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Where is it Cheapest to Cut Carbon Emissions?

David I Stern and N Ross Lambie

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About the authors

David Stern is a Hub Researcher based at the Arndt-Corden Division of Economics, Crawford School of Economics and Government, Australian National University, and Centre for Applied Macroeconomic Analysis, Canberra, ACT 0200, AUSTRALIA.

E-mail: david.stern@anu.edu.au, Phone: +61 2 6125 6130.

Ross Lambie is a PhD candidate at the Crawford School of Economics and Government, Australian National University, Canberra ACT 0200, AUSTRALIA

E-mail: ross.lambie@anu.edu.au, +61 2 6248 5364

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Abstract:

The relative cost of carbon emissions reductions across regions depends on whether we measure cost by marginal or total cost, private or economy-wide cost, and using market or purchasing power parity exchange rates. If all countries are on the same marginal carbon abatement cost curve then lower marginal costs of abatement are associated with higher energy intensities and higher total costs of abatement in achieving proportional cuts in emissions, equal emissions per capita, or common global carbon price targets. We test this conjecture using the results of the GTEM computable general equilibrium model as presented in the climate change economics review conducted by the Australian Treasury Department. Rankings of countries by costs do differ depending on whether marginal or total cost is used. But some regions, including OPEC and the former USSR, have high marginal costs and high emissions intensities and, therefore, high total costs and others like the EU relatively low marginal and total costs. Under a global emissions trading regime real economy-wide costs of abatement are higher in developing economies with currencies valued below purchasing power parity and large differences between private and economy-wide costs such as India contributing to the high GDP losses experienced in those countries.

Keywords: Climate change, costs, developing countries, computable general equilibrium

JEL Codes: Q52, Q54

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1. Introduction

Development of policy on the cutting of greenhouse gas emissions has in many countries, including Australia (Grafton and Lambie, in press) and the United States (Bang 2010), been characterized by fierce debate among opposing interest groups.

Could both sides be right in these debates? Is it possible that there are many cheap ways to cut emissions in countries such as the United States and Australia, yet the costs of abatement are higher in these countries than in other countries that are often perceived as being more environmentally responsible such as Sweden and the Netherlands? The answer might hinge on what one means by "cost".

We show that the relative ranking of countries by cost of abatement depends on both the type of policy enacted and how cost is measured. Climate change policies can involve among other options:

- Kyoto style equal percentage cuts in emissions,
- Contraction and convergence to equal per capita levels of emissions, or
- Common global carbon prices.

Each option has different effects on the costs borne by different countries and regions. Cost can be measured along three different dimensions:

- Marginal cost of abatement or the total cost of cutting emissions.
- Private abatement costs vs. social or economy-wide costs of abatement.
- Costs measured using market exchange rates or using purchasing power parity adjusted exchange rates.

Paltsev *et al.* (2007) already point out the difference between the ranking of developed economies by carbon price and by percentage consumption losses. They note the reason why marginal and total cost rankings can differ and the reasons why private and economy-wide costs can differ. The current paper's original contributions are to measure marginal economy-wide cost (rather than the carbon price which reflects marginal private cost), to point out the importance of exchange rates, and to provide rankings for a wider range of countries and regions including both Australia and the developing economies.[1]

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[1] Morris *et al.* (2008) provide graphs of marginal private abatement cost and marginal welfare change for China, India, and the Middle East in addition to the developed economies.

The next section of this paper reviews and develops the theory of different cost measurements, the third section describes the data and methods, while the final two sections present the results and conclusions.

2. Theory

Figure 1 illustrates how marginal and total costs are related. We assume in this simple, fictitious example that all countries share the same marginal cost curve and there is no trade in permits or harmonization of taxes. In order to place countries of different sizes on the same curve the graph is in terms of emissions intensity – tons of emissions per dollar of GDP - rather than emissions. We also present things in terms of emissions rather than abatement so that we can show two countries on the same curve and so that marginal cost in the more polluting country can be shown to already be positive. We assume that existing pollution control and energy efficiency policies mean that energy users could gain by increasing emissions intensity if allowed. Cutting energy intensity further would result in further costs. The country of Ameralia has an emissions intensity of 0.9, while in Swepan emissions intensity is just 0.45.[2] As a result the marginal cost of reducing emissions intensity is higher in Swepan than in Ameralia (1.49 vs. 1.05). If both countries agree to reduce emissions intensity by a Kyoto style 10% then they will both move leftward experiencing the costs shown by the two shaded areas. As we can see the total costs borne by Ameralia are greater than those borne by Swepan. Ameralia experiences total costs of 0.097 while Swepan experiences total costs of 0.069. Therefore, on the basis of marginal cost it is easier to cut emissions in Ameralia, but on the basis of total costs it is easier to cut emissions in Swepan.

This result is, of course, contingent on the specific functional form we have chosen for the marginal cost curve: $MAC = \frac{1}{\sqrt{E/GDP}}$. Additionally, if instead of a policy of equal percentage cuts, a policy of an efficient single global price for emissions was adopted then Ameralia would bear higher total costs than Swepan irrespective of the specific form of the marginal abatement cost curve. If in this example the price chosen was 1.571 or equivalently every country is required to reduce emissions intensity to 0.405 then Swepan experiences the same costs as before: 0.069 while Ameralia bears costs of 0.625!

This issue is reminiscent of the diamonds and water paradox (Stern 1999). Abundant resources such as water have a low price (marginal benefit) but because of their abundance may contribute very

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[2] These figures are purely illustrative and do not correspond to the emissions intensities or marginal costs in typical units of any countries.

much to utility (total benefit). The opposite is true of some scarce resources such as diamonds. Here countries with low marginal costs of abatement may face high total costs of abatement and *vice versa*.

