How to Limit Greenhouse Gas Emissions: Some Lessons from Public Economic Theory

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1. Widespread externalities

Economists use the term externality to describe any effect which one person s decisions have on other people, except those mediated by a price mechanism. This means that economists regard most forms of human interaction as constituting some kind of externality.

Some economists presume that institutions will arise to arrange efficient co-ordination of all activities that create externalities, through some kind of Coasean bargaining. There may be something to this in the case of really small groups, but not in general.

Widespread externality is a term introduced by Kaneko and Wooders (1986) to describe a particular kind of externality. It must be one that affects everybody or at least a very large group of people and results from activities by many, in such a way that no manageably small group can change the overall effect of the externality. This feature makes it effectively impossible to reach an efficient outcome through Coasean bargaining. A special case concerns mean widespread externalities, which are those where each individual is affected by the mean level of externality creation in the population as a whole. Greenhouse gas (GHG) emissions are a prime example.

A widespread externality is like a public good. In particular, the abatement of GHG emissions is effectively a public good. It is something which affects everybody, and benefits most people. It is also a good which we might prefer to see created by others at no cost to ourselves. That is, we would like other people, possibly in other countries, to do most of the abating.

2. Efficiency through Lindahl–Pigou Pricing

In the absence of externalities, suppose there are complete perfectly competitive markets for all commodities. Then, provided that individuals preferences are locally non-satiated (i.e., allow no local maximum for any ordinal utility function representing those preferences), one can apply the

two fundamental efficiency theorems of welfare economics due to Arrow (1951), restated in rather more generality in Hammond (1998). These two theorems tell us that:

(i) any Walrasian equilibrium with (or without) lump-sum transfers (WELT) is Pareto efficient;

(ii) provided individuals preferences are also convex and continuous, production possibility sets are convex, and all commodities are economically relevant , any non-oligarchic Pareto efficient allocation can be decentralized as a WELT.

The same results apply to economies with mean widespread externalities, provided one creates new markets for:

(i) the right to create each mean externality, whose price is effectively a Pigou tax on that externality;
(ii) each individual s personal right to experience less of each externality, whose price is effectively that individual s Lindahl price for that externality, equal to the marginal willingness to pay for a change.

Moreover, the Pigou tax is the same for all agents, and should be set equal to the mean Lindahl price in the population (as that is the marginal damage created by one extra unit of the externality per head of population). This is equivalent to the Samuelson condition for efficient public good supply that is familiar to most economists.

Trying to use such extended prices to reach a Lindahl—Pigou equilibrium, however, poses several insuperable difficulties:

(a) External diseconomies are always accompanied by fundamental non-convexities, as noticed by Starrett (1972) in particular. As economists generally understand, these non-convexities imply that any attempt to use a Lindahl pricing scheme is doomed to fail. At best, we can try to use some version of the MDP (Malinvaud/Dr ze/de la Vall e Poussin) iterative planning procedure that was developed in the early 1970s, or the kind of non-linear pricing scheme discussed in Hammond and Villar (1998).
(b) We face an intractable free-rider problem. If you did know your own marginal benefit from abatement, would you want to reveal it honestly?
(c) The effects of GHG emissions on climate, if any, remain unclear and controversial. So it is unreasonable to expect people to know their own marginal benefit from abatement, even if they were willing to report it honestly.

3. Constrained Pareto Efficiency

Because of these intractable public good problems, one is restricted to some kind of second-best, or constrained Pareto efficient allocation. Four different kinds of constrained Pareto efficiency with widespread externalities are defined and characterized in Hammond (1995). Two of those four characterizations seem worth mentioning here.

1. In the economy with a continuum of agents, an *f-constrained* Pareto efficient allocation allows no Pareto improving change for any finite coalition (Very roughly; more care over measure zero sets is needed.) Thus, no further Coasean bargains between finite groups can be used to produce Pareto improvements by altering the externalities.

In a *Nash—Walrasianequilibrium with lump-sum transfers* (or NWELT), each agent selects simultaneously:

(i) an optimal net trade subject to a budget constraint as in Walrasian equilibrium;
(ii) an optimal externality vector given the widespread externality (which each individual is powerless to affect) as in Nash equilibrium.

f-constrained Pareto efficient allocations are characterized as NWELTs in much the same way as ordinary Pareto efficient allocations are characterized as WELTs.

