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synthesis article

A synthesis of unilateral approaches to mitigating emissions leakage under incomplete policies

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This article addresses the question of what an individual jurisdiction (or a group of jurisdictions) could do to mitigate the leakage of GHG emissions that results from its (their) own regulation aimed at reducing such emissions. A novel aspect of this work is that it is focused on methods other than those involving the pursuit of environmental agreements with other jurisdictions to reduce leakage. In other words, the focus is on unilateral measures to reduce such leakage. A number of different approaches including the proper selection of the type of policy instrument and policy ramp up, improved targeting of polluting activities, targeting lifecycle emissions and adoption of additional leakage-specific policies that complement the main policy have been suggested in specific yet different policy arenas. There does not, however, appear to be an understanding of the common and distinct features of the different types of responses and the multiple approaches that might be appropriate in any specific policy context. To this end, this article synthesizes and differentiates the different approaches based on whether leakage is being mitigated *ex ante* or *in media res* and at the national or provincial level, on the tangibility of policy makers' efforts to control leakage, on the level of burden placed on regulated polluters, and on the required level of precision in the estimates of leakage.

Policy relevance
This article provides a consolidated summary of a diverse literature on the different ways in which policy makers can address the problem of the leakage of GHG benefits under unilateral policies. A salient aspect of this article is that it focuses on unilateral responses to leakage that are complementary to the pursuit of environmental agreements with other jurisdictions. It identifies the different types of response that might be appropriate under different settings.

Keywords: border adjustments; emissions; incomplete regulations; indirect emissions; LCA; leakage; permits; pollution; price effects

1. Introduction

This article considers the question of what an individual jurisdiction (or a group of jurisdictions) can do to mitigate the leakage of GHG emissions that result from its (their) own incomplete regulation to reduce such emissions. By incompleteness it is simply meant that all relevant sources of pollution are not governed by the same regulation. A salient aspect of the article is that it is focused on policy instruments other than those involving the environmental agreements with other jurisdictions. In other words, the focus here is on unilateral approaches to reducing leakage that could complement multilateral initiatives. Although this article concentrates on the leakage of GHG emissions

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(henceforth, simply referred to as leakage), several of the policy options discussed here also extend to the leakage of other types of pollutants.

A motivation underlying this work is that unilateral and incomplete environmental regulations (defined in the next section) are pervasive at different vertical levels of government such as municipal, provincial and national.[1] For instance, Norway began reducing its chlorofluorocarbon (CFC) emissions well before the Vienna Convention for the Protection of Ozone Layer was signed, and furthermore Norway's contribution to global CFC emissions was negligible (Hoel, 1991). Likewise Sweden took the lead in implementing environmental tax reform and adopted a carbon tax in 1991 in spite of accounting for only a small share of global emissions (Parry, Norregaard, & Heine, 2012). In 2003, ten states in the north-eastern US signed the Regional Greenhouse Gas Initiative (RGGI), which is the first mandatory programme in the US to reduce GHG emissions from electric power generation. In 2006, when it passed the Global Warming Solutions Act, California became the first state in the US to adopt mandatory state-wide goals for GHG reduction. In fact, there are still no mandatory GHG reduction goals at the federal level in the US.[2]

One problem with incomplete regulations for pollution reduction is the possibility that pollution might shift or leak from regulated to unregulated regions and activities (Dröge et al., 2009). In theory, both the physical amount of leakage, i.e. the quantity of a given type of pollution, and the social cost of leakage could exceed the primary or direct benefits of the policy (Hoel, 1991). In the case of GHGs, leakage could prove particularly costly as damage is a function of the global GHG concentration. Leakage could also be negative, i.e. there could be unintended positive spillovers that amplify the reduction in pollution achieved within the targeted region or sectors (Fullerton, Karney, & Baylis, 2011; Quirion, 2010). The emphasis here is on strategies for mitigating positive, i.e. harmful, leakage.

A natural solution to the leakage arising from incomplete coverage of polluters is to minimize incompleteness. This means bringing unregulated polluters under the purview of a common regulation, which requires negotiating agreements with other jurisdictions or with specific industries in other jurisdictions. In fact, this suggestion arises from standard economic analyses[3], which indicate that there is an appropriate vertical level of government for the efficient provision of any given type of public good.[4] For instance, city governments are the ideal authority to supply local public parks, national defense is a task for a national government and global problems need to be addressed through global agreements.

However, when action at the appropriate vertical level of government is either not forthcoming or is weak, there might be several justifications for unilateral action at a lower level of jurisdiction. This includes the acceptance of moral responsibility for the harm caused to others (Johansson-Stenman, 2005), setting an example that increases the prospects for action at a higher level of government (Bodansky, 2000; Hoel, 1991), reducing uncertainty about the cost of reducing emissions (Elofsson, 2007; Hoel, 1991), signalling about the real cost of inaction and thus engendering wider cooperation (Brandt, 2004), and the existence of local co-benefits such as reductions in local pollution or competitive advantages (Kousky & Schneider, 2003; Porter & Van der Linde, 1995). By reducing informational asymmetries between local and higher levels of government, some types of local actions might even help to improve the cost-effectiveness of higher-level policies (Burtraw & Shobe, 2009). For example, codes that ensure that local infrastructure such as buildings, roads or public lighting systems are designed for optimal harvesting of solar energy could make a significant contribution to pollution reduction that might not be realized with a national policy alone. The mere risk of leakage might therefore be an insufficient reason to avoid unilateral and incomplete environmental policies.