So there are at least four ways to measure the costs of emissions reductions with total cost depending on the type of policy adopted:

- Marginal cost
- Total cost of a proportional reduction in emissions
- Total costs of a global single price agreement.
- Total costs of a common global level of emissions per capita.

In reality, not every country has the same marginal abatement cost curve. Figure 2 shows that which country has the higher marginal cost of abatement can depend on the level of abatement. In order to show the real world potential importance of this issue we compare the first two and last of these methods of computing costs for the estimates presented in the Australian Treasury Review of the economics of climate change policy (Treasury 2008). We base our analysis on the Treasury Review because it is one of the most recent and comprehensive policy analyses undertaken on climate change policy. We also considered results from the 22nd study of the Energy Modeling Forum (Clarke and Weyant 2009), but they either did not provide the necessary data or were too aggregated for our purposes. The Treasury Review only presents the GDP and GNP losses (or gains) of various climate policies generated by the GTEM and G-CUBED computable general equilibrium (CGE) models. In order to estimate marginal costs we fit a cost curve to this data for each country.

But these cost curves reflect economy wide costs of climate policy and so is not identical with the typical conception of a marginal abatement cost curve in the literature, which refers to the private marginal cost of abatement.[3] Paltsev *et al*. (2007) explain that pre-existing “distortions” such as fuel taxes can drive a wedge between the private and economy-wide costs of abatement. This is illustrated in partial equilibrium terms in Figure 3, which shows the demand curve for fuel and makes a number of simplifying assumptions. In particular, we assume that fuel supply is infinitely elastic at a fixed international price, which is unaffected by the actions of the country in question, which would be a reasonable assumption for a small economy such as Australia. Due to the partial equilibrium assumption no other domestic prices or quantities are affected by the policy. The underlying price of

[3] In typical bottom up empirical studies (e.g. Creyts *et al*. 2007) different methods of abating emissions are ordered by marginal cost and aggregated into a cost curve. This is a partial equilibrium approach. By contrast Morris *et al*. (2008) use a CGE to derive the private marginal cost of abatement by running the model several times with different constraints on carbon emissions and observing the resulting carbon price.

fuel in the absence of any taxes is P, in which case demand is Q(P). Existing taxes raise the price of fuel to P+t and reduce demand to Q(P+t). The deadweight loss of this policy is the area of the triangle A. Of course, to the degree that fuel taxes correct for external effects the actual costs of the tax are lower than this, but many of these benefits are not included in the national accounts.[4] Adding an additional carbon tax c raises the price of fuel to P+t+c and reduces demand to Q(P+t+c). The private marginal cost of abatement is the area of the triangle C. But the area B reflects the tax revenue lost by the government and is an additional loss of GDP. The areas B and C as shown in Figure 3 are partial equilibrium effects and therefore upper limits that are likely to be mitigated, but not completely offset, in general equilibrium assuming that only the domestic economy adjusts to the policy. Thus total GDP losses will exceed the private costs of abatement. Therefore, we should not expect the marginal GDP costs that we derive to match private marginal costs of abatement.

Finally, we note the role of exchange rates in ranking countries by cost. As is well-known developing economies typically have undervalued currencies compared to the United States in terms of purchasing power. One US dollar buys far more in China or India than in the US when exchanged at market exchange rates. By contrast, some other developed economies have currencies that appear overvalued by this criterion. Purchasing power parity adjusted exchange rates are the exchange rates that would result in one US dollar buying the same basket of goods and services anywhere in the world. A given cost of abatement in US dollars will reflect a larger sacrifice of goods and services in China say than in Switzerland.

Therefore, when we rank countries by cost using market exchange rates the cost of abatement in China relative to Switzerland will appear much cheaper than when we rank countries using PPP exchange rates. Under a global carbon emissions trading regime with a common carbon price the private marginal cost of abatement in developing economies such as China will be much higher in terms of goods and services sacrificed than in developed economies such as Switzerland. This will tend to increase the loss of GDP in developing economies relative to GDP losses in developed economies.

3. Data and Methods

We use estimates of the cost of emission abatement from The Australian Treasury Review, which examines four different potential policy scenarios:

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[4] The benefits of reduced congestion for example will be reflected to some degree in the national accounts but probably not in CGE models used to assess the costs of climate change policy.

- CPRS-5
- CPRS-15
- Garnaut-10
- Garnaut-25

Emissions allocations relative to emissions in 2001 are given for 2020 and 2050. This gives us eight data points for each country or region. Estimates are provided for both GDP and GNP changes, which were estimated using the GTEM model.[5] We do not use the results presented for the G-Cubed model (McKibbin and Wilcoxen 1999) because G-Cubed uses different regions than GTEM and emissions scenarios are not presented for all of the G-Cubed regions in the Treasury Review. Additionally, because of the forward-looking nature of G-Cubed much of the loss of GDP occurs in the immediate aftermath of the introduction of the policy and so is not closely related to the current reduction in emissions.

Estimates of the loss of GDP differ from those of GNP because GNP includes the effects on national income of the international trade in emissions permits. Under the various scenarios not all abatement is carried out domestically and countries may buy or sell permits. Therefore, in order to estimate the domestic cost curve we need to relate changes in GDP to actual emissions reductions rather than to a country's allocation of emissions.

The following tables present this data. First, the projected changes in carbon emissions relative to 2001 under the four policies (Table 1). Garnaut-25 results in equal emissions allocations per capita globally by 2050 and is supposed to be consistent with an atmospheric concentration of 450 ppm of CO2 equivalent in 2100 after an initial overshoot. The Garnaut-10 and CPRS-5 scenarios are consistent with stabilization at 550ppm in 2100 but follow different paths to achieve the goal, while CPRS-15 is consistent with stabilization at 510 ppm (Treasury, 2008). Reductions in emissions in some regions exceed 100% due to reforestation. Table 1 also includes the reduction in emissions required to reach the Garnaut-25 target in 2050 without trade in permits.