2. An *externality constrained* Pareto efficient allocation is one that is Pareto efficient subject to the constraint that arises when the total level of each widespread externality (or more precisely, the mean per head of world population) is fixed, for some reason.

Efficient allocations in this sense can be characterized as *Pigou—Walrasian*equilibria with lump-sum transfers (or PWELTs),. This means that there are perfectly competitive markets for ordinary commodities, supplemented by Pigou taxes on externality creation.

These Pigou taxes must equal the market-clearing prices for a fixed supply of permits to create the given levels of the widespread externalities. Markets for permits of this kind were advocated some time ago by Montgomery (1972) and by Bergstrom (1976); there have been many successors since.

In a PWELT, however, there are no Lindahl prices for the environment. So no attempt is made to solve the public good problem by reaching a (probably non-existent) Lindahl–Pigou equilibrium.

4. Potential gains from trade

Rights to create externalities should be made a scarce commodity, whose allocation can be determined by a price mechanism. But should it be determined in this way? In principle, given any world-wide allocation of externalities, combined with any resulting allocation of goods and services more generally, allowing externality permits to be freely traded generates a potential Pareto improvement. In particular, there is a potential Pareto improvement over the results of any command and control system, and also over any Nash—Walrasian equilibrium (NWELT) with no restrictions at all on externality creation. An implausible exception is the special case where nobody wants to trade permits because the *status quo* (or Nash—Walrasian) allocation of externalities is already externality-constrained Pareto efficient.

An *actual* Pareto improvement means that everybody benefits all consumers, workers, investors, without exception. In contrast, a *potential* Pareto improvement means that the government has other policies available (e.g., lump-sum compensation, taxes, etc.) to convert the

potential improvement into an actual one. This is just like the (potential) gains from free trade, where international transfers may be necessary, as well as transfers within each nation, if all governments of trading nations are to have the means needed to ensure that nobody loses from adverse shifts in the terms of trade.

To repeat, allowing free trade in permits allows only a *potential* improvement. Some industries (such as coal mining) may cease to be viable; those holding significant stakes in such industries (such as coal miners) need compensation. Usually, such compensation seems possible, once the need for it is understood and accepted. In this sense, free trade of permits can improve any alternative system of controls, etc. without such trade.

In the case of GHGs, there may not be an improvement compared to what would have happened in the absence of the Kyoto Protocol, because there is no plan to compensate those who would actually gain from the additional global warming that would have occurred without the protocol. Indeed, nothing in economic theory alone tells us whether we even need the protocol that is an empirical question that theory on its own can never settle.

For the potential gains to be realized, however, requires what one might call a credible liberalization. Not only are markets (in this case, for permits) liberalized, but the opposition of those who have every right to oppose must be headed off by arranging suitable compensation or other transitional arrangements. [Such compensation is further discussed in Hammond (1993).]

One significant new problem arises from trading permits: total externalities may worsen as a result of trade, if quotas that would otherwise go unused (e.g., in Russia or the Ukraine) are sold to others who will use them. [The general possibility of this perverse effect is discussed in Hammond (1998).]

5. Prices versus Quantities

The Kyoto Protocol fixes national targets for emission reductions during the period 2008—2012. It is therefore a quota or quantitative approach. A carbon tax may be simpler or actually better because it is effectively like requiring emission permits to be bought at a fixed price. Such a tax could be combined with rebates for some historical emissions, in order to replicate many features of an emissions trading scheme. It should be pointed out, however, that this is the kind of grandfathering criticized in Cramton and Kerr (1998). Later on, I will criticize some aspects of their work, especially in this connection.

Another possible form of control is the kind of hybrid system with a price cap, as advocated by Pizer (1997, 1998). The latter paper in particular reminds us of the debate in the 1970s that was initiated by Weitzman (1974) in particular over the relative merits of setting quantities (as the Kyoto Protocol envisages) or prices (as with an international carbon tax). See also Roberts and Spence (1976), Laffont (1977), Ireland (1977) and, for other recent discussion, Hoel (1997, 1998).

