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The High Price of Low Emissions: Benefits and Costs of GHG Abatement in the Transportation Sector

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Executive Summary

Policymakers often hear calls to reduce private vehicle use and increase use of public transit and other types of mass transportation. But Canadians overwhelmingly depend on the convenience and savings associated with private automobiles. This fact has important implications for understanding the limits to pursuing economically efficient vehicle-related GHG emission reductions, and the potential social costs of trying to engineer a large change in Canadian transportation modes.

This report provides answers to three key questions:

1. How much does transportation contribute to total GHG emissions in Canada?
2. How would shifting motorists to mass transit affect GHG emissions, and at what cost?
3. How would raising the cost of gasoline (through a carbon tax) affect GHG emissions, and what would the cost be of trying to achieve a large target like a 30 percent reduction?

In 2009, Canada emitted 690 megatonnes CO_2 equivalent (MtC) of greenhouse gases (GHGs), of which 190 MtC, or 27.5 percent, were from transportation-related activities.If we define an efficient GHG reduction as one that has a marginal cost of under $25 per tonne of CO2, this would translate into an increase in the price of gasoline of about 5.9 cents per litre. In the short run, the resulting emissions reduction due to reduced gasoline consumption would be quite small, between 0.3 percent and 1.0 percent (0.3-1.3 MtC). In the long run, the reduction in emissions would be between 2.0 and 5.3 MtC. These are between 0.2 and 3.9 percent of the emission reduction commitments made under the Kyoto Protocol.

Canadians overwhelmingly depend on the convenience and savings associated with private automobiles.

It would be very costly to Canada to try and achieve a 30 percent reduction in GHG emissions from motor vehicles. In the short run it would likely require a carbon tax of about $975 per tonne, or a gasoline tax of about $2.30 per litre, and even if all the new tax revenue were returned to Canadians there would still be deadweight losses of about $9.6 billion (in other words, economic losses after accounting for the environmental benefits). In the long run it would likely require a $195 carbon tax, or a gasoline tax of about 46 cents per litre, and would cause a deadweight losses of about $2.9 billion. If cap and trade or regulatory measures are used instead of a carbon tax, the cost to households in the long run would be about $1,600 per household, per year, over and above the environmental benefits.

Few drivers who choose to avoid transit report fare price as the main reason. The most common reason is simply the availability of a car. Improvements in transit service (such as introducing light rail within cities) might benefit existing transit users but would be unlikely to generate large switches away from private vehicle use. Likewise, increasing the cost of parking and road usage might prompt greater interest in mass transit, but survey evidence indicates that such changes would still be relatively small. An increase in the cost of driving would have a proportionately stronger effect on car use than on transit use; for instance, drivers may make fewer car trips but not begin using transit or increase transit use.

There are two corridors in Canada within which the option of a high-speed rail system has been seriously considered: Windsor to Quebec City (WQ) and Calgary to Edmonton (CE). Current proposals to achieve GHG emission reductions by building high-speed rail lines require the government to pay all capital costs up front: an estimated $2.359-4.75 billion for the CE line and $20 billion for the WQ line. If the trains are able to break even on their operating costs (which is unlikely due to the strong preference for cars), the proposals imply a marginal emission reduction cost of about $77-85 per tonne, well over the efficient marginal cost of $25 per tonne. For the projects to be justified on GHG emission reduction grounds it would have to displace about 30 percent of all transportation-related GHGs. Otherwise the GHG savings would not be enough to justify the project.

Since the use of cars does not significantly change in response to making cars more expensive to drive or to improvements to transit, policymakers must therefore be careful not to assume GHG abatement provides a rationale for transportation policy decisions that would otherwise fail an ordinary cost-benefit test. In other words, bad policy ideas do not become good policy ideas just because they slightly reduce GHG emissions.

Sommaire

Les décideurs politiques entendent souvent des appels à une réduction de l'utilisation des véhicules privés et à un recours accru au transport public et à d'autres types de transport collectif. Les Canadiens dans leur très grande majorité dépendent toutefois des avantages et des épargnes que procure l'utilisation d'une automobile privée. Il est important de tenir compte de cette réalité pour bien comprendre les limites d'une politique visant à réduire les émissions de gaz à effet de serre au moyen de véhicules économiquement efficaces, de même que les coûts sociaux potentiels d'une tentative d'imposer des changements dans les modes de transport au Canada.

Cette étude offres des réponses à trois questions clés :

1. Dans quelle mesure le transport contribue-t-il aux émissions totales de gaz à effet de serre au Canada?
2. Quelles seraient les conséquences sur les émissions de gaz à effet de serre d'un déplacement des conducteurs d'automobile vers le transport collectif, et à quel prix?
3. Quel serait l'impact d'une hausse du prix de l'essence (au moyen d'une taxe sur le carbone) sur les émissions de gaz à effet de serre, et quel serait le coût d'une tentative d'atteindre une cible élevée telle une réduction de 30 %?

En 2009, le Canada a émis 690 mégatonnes équivalent CO_2 de gaz à effet de serre, dont 190 mégatonnes, ou 27,5 %, provenaient d'activités reliées au transport. Si nous définissons une réduction efficiente de gaz à effet de serre comme celle où le coût marginal est inférieur à 25 dollars par tonne de CO_2, cela se traduirait par une augmentation d'environ 5,9 cents/litre du prix de l'essence. À court terme, la réduction d'émissions provoquée par la diminution de la consommation d'essence serait très limitée, entre 0,3 et 1,0 % (0,3 – 1,3 mégatonnes). À long terme, la réduction d'émissions se situerait entre 2,0 et 5,3 mégatonnes. Ces quantités correspondent à entre 0,2 et 3,9 % des engagements de réduction d'émissions pris dans le cadre du Protocole de Kyoto.

Il serait très coûteux pour le Canada d'essayer d'atteindre une réduction de 30 % des émissions de gaz à effet de serre en s'attaquant aux véhicules automobiles. À court terme, cela nécessiterait probablement l'imposition d'une taxe sur le carbone d'environ 975 dollars par tonne, ou une taxe sur l'essence d'environ 2,30 dollars/litre. Même si tous les revenus en provenance de cette taxe étaient retournés aux Canadiens, il resterait une perte sèche d'environ 9,6 milliards de dollars (en d'autres termes, une perte économique après avoir pris en compte les bénéfices environnementaux). À long terme, cela nécessiterait sans doute une taxe sur le carbone de 195 dollars par tonne, ou une taxe sur l'essence d'environ 46 cents/litre, ce qui entraînerait une perte sèche d'environ 2,9 milliards de dollars. Si un système de plafonnement et d'échanges de droits d'émission ou des mesures réglementaires étaient utilisés plutôt qu'une taxe sur le carbone, le coût pour chaque ménage à long terme serait d'environ 1600 dollars par année, au-delà des bénéfices environnementaux qu'on en retirerait.

Le désir d'éviter de payer le prix du transport collectif serait la raison principale d'un très petit nombre de conducteurs seulement. La raison la plus fréquente est simplement la disponibilité d'une voiture. Les améliorations aux services de transport en commun (telles que la mise en place d'un système de train léger en milieu urbain) pourraient bénéficier aux utilisateurs actuels du transport en commun, mais il est peu probable qu'elles entraînent un transfert important d'usagers qui utilisaient un véhicule privé auparavant. De même, l'augmentation des coûts de stationnement et d'utilisation des routes pourraient accroître l'intérêt envers le transport collectif, mais les sondages indiquent que de tels changements seraient tout de même relativement limités. Une augmentation du coût de la conduite automobile aurait des effets proportionnellement plus élevés sur l'utilisation de la voiture que sur le recours au transport en commun; par exemple, les conducteurs pourraient faire moins de trajets automobiles mais n'utiliseraient quand même pas, ou pas davantage, le transport en commun.

