and expires in September 2014 (Government of Alberta 2012). The regulation targets large industrial companies emitting more than 100,000t per year. Existing facilities were required to immediately lower GHG emissions from combustion and venting and fugitive emissions per unit of output by 12% between 2003 and 2005. Newer facilities built after 2000 were granted a 3-year grace period, after which they are required to reduce carbon intensity by 2% per year up to 12%. In 2012, the SGER covered 106 facilities from 13 sectors, which collectively accounted for around half of total provincial emissions and around 70% of industrial emissions (Government of Alberta 2012).

The Climate Action Plan grants companies flexibility in terms of how they comply with the SGER requirements. Four compliance options are available: (a) Companies can invest in on site emission reductions or the recognition of cogeneration. Companies that outperform their target in this way earn tradable emission performance credits (EPCs). (b) Purchase and retirement of such emission performance credits from over-performing companies represents the second compliance alternative. (c) Companies can also purchase and retire domestic offset credits from sectors that are not covered in the regulation such as agriculture and transport. (d) Finally, firms can purchase a permit at the price of $15/t from the compliance fund, the CCEMF, that was created in 2009 as part of Alberta's climate change strategy. This purchasing option effectively sets a ceiling for mitigation efforts.

In 2012, the total compliance burden was 13.93MtCO2e (Government of Alberta 2012). Almost 5Mt worth of actual emission reductions and cogeneration were achieved and around 2.6Mt worth of Alberta offset credits were retired for compliance. An additional 0.65Mt worth of EPCs were submitted. Payments to the compliance fund amounted to $86M in 2012, which corresponds to an emissions volume of around 5.7Mt or 41% of the total compliance burden. From 2007 to 2012, payments to the CCEMF totalled $398M (all figures from (Government of Alberta 2012)).

Alberta's Climate Change Strategy emphasizes the key role of CCS in climate change mitigation. Projects have been implemented at a number of industrial sites in Alberta already and the Strategy promises further support for research and demonstration. CCS implementation is projected to lead to emissions reductions worth 139Mt by 2050 (Government of Alberta 2008). Another key pillar of Alberta's mitigation plan is the greening of energy production by reducing emissions related with the use of oil, coal, and gas and by promoting alternative renewable energy sources.

3 Tech Fund Revenue

The CCEMF is managed by the Climate Change and Emissions Management Corporation (CCEMC). The CCEMC is an independent organization yet it seeks alignment in its funding policies with Alberta's Carbon Capture and Storage Development Council and the province's overall mitigation strategy. This includes a focus on CCS development, cleaner energy production from fossil fuels and renewable energy, as well as energy conversation and efficiency measures.

The CCEMC's broad mandate is the establishment of or participation in funding initiatives for climate change mitigation and adaptation. As of November 2012, the Fund has invested around $161M in a portfolio of 54 projects covering a range of technologies at all stages of commercialization. The current portfolio shows a clear focus on projects in non-conventional oil extraction (worth nearly $75M or 47% of the invested funds), electric power generation ($25M or 16%), and oil and gas extraction ($26M or 16%) (CCEMC 2012). In terms of innovation stage, the majority of funding goes to projects in the market demonstration phase (around 55%) and commercialization phase (around 39%), followed by research and development projects (around 5%) and projects in technology design and development (around 2%) (CCEMC 2012). The CCEMC's 2011/12 annual report states the intention to increase investment in early stage technologies in the future.