Studies on managing leakage typically tend to analyse either one policy or a small set of policy options that tend to be frequently discussed in a particular context such as border adjustments in the case of leakage due to the effects on international competitiveness or proper targeting of the locations for conservation projects to minimize leakage under land conservation policies. It is often then either recommended or implied that the incomplete policy in question be avoided on account of leakage. However, a consolidated understanding of the common and distinct features of the different types of responses and the multiple approaches that might be appropriate in any specific policy context does not seem to exist. This article is an attempt to address this gap. To this end, this article discerns known unilateral responses to leakage based on criteria such as whether leakage is being mitigated *ex ante* or *in media res* at the national or provincial level, the tangibility of policy makers' efforts to control leakage, the level of burden placed on regulated polluters and the required level of precision in the estimates of leakage. Although the focus here is on leakage of GHG emissions, it is not simply on leakage under GHG policies such as carbon taxes or carbon cap-and-trade. Instead, the discussion draws from the literature on renewable energy policies, agricultural and land-use policies, transportation policies, energy efficiency policies and management of exhaustible resources, among others.

The rest of the discussion is organized as follows. Section 2 presents a classification of different interpretations and mechanisms of leakage. Section 3 discusses the various policy approaches to mitigate unintended spatial leakage of GHG emissions, which is the focus of the article. Section 4 provides a summary of the discussion in Section 3. Section 5 concludes by stating the distinguishing aspects of the different approaches and highlighting the policy situations that might be more appropriate for any specific approach to leakage control.

2. A taxonomy of leakage

Leakage could manifest in the form of displacement across different types of environmental burdens or displacement within a given a type of burden across space and/or time (See Figure 1). An instance of the former is a regulation that raises automobile fuel economy, which lowers the marginal cost of vehicle usage and increases vehicles miles travelled, ultimately increasing road congestion. Such displacement across problem types is avoided by ensuring that there is at least one policy instrument assigned to each different problem. For instance, if a tax per mile of road travelled existed, this would prevent an unintended worsening of the congestion problem due to improvements in fuel economy. Our focus here, however, is on leakage within a given type of burden, such as GHG pollution, for which only the aggregate level of pollution across all (relevant) areas or time frames matters. This type of leakage can manifest in the following ways:

(1) Intentional spatial leakage. An example of this type of leakage is the intentional siting of polluting facilities close to a political boundary and upstream of a river or wind flow such that pollution would spill into an adjacent jurisdiction. Such type of intentional leakage is remedied through

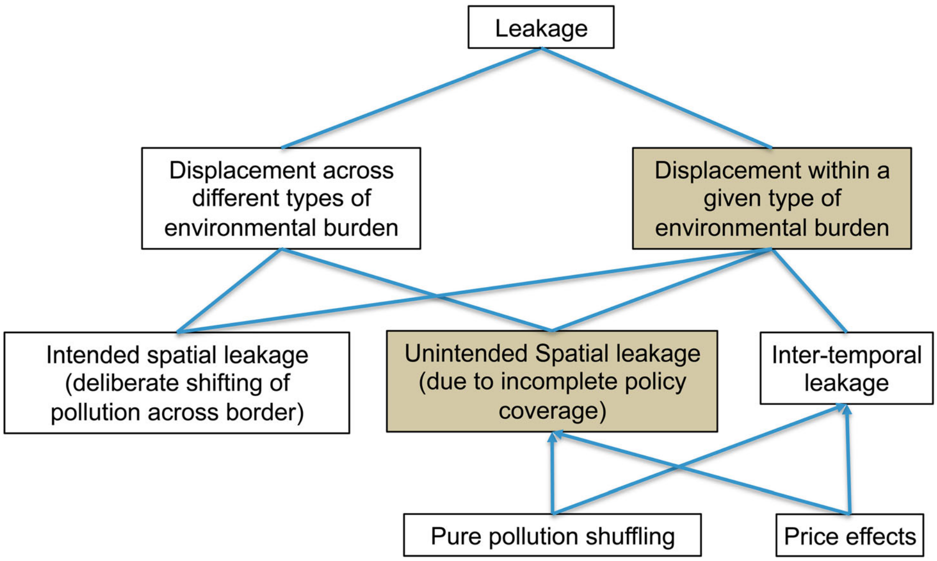

Figure 1 A taxonomy of the leakage of pollution. This article is concerned with the specific type of leakage in the highlighted boxes

liability rules and cross-border pollution obligations between jurisdictions. This type of leakage is not the concern here.

(2) Unintended spatial leakage due to incomplete regulation. Leakage in this context can manifest through two channels.

(a) Leakage due to pure shuffling: When a regulation raises the cost within the policy region of engaging in a polluting activity relative to polluting outside the region, it reduces the economic competitiveness of the policy region. This in turn might lead to the relocation of polluting facilities beyond the policy jurisdiction. To give an example, payments for agricultural land conservation or forest protection have been shown to cause land use to shift to idle farmland (Alix-Garcia, Shapiro, & Sims, 2012; Wu, 2005) or unprotected forests (Chomitz, 2002; Wunder, 2008) respectively, a phenomenon that is sometimes referred to as 'slippage'. Likewise, when a regulation raises the cost of consuming a pollution-intensive final or intermediate good it can lead to a shuffling of these goods such that cleaner goods are consumed within the policy region and the dirtier products elsewhere. A plausible example is the shuffling of high-sulphur diesel and low-sulphur diesel such that the former is consumed in areas with weaker sulphur emission standards and the latter in locations with more stringent standards. Such shuffling might have a negligible effect on the total output of the different goods, and thereby little effect on the aggregate emissions. Pure shuffling is likely to result when the policy or the region affected by the policy is not big enough to affect the market price of an activity.