Il y a deux corridors au Canada où l'option d'un système de transport ferroviaire à grande vitesse a été sérieusement considérée : le corridor de Windsor à Québec et celui de Calgary à Edmonton. Les propositions qui sont actuellement sur la table pour atteindre des réductions d'émissions de gaz à effet de serre en construisant des trains à grande vitesse impliquent que le gouvernement défraie tous les coûts d'investissement au départ. On estime ces montants à entre 2,359 et 4,75 milliards de dollars pour la ligne Calgary-Edmonton, et à 20 milliards de dollars pour la ligne Windsor-Québec. Si les trains peuvent faire leurs frais sur le plan des coûts d'opération (ce qui est peu probable à cause de la préférence marquée pour les voitures), ces propositions impliquent un coût marginal de réduction des émissions d'environ 77 à 85 dollars par tonne, bien au-delà du coût marginal efficient de 25 $ par tonne. Pour qu'on puisse justifier ces projets sur la base d'une réduction des émissions de gaz à effet de serre, ceux-ci devraient déplacer environ 30 % de tous les gaz à effet de serre liés au transport. Sinon, les réductions de gaz à effet de serre ne suffisent pas pour les justifier.

Puisque le fait de rendre les voitures plus coûteuses à conduire ou d'améliorer le transport en commun ne change pas de façon signification le recours le recours aux voitures, les décideurs politiques ne devraient pas présumer qu'une réduction des gaz à effet de serre justifie des politiques de transport qui, autrement, ne passeraient pas un simple test de coût-bénéfice. En d'autres termes, de mauvaises politiques ne deviennent pas de bonnes politiques simplement parce qu'elles permettent de réduire un peu les émissions de gaz à effet de serre.

1 Introduction

When policymakers are looking for ways to reduce greenhouse gas (GHG) emissions, they often hear calls to enact measures to reduce private vehicle use and increase use of public transit and other mass transportation modes. But this runs into the challenge that Canadians strongly prefer private motor vehicles to other options. This may partly be due to geography: Canada is a large country with a low population density and a severe climate, and these factors constrain transportation options. But the data also show that, when they have the choice, Canadians overwhelmingly prefer the convenience and savings associated with private automobiles. This fact has important implications for understanding the limits to pursuing economically efficient vehicle-related GHG emission reductions, and the potential social costs of trying to engineer a large change in Canadian transportation modes.

Policy is unlikely to change Canadian vehicle use.

This report provides answers to three key questions:

1. How much does transportation contribute to total GHG emissions in Canada?
2. How would shifting motorists to mass transit affect GHG emissions, and at what cost?
3. How would raising the cost of gasoline (through a carbon tax) affect GHG emissions, and what would the cost be of trying to achieve a large target like a 30 percent reduction?

Overall, I conclude that efficient policy choices – that is, GHG abatement options that have a reasonable chance of yielding benefits greater than costs – are unlikely to involve much change in Canadian vehicle use patterns. Also, regulatory measures to try and force large changes in vehicle and transit use are likely to yield net welfare losses for Canadians, even after accounting for environmental benefits. Policymakers must therefore be careful not to assume GHG abatement provides a rationale for transportation policy decisions that would otherwise fail an ordinary cost-benefit test. In other words, bad policy ideas do not become good policy ideas just because they yield some reduction in GHG emissions.

2 Transportation-Related Greenhouse Gas Emissions in Canada

In 2009 Canada emitted 690 MtC of GHGs, of which 190 MtC, or 27.5 percent, were from transportation-related activities (Environment Canada 2011). About three-quarters of these in turn were from road, rail, or aviation modes, and the rest were from off-road vehicles, domestic marine navigation, and pipelines. Table 1 shows Canadian GHG emissions from 1990 to 2009 from road, rail and aviation transportation modes, and also the percentage distributions and percent changes from 1990 to 2009.

Table 1 Canadian transport-related GHG emissions, 1990-2009 (kilotonnes CO_2 equiv.)

	1990	1995	2000	2005	2009	% Chg*
Roads						
Light vehicles	66,971	72,839	80,326	85,004	85,303	27.4%
Heavy vehicles	27,440	32,330	36,360	44,140	45,190	64.7%
Other	2,352	2,225	1,261	974	1,025	-56.4%
Total Roads	96,763	107,394	117,947	130,118	131,518	35.9%
Aviation	7,200	6,600	7,500	7,700	7,200	0.0%
Rail	7,000	6,000	7,000	6,000	7,000	0.0%
TOTAL	110,963	119,994	132,447	143,818	145,718	31.3%

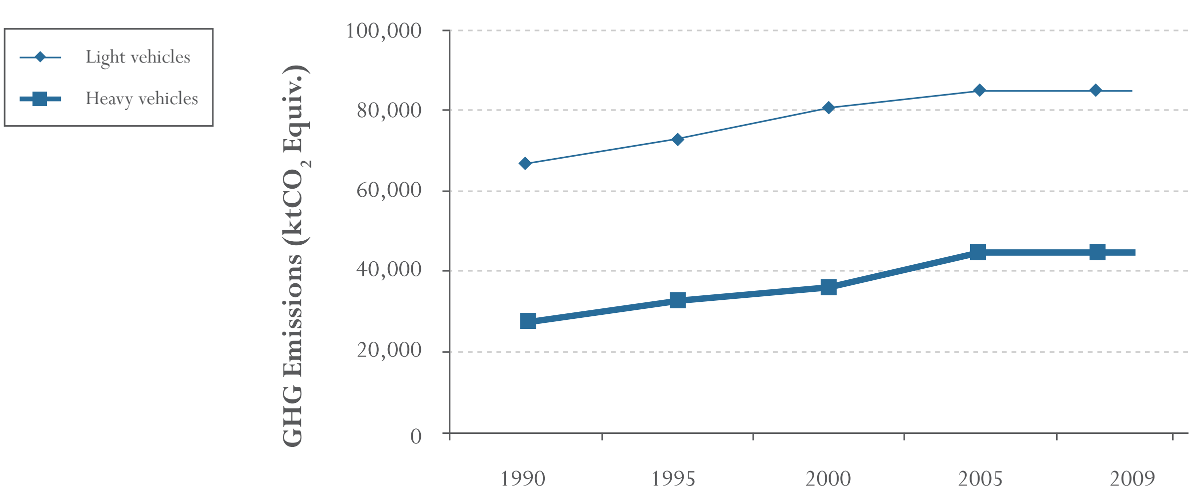
About 27.5% of GHG emissions are from transport-related activities.

Roads					
Light vehicles	60.4%	60.7%	60.6%	59.1%	58.5%
Heavy vehicles	24.7%	26.9%	27.5%	30.7%	31.0%
Other	2.1%	1.9%	1.0%	0.7%	0.7%
Total Roads	87.2%	89.5%	89.1%	90.5%	90.3%
Aviation	6.5%	5.5%	5.7%	5.4%	4.9%
Rail	6.3%	5.0%	5.3%	4.2%	4.8%
	100.0%	100.0%	100.0%	100.0%	100.0%

Source: Environment Canada (2011). *From 1990 to 2005. "Other" includes motorcycles, propane, and natural gas vehicles. Marine, off-road, and pipeline emissions are not included in the above figures.

Light-duty vehicles, including diesel and gasoline cars and light trucks, make up the largest category within transportation, and account for about 60 percent of transport-related GHG emissions per year. Aviation and rail account for relatively little, comprising less than 5 percent each. Heavy-duty vehicles, including gasoline and diesel heavy trucks, make up the rest, and comprise the fastest-growing segment. The growth trends in road-related emissions from cars and trucks (both gasoline and diesel) are shown in Figure 1.

Figure 1 Vehicle-based GHG emissions in Canada, 1990-2009



Although the trends are parallel, the growth of emissions from heavy vehicles (gasoline and diesel heavy trucks) is proportionately greater over the interval: 65 percent compared to 27 percent for light cars and trucks.

3 Transportation Mode Choice

3.1 Cost factors: Time and money

Canadians show an overwhelming preference for transportation in private automobiles. The fraction of the Canadian population 18 or older who reported going everywhere by car, either as a driver or a passenger, rose from 68 percent in 1992 to 74 percent in 2005. The proportion of Canadians who reported making at least one car journey on a survey reference day in 2005 was 87 percent in 2005, rising to 93 percent for people living 25 kilometers or more from a city centre (Turcotte 2008).