Determining the best instruments in a dynamic, probably chaotic environment, remains a challenging open problem.

6. From Theory toward Practice

In the case of GHG emissions, theory suggests:

(i) Like the Kyoto Protocol, some political process (which may as well be a black box to most economists) will determine emission targets, carbon taxes, or some subtle combination of the two. [Some economists evidently hope to be able to influence this political process with empirical analyses of the likely costs of reducing emissions, and the effects on national economies generally. Are they being too optimistic?]

(ii) Constrained by these rules, all other aspects of the economy are arranged as efficiently as possible i.e., one strives for an externality constrained Pareto efficient allocation of both goods and services in the usual sense, but also of emissions.

That is, we look for an allocation which is constrained Pareto efficient given the widespread externalities in this case, given the time-path of aggregate GHG emissions from signatory countries. This makes the right to emit GHGs a scarce commodity, just like any other, except that the total supply is determined artificially by the Kyoto Protocol instead of by the resource constraints we usually consider. This reduction of the problem allows us to think of a usual, orthodox world economy, without any widespread externalities, except that there is trade in permits to create these externalities.

7. Monitoring and enforcement

Obviously emissions or accurate indicators of emissions must be monitored to ensure compliance. Annex A of the Kyoto Protocol lists various source/sector categories. These seem to cover almost everything in a modern economy except the service sector and household use of heating fuels. (I am assuming that transport includes private cars, as it should.) This seems to require an awful lot of monitoring, suggesting the need for indicators as short cuts.

A lot of GHG emissions are of CO_2 from burning fuel. So instead of observing the emissions directly, concentrate on the output of fuels which will be burned. The monitoring task is reduced to measuring the outputs of fuel oil and petrol from refineries and of natural gas and coal which will be burned (unless there are leaks). Ideally one should also include any wood used for fuel, though this is likely to be hard. [Amongst others, Cramton and Kerr (1998) make a similar proposal.]

Fuel importers should be treated as producers, and required to obtain permits; exporters can be credited for transactions between signatories, but not for exports to non-signatory countries. In this way, permits will be needed for all fuel used in signatory countries, no matter where that fuel is produced. Only fuel that is both produced and consumed in non-signatory countries remains exempt. This will give many non-signatory countries a rather strong incentive to join the scheme, so that they can receive some permits to cover their fuel imports. Otherwise the companies that export fuel to non-signatory countries, for which no credit is given, will demand a higher price to cover the need to acquire permits.

If one insists on including agricultural emissions, it is hard to avoid monitoring each farm individually. Or can one focus instead on the suppliers of fertilizer? Forestry also poses severe

problems. But the serious monitoring problems posed by agriculture and by forestry seem to arise for any scheme that attempts to include them properly. It is not a special problem of the permit trading scheme being advocated here. And it may be more practical to concentrate on fuel output, as discussed here, at least initially. Agricultural emissions of methane (CH_4) a more potent greenhouse gas raise other challenging issues not discussed here.

8. Organizing the market

What, When, and Where to Trade?

Emissions permits can be traded like gold, or shares in oil companies, on several of the world s existing financial security markets. Trade should start as soon as possible, so those making long-term investments receive useful price signals. Derivative securities should be allowed and even encouraged, so fuel producers and users can hedge some of the risk they will face because of uncertain prices. If the USA eventually ratifies the Kyoto Protocol, there will be such markets within the USA anyway.

The subject of the trading will be permits, each granting at any time after the date of issue the right to produce fuel containing one metric ton, say, of combustible carbon. If burned properly, this fuel produces a fixed amount of CO_2; if burned improperly, it will produce less CO_2, but some dangerous CO (carbon monoxide), which ought to be prevented anyway.

Initial distribution of permits

A key difference between a market for permits and a market for agricultural products concerns the initial distribution of permits. It is usually obvious who owns a commodity, but not obvious who owns emission permits. Rules governing their distribution need to be specified before trading can begin, so as soon as possible. Separate rules within each nation are entirely possible, and probably inevitable.

