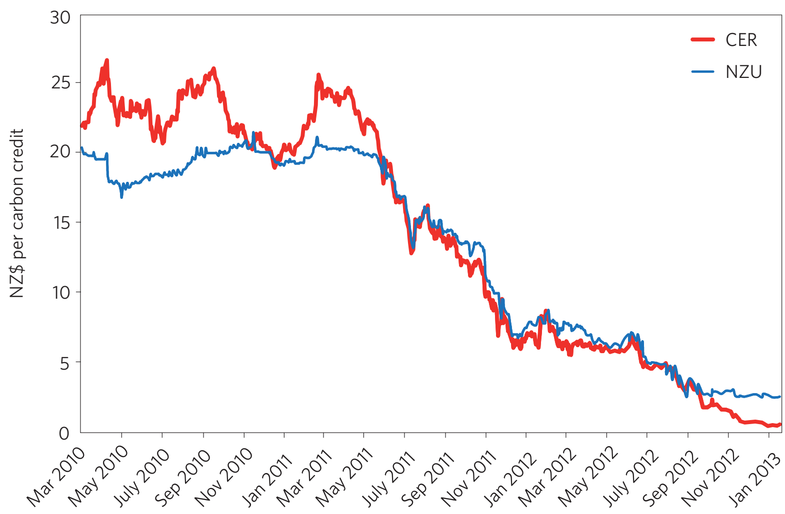

Figure 3 | The market price of NZ carbon credits on a given day (based on publicly available data). Figure reproduced with permission from ref. 7, © 2013 Future Science Limited.

Combined with international rules that exclude New Zealand from access to Kyoto units under the CP2, the government's position in international negotiations will inevitably change the dynamics of the domestic market. Although the country's disconnection from the international market is likely to increase demand for NZUs and provide incentives for afforestation and deter deforestation (for example, in the 2020s, when many managed forests are due to be harvested), the supply of additional NZUs through an auction mechanism will be needed. These issues, among others, support the idea of setting up a long-term price signal to encourage climate mitigation investments. This is consistent with the long-term 'economic resilience' objective of the NZ ETS, which includes incentivizing low-carbon technologies. In any event, an immediate halt to the flow of cheap Kyoto units remains a huge political battle.

It is clear that the NZ ETS is in need of improvements, and it is very likely that politics will decide the future of the NZ carbon market. National elections are due to be held in 2014 and, unlike Australia — where the new Liberal National coalition government dismantled the 'Climate Commission' and plans to scrap the carbon pricing mechanism — a change of government in New Zealand could see the implementation of new policy measures designed to increase the scheme's effectiveness and integrity. The major NZ opposition parties have been heavily critical of the 2012 amendments to the scheme, the lack of domestic effort, low carbon prices and the withdrawal from CP2. However, any meaningful reform will have to deal with inescapable policy trade-offs and may require the (bipartisan) political compromises found in climate policy. ❐

Luis Mundaca and Jessika Luth Richter are at the International Institute for Industrial Environmental Economics, Lund University, Tegnérsplatsen 4, 22100 Lund, Sweden.*
**e-mail: luis.mundaca@iiiee.lu.se*

References

1. *New Zealand Emission Unit Register* (Environmental Protection Authority, 2013); http://www.eur.govt.nz
2. Renowden, G. 100% useless: NZ government announces pathetic 5% emissions target. *Hot Topic* (16 August 2013); http://go.nature.com/yFUoGc
3. *Government Emission Target for 2020 Inadequate* (Victoria University of Wellington, 2013); http://go.nature.com/HYidyf
4. Groser, T. New Zealand commits to 2020 climate change target. *Beehive* (New Zealand Government, 2013); http://go.nature.com/6k8uYn
5. *New Zealand's Net Position under the Kyoto Protocol* (Ministry for the Environment, 2013); http://go.nature.com/1W5Osg
6. Emission Trading Scheme Review Panel *Doing New Zealand's Fair Share: Emissions Trading Scheme Review 2011* Final Report (Ministry for the Environment, 2011).
7. Luth Richter, J. & Mundaca, L. *Carbon Manage.* **4,** 423–438 (2013).
8. *NZ ETS 2011 — Facts and Figures* (Ministry for the Environment, 2012); http://go.nature.com/LLn63v
9. *NZ ETS 2012 — Facts and Figures* (Ministry for the Environment, 2013); http://go.nature.com/7BauGH
10. Carbon CommTrade (OM Financial Limited, 2013); https://www.commtrade.co.nz

COMMENTARY:

Carbon tax needs thresholds to reach its full potential

John C. V. Pezzey and Frank Jotzo

The political opportunities for implementing a carbon tax high enough to induce large emission cuts will be better if at first the tax is charged on the difference between emissions and fixed thresholds, rather than on all emissions as is now practised.