Local transportation choice

For local transportation, such as commuting to work, the main options are private automobile and public transit. Consumers evaluate these options with regard to money costs, time costs, and convenience factors. Data indicate that, taking all things into account, Canadians have a strong preference for private automobiles over public transit.

- In 2010, 82 percent of Canadians commuted to work by car, 12 percent took public transit, and 6 percent walked or cycled (Turcotte 2011, 33).
- Only 11 percent of Canadians use public transit as their main mode for commuting to work, and only 15 percent consider transit one of their main modes for commuting to work (Munro 2010).
- In 2003 data, Canadians traveled 1.4 billion passenger-kilometers[1] (pkms) by rail, 90.3 billion pkms by air, and 463.2 billion pkms by automobile.[2]

Canadians show an overwhelming preference for transportation in private automobiles.

The time savings of private cars can be quantified only to the extent that the comparisons are valid. According to Statistics Canada, Canadian commuters who travel by car spend an average of 24 minutes getting to work, whereas those who use public transit spend 44 minutes, or nearly twice as long (Turcotte 2011). This is not due to transit users going further: the time cost of transit is consistently higher across all distance categories. For instance, in cities with at least 250,000 persons, the average commute time for trips less than 5 kilometers was 10 minutes in private cars and 26 minutes for transit riders. For a two-way trip, adding 20 minutes each day translates into 100 minutes per week or roughly 4800 minutes per year. Valued at $25 per hour, this is a cost of $2000 annually. Studies that suggest people would save money by switching to transit may fail to take account of the time cost involved, but they certainly figure into the calculations for ordinary commuters, which is one reason so many people choose to drive.

1 Passenger-km is distance multiplied by the number of passengers in the vehicle.

2 For data see http://www.statcan.gc.ca/pub/16-201-x/2006000/9515-eng.htm.

It should not be supposed that the preference for cars is merely a matter of fashion or taste, on the level of deciding between flavours of ice cream. Many routes in an urban area are simply infeasible on transit, or impose a prohibitive time cost in comparison to driving. For routine personal trips, such as grocery shopping, private cars provide a convenient way to transport children, carry one's purchases, and change one's plans along the way as needed. Qualitative advantages of private cars can only partly be captured in empirical research, but feature prominently in the benefits people experience in their daily lives. Survey evidence from Vancouver found that service improvements sufficient to reduce the in-vehicle transit travel time to 30 percent *below* that for a single occupant vehicle would still only increase the probability of choosing transit by 3 percent (Washbrook et al. 2006).

It should not be supposed that the preference for cars is merely a matter of fashion or taste.

Transit not only takes longer, it imposes inconveniences such as the need to walk to the pickup point, exposure to weather, crowding, difficulty of carrying loads, lack of control over departure times, and so forth. Among commuters who go to work by car, only 15 percent reported having tried using public transit and more than half of those who did reported it as an inconvenient option (Turcotte 2011, 33).

The Canadian situation is not unusual in comparison to the United States. While 70 percent of US urban residents live in areas with access to transit, 93 percent of the jobs available to urban workers require a transit ride longer than 45 minutes, and 70 percent require a transit ride longer than 90 minutes (Tomer et al. 2011).

Inter-city transportation

Irregular trips between cities (that is, trips other than for the purpose of commuting to work) can be undertaken using several modes, including private car, other road transport (such as buses), rail, or airplane. The factors that affect this choice are similar to those for work-related commutes: price, time, availability, and convenience. The data show that, taking these things into account, Canadians have an overwhelming preference for automobile travel.

- The 2004 Canadian Travel Survey shows that of the 88.7 million overnight person-trips taken that year, 77.8 million (88 percent) were by car, 6.3 million (7 percent) were by airplane, 2.7 million (3 percent) were by bus, 0.9 million (1 percent) were by train, and 0.5 million (0.6 percent) were by boat (Statistics Canada 2004).
- 96 percent of same-day trips were by car, 2 percent were by bus, and the remainders were by air, rail, or boat.

Fixed and variable costs

The decision to travel by automobile is complicated by the presence of both fixed and variable costs. *Fixed* costs are those that have to be paid whether the car is used or not, and consist primarily of the purchase cost of the car, license fees, and insurance. The purchase cost may be spread out through leasing or finance arrangements, but does not change on a daily or weekly basis based on the amount driven. *Variable* costs are those that do change based on the amount driven. The major variable costs are gasoline, routine maintenance, and, in some cases, road tolls.

Car ownership is quite prevalent in Canada: on average there are about six cars for every ten persons.[3]

3 See graph at http://www.statcan.gc.ca/pub/16-201-x/2006000/4113867-eng.htm.

Because there are substantial fixed costs associated with using a car, the propensity to choose public transit is strongly dependent on the prior decision on whether to own a car.

- 69 percent of Canadian households without a car used public transit at some point in 2007, but only 36 percent of households with a car did so.
- Nationally, 73 percent of those who chose not to use public transit listed access to a car as their main reason (Munro 2010).

Once a car is purchased and licensed, the cost of making subsequent trips drops substantially. For this reason, when looking at marginal responses to, say, changes in the cost of transit and/or gasoline, the immediate reaction will be different between car owners and non-car owners. A decrease in the price of transit, for instance, might lead a non-car owner to take more transit rides, but might have little or no effect on a car owner. If price changes occur and are believed to be permanent, the car ownership decision itself may change. This takes more time, however, so examination of price responses should distinguish between those that happen in the *short run* and those that happen in the *long run*. Short run changes will typically be smaller than long run changes.

Taking the above points into account, policy discussions about transportation modes should always be grounded in some basic realities.

- The choices that people make between private cars and public transportation reflect actual differences in the services, costs, and time requirements of each.
- It is highly unlikely that transportation choices are mere expressions of trivial consumer tastes that could easily be changed through advertising or moral suasion.
- The choice to drive instead of using transit is unlikely to represent a widespread failure on the part of Canadians to tally up the relative costs and benefits of each option.
- Canadians do not have to justify their preference for cars: the advantages are real and obvious. Instead, policymakers must justify any proposal to force a switch to mass transit. While such proposals may in some cases have merit, the justification must show that such a switch would yield benefits commensurate with the loss of all the benefits of private car use.

Once a car is purchased and licensed, the cost of making subsequent trips drops substantially.

3.2 The inelastic demand for gasoline

As mentioned in the previous section, there is an immediate response to a change in the price of gasoline as consumers adjust driving habits given their existing vehicle and housing arrangement. But over a longer time frame, they may incur fixed costs related to changing cars or moving houses. So the long run elasticity will typically be larger than the short run elasticity.

There have been many studies by economists to estimate the elasticity of gasoline based on market data. Across many different developed countries and many different data sets the consistent finding is that gasoline demand is *inelastic*, since it is relatively unresponsive to price changes even in the long run.

Table 2 summarizes the findings of 10 studies, a couple of which are meta-analyses of dozens more underlying studies.

Table 2 Gasoline demand elasticity estimates for Canada and other countries

		Price Elasticity		
Study	**Sample**	**Short**	**Long**	**Not Defined**
Bentzen and Engsted (1993)	Denmark from 1948 to 1994	0.32	0.41	
Samimi (1995)	Australia from 1980 to 1993	0.02	0.12	
Puller and Greening (1999)	United States from 1980 to 1990			0.44-1.33
Kayser (2000)	United States in 1981	0.23		
Graham and Glaister (2002)	Literature review	0.3	0.6-0.8	
Nicol (2003)	Canada 1969-1992, United States 1980-1992			0.03-0.85
Hughes et al. (2006)	United States from 1975 to 1980	0.21-0.22		
Hughes et al. (2006)	United States from 2001 to 2006	0.03-0.08		
Brons et al (2008)	Meta-analysis	0.34	0.84	
Wadud et al. (2010)	Urban US households from 1997 to 2002			0.33
Havranek et al. (2011)	Meta-analysis corrected for publication bias	0.09	0.31	

Source: Herzog (2011).

Gasoline demand is relatively unresponsive to price increases.