(b) Leakage due to changes in market prices: When a regulation is large enough to affect the price of goods and activities beyond the policy region, an additional source of leakage might result. For instance, increasing the supply of renewable energy, all else fixed, will reduce the consumption of fossil fuels and hence their price, which might induce a rebound in fossil fuel use. Depending on the type of policy instrument employed to increase the supply of renewable energy and its stringency, the combined effect of changes in fuel consumption within the policy region and outside could either be a net increase or decrease in energy use. When global energy use increases it means that each unit of renewable energy displaces less than one unit of fossil fuel energy, the difference being the source of leakage.

Another example of leakage due to price effects is the phenomenon of indirect land-use change (ILUC) caused by biofuel expansion. Through competition with land for food production, a large increase in the demand for biofuels would affect the price of agricultural inputs and outputs. This would induce an increase in the consumption of agricultural inputs, one of which is farm land, which would be supplied by diverting land away from non-agricultural uses. Such types of land-use change are predicted to result in a net release of the carbon stored on such lands (Khanna & Zilberman, 2012). Other instances of price-induced leakage include regulations that raise the cost of new automobiles and therefore increase demand for older used cars (Goulder, Jacobsen, & Van Benthem, 2012) and land conservation policies that reduce the supply of forestry products leading to an increase in the world price of those products (Aukland, Costa, & Brown, 2003).

(3) Intertemporal leakage. This refers to shifting of pollution across time. One mechanism of this type of leakage is the so-called green paradox (Sinn, 2008), which posits that policies such as a carbon tax would lead the owners of fossil fuels to deplete their resources at a faster rate than they would otherwise. An example of such an effect on a shorter time scale is the adoption of time-of-use electricity pricing, which would raise prices during designated peak hours of the day and induce a shifting of energy consumption towards off-peak hours with lower prices. When electricity storage is costly enough to prevent arbitrage, this could be a source of net leakage. Unlike with spatial leakage, intertemporal leakage might result even with complete spatial coverage of a policy. As with spatial leakage it could either be pure shuffling over time or be accompanied by price effects that would affect cumulative emissions over time. See Fischer and Salant (2012) for a discussion of how four different policies, namely a pollution tax, accelerating cost reductions in the clean backstop technologies, improving energy efficiency and clean fuel regulations, result in both different rates of extraction of polluting fuels and increased cumulative emissions.

The next section describes the different policy approaches to addressing unintended spatial leakage.

3. Policies to address unintended spatial leakage of pollution

In selecting a strategy to manage leakage, it is worth bearing some technical challenges in mind. One is that the importance of leakage is an empirical question yet evidence on leakage can only be obtained *ex post*. However, this is not an intractable problem *per se*. A policy maker could use an *ex ante* estimate of leakage to implement a given policy and once evidence of actual leakage becomes available, *ex ante* estimates could be adjusted to match their *ex post* true values. Under this approach facilities that are found to have been non-compliant could be levied a fee or required to retire additional permits, whereas over-compliant facilities could be refunded excess payments or permits that they might have retired. For true up-based approaches to work *ex post* estimates cannot, however, be highly uncertain. Furthermore, even with no uncertainty *ex post*, incorrect *ex ante* estimates could cause irreversible damage. For instance, an *ex ante* estimate of leakage that turns out to be high *ex post* might have already rendered some facilities uncompetitive and caused them to exit the industry. Alternatively, a low *ex ante* estimate of leakage could cause lock-in of technologies that might prove costly *ex post*.

A second major difficulty is that leakage by definition occurs outside the scope of activities that are governed by the policy in question. To give a few examples, regulations on tail-pipe emissions from automobiles might increase emissions at the energy production stage, land conservation policies might lead to more intensive exploitation of land in areas not covered by the policy and policies aimed at reducing domestic oil use might lead to greater oil consumption abroad. Typically, the extent and the locations where leakage occurs are hard to observe and measure. In analysing leakage under land conservation policies, Aukland *et al.* (2003) state that the establishment of a baseline relative to which leakage is to be measured, and identification and monitoring of leakage are some of the