With the establishment of the CCEMF, the Alberta government opted against the recycling of SGER revenues through the general tax system. A growing body of literature assesses the environmental and welfare implications of an environmental tax reform (ETR) where levies on environmental pollution are used to reduce personal and corporate income taxes. Some studies indicate such ETR can yield a double-dividend (l. Gimenez and Rodriguez 2010): First, the environmental dividend describes the welfare increase achieved from the environmental tax assuming that revenues are paid back to households by lump-sum transfers. Second, the economic efficiency dividend is defined as the welfare gain achieved by using carbon tax revenues to reduce distorting labour, consumption, or capital taxes instead of making lump-sum transfers. However, theoretical literature shows no consensus regarding the existence and magnitude of a double-dividend from ETR (see for example (Bovenberg and de Mooij 1994) and (Bento and Jacobsen 2007) for opposing views). Whether losses in the factor markets due to higher energy prices are balanced through gains from efficiency enhancing tax revenue recycling, will depend on the initial rates of the taxes as well as the respective elasticities of substitution of labour and capital with the taxed fuels.

More recent simulation (CGE) studies of environmental tax reform have tended to find a significant role for revenue recycling, particularly via reductions in corporate taxes. The studies do not find a strong enough efficiency dividend to offset the impact of a carbon tax, but revenue recycling can significantly mitigate the costs.Mckibbin, Morris, Wilcoxen, and Cai (2012) Our work in progress finds that recycling revenue through corporate or income taxes normally dominates returning the revenue generated in a lump-sum fashion, sometimes by a significant margin.[2]

Both channels for carbon revenue recycling, support for low-carbon technologies and tax cuts, can have beneficial environmental and economic effects at the same time. Funding policies for the promotion of low-carbon technological change can have secondary economic benefits including reduced production costs, the creation of green jobs, increased competitiveness, and infant industry development (Melitz 2005). Similarly, revenue recycling through ETR can implicitly foster low carbon innovation simply by freeing companies' resources for such activities.

[2] A citation to our own work in progress be added.

4 Investment in Low-Carbon Technologies

4.1 Invention–Innovation

Technological change has two distinct phases, requiring investment in different activities:

- In the invention phase, investment in R&D implies the active search for new ideas to improve technologies or processes. Investment in R&D involves high risks as outcomes and returns are uncertain.

- A newly invented product or process enters the innovation phase, when it is first introduced to the market. In this phase of technological change investment on side of the developers is required to fund demonstration projects and commercialization activities, and on side of the users to purchase the new product and thus promote its diffusion. The decision to invest in the adoption of a new rather than the established technology is characterized by high uncertainty about the new technology's performance, operation costs, longevity etc.

In the invention phase, development expenditures are commonly very high and returns initially negative. R&D investment is only amortized with commercial technology diffusion. Mass production enables economies of scale and cost-reduction through growing experience or learning-by-doing. Such scale effects reduce the fixed costs per unit, speed up production processes, reduce error rates, reduce maintenance costs, may even lead to incremental new inventions.

With perfect competition, private actors supply both invention and innovation automatically at efficient levels. However, government action is needed if markets fail to deliver socially optimal levels of invention and innovation (Veugelers 2012). Multiple market failures can occur in relation to low carbon technologies (Jaffe, Newell, and Stavins 2005). Private investors in technological change are unable to fully appropriate the social value of their investment if the created knowledge has public good character (Mowery, Nelson, and Martin 2010). Non-priced benefits from investment in technological change will be more significant if knowledge externalities combine with environmental externalities, i.e. if the improved technology also leads to environmental benefits such as carbon emission reductions. Rennings (2010) calls this phenomenon the "double externality problem". Fischer and Newell (2008) further distinguish between knowledge spillovers from R&D activities (Griliches 1992) and learning spillovers from applying the new technology. Jaffe, Newell, and Stavins (2005) call the latter adoption externalities. Both types of knowledge spillovers as well as environmental spillovers incentivize free riding among technology developers and technology users and justify policy intervention.

Two different branches of economic theory deal with the triple externalities associated with investment in low carbon technology development and diffusion: environmental economics is concerned with the pricing of environmental externalities, and innovation economics is concerned with internalizing knowledge spillovers from R&D activities and innovation adoption (Rennings 2010). Economically efficient solution to the triple externality problem requires the integration of environmental and innovation policies (Jaffe, Newell, and Stavins 2005). In addition to the market failure justifications some scholars also suggest strategic economic arguments in favour of targeted low carbon technology policies, such as international competitiveness and the creation of 'green' jobs. However, Morris, Nivola, and Schultze (2012) and Borenstein (2011) question whether such objectives indeed warrant government intervention.