- One possibility is allowing each national government to sell all its permit entitlement and keep the revenue. This is equivalent to a carbon tax at the market price. Cramton and Kerr (1998) advocate this approach. But they say nothing about how the revenue from auctioning permits needs to be distributed appropriately in order to compensate deserving losers.
- An alternative could be to allocate some permits to existing fuel producers, based on historic output figures. Cramton and Kerr (1998) describe this as grandfathering . They regard it as inferior for a number of reasons, including the commonly held belief that the additional revenue raised from selling all licences could be used to reduce existing distortionary taxes while maintaining tax revenue constant. This loses sight of the fact that such distortions are an inevitable feature of any feasible tax system for financing public goods, welfare programs, etc. In particular, distortionary taxes and subsidies, or else a subsidy to everybody financed by distortionary taxes, are the only way to redistribute real income. So reducing them may not be desirable, and is certainly not always the best use of any additional government revenue. The same problem bedevils many discussions of carbon taxation. That said, it may still be useful to think as if the government could sell all the permits, and then use the revenue generated to allow favourable general changes in tax, subsidy and expenditure programs, including

compensation for deserving losers. See Hammond (1990) for a general discussion of some all too common misunderstandings of such distortions.

An unhappy precedent for permit sales concerns the EU fish quotas. At least within the U.K., it seems that too many fleet owners sold out, often to foreign fleets, leaving their workers unemployed and inadequately compensated. To me, this strongly suggests there is the need to give some permits, or to earmark some share of sales revenue, to compensate those who would otherwise lose their jobs, or suffer because of higher fuel prices. No doubt different countries will choose different distribution systems, as is their prerogative.

Some permits could also be given away to developing countries that agree to join the scheme. They could even be counted as additional foreign aid additional, because one certainly does not want to see permit donations replace any part of the existing meagre foreign aid programs.

Finally, international equity suggests that permits should be allocated to countries, not on the basis of historic usage, as the Kyoto Protocol implicitly envisages, but in proportion to their population on, say, January 1st, 1990. In other words, there is no more reason to grandfather at the international level than at the national level.. It is all too easy to dismiss such redistributive schemes as politically infeasible, given the highly unequal distribution of political power in the modern world. Of course, such redistribution would do much to encourage developing countries to join the scheme; indeed, it is hard to see why third world countries, apart from those most vulnerable to rising sea levels due to global warming, would want to have anything to do with the Kyoto Protocol in the absence of some such redistribution.

9. The year 2013 and beyond

During the five-year period 2008—2012 covered by the Protocol, enterprises which produce fuels containing carbon should have their outputs monitored. At the end of 2012, these enterprises should be audited, and required to surrender permits which cover their fuel production activities during the relevant period. Defaulters should be treated like delinquent taxpayers. Minor violators can be required to buy extra permits at penalty rates. Serious violators can be faced with financial penalties so severe that shareholders will be strongly motivated to vote out the management. Any unused permits may be retained for future use.

Note that, in contrast to the schemes discussed by Kerr (1998) in particular, the enforcement rule proposed here places the onus of compliance on *all* producers of carbon containing fuel without exception, whether buyers or sellers of permits, or even if they trade no permits at all. Of course, there may be some rogue governments who fail to enforce permit requirements within their own borders perhaps in a deliberate attempt to assist domestic industry, or perhaps because public officials are bribed to turn a blind eye. To reduce problems arising from these, there should be international audit teams, possibly even provided by multinational private firms. Eventually, rogue governments may have to face international financial sanctions, reductions in permit quotas, etc.

At the beginning of the year 2013, in order to cover the first four years (2009—2012) of the following five-year audit period (2009—2013), 80% of the surrendered permits should be returned to their previous owners. This supply can then be supplemented by a new issue of 20% organized

by each signatory government, according to well-established rules it has chosen. Alternatively, if abatement is to be accelerated as the result of a new more stringent international agreement, the new issue will be less than 20%. This process is to repeated at the end of 2013 for the audit period 2009—2013, and so on. In this way, five-year averages continue to be monitored, thus allowing some flexibility to accommodate macroeconomic fluctuations, etc.