In order to assess the degree of abatement, we need to compare these figures to a business as usual scenario (Table 2). We estimate 2001 emissions by adjusting the 2005 emissions by the percentage change in total carbon dioxide emissions for each region or country as given in the data provided by Boden *et al*. (2009). The resulting abatement percentages are given in Table 3. The total World level of abatement gives us an overall idea of how stringent the various policies are. GDP changes in each

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[5] For more information on GTEM see Pant (2002) and Gurney *et al*. (2009).

country under the policy scenarios are the result of two main factors – domestic mitigation efforts and the impacts of changes in the terms of trade due to abatement efforts elsewhere in the world. Table 5.15 in the Treasury Review gives these terms of trade impacts. For instance, most of the negative impact in the OPEC countries is due to trade effects rather than domestic mitigation efforts. On the other hand India gains from terms of trade effects. Its costs of mitigation are very much higher when these impacts are removed. Therefore, we subtracted the terms of trade impacts in Treasury Table 5.15 from the GDP changes in Treasury Table 5.14. Table 4 gives the modeling results from GTEM for the percentage loss of GDP relative to business as usual in 2020 and 2050 for the four policy scenarios with the terms of trade impact removed.[6]

Figure 4 presents these percentage changes in GDP compared to the percentage emissions reductions relative to BAU for all the countries in all the scenarios and both years. There both appears to be a an increase in GDP loss for greater emissions cuts with possibly an increase in the elasticity as the emissions cuts become more extreme and a wide scatter of GDP impacts across countries for a given emissions cut.

We fit a total cost curve separately for each country using ordinary least squares. The equation is the following:

$$\frac{\Delta GDP^{POL}_{ijt}}{GDP^{BAU}_{it}} = \beta_{1i} \frac{\Delta E^{POL}_{ijt}}{E^{BAU}_{it}} + \varepsilon_{ijt} \tag{1}$$

where ε_{ijt} is a random error term in country *i* under policy *j* in year *t* and:

$\frac{\Delta GDP^{POL}_{ijt}}{GDP^{BAU}_{it}}$ is the change in GDP under policy j relative to the BAU path in country *i* in year *t* with terms of trade effects removed,

$\frac{\Delta E^{POL}_{ijt}}{E^{BAU}_{it}}$ is the change in emissions under policy *j* in country *i* in year *t* relative to emissions under the BAU scenario.

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[6] Japan actually sees an increase in GDP in 2050 under all policies. This is because the rate of return of emissions intensive industries falls under climate mitigation policies and the relatively high rates of return in Japan encourage a boom in foreign investment.

As Figure 4 suggests that the elasticity increases with greater abatement we tested a quadratic term in equation (1) but in most cases its coefficient was insignificantly different from zero or as a result the coefficient of the levels term was insignificant. Clearly, this introduced a multicollinearity issue resulting in poor estimates of the coefficients.

Equation (1) is a constant elasticity function but implies that marginal cost rises as emissions intensity falls. The marginal cost of abatement is given by:

$$MC_{it} = \beta_{1i} \frac{GDP_{it}}{E_{it}} \qquad (2)$$

We can compute marginal costs in both PPP and regular exchange rate terms. The latter are relevant to international trade in emissions permits while the former are a better way to compare the domestic cost of abatement across countries.

The data used to estimate the model is that for the thirteen world regions in Tables 3 and 4 excluding the no-trade Garnaut-25 scenario.

Table 5 presents the regression results. With the exception of Canada, the equations fit very well. Japan has a negative marginal cost and Canada essentially a zero marginal cost. Given the high t-statistics, there are in many cases clearly significant differences among the cost curves for different countries (e.g. Former USSR vs. EU).

4. Results

In this section we rank countries by economy-wide costs for the following scenarios:

- Marginal costs in 2005 in PPP terms
- Marginal costs in 2005 in regular exchange rate terms
- Total costs for a 10% cut by 2020
- Total costs for the Garnaut-25 policy without trade in 2050

Table 6 shows the ranking of countries by the four methods. The estimate of marginal costs in 2005 uses equation (2) and data from the Penn World Table (Heston *et al*., 2009) and CDIAC (Boden *et al*., 2009). We estimated the costs of a 10% cut in emissions and for the Garnaut-25 2050 without trade in permits using equation (1). For both these scenarios the losses do not include terms of trade effects only the domestic costs of mitigation.

Japan and Canada are always the two cheapest regions with negative costs under any scenario, but the other placings vary depending on the method used to assess costs. Marginal cost levels and rankings differ depending on whether PPP or regular exchange rates are used. Abatement in China and OPEC is cheaper than in the EU-25 under non-PPP rates and more expensive as measured by PPP rates. There is less variation in marginal costs and much more variation in emissions intensities using the non-PPP rates.

We can see from Table 6 that the GDP costs of a 10% cut in emissions are driven by PPP marginal cost and PPP emissions intensity. By equation (2), marginal cost multiplied by the emissions intensity will equal the abatement elasticity. Therefore, multiplying the second and third columns of Table 6 together and dividing by -10,000 yields the percentage changes in GDP in the eighth column, which are simply the elasticity multiplied by -0.1. Figure 5 displays the actual relationship between PPP marginal cost and PPP emissions intensity. It is an empirical analogue to Figure 1. Clearly there are at least five distinct curves.

In the following, we give some examples of how marginal and total costs relate for countries with similar abatement elasticities. Though the European Union's marginal cost of abatement in PPP terms is 60% higher than that of the United States (and almost double at regular exchange rates) its GDP cost of meeting the two targets is almost identical to that of the US due to Europe's lower PPP emissions intensity. Of course, the model is constructed so that if the abatement elasticity is the same in two countries then their percentage GDP loss will be equal for an equal percentage abatement.