Carbon pricing policies are the economically most efficient solution to fixing the environmental externality problem (Jaffe, Newell, and Stavins 2005). Internalizing the social cost of emitting carbon into the atmosphere inherently drives investment in low emission technologies yet complementary measures may be necessary to incentivize private firms to achieve the socially efficient level of R&D activities (Gans 2012) and to invest in the early adoption of new, low carbon technologies (Jaffe, Newell, and Stavins 2005).Fischer and Newell (2008) conclude that a combination of carbon pricing policies, R&D subsidies, and adoption subsidies yields the greatest emissions reductions at the lowest economic cost. Veugelers (2012) and Acemoglu, Aghion, Bursztyn, and Hemous (2009) and Bosetti, Carraro, Duval, and Tavoni (2011) also illustrate the importance of a strong carbon price signal for increasing the effectiveness of technology development and diffusion programs. While Jaffe, Newell, and Stavins (2005) emphasize that targeted public technology funding is economically costly and should generally complement rather than replace environmental policies, stand-alone technology policies can be the second best option if carbon pricing, the first best policy choice,is impossible to implement for political reasons (Fischer and Newell 2008). Schneider and Goulder (1997) also find that research subsidies alone do not achieve least cost emission reduction but a carbon tax is the better instrument. Assuming a combination of environmental and technology policy measures, government revenues from carbon pricing instruments such as taxation, auctioning of emission permits or in the case of Alberta compliance payments can be used to fund low carbon technology policies.

Technology policies either promote low carbon technology development or technology diffusion:

Technology-push programmes R&D grants, tax cuts and similar policies to lower the cost and risks for private firms associated with technology development address inefficiently low levels of investment in low carbon inventions. R&D activities that are unlikely to yield any return for private firms can also be performed by fully funded public research institutions (Jaffe, Newell, and Stavins 2005).

Demand-pull programmes Direct subsidies (e.g. feed-in tariffs) and tax credits for purchasers of new technologies, public procurement, and import quotas address inefficiently low levels of adoption of existing low carbon technologies by creating demand.

A clear distinction between market-pull policies promoting invention and technology-push policies promoting innovation is often impossible. Demand-pull policies in the long run are likely to also trigger investment in technical improvement as the pay-off for successful inventions increases. Similarly, technology-push policies may foster adoption of one technology by providing a complementary technology (Nemet 2009). The fund's current funding policy focuses largely on technology-push activities. Funding is directed mostly to technologies that are already in the commercialization phase, yet support is still granted to technology suppliers for bringing the technology to the market than to technology users for its adoption. The SGER itself can be considered a demand-pull initiative as it increases firms' willingness to purchase low carbon technologies.

4.2 Effectiveness of Adoption Subsidies

Early adopters of existing but still novel technologies face high risks regarding technology performance, reliability, and operating costs. Even assuming environmental externalities are fully priced, additional subsidies may be needed to compensate early adopters for not choosing the incumbent established technology but taking the risk of innovation and thereby creating new learning and experience effects that benefit society as a whole (Mowery, Nelson, and Martin 2010). Adoption subsidies aim at market building and demand creation.

The effectiveness of demand-pull policy programmes has been subject to much conceptual and empirical research. Three broad research streams can be distinguished:

- One set of studies examines the source and scope of learning externalities in alternative energy industries. Considered technologies include offshore wind power (van der Zwaan, Rivera-Tinoco, Lensink, and van der Oosterkamp 2012), photovoltaics (Wand and Leuthold 2011), clean coal (Nakata, Sato, Wang, Kusunoki, and Furubayashi 2011), and CCS (Li, Zhang, Gao, and Jin 2012). These studies commonly explain the occurrence of cost reductions and quality improvements with increasing output by reference to learning or experience curve models, economies of scale, spillover effects from research and development or declining input factor prices. Learning effects in production and use of the new technology can create positive feedback dynamics. Once a critical level of technology diffusion has been reached, prices have diminished to a competitive level and the technology is able to sustain its growth without requiring further public funding (Melitz 2005). This phenomenon is sometimes called dynamic cost efficiency (Sanden 2005).