10. OPEC

Under the scheme proposed here, oil importers are required to have permits to produce fuel from imported oil, or to import fuel refined from crude oil. So much of OPEC s oil output is already covered, even in OPEC countries which do not join the list of signatories.

There will be an incentive, however, to export more refined products and less crude oil, so that the fuel that gets used in refining does not require permits. One possible way to reduce this perverse incentive is to require fuel importers to acquire permits not only for their fuel imports, but also for the fuel that can be presumed to have been burned during the refining process. Making these extra permit requirements sufficiently arduous will provide incentives for fuel importers to put pressure on OPEC countries to join, so that only the true amount of fuel used in oil refining within OPEC countries need permits, and not some deliberate over-estimate of fuel use. The same goes for all multinational oil companies operations outside signatory countries which result in exports to signatory countries.

11. Clean Development

Part of the Kyoto Protocol envisages a clean development mechanism, intended to give credit for investments undertaken before 2008 which can reduce CO_2 emissions for decades to come. For example, it can help promote investments in new more fuel-efficient electric power plants, and especially in alternatives to new but inefficient coal-burning plants in China and India which will have the added bonus of reducing the heavy pollution often found in those countries. Other carbon fuel-saving devices should also be covered.

Without permit trading, this credit would apparently go to the developed nations whose corporations undertake such investment. This leaves no benefit at all for the host developing countries. And assigning credit is complicated for investments undertaken by multinational corporations. With permit trading, on the other hand, the credit can take the form of permits which cover the estimated reduction in the consumption of carbon containing fuel. Some of these permits can go directly to the investing firms, with the remainder going to the host developing country.

Even before developing countries formally join the trading scheme, and so before they have their permit entitlements determined, they can still accumulate credits which will eventually be added to whatever entitlements emerge from the negotiating process.

12. Conclusions

Supplementing the Kyoto Protocol quotas by allowing unrestricted international trade of emission permits seems desirable, provided measures are taken to protect deserving losers whose livelihood may be at stake. This is a routine extension of the usual gains from trade arguments.

There is one obvious difference from the usual gains from trade arguments, however. Quotas which would otherwise have gone unused will be transferred to those most keen to use them the highest bidders in the market. This possibility appears to have been overlooked, though it may be the grain of truth which underlies the claim made by some Europeans that Russia and the Ukraine will be allowed to sell hot air if their national macroeconomies remain too depressed for their existing quota allowances to put any binding constraints on their emissions.

Offsetting this possibility of increasing GHG emissions is the prospect of speculative hoarding, especially if it is thought that permit prices will rise in response to a tightened supply of permits designed to decelerate further the rate at GHGs are emitted.

When determining future targets or supplies of permits to different countries, the market price gives some indication of the true marginal cost of abatement. So some feedback from price to quantity seems desirable. In particular, if the price of permits is low, this suggests that a more restrictive supply of permits can be afforded.

Monitoring fuel outputs is surely easier than monitoring emissions directly, and may have desirable side effects.

Giving national governments the right to dispose of their permit allowance as they see fit offers them significant power. One hopes it will be used wisely.

Appendix: Background Reading

For the latest work suggesting how small groups or clubs of agents may be able to achieve efficient allocations through some kind of Coasean bargaining:

Bryan Ellickson, Birgit Grodal, Suzanne Scotchmer and William Zame (1998) Clubs and the Market *Econometrica* (forthcoming).

For work on widespread externalities, their effects, their proper regulation, and some useful notions of constrained efficiency in their presence:

Mamoru Kaneko and Myrna Wooders (1986) The Core of a Game with a Continuum of Players and Finite Coalitions: The Model and Some Results, *Mathematical Social Sciences,* **12**: 105—137.

Peter Hammond (1995) Four Characterizations of Constrained Pareto Efficiency in Continuum Economies with Widespread Externalities, *Japanese Economic Review* **46**: 103—124.

For further and more technical details concerning the efficiency theorems of welfare economics, see:

Peter Hammond (1998) The Efficiency Theorems and Market Failure, in A.P. Kirman (ed.) *Elements of General Equilibrium Analysis* (Oxford: Basil Blackwell) ch.˚6, pp.˚211—260.