There is much fresh interest in national climate policies, despite the gridlock in international climate negotiations[1]. Of the two highest greenhouse gas ('carbon') emitters, China has signalled its intention to introduce carbon pricing[2] — a carbon tax and/or carbon (emissions) trading scheme — and the USA is taking a regulatory route after earlier efforts to implement a trading scheme failed[3]. Pricing carbon emissions is widely accepted as being far cheaper for countries overall than regulation[4], but a 'high' global price in the order of US$50 per tonne of carbon dioxide

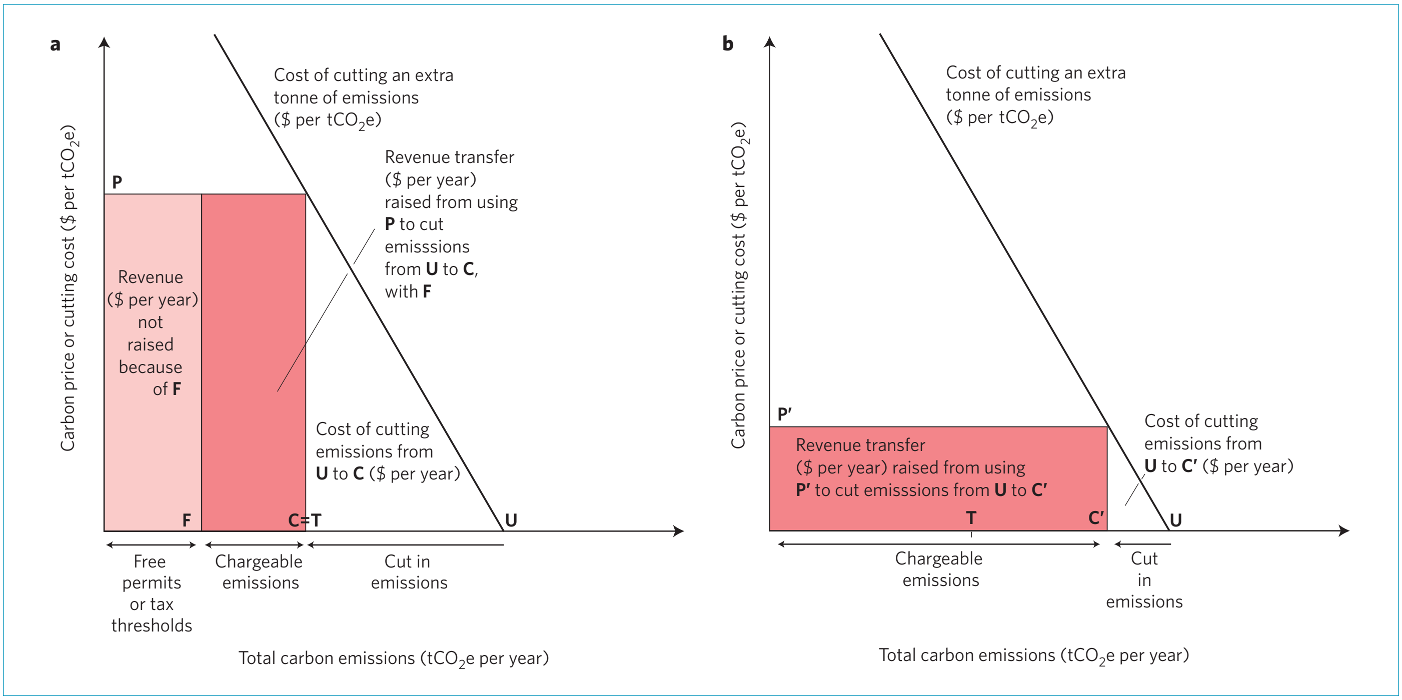

Figure 1 | A simplified illustration of how free carbon can enable a higher carbon price without increasing revenue. **a**, Charging a price **P** on all carbon emissions that is high enough to achieve large cuts, from uncontrolled carbon **U** to controlled carbon **C** equalling target **T**, typically yields a politically unacceptable level of revenue (pink plus red areas = **P×C**). Revenue can be lowered to an acceptable level (red area only = **P×(C−F)**) by granting free carbon **F**. **b**, With no free carbon, only a low price **P′** can be charged, so controlled carbon **C′** greatly exceeds the target, if revenue (red area = **P′×C′**) is to stay the same (the graphs are drawn so that the two red areas are equal). The illustration is simplified because it ignores the likely fall in revenue from other types of taxes not related to carbon and rise in deadweight loss caused by a carbon price[10], effects that would be stronger under the higher price in Fig. 1a.

equivalent (tCO_2e) is still needed to induce significant cuts in emissions, with this price rising steeply as global control is delayed[5].

Taxing rather than trading carbon has the advantage of creating a stable price[4], while not undermining other carbon control efforts that have a role where carbon pricing is impossible or ineffective[6]. But as we show later, a key problem is that charging anything near US$50 per tCO_2e on all emissions will raise far more revenue than has been acceptable in existing tax or trading schemes. This has been a reason to avoid imposing large burdens on carbon-intensive producers in the jurisdictions that favour carbon trading, carbon taxation with low tax rates and many exemptions, and/or regulation[4,7,8].

There are many other factors important in policy debates about carbon taxation, including its environmental benefit and cost-effectiveness[9], and its possible distributional inequity (higher relative impact on poor households)[4,10]. But carbon-intensive industries are highly concentrated, and thus can and do lobby powerfully[11] (if often indirectly) for their interests. Achieving beneficial revenue neutrality — by recycling all the revenue in ways that improve economic efficiency and equity — will improve carbon taxation's broader political appeal, but will not relieve lobbying pressure as much as raising less revenue initially. Ignoring this regrettable reality has arguably made 'high', environmentally desirable carbon taxes politically much less feasible.

Yet the revenue problem can be avoided by abandoning the economically desirable but politically stifling presumption that a tax should be charged on every unit of emissions. Instead, governments can use a long-established idea they have so far ignored almost everywhere, by giving 'free carbon' as tax thresholds. These are essentially equivalent (symmetric) to free permits or allowances in carbon trading schemes, and work somewhat like income-tax thresholds. Emitters are charged tax only on the difference between their actual emissions and the emission thresholds they have been given, so the tax rate can in principle be as high as required, without raising and transferring politically unacceptable amounts of revenue from emitters to governments[12–14].