- Another body of literature investigates the effectiveness of a specific type of adoption policies, namely demand-side management (DSM) programs that aim to change energy consumption behaviour of end-users such as households, small businesses, and municipalities. [3].Promotion of energy efficiency represents the third pillar of Alberta's Climate Change strategy and CCEMC funded projects to enhance energy efficiency are estimated to achieve close to 0.5 MtCO2e per year (as of May 2012) (CCEMC 2012). Energy efficiency projects in the fund's current portfolio are largely concerned with technical solutions for industrial energy savings as opposed to demand-side management projects. Gillingham, Newell, and Palmer (2004) review studies on the effectiveness of energy conservation tax credits to households and find overall mixed results and a lack of data. Using a panel data set of 38,500 tax returns over the years 1979-1981, Hassett and Metcalf (1992) investigate the impact of energy conservation tax credits on investment and identify a significant positive relation. Similarly, a recent policy brief (Brownlee 2013) investigates the success of of retrofit programs financed by municipalities or utilities. The results show that emerging best practises in Canada may have made residential energy-retrofit

[3] The literature distinguishes between three components of demand side management: energy efficiency (mainly achieved through technical solutions), conservation (achieved through behavioural changes), and load management (change of consumption patterns through information on peak/non-peak times and price signals) (Carley 2012)

subsidies more attractive than were previously believed to be. Importantly, any energy efficiency policies carry the risk of triggering rebound effects that may partly or fully offset the positive impact of greater efficiency on carbon emissions (Greening, Greene, and Difiglio 2000). In terms of Alberta's potential for reducing GHG emissions through energy efficiency investment Row and Mohareb (2014) very recently estimated the annual mitigation potential by 2020 if all currently economic energy efficiency measures were implemented at 27Mt (that is more than twice the SGER compliance burden in 2012). Although Row and Mohareb (2014) find that net annual savings from reduced energy consumption associated with these measures would amount to \$1.5 B by 2020, non-financial barriers prevent investment. Row and Mohareb (2014) recommend using the CCEMF to promote energy efficiency investments in the residential, commercial and small industrial sectors by addressing key barriers such as the lack of information and access to capital financing, high transaction costs and high perceived risks. Notwithstanding the potential for energy savings, econometric studies tend to find dramatically lower cost-effectiveness of demand side management programs.Rivers and Jaccard (2011)

- A third body of research investigates how such economies of scale, learning effects, and the good fit of new technologies with existing lifestyles, and infrastructures may lead to path dependencies in technology trajectories. Lock-in of dominant technological solutions can entail a discontinuation of the search process for alternative, possibly superior solutions and non-incremental technical improvements because once a "technological paradigm" has been established it dictates the definition of the problem, the definition of progress towards its solution and as such the long-term "technological trajectory" (Dosi 1982). Public funding for the adoption of prescribed technologies can enhance increasing returns on investment in the promoted technologies, enhance path-dependence and thus inadvertently help the inefficient narrowing of the technological search process (Kverndokk, Rosendahl, and Rutherford 2004).