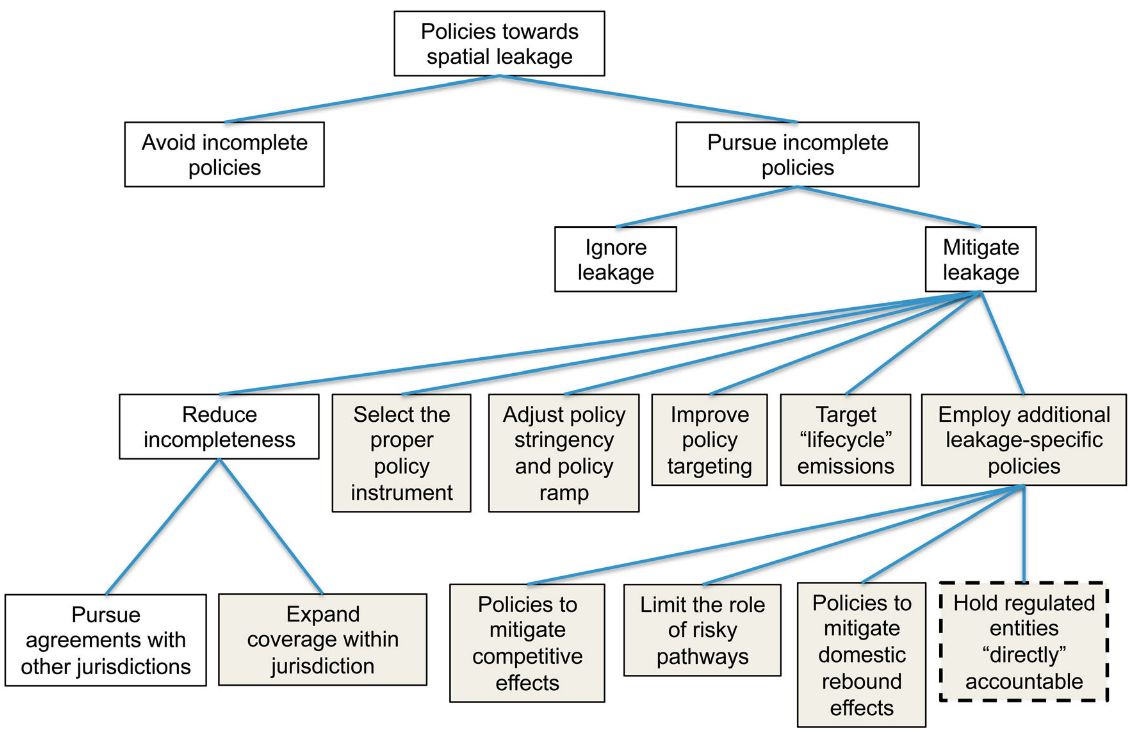

Figure 2 A schematic representation of various responses to spatial leakage under an incomplete policy. Shaded boxes represent options to mitigate leakage through means other than pursuing agreements with other jurisdictions, i.e. unilateral measures. The dashed box highlights the only option that involves placing the burden of leakage entirely on regulated domestic entities by holding them 'directly' accountable

most challenging aspects to managing leakage. And in many cases, even when observable, policy makers would at best be able to exercise only partial control over the sources of leakage.

With this background, one classification of the various ways of limiting leakage is presented in Figure 2, each of which is discussed in detail below:

(1) Avoid incomplete policies. This is an extreme measure but one that might be justified under some conditions, such as when there is reasonable cause for concern that the social cost of leakage might be large enough to offset the direct net social benefits and when any approach to leakage control (discussed next) is likely to be ineffective. There is a large literature analysing emission leakage under regional and national renewable energy policies or carbon policies – the basic conclusion is that such policies are a costly way to improve the environment. See (Rajagopal, 2016) for a review of studies quantifying leakage in different policy arenas. However, most of these studies conform to the standard static economic model and therefore positive spillovers such as innovation, learning by doing, reducing uncertainty and engendering cooperation towards higher-level agreements are rarely considered and are often hard to quantify. Furthermore, studies typically analyse one or two policies at a time, while ignoring other policies both within and outside the policy jurisdiction that might interact with the policy in question. To give an example, consider the interaction of a fuel carbon standard such as the California Low Carbon Fuel Standard (LCFS) with a vehicle fuel economy regulation such as the US federal Corporate Average Fuel Economy (CAFE) standard. Fuel economy standards reduce the cost of driving, which would lead to a rebound in fuel consumption whereas an LCFS is likely to raise the cost of fuel consumption. If the primary policy being analysed is the CAFE regulation, then studies that ignore the LCFS would over predict the extent of the leakage relative to those that take the LCFS into consideration. Alternatively, if the primary policy being analysed were the LCFS, then studies that ignore the CAFE regulation would under-predict the extent of leakage relative to those that take CAFE into consideration. Although this type of study is useful for selecting among different types of policy instruments (say taxes versus standards), caution is needed when using them to decide whether to pursue or abandon action altogether on account of leakage. Furthermore, when there is political support for undertaking unilateral action, abandoning it because of leakage is unlikely. This is self-evident from the fact that incomplete policies are pervasive as opposed being the exception. Finally, avoiding or forgoing a unilateral policy is likely to be simpler *ex ante* as opposed to abandoning an existing policy solely on account of leakage.

(2) Pursue incomplete policies. When avoiding or abrogating incomplete policies on account of leakage is either unjustified or is politically infeasible, the alternative is to tolerate leakage and attempt to mitigate it. The rationale for incomplete policies (discussed in the introduction) is essentially the reason for tolerating leakage. The following types of responses to leakage are available.

    (a) Ignore leakage. Under certain conditions the benefits of ignoring leakage could outweigh the costs of leakage control. One example is when leakage, albeit uncertain, is generally predicted to be a second-order effect that does not significantly diminish the direct reduction in emissions. If leakage mitigation entails a level of transaction costs that exceeds the benefits of leakage mitigation, then simply ignoring leakage might be justified. Another reason to ignore leakage is in the case of stacked or nested regulation, which means that the unilateral policy at a lower of level government co-exists with a policy at a higher level of government and the marginal impact of the lower-level regulation is merely to reshuffle pollution spatially without affecting the aggregate level of pollution. One example would be a provincial carbon tax or provincial renewable energy policy that is nested within a national cap on carbon emissions. Any additional emissions reduction within the province is offset by an increase in pollution in the rest of the nation (Goulder *et al.*, 2012; Huang, Khanna, Önal, & Chen, 2013). Of course, one has to then justify the need for the additional lower-level policy when there is a higher-level policy targeting the same type of pollution. Some of the reasons discussed earlier for incomplete policies might again be relevant here.

(b) Mitigate leakage. Ignoring leakage altogether might be too simplistic, especially *ex ante*, when a wider range of policy options are available as opposed to *in media res*. Not all of the following approaches are mutually exclusive.