But neither should revenue be deficient: as we explain below, it is needed to improve both distributional equity (itself worsened by free carbon) and economic efficiency. So for either tax or trading, free carbon should be limited, and ideally only a transitional measure. In summary, we argue that to make a high enough carbon price politically more acceptable, limited thresholds should be considered, in combination with beneficial revenue-recycling, whenever carbon taxation is proposed — just as some free permits are recognized as a pragmatic, politically important part of the introduction of carbon trading[15].

How free carbon works

Both tax and trading can use free carbon to impose a higher carbon price without increasing the revenue raised by a pricing scheme, as shown in a simplified way in Fig. 1. In Fig. 1a the total net revenue transferred from emitters to the government is:

$$\begin{aligned}&\text{Revenue (\$ per year)}\\&\quad = \text{Price of carbon (\$ per } tCO_2e)\\&\qquad \times \text{(Controlled carbon}\\&\qquad\quad -\text{Free carbon) (}tCO_2e \text{ per year)}\end{aligned}$$

with free carbon being some fixed level in tCO_2e per year. If this revenue is some maximum politically acceptable amount, then without free carbon only a lower carbon price and emissions cut are possible (Fig. 1b).

Large, carbon-intensive companies such as electricity generators and steelmakers have both a strong motive and the ability to

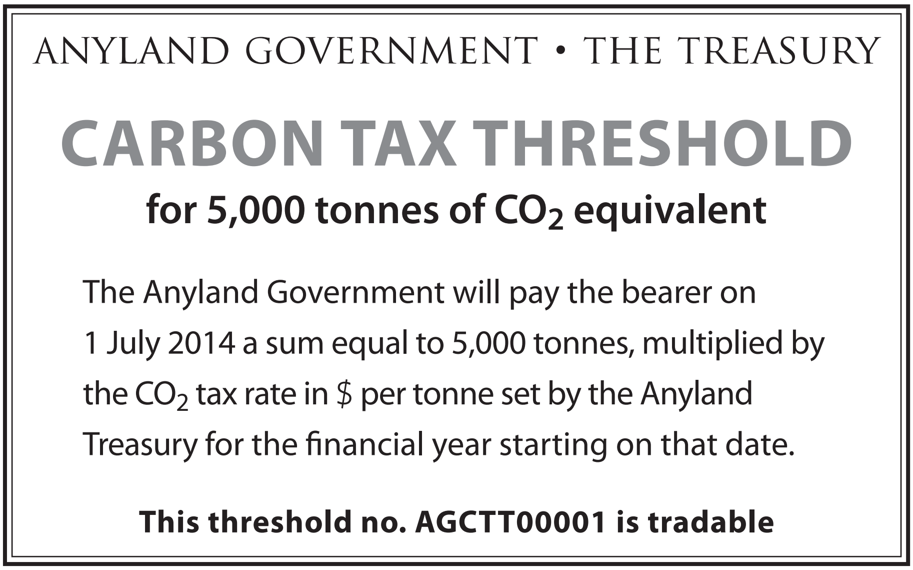

Figure 2 | A notional illustration of a carbon tax threshold treated as a property right, and therefore tradable.

lobby politically[11] for more free carbon. But households, the final consumers of carbon-intensive goods, ultimately bear most of the cost of emission control because companies pass through most of it as higher energy prices[16]. These can hit poor households disproportionately hard[17], and as evident from the US debate[18] and the Australian carbon pricing mechanism[19], form another major political problem with carbon pricing. Governments thus need to keep free carbon low enough (hence revenue high enough) to fund fiscal assistance to households, such as higher welfare payments. Moreover, because of cost pass-through, carbon-intensive companies do not need much free carbon (less than 15% of total permits in one recent US study[16]) to prevent losses of profits.

Giving less free carbon also enables more efficiency-enhancing revenue recycling, such as lowering existing, distortionary tax rates ('environmental/ecological tax reform'[20,21]), which may boost support from businesses[22], and supporting low-carbon technologies. Finally, raising more carbon revenue may be preferable to other ways of cutting budget deficits[22].

Free carbon thus plays a key role in balancing opposing political and economic interests, a role widely fulfilled in carbon trading by free permits. Yet the academic literature generally ignores carbon tax thresholds[1,22] or mentions them only in passing[4,10,15]. They remain legally and institutionally undeveloped, and policymakers have so far overlooked thresholds when considering carbon taxes.

Free carbon design issues

Free carbon is not a panacea that makes carbon pricing painless. Even with the overall costs of cutting emissions (the white triangles labelled in Fig. 1) minimized by pricing and revenues lowered by using thresholds, a carbon tax anywhere near US$50 per tCO_2e may be politically infeasible in many countries, precisely because it would trigger the economic shifts needed for large emission cuts.

Also, thresholds inevitably raise other, still contentious issues. Governments must choose the duration and economy-wide total of thresholds, and their allocation among emitters and other stakeholders. But these very issues have been dealt with for free permits, because of their basic symmetry with thresholds[12–14] (see section S1 of the Supplementary Information for details). The threshold or free permit total is particularly important, as every dollar given to industry is unavailable for beneficial recycling. There is, however, no universal rule for the maximum acceptable amount of carbon revenue, or politically necessary level of free carbon: it depends on the economic and political context, and can decrease over time. For example, most carbon trading schemes initially give the majority of permits for free, but the EU scheme has moved from initially 95–90% free allocations[23] to about 60% now[24]. The Australian scheme initially gave about 50% free permits, but has provisions to reduce free carbon over time[19].