4.3 R&D Subsidies

In the long term, the mitigation of climate change will require radical, non-incremental technological change and therefore investment in R&D (Veugelers 2012). Much of the existing literature implies that technology-push programs are the key driver of non-incremental technological change, with demand-pull forces in a complementary yet less dominant role (di Stefano, Gambardella, and Verona 2012). Watanabe, Wakabayashi, and Miyazawa (2000) describe a virtuous cycle that public R&D support can induce in the presence of knowledge and learning spillovers: Technology development funding enhances the economy's knowledge stock, which leads to greater production of new technologies, which in turn reduces production costs through growing experience and scale effects. The sinking cost not only motivate ever larger production volumes but also free resources for investment in new R&D projects, thus closing the virtuous cycle. Watanabe, Wakabayashi, and Miyazawa (2000) observe these dynamics in Japan's solar photovoltaic power generation industry. Nevertheless, empirical literature examining the promotion of clean technology development (often measured by number of registered patents) achieved through environmental policies in general, and research subsidies in particular, is surprisingly limited (Veugelers 2012). Nevertheless, two conclusions can be drawn from the reviewed studies:

- Public R&D expenditures are more likely to effectively promote invention if targeted on projects that yield significant social value but relatively small returns for private investors, i.e. where the market failure causing under-investment is particularly pronounced (Clausen 2007). The gap between private and social return is particularly large for many basic research projects and technologies that are promising yet still early in early development stages and far from marketization (Mowery, Nelson, and Martin 2010).

- The effectiveness of public R&D subsidies to trigger additional investment is compromised if public funds merely crowd out private money. Instead, public support should incentivize private engagement because ultimately, a combination of both funding sources is needed to realize the low-carbon technology transition (Mowery, Nelson, and Martin 2010). Almus and Czarnitzki (2001) investigate the effect of R&D subsidies on private firms' R&D expenditures in Eastern Germany. The results indicate that on average, public funding achieves higher R&D investment. Other studies show significant (Busom 2000) or even full (Wallsten 2000) crowding-out effects.

- A recent global study on the need for R&D support yields interesting results regarding the performance of clean technology promotion. Marangoni and Tavoni (2013) employ a global integrated assessment model to investigate the contribution of international cooperation on clean energy R&D to achieving the 2 degree target. The policy simulations assume relatively large knowledge externalities that are fully integrated due to the global scope of the model. Still, at least in the short run, cooperation in international clean energy R&D slightly under performs compared to a continuation of fragmented mitigation actions currently observed. While this finding can only be regarded with care in the context of Alberta's SGER revenue recycling options, its message seems clear: Even under somewhat ideal conditions (i.e. assumed large spillover effects and cross-border integration) does R&D funding only show limited environmental and economic effectiveness. Nevertheless, Marangoni and Tavoni (2013) also claim that significant clean energy investment is important for achieving the low carbon necessary to meet ambitious emission reduction targets but carbon pricing also incentivizes such investment.

4.4 Comparison

Implicitly, all climate change policies including taxes, subsidies, regulations attach a price to emitting. Policies should be chosen as to achieve the set environmental target with least economic costs. Hence, comparing the performance of demand-pull and technology-push policies requires both a comparison of environmental effectiveness and economic costs.

Surprisingly, the literature only provides patchy empirical evidence of effectiveness and efficiency of both invention and innovation subsidies (Veugelers 2012) because programme success is difficult to measure (Jaffe, Newell, and Stavins 2005). Existing case studies generally indicate differential results: specific financial support measures have varying impacts on different technologies so that general conclusions are difficult to draw (Veugelers 2012). However, there is large agreement in the literature that effective climate change mitigation requires more than a one-off specific technology intervention but rather a large-scale transition of the socio-economic system (Mowery, Nelson, and Martin 2010). Most scholars conclude that investment in both development of new and diffusion of existing technologies are necessary to achieve such a transition (see Mowery, Nelson, and Martin (2010) and Rennings (2010)). (Nemet 2009) the relative effectiveness of technology-push and demand-pull policies depends on the type of invention one wants to achieve, either incremental or non-incremental. Investment in radical, non-incremental inventions means investment in future emission reductions, while investment in enhanced deployment of existing technologies promises to yield more near-term impacts on emissions. Action in both time frames is needed to tackle climate change (Veugelers 2012). If the early adopters' experiences are fed back to the technology providers, technology adoption and technological improvement can actually reinforce each other (Mowery, Nelson, and Martin 2010). In short, processes of technological change are complex and neither strong technology-push nor demand-pull approaches approaches to managing technological change can be effective on their own (Dosi 1982).