  (i) Reduce incompleteness. Expanding the reach of a leaking policy to include polluting sources to which emissions might leak can both reduce the extent of leakage and reduce the cost of pollution reduction. Such expansion could be intrasector, intersector, intraregion and/or interregion. An intrasector example is relaxing enrollment criteria under land conservation programmes to include currently idle farmland to which production might shift when farmers retire farmland that is currently. Whereas domestic polluters can be coerced into being regulated, polluting facilities located outside can only be coaxed, nudged or when the capacity exists, indirectly coerced to participate or cooperate. The transaction cost associated with either negotiating or coercing could be high and exceed the benefits of leakage reduction in this manner. Although financial subsidies might elicit cooperation more easily, they impose a fiscal burden and the political preference might be to support domestic industries on the margin.

  (ii) Select the proper type of policy instrument. The proper choice of policy instrument can mitigate leakage for any given level of incompleteness. Consider a choice between four policies to achieve a given reduction in pollution from the transportation fuel sector – a fuel GHG emission tax, a fuel GHG performance standard, a renewable fuel mandate and a renewable fuel subsidy. Each of these policies will reduce the price of transportation fuels for consumers outside the policy region causing them to increase their fuel consumption, which is a leakage. However, each of these policies would have a different effect within the policy region. A GHG tax will raise the domestic fuel price while a subsidy will reduce it. Fuel prices could either increase or decrease under a renewable fuel mandate or GHG performance standard depending on the market conditions and the stringency of the regulation. Policies that raise the domestic cost of fuel consumption reduce domestic fuel consumption, which counteracts the rebound abroad, whereas policies that lower the domestic cost of fuel consumption would induce a rebound in fuel consumption within the policy region in addition to the rebound outside the policy region. In this regard, a fuel subsidy is clearly inferior to a fuel tax while the other two policies could either be inferior or superior depending on the fuel price effect. The basic point is that policies that raise the domestic cost of consuming polluting goods help counteract the rebound effects manifesting outside the policy jurisdiction. Therefore, if the primary policy instrument is one that would lower the cost of consuming polluting goods then an additional policy (or policies) to offset any decline in cost of consumption would counteract the external rebound and mitigate leakage. Without doubt, the distributional consequences would also be different under each policy, and those might conflict with the objective of mitigating leakage.

A second example to show the importance of the proper choice of policy instrument is the case of nested regulation, i.e. when a regulation at a lower level of government rests alongside a higher-level regulation. As mentioned earlier, with a national emission permit system in place, an effort to further reduce provincial emissions could suffer from a 100% offsetting increase in emissions in other provinces. However some combinations of policies at the federal and provincial level might minimize leakage from unilateral lower-level policies. Interestingly, this is one context in which a provincial renewable energy regulation might be able to reduce national emissions while a provincial emission pricing policy (a pollution fee or tradable pollution permit) might not. See Accordino and Rajagopal (2016) who model leakage under different combinations of nested regulations.

This option is most effective *ex ante* as changing the policy instrument once a regulation is in effect can be costly. For the same reason the next option is also best exercised *ex ante*.

(iii) Selecting the proper level of the policy and the ramping up of policy. This option is particularly relevant for leakage due to price effects. A bigger policy shock, all else fixed, will lead to bigger price effects, which in turn would lead to a bigger change in consumption both within the policy region and outside. Consider the case of a national renewable fuel mandate. A bigger mandate would lead to a bigger decrease in the world price of oil, and therefore, bigger increase in oil consumption abroad. However, a bigger mandate might lead to a bigger price increase (or a smaller decline in price), which would reduce domestic oil consumption by a larger amount. The net change in global oil consumption could either be greater or lesser under a bigger mandate. The effect of a bigger renewable fuel mandate on prices in other sectors might, however, be different. For instance, biofuel mandates increase the demand for crops and inputs to crop production such as land, water and farm chemicals. Pollution associated with the higher aggregate consumption of farm inputs is a source of leakage.

This approach presents two challenges. One is that determining the appropriate level of the policy target might necessitate the use of simulation models of market equilibrium, whose predictions, being sensitive to assumptions about uncertain model inputs, are themselves uncertain. The second issue concerns the use of this approach *in media res*. Reformulating policy targets *in media res*, say in the form of reducing the level of the subsidy or mandate or imposing new more stringent environmental standards, creates policy uncertainty, which in turn increases financial uncertainty in the types of investments that the policy seeks to nurture.

Therefore, in the future, the policy maker would be expected to provide ever greater support to achieve a given level of investment in new technologies. Predicting the cost of this approach therefore requires dynamic modelling of investor behaviour. To give an actual, and timely example, interest groups such as the oil refining industry and environmental organizations have each been lobbying for a relaxation of the annual targets for biofuel consumption under the Renewable Fuel Standard (RFS), albeit for different reasons. While the oil industry's argument concerns the cost of ethanol blending due to the so-called ethanol blend wall constraint[5], the environmental groups' argument for relaxation of the mandates is on account of the perceived environmental and food price effects of biofuels.

(iv) Improve policy targeting. Proper targeting of an incomplete policy might reduce the extent of leakage and targeting could occur along multiple dimensions. One dimension is the selection of the target sectors, activities or micro-units that are less likely to relocate to jurisdictions with weaker regulation. To give an example, emissions from the electric power sector might under some conditions be more effectively reduced by regulating the extraction of primary fossil fuels as opposed to regulating electricity power plants or consumers. One reason for this might be that the higher cost of transporting heavy or bulky materials to new destinations (say, the need for new pipelines to reroute existing natural gas supplies) might limit the ability of regulated facilities to easily relocate to jurisdictions with weaker environmental regulation. Building codes are another example of regulation that might be less prone to leakage due to relocation. Although in theory codes that increase the cost of buildings can induce construction to shift to locations with weaker regulations, the greater concern appears to be leakage under zoning regulations that restrict new construction (Glaeser & Kahn, 2010; Pollakowski & Wachter, 1990).