However, as tax thresholds have been neglected by policymakers, design issues peculiar to thresholds but irrelevant to free permits remain barely explored. One such issue is that for thresholds not to dilute any control incentives, they would need to take the form of tradable property rights, as illustrated in Fig. 2. However, it may be simpler legally and administratively, if less cost-effective, to instead create thresholds as non-tradable entitlements similar to personal income-tax thresholds. A second problem, pivotal in the failure to introduce a European carbon-energy tax[23] in the 1990s, is which jurisdictional levels have the power to tax. Both of these legal issues could be avoided by using a tax-like trading mechanism, such as permits with a fixed price as in Australia[19], or trading subject to a price ceiling and floor close enough to form a tight price 'collar'[25,26].

Evidence from carbon pricing so far

In the current Australian carbon pricing scheme, which the newly elected Conservative government intends to repeal, permits have a government-determined 'fixed' price starting at AU$23 per tCO_2e during the initial phase, effectively making a formal trading scheme a tax. Following lobbying pressure, about half of the potential revenue is initially not raised from emitters, by giving them free permits or cash.[19] This sets an important precedent for how a threshold-like arrangement can help to win acceptance for a carbon tax-like scheme. Significantly different is South Africa's plan for partial exemptions from its carbon tax for some industries, with exemptions linked to controlled emissions, which would reduce the effective tax rate by up to 90%[27]. By contrast, our carbon tax thresholds would leave the tax rate on each extra tonne of emissions undiminished.

Free carbon has been much used where it is institutionally accepted, namely in trading schemes. Of eleven such schemes enacted in eight countries, ten allocate high proportions, often over 90%, of free permits[28]. The exception — the US Regional Greenhouse Gas Initiative — until 2013 had an emissions target so unambitious that its price never exceeded US$3.5 per tCO_2e (ref. 29). Pilot carbon trading schemes in China are planning to allocate the large majority of permits for free[30].

By contrast, none of eleven tax schemes, mostly in Northern Europe, gives any partial exemptions (that is, thresholds) to emitters[31]. Instead, many industrial sectors face much lower tax rates or get total exemptions, thus undermining the schemes' overall performance.

The importance of free carbon is also shown by the history of carbon pricing proposals. Free permits were important in the EU decision to adopt carbon trading rather than a tax[23]. In 2005, the New Zealand government planned a carbon tax with no thresholds, many sectoral exemptions and all revenue recycled as lower existing taxes. A review scrapped the plan, with the unfairness and inefficiency of its exemptions given as the key reason[32], and New Zealand now has a carbon trading scheme with ample free permits[33]. Lobbying by carbon-intensive companies secured steep rises in free carbon during the early development of the Australian carbon pricing scheme in 2008–2009[34]. The US administration's 2009 proposal to auction all permits in a trading scheme contrasted sharply with the 85% and 88% free permits recommended by subsequent Congressional bills[35].

Last but perhaps most important, the highest net carbon pricing revenues achieved in practice are small fractions of either GDP or central government's revenue from all taxation, and are far below what an ambitious, 'high' price would yield if charged on all emissions. The highest carbon tax revenue raised so far, in the Netherlands, has been about 0.9% of GDP or 4% of central tax revenue; whereas in the EU as a whole, carbon trading revenue would now be roughly 0.1% of GDP or 0.5% of central tax revenue under typical 2008–2012 prices, or much less under the prices prevailing in 2013. Yet a global price of US\$50per tCO_2e would initially, if charged on all current CO_2 emissions with no decrease in emissions assumed, raise revenue worth about 2% of GDP or 12% of central tax revenue in the USA, and about 8% of GDP or 75% of central tax revenue in China (Supplementary Tables S1 and S2, with selected results illustrated in Fig. 3).

Increased perception of the urgent need to control global warming[5] combined with budgetary deficits[22] may gradually make using carbon pricing to raise revenue more acceptable, but reaching anywhere near such revenue levels seems politically implausible in the medium term. We conclude that for a carbon tax, or tax-like mechanism, to reach its full potential, its proponents need to consider including carefully designed thresholds to balance conflicting economic and political pressures on revenues. The need will be particularly acute in newly industrializing countries with high carbon intensity, including China, if they wish to introduce a 'high' carbon tax. Developing the tax threshold concept, and dropping the needless presumption that all emissions from each included source must be taxed, are thus urgent tasks for climate policymakers. ❐

John C. V. Pezzey[1] and Frank Jotzo[2,3] are at [1]Fenner School of Environment and Society, Australian National University, Canberra, Australian Capital Territory 0200, Australia, [2]Crawford School of Public Policy, Australian National University, Canberra, Australian Capital Territory 0200, Australia, [3]Centre for European Economic Research, Mannheim 68161, Germany.*
**e-mail: jack.pezzey@anu.edu.au*