Some of the key points are:

- Elasticity values appear to have declined after 2000 relative to earlier decades and are lower in Canada, the United States, and Australia compared to other regions.
- The short run elasticity of demand for gasoline is likely between 0.05 and 0.2. That means that a 10 percent increase in the price of gas yields a short run response of only 0.5 percent to 2 percent.
- The long run elasticity is likely between 0.3 and 0.8, so even over time, gasoline demand is relatively unresponsive to price increases.

In addition to studying consumer demand for gasoline, economists have estimated elasticities for many other commodities, including public transit. Balcombe et al. (2004) reviewed UK work on this issue and found that bus fare elasticities are about 0.4 in the short run and 1.0 in the long run. Table 3 shows estimates from a literature review (Litman 2004) that distinguished between peak and off-peak hours.

Table 3 Transit demand elasticity estimates

	Fare Elasticity			Elasticity with Respect to Car Ownership Costs		
Sample	**Short**	**Long**	**Not Defined**	**Short**	**Long**	**Not Defined**
Overall	0.20-0.50	0.60-0.90		0.05-0.15	0.20-0.40	
Peak Hours	0.15-0.30	0.40-0.60				
Off-Peak Hours	0.30-0.60	0.80-1.00				

Source: Litman (2004).

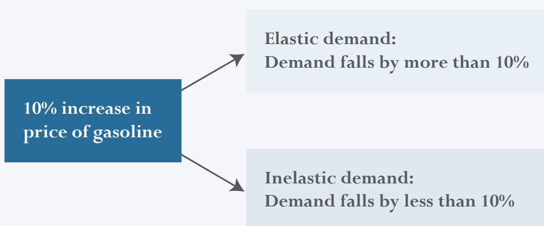
Fare elasticities are 50 percent lower during peak hours than during off-peak hours and in all cases are inelastic. Litman also reported cross-price elasticities with car ownership costs (the percent increase in transit usage given a percent increase in car ownership costs) of 0.05-0.15 in the short run and 0.2-0.4 in the long run.

Estimates of elasticities for transportation modes and fuel types are key parameters in models of the costs of greenhouse gas emission reduction policies. The next section discusses how these costs are measured.

What is elasticity?

A convenient way to summarize market behaviour is through the use of *elasticities.* This is simply the ratio of the percent change in one variable to the percent change in another variable. Suppose the price of gasoline rises by 10 percent. What would happen to the demand for gasoline? Using Figure 2 we can categorize the possible responses based on whether the quantity demanded falls by more than 10 percent or less than 10 percent.

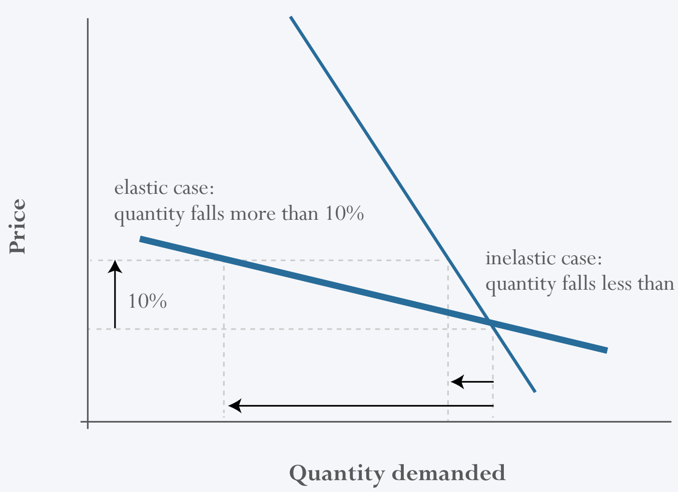
Figure 2 Elastic and inelastic price responses



If a 10 percent increase in price leads to a fall in demand of less than 10 percent we say that demand is *inelastic*. If the reduction in demand was only, say 5 percent, we would say the elasticity parameter was 5/10, or 0.5. If the fall in demand was greater than 10 percent we would say demand is elastic. An elasticity parameter greater than 1.0 implies demand is *elastic*.[4]

Another way of representing the same concept is with a demand curve. This shows the relationship between the price of a commodity and the level of demand. Since higher prices lead to lower sales, the relationship is downward sloping. Figure 3 shows two examples of demand curves. In the *inelastic* case, a 10 percent increase in price causes only a small change in the quantity demanded. In the *elastic* case, the quantity demanded falls by more than 10 percent. In a demand curve diagram, the steeper the demand curve, the smaller the elasticity.

Figure 3 Inelastic and elastic demand curves



4 Note that we are using absolute values. The percent change in price is positive and the percent change in demand is negative, so the elasticity is a negative number, but it is convenient to ignore the minus sign.

4 Analysing Costs and Benefits of Emission Reductions: Some Economic Concepts

4.1 Cost concepts

We now turn to the question of how we decide if GHG reduction proposals are sensible or not. Economists typically frame the analysis in terms of two questions:

Is the suggested policy the cheapest possible way of reducing emissions?

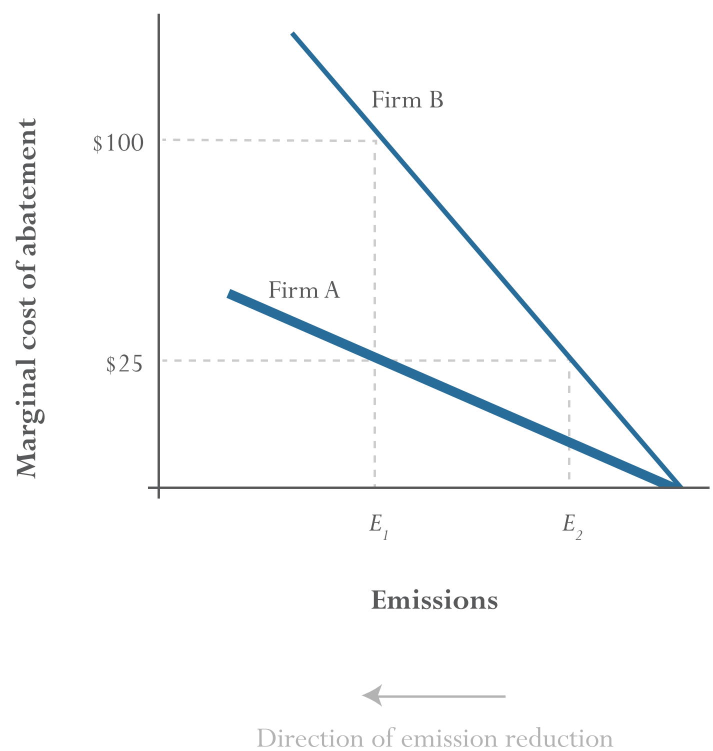
- Given the emission reduction target, is the suggested policy mechanism the cheapest possible way of achieving it?
- Is the emission reduction target itself set at the optimal level?

In order to do the analysis required for answering these questions we need a simple tool from economics called the *marginal abatement cost* function.

Marginal abatement costs and emission abatement

Figure 4 shows a pair of *marginal abatement cost curves* for two hypothetical firms. The term "marginal" indicates that the height of the curve shows the cost of the *next* unit of abatement. Since the horizontal axis shows emissions, abatement (or emission reduction) is read from right to left.

Figure 4 Marginal abatement cost curves



For emitter A, the marginal abatement costs are relatively low. A shallow marginal abatement cost curve indicates that the cost of additional units of abatement rise slowly.

For emitter B, the marginal abatement costs go up relatively quickly. At each level of abatement, the cost of one more unit of emission reductions rises more rapidly for Firm B than for Firm A.

The key to understanding the economics of emissions control is the following: All emissions control policies involve a target either on the horizontal axis (emissions) or the price axis (marginal cost). A regulator can target one, but not both. Having targeted the quantity of emissions, the market will determine the marginal cost. If the regulator intends to target the marginal cost, the market will determine the resulting quantity of emissions.