One interesting aspect in comparing the economic returns on technology-push and demand-pull for the domestic government is the likelihood that the knowledge and learning induced by domestic R&D and adaptation funding will actually spill across borders and hence benefit foreign economies. Peters, Schneider, Griesshaber, and Hoffmann (2012) find that domestic technology-push initiatives do not promote technology development abroad, whereas the innovation effects of demand-pull policies do spill over national borders. Consequently, Peters, Schneider, Griesshaber, and Hoffmann (2012) recommend cross-border cooperation on market creation for low carbon technologies. In the context of Alberta's technology funding strategies, focus on R&D support may ensure that the generated knowledge externalities can be fully appropriated within the province.

From a more holistic perspective, some authors moreover emphasize the interplay between technological change and social/institutional change (Rennings 2010). Supply of inventions and demand for innovations are shaped by the existing and interacting economic, institutional and technical infrastructures (Dosi 1982). Hence, even a combination of invention and innovation support policies standing alone may be insufficient to trigger technological transformation if the wider policy landscape is not conducive to promoting the development of a low carbon economy. For example, Romer (2000) discusses how support for education and training for scientists and engineers can fruitfully complement public research funding. Herring and Roy (2007) claim that policies promoting lifestyle changes will be necessary to prevent rebound effects from carbon efficiency improvements.

Finally, to the extent that technology incentives are delivered through tax expenditures (accelerated write-offs or tax credits) there are concerns about the (negative) revenue-recycling effects. That is, because they involve expenditures rather than generate tax revenues, they tend to be less economically efficient.[4] (Duff and Wiebe 2009)

[4] Duff and Wiebe (2009) also suggests there are other concerns with the tax expenditure approach related to their transparency and evaluation.

5 Governance and Transparency Issues

The CCEMC website provides information on funding application policies and the criteria for project selection. A standardized methodology for project evaluation is used in order to keep the selection process as objective and transparent as possible. Moreover, a third party reviewer and a Fairness Monitor are involved in every decision process to ensure objectivity. The CCEMF's Board of Directors decides on the final funding approval based on the information provided by an Evaluation Committee, the third party reviewer, and the Fairness Monitor's report. The Board of Directors consists of energy and manufacturing industry representatives, one academic, and representatives from other industries representing the public at large. The importance of transparency, credibility, and time consistency in funding policies is emphasized in the literature for being crucial to shape actors' long-term expectations (Mowery, Nelson, and Martin 2010). In other words, investment in innovation requires maximization of certainty and predictability of environmental policy (Johnstone, Hascic, and Kalamova 2010).

Yet, even assuming that selection procedures are transparent, stable, and openly communicated, fundamental issues around the concept of 'picking winners' remain (Nelson and Langlois 1983). In particular, two issues are discussed in the literature: First, the greater the degree of centralization in technology development and diffusion funding, the greater the risk of losing valuable technical diversity. Invention and innovation are search processes that generally benefit from broad portfolios and risk-taking. Premature focus of funding efforts on a limited number of technological options increases the likelihood of creating path dependence (Mowery, Nelson, and Martin 2010). Decentralization of funding sources and allocation is especially desirable in the early stages of technology development to avoid premature technology lock-in. Yet a certain degree of centralized administration is also important as to promote coordination among initiatives and to avoid redundant efforts.