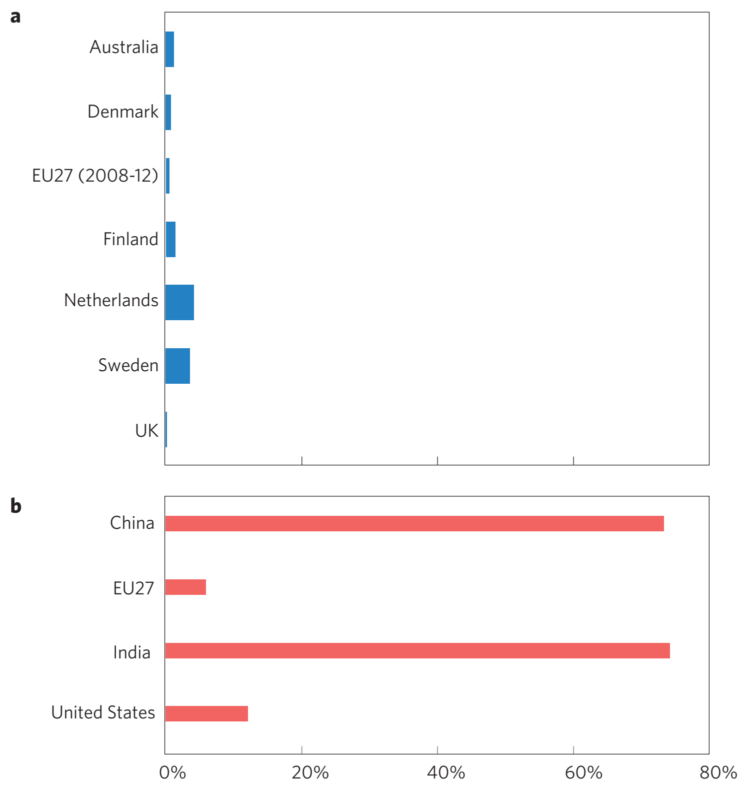

Figure 3 | Past and potential future carbon price revenues, as shares of central government tax revenue. **a**, Carbon pricing revenue as a share of central tax revenue over various time periods from 2003 onwards. **b**, Hypothetical revenue from a US\$50 per tCO_2e carbon price charged on all emissions, plotted as a proportion of central tax revenue. Data from Supplementary section S2.

References

1. Victor, D. G. *Global Warming Gridlock* (Cambridge Univ. Press, 2011).
2. *12th Five-Year Plan (2011–15)* (National People's Congress, 2010).
3. Burtraw, D. & Woerman, M. *US Status on Climate Change Mitigation* Discussion Paper 12–48 (Resources for the Future, 2012).
4. Aldy, J. E., Krupnick, A. J., Newell, R. G., Parry, I. W. H. & Pizer, W. A. *J. Econ. Lit.* **48,** 903–934 (2010).
5. Rogelj, J., McCollum, D. L., Reisinger, A., Meinshausen, M. & Riahi, K. *Nature* **493,** 79–83 (2013).
6. Goulder, L. H. & Stavins, R. N. *Am. Econ. Rev.* **101,** 253–257 (2011).
7. Svendsen, G., Daugbjerg, C., Hjøllund, L. & Pedersen A. *Energy Policy* **29,** 489–497 (2001).
8. Goulder, L. H. & Parry, I. W. H. *Rev. Environ. Econ. Policy* **2,** 152–174 (2008).
9. Baranzini, A. & Carattini, S. in *Global Environmental Change* (ed. Freedman, B.) (Springer, 2013).
10. Metcalf, G. E. *Rev. Environ. Econ. Policy* **3,** 63–83 (2009).
11. Olson, M. *The Logic of Collective Action* (Harvard Univ. Press, 1971).
12. Pezzey, J. *Can. J. Econ.* **25,** 983–991 (1992).
13. Farrow, S. *Econ. Lett.* **49,** 217–220 (1995).
14. Pezzey, J. C. V. *Environ. Resour. Econ.* **26,** 329–342 (2003).
15. Stavins, R. N. *Harvard Environ. Law Rev.* **32,** 293–371 (2008).
16. Goulder, L. H., Hafstead, M. A. C. & Dworsky, M. S. *J. Environ. Econ. Manage.* **60,** 161–181 (2010).
17. Grainger, C. A. & Kolstad, C. D. *Environ. Resour. Econ.* **46,** 359–376 (2010).
18. Gale, W. G., Brown, S. & Fernando, S. *Carbon Taxes as Part of the Fiscal Solution* (Brookings Institution, 2013).
19. Jotzo, F. *Nature Clim. Change* **2,** 475–476 (2012).
20. Pearce, D. W. *Econ. J.* **101,** 938–948 (1991).
21. Baranzini, A., Goldemberg, J. & Speck, S. *Ecol. Econ.* **32,** 395–412 (2000).
22. Aldy, J. E. *Oxford Energy Forum* **91,** 13–16 (2013).
23. Convery, F. J. *Environ. Resour. Econ.* **43,** 391–412 (2009).
24. *The EU Emissions Trading System (EU ETS)* (EU, 2013).
25. McKibbin, W., Morris, A. & Wilcoxen, P. in *Climate Change Policy: Recommendations to Reach Consensus* 26–34 (Brookings Institution, 2009).
26. Fell, H. & Morgenstern, R. D. *Environ. Resour. Econ.* **47,** 275–297 (2010).
27. *Updated Carbon Tax Policy Paper* (South African National Treasury, 2013); http://go.nature.com/9MCByu
28. Passey, R., Bailey, I., Twomey, P. & MacGill, I. *Energy Policy* **48,** 551–561 (2012).
29. Auction Results: Allowances Offered and Sold (Regional Greenhouse Gas Initiative, 2013); http://www.rggi.org/market/co2_auctions/results
30. Lo, A. Y. *Nature Clim. Change*, **2,** 765–766 (2012).
31. Sumner, J., Bird, L. & Dobos, H. *Clim. Policy* **11,** 922–943 (2011).
32. *Climate Change — Review of Policy and Next Steps* (New Zealand Climate Change Office, 2005); http://go.nature.com/9lVDLi
33. Jiang, N., Sharp, B. & Shen, M. *New Zeal. Econ. Papers* **43,** 69–79 (2009).
34. Pezzey, J. C. V., Mazouz, S. & Jotzo, F. *Aust. J. Agr. Resour. Econ.* **54,** 185–202 (2010).
35. *Comparison of the American Power Act (Kerry-Lieberman) and the American Clean Energy and Security Act (Waxman-Markey)* (Pew Center, 2010).