To understand what this means, suppose the regulator orders each emitter to reduce emissions to the level E_1. For emitter A this implies that the last unit of emission abatement costs $25, while for emitter B it implies the last unit of emission reduction costs $100. Now suppose the regulator did not intend emitters to pay more than $25 to reduce emissions. By imposing a target on the emissions quantity axis (namely E_1), the regulator forces the marginal costs to go above the intended level.

If the regulator caps the marginal cost at $25, Firm B will not reach the emissions level E_1. Instead it will reduce emissions only to the level E_2. Below this point the firm's marginal abatement costs are above the cut-off. But the regulator cannot cap the marginal cost at $25 while asking both firms to cut emissions to E_1.

There is always an implied marginal cost target

It is much more common for regulators to target the emission quantity than the emissions price, or marginal cost. But in reality, there is always an implied emissions price. If the regulator picks a target like E_1 and insists that it be enforced, then that implies the marginal cost cut-off is at least $100; in other words we are willing to force emitters to incur costs of $100 per tonne in order to reduce emissions.

The inverse relation

A regulator can target emissions or cost, not both.

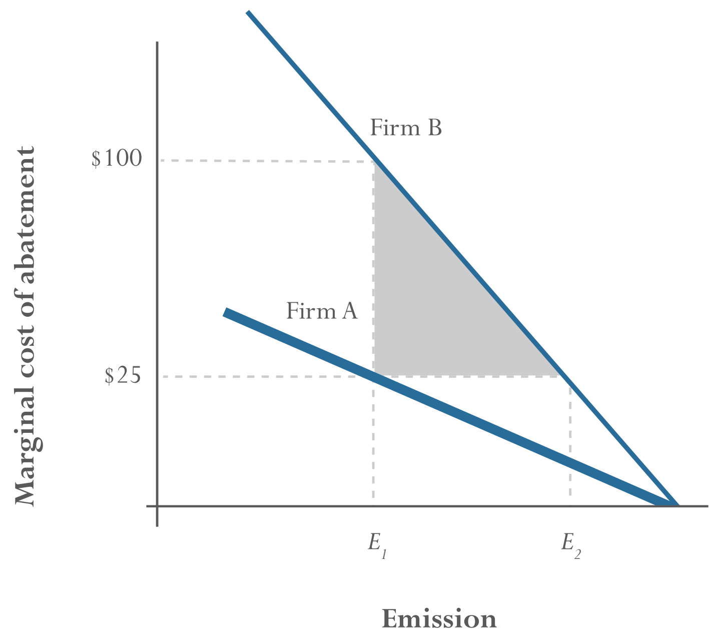
There is an inverse relation between the marginal cost cut-off and the volume of emission reductions that can be achieved. The higher the acceptable marginal cost of abatement, the lower the resulting emissions level will be. The lower the acceptable marginal cost, the higher the resulting emissions level will be.

In this way the marginal abatement cost curve resembles a demand curve. In effect it shows the demand for emissions at each marginal abatement cost level. If the cost to the firm of each unit of its emissions (such as under an emissions tax) was $25 per tonne, firm A would reduce emissions to level E_1. Reductions in emissions save the firm $25 per tonne in emission fees. Reducing emissions below E_1 is not worthwhile since the marginal cost of further abatement is higher than the savings in emission fees. The reason Firm B only abates down to E_2 whereas Firm A reduces emissions down to E_1 is that they have different marginal abatement costs.

Mistakes in target setting

What happens if a regulator only intends for firms to incur a cost of, say, $25 per tonne for abatement, but imposes a target that implies a marginal cost of, say $100 per tonne? Figure 5 shows that the result for firm B is a gap between the intended ($25) and the actual ($100) marginal cost.

Figure 5 Costs of policy errors



The area shaded in gray represents the total cost for firm B of abatement over and above what the regulator intended. In economics jargon, it represents the *welfare loss* of the targeting error, on the assumption that the $25 per tonne price target reflects the maximum value to society of the emission abatement.

Policymaking inevitably involves mistakes. Would it have been better for the policymaker to set a price target instead of a quantity target? The answer depends on two things.

- First, if there are known danger thresholds associated with emissions, the regulator may decide that a quantity target is necessary, regardless of the costs. This may be the case with highly toxic local emissions, for instance. It is less likely to be the case with general air pollutants that mix over large areas, since emissions from any one source have relatively small effects on the overall concentration. In the case of carbon dioxide, since marginal damages of emissions do not change over the entire range of a country's emissions, this consideration does not apply.
- Second, if the marginal abatement cost curve is relatively steep, it is more likely that targeting an emissions quantity will lead to relatively larger welfare costs than would an emissions price target.

4.2 Efficiency considerations

Once an emissions price target is established, it provides a cut-off above which it is inefficient to force abatement to occur. If one industry is able to reduce emissions at $25 per tonne, it is inefficient to force another industry to cut emissions if its marginal abatement cost is, say, $100 per tonne, since the same benefit could have been achieved at one-quarter the cost by having the first industry do the abating.

Economists have long favoured using price-based emission reduction policies in order to avoid this sort of inefficiency. An example of such a mechanism is an emissions tax. If the polluters in Figure 4 are each charged $25 per tonne of emissions, firm A will cut emissions back to E_1 and firm B will cut emissions back to E_2. To achieve that amount of abatement, this is the most efficient way to distribute targets between the two emitters.

Economists have long favoured using price-based emission reduction policies.

In other words, the emitter with the steeper marginal abatement curve ought to abate less than the one with the shallower marginal abatement cost curve.

It is important to recognize that "success" of a price-based instrument is not measured by whether the emission reductions achieve some arbitrary quantity target. In this example, it is not the case that the tax is "successful" in reducing firm A's emissions but "unsuccessful" at reducing firm B's emissions. The tax was successful at reducing each firm's emissions up to the point where further emission reductions would be inefficient. The fact that Firm B undertook relatively little abatement is not a failure as it is the efficient outcome.

4.3 Marginal benefits of emission reductions

As with costs, it makes more sense to discuss the marginal benefits of emission reductions, rather than the *total* benefits. That is because any one policy only ever affects emissions at the margin. The best way to find out the optimal level of emission reductions is to think of it in terms of small steps. We reduce emissions up to the point where the benefit of a further unit of emission reductions, or the *marginal* benefit of emission reductions, is no longer high enough to offset the marginal cost of emission reductions.

In the case of greenhouse gas emissions, what is the marginal benefit? Hundreds of studies have been done on this topic, with a wide range of results. Analysts use computer models to project the changes in the climate around the world, and then they use economic models to assign a value to those changes. In some places the changes are expected to be, on balance, beneficial. In some places they are expected to be harmful. The majority of studies report costs typically in the range of $10-$30 per tonne of carbon dioxide (CO_2) emissions (Tol 2005, 2007). In a survey of over 200 estimates of the economic consequences of climate change, Tol (2007) reported that the median of peer-reviewed studies using a 3 percent discount rate is $20 per tonne of CO_2, and with risk-adjustment this rises to $25 per tonne. Only 1 percent of such estimates are above $78 per tonne. Also, Tol (2007) noted that the median estimates have been falling over time.

This provides an approximate cutoff for the efficient amount of CO_2 emissions to seek from each emissions source. Those that can reduce most of their emissions for, say, $25 per tonne, would be asked to do so, but those sources whose abatement options mainly cost above $25 per tonne should not be required to do so.

In order to charge drivers the social cost of their CO_2 emissions, we can compute a gasoline tax rate as follows.

- One litre of gasoline yields 2.356 kg of CO_2. A tax of $25.00 per tonne equals $0.025 per kilogram, or 5.9 cents per litre.
- The tax per litre of diesel would work out to be a little bit higher, at 6.8 cents per litre.[5]

4.4 Efficiency and the pricing principle

Economists tend to think of optimal emission reductions as a pricing problem, even when policymakers prefer not to use emission taxes. For the purpose of this study, we do not need to assume that policymakers are going to implement an emissions tax of $25 per tonne of CO_2 in order to draw policy-relevant conclusions. Instead, we need only ask, *if we did* impose such a tax, what would the likely market response be? This provides guidance on what the efficient level of abatement requirements would be, if they were imposed in the form of direct emission reduction targets.