China has lower PPP marginal costs than the rest of East and South Asia (excluding Japan and India) or the Rest of the World (ROW) but a much higher PPP emissions intensity. As a result it has almost the same GDP loss from the 10% proportional cut and higher costs than those two regions from meeting the Garnaut-25 scenario. Russia and South Africa have lower PPP marginal costs than India or Indonesia but again much higher PPP emissions intensities. As a result they both have higher GDP losses under Garnaut-25.

5. Discussion

> "Aggregate costs largely depend on the share of energy- and emission-intensive industries in the economy (as this determines the extent of economic restructuring required), while marginal costs depend on the nature of opportunities to reduce emissions within the economy. Some economies, such as Japan, have relatively low aggregate costs but high marginal costs, while others, such as China, have relatively high aggregate costs but low marginal costs. Australia's costs, both aggregate and marginal, are relatively high. The marginal cost of mitigation tends to be lower in developing economies, compared with developed economies, as developed economies already tend to use more low-cost clean technologies than

> developing economies because of higher energy costs and higher energy-efficiency standards." (Treasury, 2008 109).

This statement from the Treasury Review argues for an inverse relation between marginal and total costs. We find some support for these arguments in the results of the modeling carried out by Treasury but also significant deviations. In particular, the results suggest that at the macro-economic level marginal costs are negative in Japan. In PPP terms costs are moderate to high in developing economies. Even using regular exchange rates, the US has lower marginal costs than any developing economy except China. As the regression results show, marginal abatement cost curves differ significantly across countries. It might even be possible to conclude from Figure 5 that there is a positive relationship between marginal cost and emissions intensity in the cross-section of countries rather than the negative relationship posited in Figure 1.

The Treasury Review concludes that if all countries are in a global emissions trading system as of 2020, India, Indonesia, and Other South and East Asia would be sellers of permits while the EU, the US and OPEC would be buyers. The allocation of all countries is less than their BAU emissions so one would expect that countries with high marginal costs of abatement would buy permits and those with low marginal costs of abatement would sell them. The G-Cubed permit sale and income transfer results are very different to GTEM, especially for 2050. According to G-Cubed China, Japan, and the US end up being permit sellers in 2050 while the rest of the world is a net purchaser. Those results are more congruent with the marginal costs estimated here, even though those costs were derived from the GTEM output.

From Table 6 we saw that the selling regions have relatively high marginal costs as measured using either PPP or market exchange rates. The global emissions price under the policy scenarios ranges from $US21 to $US39 in 2010 and $US31 to $US52 in 2020 (Treasury, 2008). This suggests that there is a very significant wedge between private and economy-wide marginal costs in the selling regions all of which have economy-wide marginal costs in 2005 that are far in excess of emissions price. It makes sense that pre-existing distortions would be large in South and South-East Asia. From Table 3 we see that abatement relative to business as usual is greatest in these selling regions. Market energy intensity is higher in these regions than in the developed economies (though not as high as in Russia and China) and so they can move relatively far down their private marginal abatement cost curves until private marginal abatement cost equals the global emissions price.

6. Policy Implications and Caveats

We have shown that whether a country is a relatively low-cost or high-cost location for carbon abatement depends on whether we measure costs using marginal or total cost of abatement, private or economy-wide costs of abatement, and using market or PPP exchange rates. It is usual in the literature – as in the quote from Treasury (2008) above - to think in terms of private marginal market exchange rate costs. According to the GTEM model there is a bigger gap between private and economy-wide costs in South and South-East Asia than elsewhere and these countries also tend to have undervalued currencies in terms of purchasing power. Under a global trading regime the owners of permits in these countries would find it profitable to sell them on the global market. Due to the gap in exchange rates they will push their own private marginal costs of abatement in real terms far higher than polluters in developed economies. The high distortions in these economies will impose even greater costs on these economies. Of course, the sellers of permits will receive income for the permit sales, which means that GNP losses will not be as great as GDP losses in these countries. Additionally, terms of trade effects benefit oil importers such as India. Even so, the Treasury Review shows that GNP losses are higher in these countries and China than in all developed economies apart from Australia and Canada. Depending on who has the rights to permit revenue, the distributional impacts could be substantial.

These results might not hold up in G-Cubed, which shows much greater losses in Europe than does GTEM. Also, the results in this paper are meant to be simply illustrative of the potential relationships. They are dependent on the modeling assumptions made by the developers of the GTEM model and the scenarios built by the Australian Treasury team. We had very few data points with which to estimate our regressions and assumed a very simplistic constant elasticity model.

The relationships highlighted by these results raise some interesting implications for the choice of mitigation policies in different countries. A significant issue for countries with a high abatement elasticity concerns their willingness to rely solely on a global emissions trading scheme to achieve their emissions reductions. As the results show, a country's abatement elasticity is a key determinant of its GDP losses and reflects the impact of pre-existing distortions on the ability of the economy to substitute away from emissions intensive goods and services. Given the size of the economy-wide costs in some countries and regions, the possibility of them incurring large adverse distributional outcomes and/or efficiency losses arising from pre-existing distortions, may make it politically unacceptable for governments to commit to the type of global emissions trading schemes analyzed by the Treasury Review. Furthermore, Böhringer et al. (2009) find that where there are substantial differences in private and social marginal abatement costs there may be the opportunity for governments to implement welfare improving policies that depart from global emissions pricing. Such policies may include differential emissions pricing between sectors and countries, or overlapping regulations in the form of multiple emissions abatement policies targeted at high emissions sectors within a country. Whether or not these policies are welfare improving depends on their ability to mitigate the economy-wide costs of the pre-existing distortions. It, therefore, may be the case that countries such as Indonesia, India and those in Other South and East Asia, which have high abatement elasticities, have an incentive to implement a mix of policies that reflect their individual circumstances, while those countries with a low abatement elasticity rely to a greater extent on international emissions trading.