Acknowledgements

We thank F. Convery, M. Grubb, S. Hatfield-Dodds, A. Morris, T. Sterner and D. Victor for helpful comments, and C. Hilliker for technical assistance with the figures.

Additional information

Supplementary Information is available in the online version of the paper.

nature climate change

SUPPLEMENTARY INFORMATION
DOI: 10.1038/NCLIMATE 2054

Carbon tax needs thresholds to reach its full potential

John C. V. Pezzey[1] and Frank Jotzo[2]

1. Fenner School of Environment and Society, Australian National University, Canberra, ACT 0200, Australia (jack.pezzey@anu.edu.au).

2. Crawford School of Public Policy, Australian National University, Canberra, ACT 0200, Australia.

S1: Free carbon design issues that apply symmetrically to a tax and to trading

Many issues about designing free carbon – that is, emission thresholds that offset the amount charged under a carbon tax, or freely allocated emissions permits (also known as allowances) under emissions trading – apply equally to tax thresholds and free tradable permits, because of their underlying symmetry[1,2]. To clarify this, note that the main paper's formula for total government revenue from a carbon pricing scheme is the sum of similar formulae for the revenue from each single emitter (i):

Revenue(i) [\$/year] = Price of carbon [\$/tCO_2-e] × [Controlled carbon(i) – Free carbon(i)] [tCO_2-e/year]

For maximum environmental and cost effectiveness of the carbon price, free carbon must be designed so the full price is still paid for any extra tonne of carbon emitted, which requires two design features.

Firstly, free carbon, for each emitter and for the total scheme, must be a fixed level in tCO_2-e/year, derived from historic emissions or by some other means, but in any event independent of ‘controlled carbon’ (our term for the carbon emissions level that occurs after control measures are taken by emitters in response to the carbon price). This independence happens with the typical ‘grandfathered’ allocations of free permits used in many trading schemes, and with the negotiated fixed levels of free permits under Australia’s fixed-price scheme[3].

The second design feature is that for maximum threshold-permit symmetry, the revenue formula above should apply even when an emitting company's controlled carbon falls below its free carbon, meaning the company then gets money from, rather than pays money to, the government's carbon pricing scheme. For the whole scheme, though, the free carbon total must be chosen low enough to be always below the controlled carbon total, if the government's total revenue is to stay positive. This happens automatically with carbon trading, because controlled carbon equals total permits which free permits can never exceed; but it may not happen with carbon tax thresholds, if the government sets the carbon tax rate too high in relation to total free carbon. That is one way in which tax thresholds design must differ from free permits design. The main paper lists two potential legal differences, and the Weitzman-based literature on tax versus trading gives many others[4,5].

However, our stress here is that many of the most contentious free carbon design issues do apply symmetrically to tax thresholds and free permits, including the following.

(a) As with free permits[6], the government must choose the duration and total level of tax thresholds to balance competing political and economic interests. A longer duration gives a longer-term, hence more useful price signal to emitters, but leaves the government less flexibility in managing its revenues. The key issues about the total level of thresholds or free permits are addressed in the main paper.

(b) As with free permits, there are several good reasons for making thresholds temporary and transparently allocated. These are because the main role of free carbon should be to ease the political transition to a carbon price; because raising revenue for environmental tax reform improves welfare[7]; because large and/or permanent tax thresholds would encourage more wasteful lobbying[8]; and because as noted in the main paper, quite small free carbon shares will typically suffice to preserve industry profits.

(c) As with free permits, allowing tax thresholds to be tradable property rights means they do not prevent economically efficient closure of carbon-intensive companies. Suppose emitting company *i* owns its Free carbon(*i*) as a property right, and then closes down so Controlled carbon(*i*) becomes zero. According to the revenue formula above, the company gets paid [Price × Free carbon(*i*)] by selling Free carbon(*i*) at the market price. (If tax thresholds are property rights, they will be tradable on private markets, just like tradable permits.) Closing down thus reduces company *i*'s net carbon payment by [Price × Controlled carbon(*i*)]. Assuming no ‘carbon leakage’ as described next in (d), and that the price equals environmental damage per tonne of emissions, this reduced payment is the economically efficient long-run incentive to close down that the company should face (or that a new company should pay in order to enter the industry)[9].

(d) Wherever emitting companies compete internationally, any reduction in their output and emission levels may be partly or fully offset by expansion of companies in countries with no carbon price. Special measures are then needed to avoid this inefficient ‘carbon leakage’[10,11]. As with free permits, these measures can include allocating tax thresholds not as a property right, but on condition of continued output of products, or in proportion to output, in both cases provided emission-relevant output can be adequately measured. A carbon tax with thresholds allocated in proportion to output would be somewhat similar to the concept of ‘refunded emission payments’[12]. The exact anti-leakage provisions may differ between free permits and tax thresholds, in part depending on the institutional and legal context.

(e) Including thresholds in a carbon tax makes no difference in principle to the practicalities of choosing whether the point of regulation, for either tax or trading scheme, should be "upstream", at minemouths or wellheads where fuels enter the economy, or "downstream", where fuels are combusted[13].