For an explanation of the fundamental non-convexities that arise whenever there are external diseconomies, and for a suggested approach to overcoming such non-convexities through some kind of non-linear pricing scheme:

David Starrett (1972) Fundamental Nonconvexities in the Theory of Externalities, *Journal of Economic Theory* **4**: 180—199.

Peter Hammond and Antonio Villar (1998) Efficiency with Non-Convexities: Extending the Scandinavian Consensus Approaches, *Scandinavian Journal of Economics* **100** (1998), 11—32.

For general discussions relevant to markets for emissions permits:

David Montgomery (1972) Markets in Licenses and Efficient Pollution Control Programs, *Journal of Economic Theory*, 5: 395—418.

Theodore Bergstrom (1976) Regulation of Externalities, *Journal of Public Economics*, 5: 131—138.

Michael Hoel (1997) How Should International Greenhouse Gas Agreements Be Designed? in P. Dasgupta, K .-G. M ler and A. Vercelli (eds.) *The Economics of Transnational Commons* (Oxford: Clarendon Press), ch. 8, pp. 172—191.

Peter Cramton and Suzi Kerr (1998) Tradable Carbon Permit Auctions: How and Why to Auction Not Grandfather, Resources for the Future, Discussion Paper 98-34.

For a general much less technical discussion of how to make market liberalization more credible:

Peter Hammond (1993), Credible Liberalization: Beyond the three theorems of neo-classical welfare economics, in D.B s (ed.), *Economics in a Changing World, Vol.˚3: Public Policy and Economic Organization* (IEA Conference Volume No.˚109) (London: Macmillan), ch. 3, pp. 21—39.

For a discussion of how allowing permit markets could add to total emissions:

Peter Hammond (1998), Rights, Free Exchange, and Widespread Externalities, in J.-F.˚Laslier, M.˚Fleurbaey, N.˚Gravel and A.˚Trannoy (eds.) *Freedom in Economics: New Perspectives in Normative Analysis* (London and New York: Routledge), ch.˚11, pp.˚139—157.

For some of my thoughts on distortionary taxes and some related matters:

Peter Hammond (1990), Theoretical Progress in Public Economics: A Provocative Assessment, *Oxford Economic Papers*, 42: 6—33; also in P.J.N. Sinclair and M.D.E. Slater (eds.) *Taxation, Private Information and Capital* (Oxford: Clarendon Press, 1991).

For alternatives to fixed a quota of emissions for the group of signatory countries as a whole (which is what Kyoto with international emissions trading will give us):

Martin Weitzman (1974) Prices vs. Quantities, *Review of Economic Studies*, 41: 477—491.

Marc Roberts and Michael Spence (1976) Effluent Charges and Licenses under Uncertainty, *Journal of Public Economics* , 5: 193—208.

Jean-Jacques Laffont (1977) More on Prices vs. Quantities, *Review of Economic Studies*, 44: 177—182.

Norman Ireland (1977) Ideal Prices vs. Prices vs. Quantities, *Review of Economic Studies*, 44: 183—186.

Partha Dasgupta, Peter Hammond and Eric Maskin (1980) On Imperfect Information and Optimal Pollution Control, *Review of Economic Studies*, 47: 857—860.

Michael Hoel (1997) How Should International Greenhouse Gas Agreements Be Designed? in P. Dasgupta, K .-G. M ler and A. Vercelli (eds.) *The Economics of Transnational Commons* (Oxford: Clarendon Press), ch. 8, pp. 172—191.

Michael Hoel (1998) Emissions Taxes versus Other Environmental Policies, *Scandinavian Journal of Economics*, 100: 79—104.

William Pizer (1997) Optimal Choice of Policy Instrument and Stringency under Uncertainty: The Case of Climate Change, Resources for the Future, Discussion Paper 97-17.

William Pizer (1998) Prices vs. Quantities Revisited: The Case of Climate Change, Resources for the Future, Discussion Paper 98-02.

For a more thorough discussion of some enforcement problems:

Suzi Kerr (1998) Enforcing Compliance: The Allocation of Liability in International GHG Emissions Trading and the Clean Development Mechanism, Resources for the Future, Climate Issue Brief #15.