Returning to the question we opened the paper with – whether the costs of abatement in the United States might actually be high, these results do not support this proposition however cost is measured. Neither do the G-Cubed results. According to GTEM, costs in Australia in real terms are fairly moderate whether marginal or total cost is used.

Though the difference between marginal and total cost has important effects, the gaps in costs produced by the difference between private and economy-wide cost and due to differences between market and PPP exchange rates look to be much more significant.

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Table 1. Percent Change in Carbon Emissions Relative to 2001 Under GTEM

	2020				2050				
	CPRS-5	CPRS-15	Garnaut-10	Garnaut -25	CPRS -5	CPRS -15	Garnaut -10	Garnaut -25	Garnaut -25 No Trade
United States	-19	-26	-20	-33	-62	-74	-62	-83	-89
EU-25	-16	-22	-16	-26	-48	-57	-47	-63	-82
China	120	99	128	89	89	75	91	47	-45
Russia + CIS	11	2	10	-7	-56	-77	-54	-85	-85
Japan	-15	-19	-14	-20	-50	-57	-49	-63	-86
India	38	25	54	30	139	89	145	56	90
Canada	-5	-12	-4	-16	-36	-53	-35	-63	-89
Australia	3	-8	3	-15	-42	-71	-39	-77	-90
Indonesia	-23	-33	-21	-40	-25	-53	-12	-61	-39
South Africa	26	14	26	5	-4	-32	-7	-56	-70
Other South and East Asia	-43	-54	-39	-63	-95	-136	-76	-142	-49
OPEC	45	36	48	32	106	66	94	0	-54
Rest of the World	47	47	2	-17	43	16	52	-2	11
World	21	12	15	-4	-2	-22	2	-39	-50

Source: Tables 5.2 and 5.17 Treasury (2008)

Table shows percentage cuts in emissions from domestic abatement. Cuts can exceed 100% due to reforestation

World emissions are not the same with and without trade due to intertemporal banking of permits.

Table 2. Business as Usual Scenario: Gt CO2 equivalent

	2001	2005	2020	2050
United States	6.9	7.2	7.7	9.4
EU-25	4.8	4.9	5.2	5.5
China	4.5	7.2	16.1	31.4
Russia + CIS	3.1	3.3	4.7	5.5
Japan	1.3	1.4	1.3	1.1
India	1.5	1.8	3.7	11.7
Canada	0.8	0.8	0.9	1.2
Australia	0.5	0.6	0.7	1
Indonesia	0.7	0.8	1	2.2
South Africa	0.4	0.5	0.7	1.4
Other South and East Asia	1.5	1.7	1.9	3.7
OPEC	1.5	1.8	2.9	6.2
Rest of the World	6.4	7.2	10.2	22.2
World	33.9	39.2	57.0	102.5

Source: Table 3.1 Treasury (2008), Authors' calculations using Boden *et al*. (2009) and Heston *et al*. (2008)

Table 3. Percent Abatement Relative to Business as Usual

	2020				2050				
	CPRS-5	CPRS-15	Garnaut-10	Garnaut -25	CPRS -5	CPRS -15	Garnaut -10	Garnaut -25	Garnaut-25 No Trade
United States	-27	-33	-28	-40	-72	-81	-72	-87	-92
EU-25	-22	-27	-22	-31	-54	-62	-53	-67	-84
China	-39	-45	-37	-48	-73	-75	-73	-79	-92
Russia + CIS	-27	-33	-27	-39	-75	-87	-74	-92	-92
Japan	-12	-16	-11	-17	-39	-47	-38	-55	-83
India	-43	-49	-37	-47	-69	-75	-68	-80	-75
Canada	-20	-26	-20	-30	-60	-70	-59	-77	-93
Australia	-22	-30	-22	-36	-69	-85	-68	-88	-95
Indonesia	-50	-56	-48	-61	-78	-86	-74	-88	-82
South Africa	-20	-28	-20	-33	-70	-78	-71	-86	-90
Other South and East Asia	-56	-65	-53	-72	-98	-114	-91	-117	-80
OPEC	-24	-29	-23	-31	-50	-59	-53	-76	-89
Rest of the World	-8	-8	-36	-48	-59	-67	-56	-72	-68
World	-28	-33	-32	-43	-68	-74	-66	-80	-83

Source: Tables 3.1, 5.2, and 5.17 Treasury (2008), Boden et al. (2009), Authors' calculations

Table 4. Percent Change in GDP Relative to Business as Usual: GTEM

	2020 CPRS-5	CPRS-15	Garnaut-10	Garnaut-25	2050 CPRS-5	CPRS-15	Garnaut-10	Garnaut-25
United States	-0.4	-0.6	0.1	0.1	-0.4	-0.9	-0.2	-0.9
EU-25	-0.3	-0.3	0	-0.1	-0.1	-0.3	-0.4	-1.1
China	-1.3	-1.8	-1	-2	-2.8	-3	-1.7	-2.3
Russia + CIS	-2.6	-3.7	-3.4	-5.9	-9.2	-14.4	-8.8	-16.7
Japan	-0.3	-0.2	-0.5	-0.6	0.9	1.2	0.4	1.2
India	-0.9	-1.2	-2.4	-3.5	-10.6	-11.9	-12.5	-15.2
Canada	0	-0.1	0.1	0	0.9	0.1	0.6	-1
Australia	-0.4	-0.5	-0.3	-0.4	-0.7	-2.9	-0.5	-3.3
Indonesia	-0.4	-0.6	-2.4	-4.3	-5.3	-6.8	-4.6	-7.9
South Africa	-2.8	-3.7	-3.1	-4.8	-8.2	-10	-7	-9.9
Other South and East Asia	-0.5	-0.6	-0.4	-0.9	-4	-5.3	-3.6	-6.4
OPEC	-0.3	-0.6	-0.3	-0.7	0.2	-1.5	-0.8	-4.4
Rest of the World	-0.3	-0.3	-0.8	-1.3	-1.9	-2.1	-2.4	-3.3