Second, funding allocation processes are at risk of capture by lobbying groups and vested interests. Ideally, funding decisions would be guided solely by scientific and user interests. Support should be granted to technologies with the lowest abatement costs and the greatest probability of market penetration (Morris, Nivola, and Schultze 2012). Efficient allocation is facilitated if the funder has access to insider information on the new technology. This is more likely the case for generic research or if the funding agency is at the same time also a user of the technology (Nelson and Langlois 1983). However, most invention and innovation investments are characterized by a large information asymmetric between the technology developer and the funding agency (Jaffe, Newell, and Stavins 2005). Due to incomplete information, funding agencies' decisions will be based on somewhat subjective expectations about profitability and commercial potential. This process of 'picking winners' can then more easily be captured by interest groups who may steer funding toward sub-optimal technologies or towards projects where public funds merely crowd-out private investment rather than create additional incentives (Nelson and Langlois 1983). Whether or not such capture actually occurs, already the perception of biases in decision-making alone may be sufficient to erode public trust and credibility of the funding policies. Morris, Nivola, and Schultze (2012) therefore claim that "funding decisions ought to be insulated as much as possible from rent-seeking by interest groups, purely political distortions, and the parochial preferences of legislators." A broad portfolio approach to funding allocation is generally recommended to both prevent technological lock-in and mitigate the investment risks associated with the large uncertainty around future developments (e.g. of global energy markets) (Jaffe, Newell, and Stavins 2005).

Once targeted technology funding decisions have been made, it is important to maintain open communication channels between the funding agency, the private sector researchers, and technology users (Mowery, Nelson, and Martin 2010). Funding agencies should engage in ongoing monitoring and performance assessment of their technology policies (Morris, Nivola, and Schultze 2012). Mowery and Rosenberg (1979) also emphasize the importance of fostering communication between basic research institutions, the non-commercial sector, private firms and laboratories as well as technology users for the purpose of both more effective invention of new technologies and diffusion of existing technologies.

For comparison, revenue recycling through the general tax system can be a very transparent alternative. With revenue recycling through tax cuts, the overall governance challenge regarding the use of carbon revenues is effectively placed in the hands of a democratically elected provincial government. If the revenue is used to cut corporate taxes, leaving companies more resources for R&D the task of picking technology winners is effectively conferred to private companies, who may have more insider knowledge than any funding agency. Granting firms flexibility in meeting environmental targets unleashes a search for new technologies and induces adoption of the most effective and efficient solutions (Johnstone, Hascic, and Kalamova 2010).

6 Conclusion

Tech Fund revenues can be allocated based on several objectives:

1. improving economic efficiency
2. reducing current emissions
3. reducing future emissions
4. speeding up adoption of existing technologies
5. promoting development of future technologies

To some extent 5 also impacts 1 and 3. Similarly 4 also impacts 1 and 2. Objectives 4 and 5 may at odds to at least some extent.

The 'best' use of the available funds depends to some extent on the weights assigned to these competing objectives. The focus in the current project portfolio on demonstration and commercialization of existing technologies seems to have been motivated by the objective to achieve a wide adoption of existing technologies and the associated near-term reductions in emissions. The announced move to earlier stage technologies suggests a move toward the earlier end of the technology spectrum.

The reviewed literature emphasizes the difficulties with measuring the economic efficiency of technological supports relative to different revenue recycling options. Free-riding, rebound effects and crowding out effects further complicate estimating the actual impacts of subsidy policies on firms' investment in technological change and environmental performance. In the face of large uncertainty and imperfect information, many authors recommend a generally flexible and diverse approach to climate change mitigation policies, in terms of policy instruments, invention and innovation support, and promoted technologies. So far, the CCEMF's allocation of funds seems to have been focused on technology-push programs and technologies at the demonstration and commercialization stages. Diversification of support to include greater emphasis on early technology development and later demand-pull programmes may help better address knowledge externalities from R&D and learning spillovers from wide technology utilization.

Revenue recycling through personal and corporate tax cuts can be a transparent and stable alternative to targeted technology funding. Tax cuts for firms may also have a positive impact on investment in technological change. It can always be considered a key reference point for assessing the CCEMF's performance.

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