For instance, if, under a $25 per tonne CO_2 emissions tax, the pulp and paper industry made significant changes to its processes that resulted in a 75 percent reduction in emissions, but motor vehicle users were observed not to make any changes in their driving habits, that would indicate that the marginal abatement costs for drivers were above $25 per tonne. If regulations were then issued that forced greenhouse gas emission reductions through alterations to driving patterns, this would guarantee a welfare loss, since the emission reductions would have to cost more than the $25 cut-off.

As will be shown in the next section, the fact that gasoline demand elasticities are so low indicates that, in response to a reasonable emissions fee for carbon dioxide, the transportation sector would undertake only minimal emission reductions. Forcing even further reductions would guarantee a deadweight loss even after taking into account the environmental benefit of the reduced emissions. Also, arguments for subsidizing alternative transportation modes such as high-speed rail depend on assuming an extremely (and implausibly) high marginal social benefit of CO_2 emission reductions.

5 There are about 642.6 grams of carbon in a litre of gasoline (Jacques 1990). One gram of carbon becomes 44/12 (=3 2/3) grams of CO_2 when the carbon atoms bond with oxygen, so one litre of gasoline yields 2.356 kg of CO_2.

5 GHG Reductions in the Transportation Sector

5.1 Tax-induced reductions in motor fuel consumption and GHGs

We define an efficient reduction option herein as one that has a marginal cost of under $25 per tonne of CO_2. As noted above, this translates into an increase in the price of gasoline of about 5.9 cents per litre. With current gasoline prices of approximately $1.10-1.20 per litre this amounts to a price increase of about 4.9-5.4 percent. Rounding that to 5 percent and applying the elasticities in Table 2 we can predict the following reductions in motor fuel consumption, and therefore in CO_2 emissions.

- In the short run, the reduction in emissions would be between 0.25 percent and 1 percent. This equates to between 0.3 and 1.3 MtC.
- In the long run, the reduction in emissions would be between 1.5 and 4.0 percent. This equates to between 2.0 and 5.3 MtC.

Putting these into perspective, in 2009, total Canadian emissions were 690 MtC, and compliance with the Kyoto Protocol (6 percent below 1990 emissions of 590 MtC) would have required emission reductions totaling 135.4 MtC. In the short run, efficient changes in motor fuel consumption would translate into only 0.2-0.8 percent of the total Kyoto commitment, and in the long run it would translate into 1.5-3.9 percent of the total Kyoto commitment.

In the appendix I use the above information to derive approximate short run and long run marginal abatement cost curves for motor vehicle fuel consumption. We can use this information to generate a first-order approximation of the cost to Canadians of trying to achieve a 30 percent reduction in GHG emissions from motor vehicles, which amounts to a reduction of about 39 MtC below the 2009 level of 131 MtC.

Efficient changes in motor fuel consumption would translate into only a tiny percent of the total Kyoto commitment.

- In the short run this would require a $975 per tonne carbon tax, or a gasoline tax of about $2.30 per litre. The total tax revenue collected would be about $7234 per household per year.[6] If all the tax revenue were given back to Canadians this still would leave a deadweight loss of about $9.6 billion per year if the efficient carbon price were $25 per tonne (in other words, would cost $9.6 billion more than the benefits, if the benefits have a marginal value of $25 per tonne of emission reduction.) With 12.4 million households this implies a cost of $774 per household for the first year or so.
- In the long run this would require a $195 carbon tax, or a gasoline tax of about 46 cents per litre. Even if all the tax revenue were given back to Canadians it would cause a deadweight loss of about $2.9 billion if the efficient carbon price were $25 per tonne. This is a cost of about $234 per household per year.
- The tax revenue in the long run would be $195 x 92 MtC, or $17.94 billion per year. If this represents a net increase in taxes it would cost Canadians $1447 per household per year over and above the $234 deadweight loss.

6 $975 per tonne times 92 MtC equals $89.7 billion, per 12.4 million homes is $7,234 per home.

- If the emission reductions are achieved through regulatory measures or cap and trade rather than tax measures, the figures shown for tax revenues will not accrue to the government and cannot be recycled back to households, but they will still be out-of-pocket costs to households. Hence the costs to households will be the deadweight losses plus the indicated tax amounts. In the long run this would imply a cost of $1681 per household per year to hit a 30 percent emission reduction target. The implied benefit of the emissions reduction would be $79 per household per year, yielding a net loss to each household of about $1600 per year, even after counting the benefits of the emission reductions.

Current proposals to build high-speed rail lines require the government to pay all capital costs up front.

In summary: If the marginal cost of GHG abatement policy is capped at an efficient level (here taken to be $25 per tonne of CO_2), the corresponding effect on the price of gasoline (6 cents per litre) would yield effectively no change in vehicle usage and no appreciable reduction in GHG emissions from private cars. If policymakers try to hit an arbitrary target of reducing motor vehicle GHG emissions by 30 percent using a carbon tax, it will require a short run price increase of about $2.30 per litre, falling to about 46 cents per litre in the long run. At the latter rate Canadians would be paying $1447 per household per year in new gasoline taxes and experiencing an additional $234 per household per year in deadweight losses. If the same target were reached using cap and trade or regulatory measures, the deadweight loss per household would be about $1600 per year.[7]

5.2 High-Speed Rail

There are two corridors in Canada within which the option of a high-speed rail system has been seriously considered: Windsor to Quebec City (WQ) and Calgary to Edmonton (CE). Each corridor presents significant challenges for the construction of a fast train. Along the WQ line, there are existing rail lines but they are not suitable for high-speed trains. New lines would have to be built, which would require negotiating right-of-way allowances from landowners, which may prove difficult and costly.

To consider the options from a cost point of view, data are available from the Van Horne Institute (2004, 2011) for the CE corridor, both in terms of construction costs and potential GHG emission reductions. Taking these estimates at face value, under the so-called "CPR" option, the system would have upfront capital costs of $2.359 billion and would reduce GHG emissions by 1.8 MtC annually. If we assume that the operating revenues reflect the social willingness to pay for the savings in time and congestion along the CE route, and further we assume that these revenues fully cover the operating costs over the 30-year life of the project, the remaining cost to the public is the capital expenditure.[8] If the remaining benefit is the reduction in GHG emissions, we can ask what they would have to be to justify subsidizing the upfront capital costs. A 30 year annuity of $2.359 billion at

7 Two other analytical aspects to these calculations should be mentioned. First, in the case of cap and trade, some households would experience an increase in wealth through the capitalization value of the permits. In effect the policy would result in a large transfer of wealth from drivers to owners of major energy firms. In the case of regulatory measures, these capitalization benefits disappear from the calculations. Second, if the revenue is recycled to households by reducing a particularly distortionary tax, some improvement in output and income may be generated. However, if the current tax mix is inefficient the gains from improving it should not be considered a benefit of the GHG policy, but should be considered a stand-alone benefit from incremental tax reform.

8 This is the same finding of the Eco-train consortium investigating the WQ corridor option: operating revenues may cover operating costs, but the government will have to cover the project capital costs. See http://www.tc.gc.ca/eng/policy/acg-acgb-high-speed-rail-2956.htm.

4 percent interest is worth $131.17 million annually. That works out to $76.76 per tonne of emissions reduced.

Under the so-called "Greenfield Electric" option, emission reductions of 3.1 MtC would be achieved at a cost of $4.75 billion. The annuity calculation indicates that, if the trains operate on a breakeven basis and the public willingness to pay therefore fully covers the operating costs, the upfront capital costs equate to $85.20 per tonne.

At $25 per tonne, the social value of displaced emissions would only be $45 million annually under the CPR option and $77.5 million annually under the Greenfield Electric option.