So although tax thresholds raise many contentious political, economic and administrative issues, the biggest ones are no different from those already faced and resolved in a workable way with free permits.

S2: Calculations of carbon pricing revenues relative to GDP and central tax revenue

Background

Here we calculate past revenues for existing carbon (emissions) taxation or (carbon) emissions trading schemes – together called carbon-pricing schemes – and compare them to short-run revenues for potential schemes charging a carbon price of \$50/tCO_2 on all current CO_2 emissions in six large countries. (Basing our calculations on all greenhouse gas emissions, which are higher but less reliably measured, would merely strengthen the qualitative conclusions to be drawn.) In Tables S1 and S2, respectively, we compute actual past and potential future revenues relative to GDP and to central tax revenue.

The tax revenue data we use for countries[14] (also used by Tol[15]) and for Canadian provinces[16] include only 'central' revenue, and thus omit the revenues of lower tiers of government. These non-central taxes can be sizeable, so including them would markedly reduce some of the percentage shares of carbon pricing revenue in tax revenue that are shown in our Tables, but this also would not alter the qualitative conclusions.

As noted by Tol[15], multiplying current carbon emissions by any high (for example, \$50/tCO_2) carbon price, as we do in Table S2, ignores the desired fall in emissions that would happen over time in response to that price, and so computes only a hypothetical short-run revenue level. However, carbon price levels are generally expected to rise over time, which would offset falling emissions levels.

Past revenue raised by carbon pricing schemes

Table S1 shows revenue from enacted carbon pricing schemes as percentages of GDP and of central tax revenue.

The carbon-pricing revenue data in column (1) were derived as follows:

– we took carbon tax revenues for Denmark, Finland, Netherlands, Quebec, Sweden and UK from Table 2 in Sumner *et al.*[17], which are for the years shown;

– for the first, fixed-price year (2012-13) of Australia's carbon trading scheme, we used government data for net receipts[18];

– for British Columbia, we used carbon tax revenue for 2011-12 from p.935 of Sumner *et al.*[17], since this was much higher than in 2008 and so better represents a maximum political willingness to be taxed;

– for the European Union's carbon Emissions Trading Scheme (EU ETS), we used European Commission data[19] on the emissions now covered by the EU ETS and the proportion of emissions expected to be auctioned in 2013, the first year of the EU ETS's third phase. For permit prices, we used a typical price of €15/tCO_2 for 2008-12 and of €4/tCO_2 for the first half of 2013[20] to compute total government trading revenue as in Table S1a.

We took the GDP data in column (2) of Table S1 from the World Bank[21] for countries, including all those in the EU-27 (the current European Union of 27 countries); and from Statistics Canada[22] for Canadian provinces, using 1 C$ = 0.955 US$.

We took the central government tax revenues in column (3), as percentages of GDP, from the World Bank[14] for countries, including all those in the EU-27. For British Columbia and Quebec, we took GDP and central government tax revenue in C$ respectively from Statistics Canada[22,16], and computed tax shares in GDP as shown in Table S1b.

The last two columns of Table S1 then calculate carbon pricing revenue as percentages of GDP and of central tax revenue, as shown.

Potential revenue from a $50/tCO₂ carbon price on all emissions

For Brazil, China, the EU-27, India, South Africa and the United States in 2009, Table S2 shows CO_2 emissions from fossil fuels and cement in column (1); GDP in column (2); and central tax revenues as percentages of GDP in column (3), respectively taken from the World Bank[23,21,14], except for the United States' tax revenue. Because the World Bank's central tax revenue number excludes social security contributions, it is misleadingly low for the United States; so our US number here includes these contributions, using OECD data for 2010.[24,25]

The last two columns of Table S2 then calculate potential short-run revenue from a \$50/tCO_2 carbon price levied on all emissions, with no thresholds and not taking into account any fall in emissions in response to the price, as percentages of GDP and of central tax revenue.

References

1. Pezzey, J. "The symmetry between controlling pollution by price and controlling it by quantity," *Canad. J. Econ.* **25**, 983-991 (1992).
2. Farrow, S. "The dual political economy of taxes and tradable permits," *Econ. Lett.* **49**, 217-220 (1995).
3. Jotzo, F. "Australia's carbon price," *Nature Clim. Change* **2**, 475-476 (2012).
4. Weitzman, M. L. "Prices vs. quantities," *Rev. Econ. Stud.* **41**, 477-492 (1974).
5. Pezzey, J. C. V., Jotzo, F. "Tax-versus-trading and efficient revenue recycling as issues for greenhouse gas abatement," *J. Environ. Econ. Manag.* **64**, 230-236 (2012).
6. Stavins, R. N. "A meaningful U.S. cap-and-trade system to address climate change," *Harvard Environ. Law Rev.* **32**, 293-371 (2008).
7. Goulder, L. H. & Parry, I. W. H. "Instrument choice in environmental policy," *Rev. Environ. Econ. Policy* **2**, 152-174 (2008).
8. Nordhaus, W. D. "To tax or not to tax: alternative approaches to slowing global warming," *Rev. Environ. Econ. Policy* **1**, 26-44 (2007).
9. Pezzey, J. C. V. "Emission taxes and tradable permits: a comparison of views on long run efficiency." *Environ. Resource Econ.* **26**, 329-342 (2003).
10. Felder, S. & Rutherford, T. F. "Unilateral CO_2 reductions and carbon leakage: The consequences of international trade in oil and basic materials," *J. Environ. Econ. Manag.* **25**, 162-176 (1993).