A second type of targeting could be with a view to minimizing rebound effects. For instance, targeting energy efficiency improvements in activities that are price inelastic can minimize the so called direct rebound effect, i.e. a rebound in demand for the same service experiencing a reduction in cost of service due to greater energy efficiency (Gillingham, Kotchen, Rapson, & Wagner, 2013). For instance, the demand for refrigeration has been estimated to be less price elastic relative to the demand for air conditioning (Davis, Fuchs, & Gertler, 2014). Targeting efficiency improvements in price inelastic services, however, does not address 'indirect rebound' effects (Sorrell, 2009), which refers to the monetary savings being expended in other energy consuming activities. A related strategy is careful targeting of the geographic location for intervention. For instance, forest protection efforts tend to suffer from higher rates of leakage when programme participants do not have market access or tend to be subsistence farmers. Under either of these conditions, participants are forced to shift their original activities to unprotected areas (Chomitz, 2002), which represents a type of rebound effect. Pre-emptive enrollment of lands in such areas into the programme and providing alternative means of employment would minimize leakage and are in essence a superior policy targeting (Wu, Zilberman, & Babcock, 2001). For leakage associated with land-use activities, tracking and managing leakage at a national level would minimize transaction cost as opposed managing it on a project by project basis when there are multiple projects and policies affecting land use (Plantinga & Richards, 2008).

Another dimension to targeting is through proper selection of the point of regulation. One point of regulation could be the point of extraction of the primary inputs that ultimately cause pollution (for example, carbon-rich inputs such as coal, oil, gas or land conversion). Another could be the point of actual emissions (for example, power plants, industrial outlets or driving) (Bushnell & Mansur, 2011). Yet another option is to regulate final consumer goods based on embodied emissions, which is discussed separately later. A fourth dimension to targeting is to select activities that confer significant local co-benefits in addition to providing higher-scale public goods. For instance, electric vehicles would improve air quality more than biofuels even when both provide similar GHG benefits. That said, there might be other differences such as cost complicating the comparison and these co-benefits might be better realized through dedicated policies.

(v) Regulate lifecycle emissions: This could be considered yet another type of targeting. Lifecycle emissions refers to the aggregate emissions attributable to a fixed quantity of a final product (say, a gallon of gasoline, a kilowatt hour of electricity from natural gas, or a calorie of food) or service (say, commuting, lighting, space cooling, or hunger satisfaction), across all stages from extraction of raw materials through to end-of-life for every material associated with the consumption of the product regardless of the spatial coordinates of the emissions (Hendrickson, Lave, & Scott Matthews, 2006). The utility of this concept can be grasped through an example. More than 80% of the lifecycle GHG emissions associated with driving a gasoline vehicle occur at the point of combustion, whereas those for electric vehicles (EVs) are entirely before driving (Lave, MacLean, Hendrickson, & Lankey, 2000). Therefore, a realistic picture of the benefits of switching from gasoline to EVs necessitates a comparison of lifecycle emissions. Done right, policies such as border adjustments necessitate a lifecycle view of pollution associated with both domestic and imported goods (Levinson, 2010). However, the traditional approaches to lifecycle assessments (LCA) are technology-centric and involve strong assumptions, and therefore estimates from LCAs have to be interpreted with caution in a policy context (Rajagopal & Zilberman, 2013). The appropriate role and form of LCAs in the public policy realm is an active area of debate and research (McManus & Taylor, 2015; Rajagopal, 2014). Policy makers' concern for leakage, however, captures a fundamental motivation behind the emergence of LCA.

(vi) Employ additional leakage-specific policies. A number of different policies complementing the primary policy causing leakage are discussed in the literature. The literature on environmental regulation and international trade suggests different policies whose primary motivation is to ensure that domestic industries remain competitive. The suite of such policies includes border adjustment policies, rebating emissions taxes or free allocation of allowances under a tradable emission permit system (discussed in the next paragraph), state aid to domestic producers and agreements with producers in specific sectors abroad (Böhringer, Fischer, & Rosendahl, 2014; Dröge et al., 2009; Martin, Muûls, de Preux, & Wagner, 2014). Border adjustment in the form a tariff on imports is one approach to offset the competitive effects of a domestic environmental regulation such as a pollution tax or standard that raises cost of domestic production. While an import tariff introduces parity between consuming domestically produced goods and imported goods, domestically produced goods still remain uncompetitive in export markets. This may be remedied through a subsidy for domestic exports. Border adjustment policies, while they eliminate the unintended economic effect of environmental regulations on the domestic economy, they also raise the cost of achieving a given environmental target.