Source: Tables 5.14 and 5.15 Treasury (2008)

Table 5. Regression Results

Region	% Abatement	Adjusted R2
United States	0.0076	0.3560
	4.0930	
EU-25	0.0081	0.3374
	3.8104	
China	0.0336	0.6017
	13.2817	
Russia + CIS	0.1492	0.8747
	14.1844	
Japan	-0.0167	0.4826
	-2.8940	
India	0.1385	0.5707
	6.1884	
Canada	-0.0009	-0.0127
	-0.2382	
Australia	0.0241	0.5551
	4.8780	
Indonesia	0.0643	0.5383
	6.7823	
South Africa	0.1182	0.9364
	25.4041	
Other South and East Asia	0.0372	0.5859
	5.8591	
OPEC	0.0292	0.4115
	3.4827	
Rest of the World	0.0360	0.8453
	12.1467	

t-statistics appear in italics below the coefficients

Table 6. Alternative Rankings

PPP			Non-PPP			GDP Loss 10% Cut by 2020 – With Permit Trading		GDP Loss Garnaut-25 in 2050 – No permit trading	
	Marginal Cost in 2005	Emissions Intensity in 2005		Marginal Cost in 2005	Emissions Intensity in 2005				
Japan	-$179	0.09	Japan	-$214	0.08	Japan	0.17%	Japan	1.38%
Canada	-$7	0.14	Canada	-$7	0.13	Canada	0.01%	Canada	0.09%
United States	$59	0.13	China	$50	0.67	United States	-0.08%	EU-25	-0.69%
EU-25	$95	0.09	United States	$59	0.13	EU-25	-0.08%	United States	-0.70%
OPEC	$164	0.18	OPEC	$77	0.38	Australia	-0.24%	Australia	-2.29%
Australia	$168	0.14	EU-25	$117	0.07	OPEC	-0.29%	Rest of the World	-2.45%
China	$186	0.18	Other South and East Asia	$169	0.22	China	-0.34%	OPEC	-2.59%
Other South and East Asia	$365	0.10	Australia	$179	0.14	Rest of the World	-0.36%	Other South and East Asia	-2.97%
Rest of the World	$426	0.08	Indonesia	$207	0.31	Other South and East Asia	-0.37%	China	-3.10%
South Africa	$483	0.24	Russia + CIS	$229	0.65	Indonesia	-0.64%	Indonesia	-5.26%
Russia + CIS	$625	0.24	Rest of the World	$230	0.16	South Africa	-1.18%	India	-10.42%
Indonesia	$797	0.08	South Africa	$255	0.46	India	-1.38%	South Africa	-10.70%
India	$1,312	0.11	India	$284	0.49	Russia + CIS	-1.49%	Russia + CIS	-13.65%

Losses of GDP do not include terms of trade effects. Also the total loss or gain in income in a country should be measured by GNP, which includes the value of emissions permits traded internationally.