11. Böhringer, C., Carbone, J. C. & Rutherford, T. F. "Unilateral climate policy design: Efficiency and equity implications of alternative instruments to reduce carbon leakage," *Energy Econ.* **34**, S208-S217 (2012).
12. Sterner, T. & Isaksson, L. H. "Refunded emission payments theory, distribution of costs, and Swedish experience of NO_x abatement," *Ecol. Econ.* **57**, 93-106 (2006).
13. Aldy, J. E., Krupnick, A. J., Newell, R. G., Parry, I. W. H. & Pizer, W. A. "Designing climate mitigation policy," *J. Econ. Lit.* **48**, 903-934 (2010).
14. World Bank, *World Development Indicators,* http://data.worldbank.org/indicator/ GC.TAX.TOTL.GD.ZS/countries (accessed March 2013).
15. Tol, R. S. J. "Leviathan carbon taxes in the short run," *Climatic Change* **114**, 409 (2012).
16. Statistics Canada, *Consolidated government revenue and expenditures,* http://www.statcan.gc.ca/ tables-tableaux/sum-som/l01/cst01/govt56b-eng.htm (accessed March 2013).
17. Sumner, J., Bird, L. & Dobos, H. "Carbon taxes: A review of experience and policy design considerations," *Clim. Policy* **11**, 922 (2011).
18. Australian Treasury, *Budget 2012-13: Australian Government Budget Outcome,* Table 3, http://www.budget.gov.au/2012-13/content/fbo/html/part_1.htm (accessed October 2013).
19. European Commission, *Climate Action / Allowances and caps,* http://ec.europa.eu/clima/ policies/ets/cap/index_en.htm (accessed January 2013).
20. Point Carbon, www.pointcarbon.com (accessed April 2013).
21. World Bank, *World Development Indicators,* http://data.worldbank.org/indicator/ NY.GDP.MKTP.CD (accessed March 2013).
22. Statistics Canada, *Gross Domestic Product*, http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/ cst01/econ15-eng.htm (accessed March 2013).
23. World Bank, *World Development Indicators,* http://data.worldbank.org/indicator/EN.ATM.CO2E.KT /countries (accessed March 2013).
24. OECD, *Taxes by level of government, Table E*, http://www.oecd.org/ctp/tax-policy/revenuestatisticstaxesbylevelofgovernment.htm (accessed October 2013).
25. OECD, *Revenue Statistics – Comparative tables*, http://stats.oecd.org/Index.aspx?QueryId=21699 (accessed October 2013).

Table S1. Revenue for existing carbon-pricing (C-price) schemes, as percentages of GDP, and of central tax revenue.

Country or province	*(1) C-price revenue, US$bn/yr*	*Year of C-price revenue data*	*Year of GDP / tax revenue data*	*(2) GDP, US$bn/yr*	*(3) Central tax revenue, as % of GDP*	*(1) / (2) = C-price revenue as % of GDP*	*(1) / [(2)x(3)] = C-price revenue as % of central tax revenue*
Australia	3.73	2012-13	2012	1521	20.5%	0.25%	1.20%
British Columbia	0.91	2011-12	2011 / 09	208	18.0%	0.44%	2.44%
Denmark	0.91	2008	2008	344	34.8%	0.26%	0.76%
EU27 (old price)	15.60	2008-12	2009	16359	18.7%	0.10%	0.51%
(recent price)	4.16	2013	2009	16359	18.7%	0.03%	0.14%
Finland	0.75	2007	2007	246	21.7%	0.30%	1.40%
Netherlands	4.82	2003	2003	538	21.6%	0.90%	4.14%
Quebec	0.19	2008	2008 / 09	300	22.7%	0.06%	0.28%
Sweden	3.67	2007	2007	463	22.4%	0.79%	3.54%
UK	1.19	2006-07	2006	2453	27.9%	0.05%	0.17%

Table S1a. Carbon-pricing revenue for EU ETS, estimated for 2013.

Variable	*Values*		*Units*
Emissions covered by EU ETS	2	2	GtCO2
Proportion of emissions auctioned	40%	40%	
Typical 2008-12 and early 2013 emission prices	15	4	€/tCO2
→ Government trading revenue	12.00	3.20	€bn
×1.3 US$/€ =	15.6	4.16	US$ bn

Table S1b. Central tax revenue for British Columbia and Quebec in 2009.

Province	*GDP, C$M*	*Tax revenue, C$M*	*Tax revenue as % of GDP*
British Columbia	195,670	35,151	18.0%
Quebec	316,276	71,770	22.7%

Table S2. Potential short-term revenues from $50/tCO2 carbon price, not allowing for response of emissions to price. Data are for 2009, except as noted in text.

Country	*(1) CO2 emissions from fossil fuels and cement (MtCO2)*	*(2) GDP (USbn$)*	*(3) Central tax revenue (% of GDP)*	*(1) x .05 / (2) = revenue from $50/tCO2 price on all emissions, as % of GDP*	*(1) x .05 / [(2)x(3)] = revenue from $50/tCO2 price on all emissions, as % of central tax revenue*
Brazil	367	1,622	15.4%	1.1%	7.4%
China	7,687	4,991	10.5%	7.7%	73.3%
EU-27	3,618	16,359	18.7%	1.1%	5.9%
India	1,979	1,361	9.8%	7.3%	74.2%
South Africa	499	283	25.5%	8.8%	34.6%
United States	5,300	13,898	15.7%	1.9%	12.1%