Another option discussed in the trade literature is to rebate the fees collected under an emission tax or equivalently to freely allocate permits to each domestic firm (which could be done either by grandfathering or allocating in proportion to current output, referred to as output-based allocation (OBA)). The combination of fees and rebates or free allocation both maintains the incentive to abate and preserves the competitiveness of domestic regulated firms, which reduces leakage (Böhringer *et al.*, 2014). Demailly and Quirion (2006) compare the tradeoff between competitiveness and emissions leakage under grandfathering and under OBA for the EU cement industry. Their simulations suggest that although grandfathering is suited for ensuring profitability in exchange for production losses and emissions leakage, OBA is more suited to ensuring that there is no loss in domestic output and containing leakage in exchange for less emissions reduction. Martin *et al.* (2014) argue that although approaches that compensate domestic industries might be justifiable as an industrial policy, they run counter to the 'polluter pays' principle. By bridging the cost gap between countries with and without commitments to reduce GHG emissions, the Clean Development Mechanism, which is part of the Kyoto Protocol (KP), is also expected to reduce carbon leakage (Kallbekken, 2007). The basic point is that trading of emissions credits builds flexibility that not only reduces the overall cost of abatement but also reduces leakage.

Leakage due to competitive effects is only one channel of leakage due to trade linkages. A second channel of leakage is through the effect on the international price of goods. This channel of leakage is particularly relevant for environmental regulations in regions that are 'large' in a trade context (Quirion, 2010; Zhang, 2012). Furthermore, this type of leakage is not remedied through border adjustment policies. As more regions of the world adopt a carbon tax, there will be two counteracting effects. The primary effect will be that the demand for carbon intensive goods will fall ever more. This will cause a larger fall in the international price of such goods. With a diminishing marginal utility of consumption, the rate of rebound falls with a fall in the price. This means with increasing global coverage of GHG policies, the size of leakage (or rebound) from unregulated markets falls relative to the primary demand reduction effect within the regulated regions. A note of caution is that the rebound discussed so far is that due to solely to the price effect. When the fall in the international price is large enough to raise (real) income then there could be an income effect that increases the total rebound from the unregulated regions. Despite this, border adjustment mechanisms can mitigate leakage effectively although there may be legal barriers to overcome in the form of international trade agreements and federal regulations on interstate commerce.

A second type of complementary policy could be to cap or limit the role of compliance activities that are vulnerable to leakage. Consider the case of the California LCFS[6]. Compliance with this regulation is expected to be achieved by blending low-GHG biofuels with gasoline. However the true GHG intensity of some types of biofuels such as corn ethanol or sugarcane ethanol are more uncertain than others. One response then is to limit the maximum extent to which a regulated entity could rely on such risky biofuel pathways. A modification to the LCFS might be to limit the maximum share of specific biofuel pathways to say, 25% or 50% of total compliance activities. The fact that the US RFS mandates 21 billon gallons of second-generation biofuels but only 15 billion gallons of first-generation biofuels is partially motivated by the greater risk of policy backfire from the latter types of biofuels. To give another real example of such an approach, the RGGI, which is the first mandatory CO_2 emission reduction programme in the US, limits the use of offset allowances to 3.3% of a power plant's compliance obligation in each control period.[7] Offsets are credits for emissions avoided through mitigation activities undertaken by unregulated entities. It is of general concern as to whether those activities are truly 'additional', in that they would not have occurred in the absence of the regulation in question. For if offsets are not additional, they weaken the regulation, which is akin to leakage.

A third broad category of response would be to enact additional policies that minimize rebound effects within the policy jurisdiction. To reiterate an earlier point, when the primary policy instrument is one that would lower the cost of consuming polluting goods then an additional policy that would raise the cost would be natural complement. Reiterating an example discussed earlier, a fuel emission standard that would raise the cost of transportation fuel would be a natural complement to an automobile fuel economy regulation that reduces the cost per kilometre or mile of driving. Without doubt, an obvious concern with this approach is the political impediments to a policy that raises the cost of energy, which in the first place is the justification for costlier approaches such as subsidies and regulations. To reiterate another point made earlier, slippage under forest conservation policies can be mitigated by providing alternative means of employment to programme participants who might dependent on such forests for employment.

A fourth option is to tax the regulated producers based on predicted leakage per unit of the risky technology. The tax could either be explicit or implicit. Although an actual example of an explicit tax on emissions based on the level of leakage does not seem to exist, the approach under the LCFS is an example of a regulation that implicitly taxes emission leakage. Under this regulation, each type of biofuel is assigned an estimated indirect GHG intensity rating that is taken as given by each regulated entity producing that particular type of biofuel (Witcover, Yeh, & Sperling, 2013). This raises the effective GHG intensity of a biofuel, which means that to achieve a given reduction in the emission intensity of gasoline, a higher blending ratio of biofuels in gasoline might be required. Depending on the chosen rating for indirect GHG intensity and a biofuel producer's own direct emission intensity, some biofuel pathways might become either uneconomical or simply infeasible as a compliance option. This amounts to an indirect tax on producers of such biofuels and in the worst case a de facto ban on their use as a compliance option. As highlighted in Figure 2, this approach is different from the others in that the other approaches only indirectly affect domestic polluters. It also requires that leakage is predicted to a level of precision higher than for other approaches and has proven highly controversial (Mathews & Tan, 2009). Zilberman, Hochman, and Rajagopal (2011) present different arguments as to why this approach is better avoided.

4. Summary

To summarize, the different approaches discussed exhibit similarities but at the same time differ along multiple dimensions, making some more suitable over others in specific situations. Some strategies are appropriate *ex ante* whereas others are appropriate both *ex ante* and *in media res*. Selection of the proper target activities for regulation, selection of the proper policy instrument and/or the level and timing of a policy are all best utilized *ex ante*, while border adjustments could be imposed both *ex ante* and *in media res*.