Figure 1. Common Marginal Abatement Cost Curve

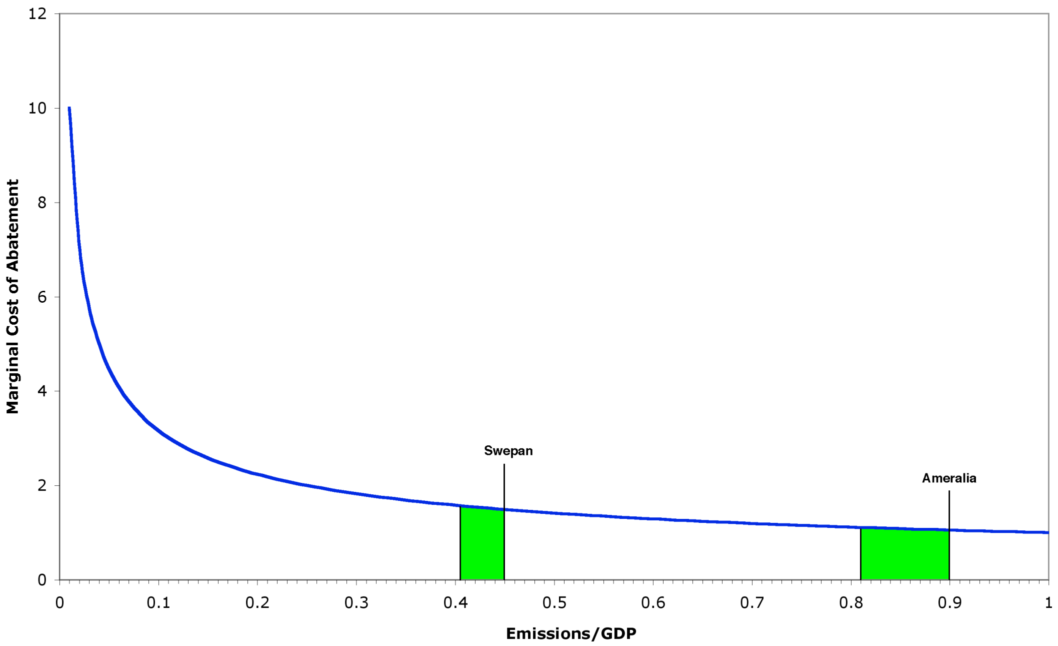

Figure 2. Different Marginal Abatement Cost Curves

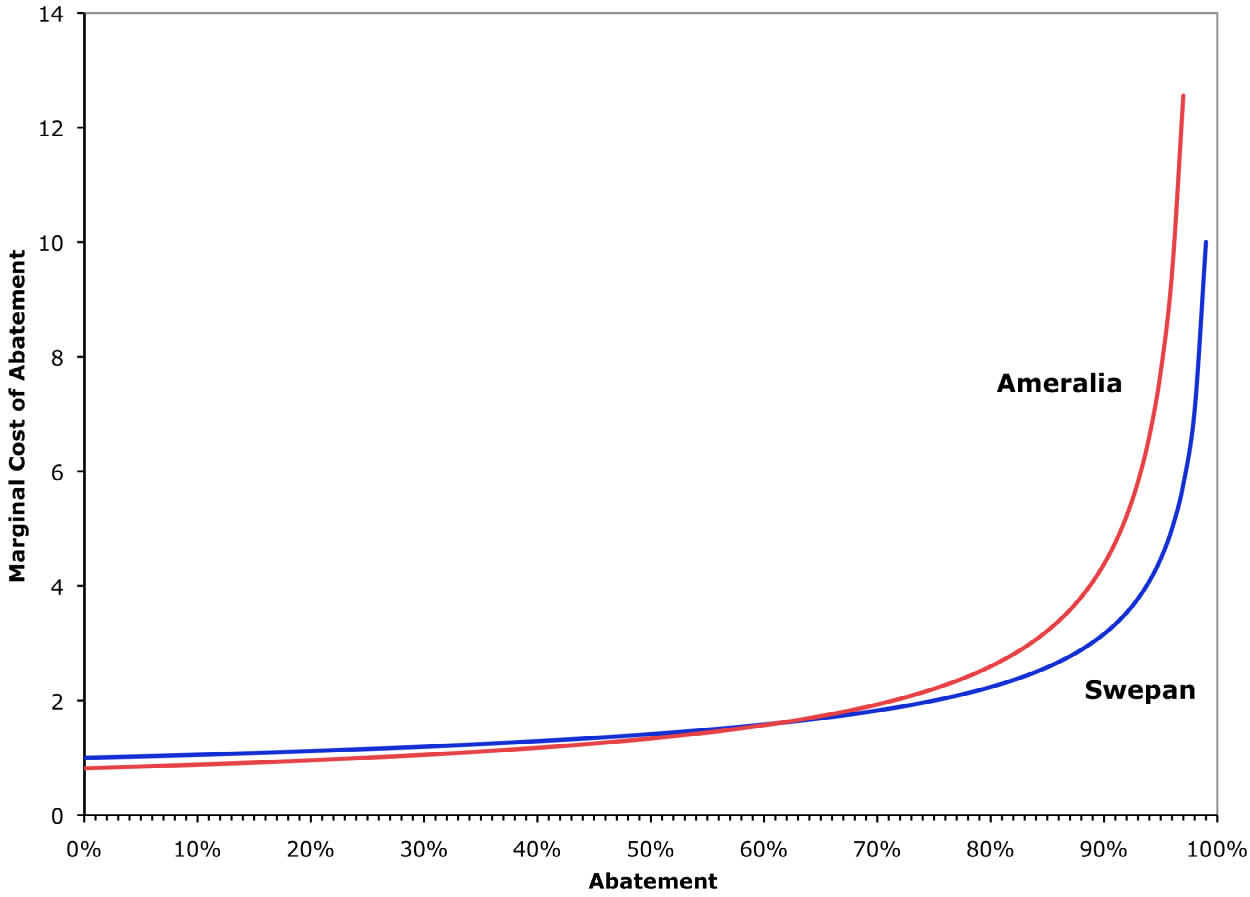

Figure 3. Effect of Fuel Taxes on Social Cost of Abatement

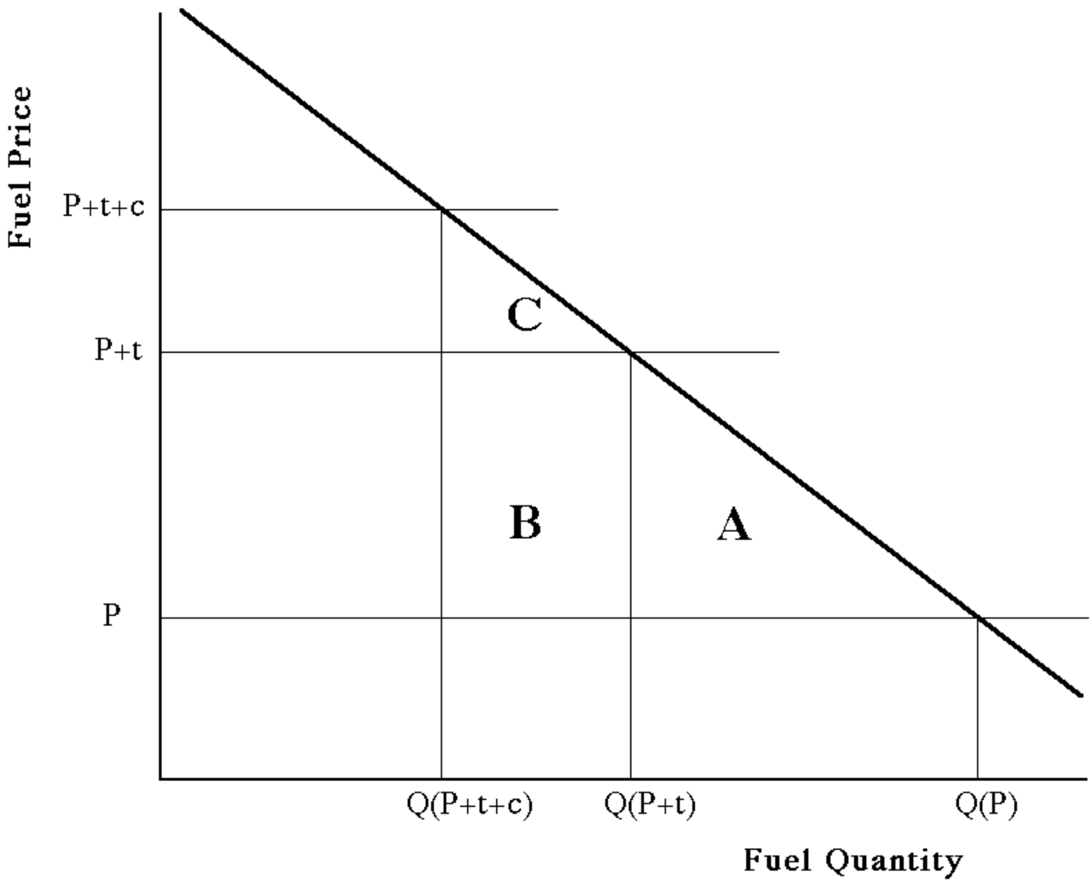