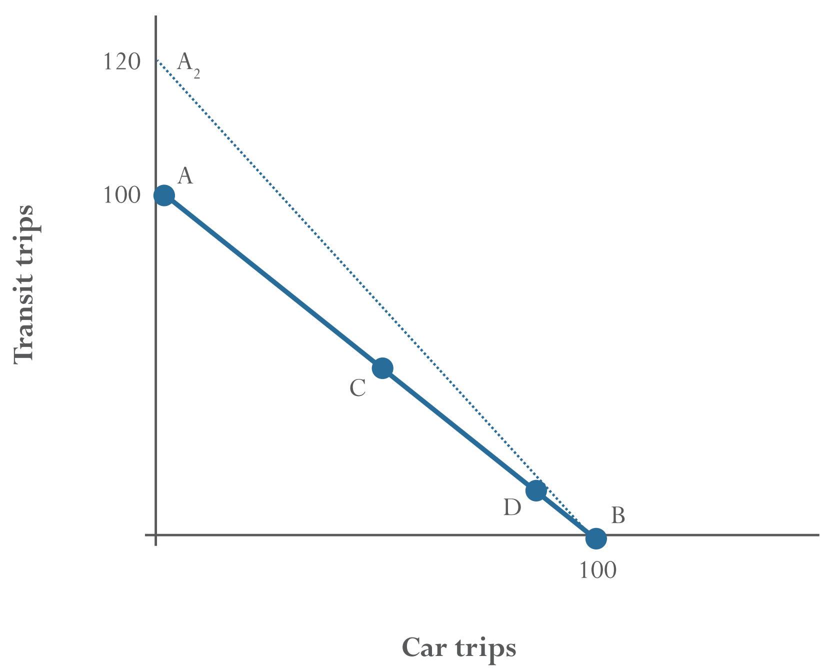
If a high-speed rail project could be implemented in the WQ corridor, the typical estimated costs are in the neighbourhood of $20 billion (Transport Canada 1995, 2011), which has an annuity value of $1.112 billion over thirty years. If the social cost of carbon is $25 per tonne, for the project to be justified on GHG emission reduction grounds it would have to displace 44.5 MtC of emissions, which is about 30 percent of all transportation-related GHGs. Otherwise the GHG savings would not be enough to justify the project.

5.3 Switching to transit

Section 3 indicated that Canadians demonstrate a strong preference for using cars rather than transit to commute and to take other trips. Is it possible to induce people to make a large-scale switch away from cars and towards transit? To understand how economists answer this question we use an economic modeling tool called the *budget constraint*.

Figure 6 shows a diagram in which transit trips are on the vertical axis and car trips are on the horizontal axis.

Figure 6 Transportation budget constraint



In Canada about 80 percent of trips are by car and only a fraction are by transit.

Suppose a consumer allocates \$100 for transportation each month, and each trip costs \$1 whether it is done by transit or by car, taking into account all variable costs including time, fuel, fare, et cetera. The thick, downward sloping gray line is called the budget constraint. It shows all the combinations of transit and car travel she can afford. She might choose to make all of the trips by transit, which would correspond to point A. Or she might rely solely on her car, which would correspond to point B. Or she might choose half and half, such as point C.

As noted above, on average the distribution in Canada is more like point D, where most trips (about 80 percent) are by car, and only a fraction are by transit.

Transit demand is not very responsive to incentives.

Now suppose that the consumer is initially at point D, and we subsidize the cost of using transit by 20 percent, from \$1 per trip to 80 cents per trip. This can take the form of a reduction in the fare, but also a reduction in the time cost (due to faster service, scheduling improvements, or more access points) or an improvement in other convenience aspects.

How will this affect her choice between driving and using transit? We first need to distinguish between people who primarily use transit versus those who do not. If she only takes transit, and she puts the entire value of the cost savings into increased transit use, she can now afford \$100/0.8 = 120 trips per month. So point A would move up to point A_2. On the other hand, if she never uses transit, her transportation decisions would not change at all. She would stay at point B. Her new budget constraint will therefore be the thin, dotted line connecting A_2 and B.

If her preference for car trips was initially based on factors other than the price of transit, such as convenience, access and so forth, then a reduction in the fare price is likely to have relatively less effect on subsequent use of transit than otherwise. In the 2007 Households and the Environment Survey, Statistics Canada asked households that did not use transit what were the main factors affecting their decision. The responses were:

- Have access to a car (73 percent)
- Inconvenient scheduling (27 percent)
- Living too close to the destination to make it worthwhile (23 percent)
- Transit takes too long (21 percent)
- Service is too infrequent (21 percent)
- Cost of using transit (4 percent) (Munro 2010).

Two points are of key interest. First, merely having access to a car was sufficient, for 73 percent of respondents, to choose not to use transit at all. Second, only 4 percent of respondents said the price of transit was the main factor in their decision. In combination with what we already know about the low price elasticities for gasoline demand we can conjecture that, on average, consumers would respond to a reduction in the price of transit with very little increase in transit ridership.

Consumers are more likely to respond to improvements in the quality of transit service than mere reductions in price. However, it remains the case that transit demand is not very responsive to incentives. As mentioned above, survey evidence from Vancouver found that service improvements sufficient to reduce the in-vehicle transit travel time to 30 percent below that for a single occupant vehicle still only increased the probability of choosing transit by 3 percent. (Washbrook et al. 2006)

From the data in Table 3 it appears to be important to distinguish between peak hours and off-peak hours, which correspond to commuting- versus non commuting-related trips. The heaviest use of transit is for peak hour commuting, but that usage is also the least responsive to price changes. The more responsive group is the group of off-peak users, but that is a relatively small component of total use, and is nonetheless still inelastic.

Taking all these points together we expect that, given the existing combination of automobile and car use, and Canadians' stated and revealed preferences for vehicle use, a reduction in the cost (or increase in the convenience) of transit will cause some increased use, mainly in the off-peak hours, but little change in dominant, peak hours use.

In terms of the budget constraint model, the question is where the consumer would end up after leaving point D and moving to a point on her new budget constraint. The answer is that it would be somewhere above and to the right of point D. In other words, some of the savings from the lower cost of transit would lead to taking more transit trips, but some might also go towards taking more car trips.

Figure 6 could also be used to show that an increase in the cost of driving would have a proportionately stronger effect on car use than on transit use. The study by Washbrook et al. (2006), and others they cite, show that road charges and parking charges tend to be most effective at reducing vehicle usage. However the elasticities are still small, on the order of 0.3. This implies that a 10 percent increase in road charges or parking fees would lead to an approximately 3 percent decrease in the probability of a consumer driving alone to work.

The advantages of private vehicle usage are so substantial that policy makers must meet a very high burden of proof before concluding that policy changes would yield net social benefits.

6 Conclusions

Transportation contributes just fewer than 30 percent of Canadian GHG emissions. If governments seek to reduce national GHG emissions by a large amount, it is unlikely that much of the reductions can come from transportation activity without incurring significant deadweight economic losses, even after counting environmental benefits arising from reduced GHG emissions.

Demand elasticities for gasoline and for transportation modes are very low in developed countries like Canada, and Canadians strongly depend on private cars for work-related commuting and other domestic travel. As a result, both the short run and long run marginal abatement costs rise rapidly as emission limits are reduced.

If Canada were to seek to implement reductions in GHG emissions up to a marginal cost of $25 per tonne of CO_2, which is comparable to mainstream estimates of the social cost of carbon (on the assumption that model projections of the climate impacts of GHGs are correct), short run emission reductions from transportation would be under 1 percent, or about 1 MtC. In the long run that amount might rise to between 2 and 5.3 MtC. This is less than 4 percent of the emission reductions proposed under the Kyoto Protocol.

Attempts to force emission reductions beyond this amount risk rapidly escalating deadweight losses because of the inelastic nature of demand for transport in private vehicles. Achieving a 30 percent emission reduction from transportation in the short run would require a carbon tax of about $975 per tonne ($2.30 per litre of gasoline). Even if all the tax revenue were given back to households this would cause deadweight losses of $9.6 billion, or $774 per household per year. After allowing for long run adaptations to the price changes, the emission tax would have to be maintained at about $195 per tonne of CO_2, or 46 cents per litre of gasoline. Perfect revenue neutrality would still result in a national deadweight loss of about $2.9 billion nationally. Use of cap and trade or regulatory measures to achieve the same result would lead to a permanent cost of about $1600 per household per year over and above the benefits of emission reductions.