The various options can also be differentiated on the basis of the level of burden placed on domestic regulated polluters for reducing leakage. For instance, border adjustments and output-based rebates subsidize domestic industries. Expanding policy coverage to other domestic sectors, selecting the proper policy instrument and adjusting the stringency all have, at best, an indirect effect on currently regulated polluters. In contrast, holding regulated entities accountable as under the LCFS regulation places the burden of leakage directly on the regulated entities.

Some strategies involve active management of leakage while others are passive. Border adjustments, output-based rebates, targeting life cycle emissions and holding entities directly accountable as under the LCFS can be considered active management of leakage. Reducing incompleteness, careful selection of the primary policy instrument and its stringency, the target activities for regulation and limiting the role of risky pathways might be termed more passive approaches to leakage.

The required level of precision in the estimates of leakage is another differentiating factor. Despite being context-specific, the size of leakage is generally uncertain, and uncertainty increases when there are price effects and when the price changes impact production and consumption on a global scale. Heterogeneity in production also contributes to uncertainty. Holding regulated entities directly accountable for leakage as under the LCFS regulations requires precise estimates. Border adjustments also require precise estimation of the lifecycle emissions associated with finished goods produced domestically and abroad.

Some types of efforts to limit leakage are less tangible than others. Explicit additional policies to limit leakage from the main policy, such as border adjustments or targeting of life cycle emissions, are tangible whereas accounting for leakage implicitly *ex ante* while selecting the type of the main policy instrument, its level or timing are less tangible.

5. Conclusion

That an optimal vertical level of government for efficient provision of a given public good exists represents a static view of the policy world. From a dynamic perspective, incomplete policies are an essential step before action at the appropriate level of government. In the interim, leakage of pollution is inevitable and there are a number of ways in which it can be addressed. Depending on whether leakage is managed *ex ante* or *in media res*, at the national or provincial level, the level of burden to be placed on regulated polluters, whether it is to be managed actively or passively, the precision in the available estimates of leakage and the tangibility of policy makers' efforts to control leakage, a number of options are available to policy makers.

The different approaches to leakage management are not all mutually exclusive. Depending on the potential size of leakage, and both the capacity of and the budgetary resources available to policy makers, one or more among these approaches might be pursued. For instance, selecting the right type of policy instruments, the right level of the policy, proper targeting of activities for regulation and enacting additional leakage-specific measures are complements. Within each specific broad approach a number possibilities exist and here some might be superior to others. For example, in the context of policies for reducing emissions from energy use, instruments that raise the domestic cost of consumption of fossil fuels, say, through a tax or an emission permit system, are superior to those that lower the cost of energy consumption, say, through a subsidy for cleaner fuels. This is because although each policy is likely to result in an increase in energy consumption outside the policy region, a subsidy-based policy would also result in a rebound within the policy region. By reducing domestic energy consumption, a policy that raises the cost of domestic energy consumption counteracts the rebound occurring outside. If subsidies happen to the only feasible approach, then the subsidies are better targeted to activities that are price inelastic as opposed being price elastic as this would minimize the direct rebound effect. The literature on mitigating leakage due to loss of international competitiveness of domestic industries suggests that purely from an emissions reduction standpoint full auctioning and grandfathering emission allowances are superior to output-based allocation of allowances.

Leakage due to price effects could be mitigated by careful selection of the stringency of the policy and ramping up its stringency gradually over time. For instance, a gradual increase in the emissions reduction goals would allow domestic industries to adopt new technologies and resist the urge to relocate to unregulated regions. To give another example, slowly increasing the targets for biofuel production would simultaneously reduce the effect of the policy on agricultural commodity prices and would also allow farmers to meet the demand for both food and feedstock for biofuel by intensifying agriculture and reducing the pressure to convert non-farmland to farmland. When there is a risk that the environmental benefits of a specific type of technology might be lost as a result of leakage due to price effects (the risk to the GHG benefits of biofuels due to indirect emissions being a case in point), an upper bound could be specified on the extent to which obligated parties might rely on such a technology for compliance.

As the size of the policy jurisdiction relative to the size of the overall market across which leakage might manifest shrinks, the transaction costs of estimating and managing leakage would probably increase relative to the benefits of controlling leakage. In such cases, carefully targeting the activities to be regulated, selecting the right policy instrument and stringency level and avoiding active management of leakage *in media res* might be a better strategy. Finally, it is worth re-emphasizing that the unilateral approaches to leakage control discussed here should be viewed as complementary to efforts to expand policy coverage through environmental agreements.

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Notes

1. See http://web.law.columbia.edu/climate-change/resources/climate-change-laws-world for a database of world-wide climate change laws.
2. Note that the Clean Power Plan announced by the US Environmental Protection Agency (EPA) in 2015 only sets targets for the intensity of GHG emissions from electric power generation. See http://www2.epa.gov/cleanpowerplan/clean-power-plan-existing-power-plants.
3. A standard economic model rests on the assumptions of unbounded rationality, unbounded selfishness and unbounded willpower (Thaler & Mullainathan, 2008).
4. A public good is one that is both non-rivalrous in nature, i.e. that can be simultaneously be enjoyed by many and is costly to restrict consumption to a select few such as those who pay for it. Benefits from reducing GHG emissions is a classic example. Its benefits will be reaped by everyone not just those who might incur a cost from the efforts to reduce such emissions (Ostrom & Ostrom, 1999).
5. http://www.platts.com/latest-news/agriculture/washington/oil-industry-presses-us-epa-to-lower-2014-ethanol-21416795
6. http://www.arb.ca.gov/fuels/lcfs/CleanFinalRegOrder112612.pdf
7. See http://www.rggi.org/market/offsets

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