Figure 4. Change in GDP and Emissions Relative to BAU

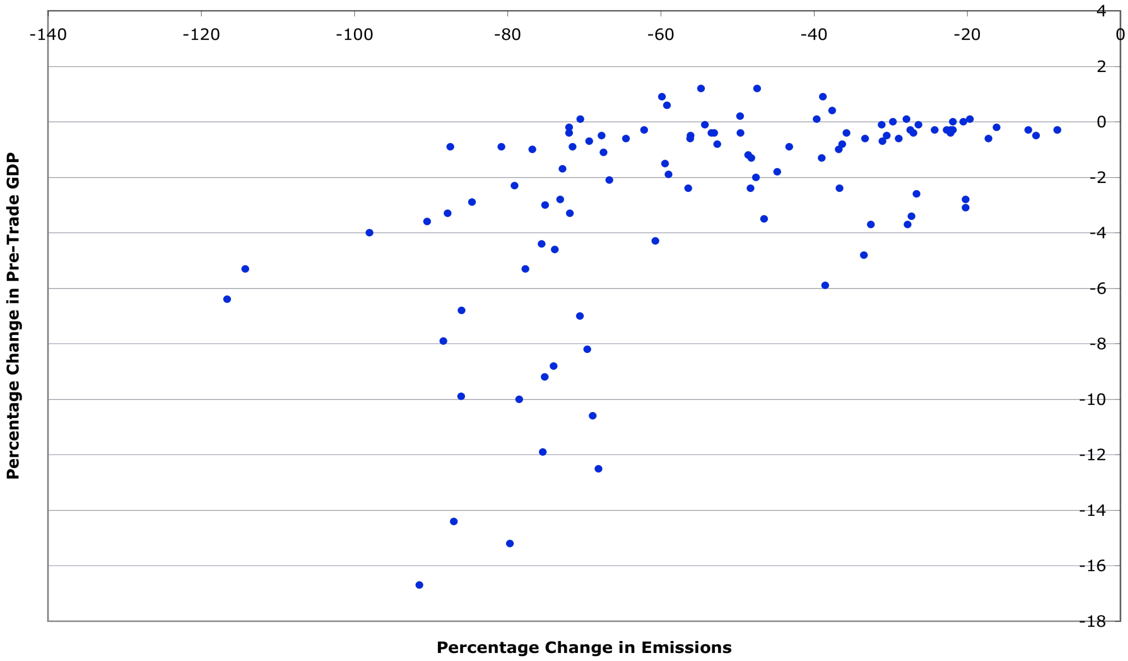

Figure 5. PPP Marginal Cost and Emissions Intensity

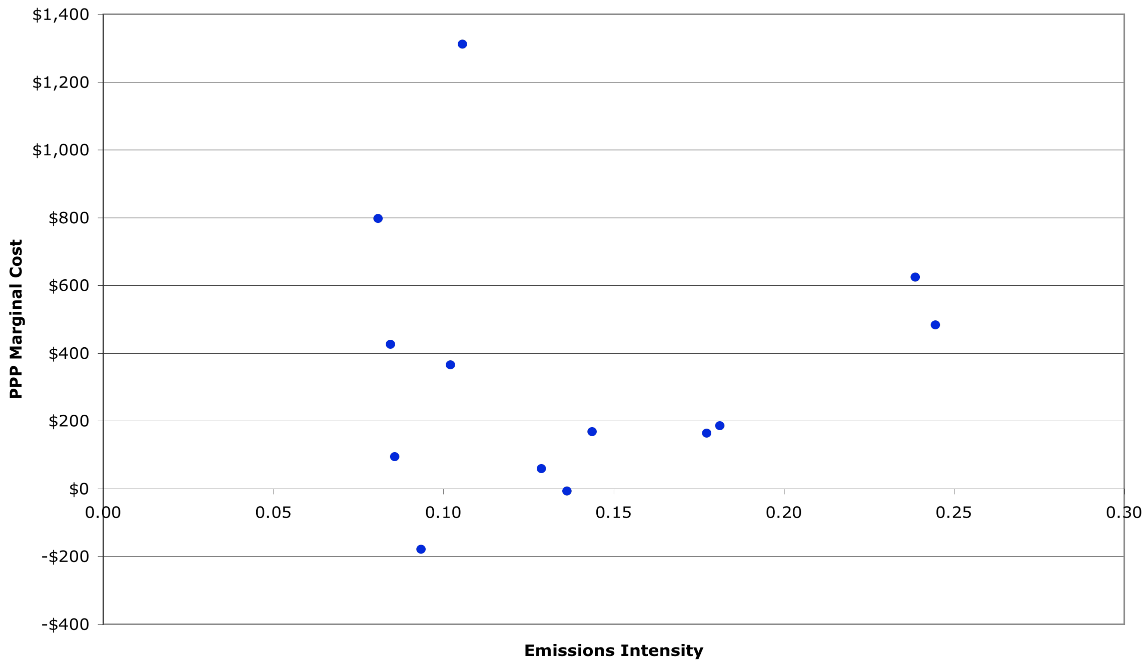

Figure 6. Market Marginal Cost and Emissions Intensity