Proposals to achieve GHG emission reductions by building high-speed rail lines imply a marginal emission reduction cost of about $77-85 per tonne if the trains are able to break even on their operating costs. This is likely higher than the marginal benefits of the potential emission reductions.

Drivers who do not choose to use public transit rarely cite the fare price as the main reason. Cutting the cost of transit is unlikely, therefore, to make a big difference in ridership. Increasing the cost of road usage and reducing the time required to make trips using mass transit may induce greater interest in transit, but survey evidence indicates that such changes would still be relatively small. In addition, the advantages to Canadians of private vehicle usage are so substantial that policy makers must meet a very high burden of proof before concluding that measures to penalize car usage and force greater reliance on public transit would yield net social benefits. It is unlikely that a realistic estimate of the benefits from GHG reductions would suffice to furnish such proof.

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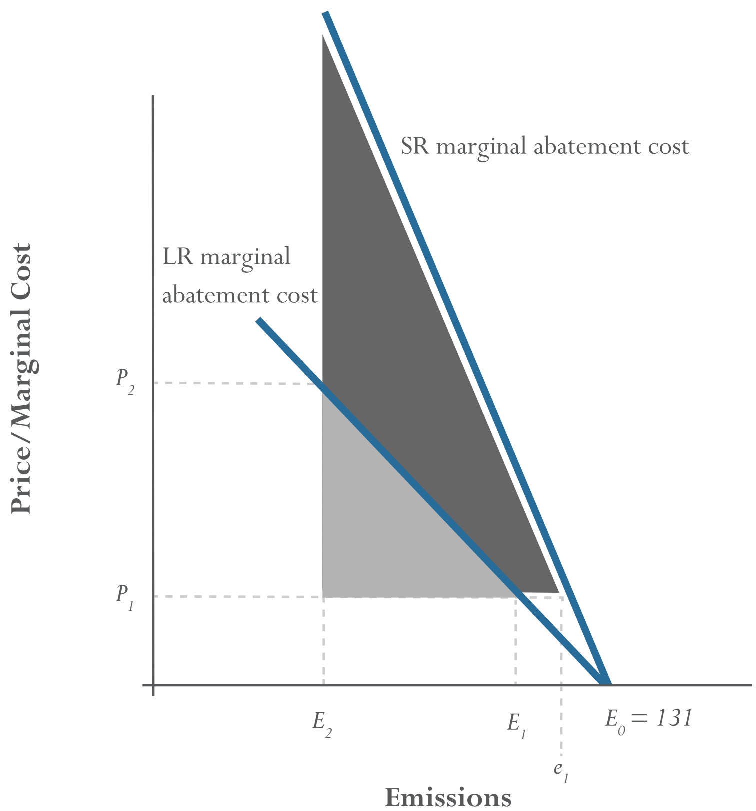
Appendix: Derivation of approximate short run and long run marginal abatement cost curves for motor vehicle fuel consumption



The above diagram shows a short run and long run marginal abatement cost curve (MAC) with two emission/price pairs marked. For information on the theoretical derivation of an MAC and the derivation of welfare changes, etc., see McKitrick (2010). E_0 represents the unregulated emissions level, which for Canadian GHG's from transportation in 2009 was 131 MtC. Let P_1 equal a \$25 per tonne fee on CO_2 emissions. e_1 represents the short run emissions under such a tax and E_1 represents the long run emissions. Using the elasticity-based calculations in Section 5.1 we can estimate a short run emissions decline of 1 MtC and a long run decline of 5 MtC. Note these estimates do not take into account second-order effects due to income changes, cross-price effects, and so forth. Thus we can label some point pairs as follows:

$(E_0, 0) = (131, 0)$,

$(e_1, P_1) = (130, 25)$,

$(E_1, P_1) = (126, 25)$.

These point pairs suffice to calculate local linear equations approximations to the MACs. Using simple algebra we obtain:

short run: $MAC = 3275 - 25E$,

long run: $MAC = 655 - 5E$.

Note that these are linear approximations for the neighbourhood of E_0, and yield only first-order information that will be inaccurate depending on how convex the MACs are away from that point.

A 30 percent reduction in emissions would imply emissions of 92 MtC. Let E_2 represent that amount. Then we can estimate the emissions tax necessary in the long run (P_2) and the short run (P_3, not shown) to get emissions down to that level. To do this we substitute E_2=92 into each of the SR and LR MAC equations.

short run: 3275 – (25 x 92) = $975

long run: 655 – (5 x 92) = $195

Now we can compute the associated welfare losses. In the long run they are equal to the light gray shaded triangle, and in the short run they are equal to that plus the hatched triangle. Thus we have

short run loss = ½ x (130-92) x (975-25) = $18.05 billion, and

long run loss = ½ x (12 6-92) x (195-25) = $2.9 billion.

Author Biography

Professor McKitrick holds a BA in economics from Queen's University, and an MA and Ph.D. in economics from the University of British Columbia. He was appointed Assistant Professor in the Department of Economics at the University of Guelph in 1996, Associate Professor in 2001 and Full Professor in 2009. He is also a Senior Fellow of the Fraser Institute in Vancouver B.C., a member of the Academic Advisory Boards of the John Deutsch Institute in Kingston Ontario and the Global Warming Policy Foundation in London, UK.

His area of specialization is environmental economics and policy analysis. His research areas include modeling the relationship between economic growth and pollution emissions; regulatory mechanism design; and various aspects of the science and policy of global warming. His economics research has appeared in such journals as *The Journal of Environmental Economics and Management, Economic Modeling, The Canadian Journal of Economics, Empirical Economics, The Energy Journal,* and *Environmental and Resource Economics*. His physical science research has appeared in journals such as *Journal of Geophysical Research, Geophysical Research Letters, Climate Research, The Journal of Non-Equilibrium Thermodynamics and Proceedings of the National Academy of Sciences.* He is the author of the advanced textbook *Economic Analysis of Environmental Policy,* published by the University of Toronto Press in fall 2010. In 2002 he and Christopher Essex of the University of Western Ontario published the book *Taken By Storm: The Troubled Science, Policy and Politics of Global Warming* which was awarded the $10,000 Donner Prize for Best Book on Canadian Public Policy.

Professor McKitrick is widely-cited in Canada and around the world as an expert on global warming and environmental policy issues. He has been interviewed by media around the world, including *Time, The New York Times, The Wall Street Journal, The National Post, The Globe and Mail,* the CBC, BBC, ITV, Fox News, Bloomberg, Global TV, CTV, and others. His commentaries have appeared in many newspapers and magazines, including Newsweek and the Financial Post. His research has been discussed in such places as *Nature, Science, The Economist, Natuurwetenschap & Techniek, The National Post, The Globe and Mail* and in a front page article in the *The Wall Street Journal* (Feb 14 2005).

Professor McKitrick has made invited academic presentations in Canada, the US and Europe, and he has testified before the US Congress and the Canadian Parliamentary Finance and Environment Committees. In 2006 he was one of 12 experts from around the world asked to brief a panel of the US National Academy of Sciences on paleoclimate reconstruction methodology.

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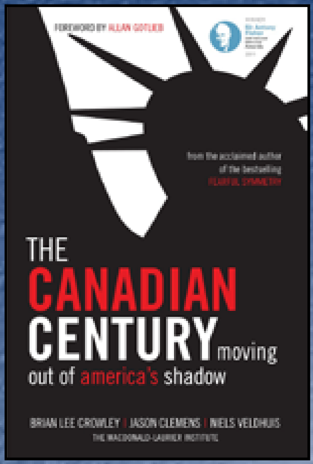

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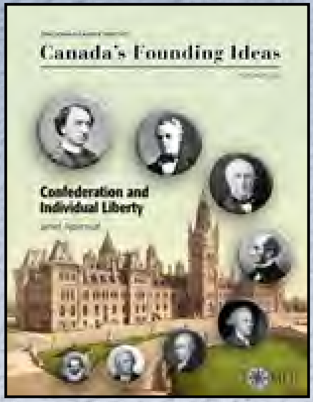

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- Hon. James S. Peterson, former Minister of International Trade and Member of Parliament for 23 years

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