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REGULATION BY PRICES, QUANTITIES, OR BOTH: A REVIEW OF INSTRUMENT CHOICE

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Choosing appropriate policy instruments is an important part of successful regulation. Once objectives are agreed and suitable targets adopted, policy-makers can employ command-and-control regulation and/or economic instruments, and choose between fixing a price or a quantity. This paper examines the relative advantages of price, quantity, and hybrid instruments according to: their efficiency under uncertainty; the trade-off between credible commitment and flexibility; implementation; international considerations; and political economy. Various illustrations of the theory are provided, with two detailed applications to climate change and transport policy, specifically congestion and 'safety pricing'.

I. INTRODUCTION

Regulation is not getting any easier. Demographic shifts are placing greater pressure on health services around the world, and intelligent regulation is urgently needed to achieve better patient outcomes at reduced cost (see Appleby and Harrison, 2006). The energy sector in many countries is now at a crossroads—the new regulatory framework must provide incentives for major private investment in energy infrastructure, to ensure security of supply and reduce greenhouse-gas emissions. Pressure on road and rail networks is ever increasing. And in Western countries, pensions policies are subject to important regulatory reviews.

The sheer scale of these challenges underlines the need for sophisticated regulatory responses. In the United Kingdom, government has reacted with a proliferation of targets. Some have successfully

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resulted in substantially improved public outcomes, but others have produced laughable results reminiscent of the Soviet regime. As a result, many in the private and public sectors have strengthened calls for a reduction in red tape. There are, indeed, reasons to suspect the amount of regulation is too high (Helm, 2006 (this issue)). Arguably an even more pressing concern is for regulatory targets and instruments to be designed to achieve social objectives at lowest cost. Yet many of the basic insights of economic theory which provide guidance on difficult questions of instrument choice—including theory on prices and quantities discussed in this paper—do not appear to have been absorbed by policy-makers, and certainly have not been consistently applied in public decision-making.

This paper reviews the literature on the choice between prices and quantities, including an update on recent developments. Although much of this literature is motivated by environmental problems, there are important lessons here which could be fruitfully applied to health, energy, transport, education, and other policy areas. It is true that some care is required in this 'intellectual technology transfer' process—much environmental economic theory focuses on regulation intended to internalize negative externalities, while the motivations for intervention in other sectors are very often to control market power or to internalize positive externalities. Perhaps more importantly, environmental regulations are often directed at largely self-interested firms for whom environmental protection is not their core business.[2] In contrast, regulation in health care and education must be conscious of, and take care to protect, more altruistic impulses. Generating the positive externalities of good health and a well-educated population is often an important motivation for people working in these sectors, and the policy approach must account for this.

These differences, however, do not prevent valuable insights from emerging. The lessons from environmental economics remain mostly theoretical, because we have yet to observe wide-ranging application of economic theory to environmental policy.[3] Nevertheless, there has been a gradual trend towards the use of market-based instruments for environmental policy, probably because efficiency considerations are increasingly important as environmental targets become more ambitious (Aidt and Dutta, 2004). Similarly, the demands placed on other public sectors are also increasing, such that efficiency concerns will only become more important as time passes. It would be a reasonable gamble to bet on the increasingly fruitful application of economic analysis in sectors such as health, education, and transport.

This paper intends to contribute to that process, and also suggests that practitioners in one field of regulation may benefit from study of the hard-won lessons in others. As such, section II provides a very brief outline of the regulatory process to provide context for the question of interest here, namely the choice of instrument to achieve a given target. Section III considers the broad choice between economic instruments and command-and-control regulation, and section IV reviews the basic concepts of price and quantity instruments, including their underlying duality. Section V provides a review of canonical economic theory on instrument choice, in addition to surveying some more recent results. The issues addressed are: efficiency under uncertainty (section V(i)), commitment, credibility, and flexibility (V(ii)), implementation (V(iii)), international issues (V(iv)) and political economy (V(v)). This is far from an exhaustive list—market structure is notable by omission[4]—but represents some of the more important considerations. Various illustrations of the theory are provided as the paper progresses, but section VI provides a focused application to climate policy, and section VII applies the theory to transport policy, examining congestion pricing and the notion of 'safety pricing', where road prices are a function of speed travelled. Section VIII concludes.

[2] This is not to suggest that there are not green organizations devoted to promoting the positive externalities of a healthy natural environment. Rather, it is to point out that polluting, rather than green, firms tend to be the subject of most environmental regulation.

[3] As Helm (2005) notes, it remains the exception, rather than the rule, that economic instruments are used in environmental policy, and even when they are, the result tends to reflect politics and vested interests.

[4] The industrial economics literature deals with the choice between price and quantity instruments in the regulation of natural monopolies (e.g. Chen, 1990; De Fraja and Iossa, 1998). There, price-cap regulation has been preferred to rate-of-return regulation. While regulation of monopoly and market power is extremely important, it is not the focus of this paper.

II. THE REGULATORY PROCESS: OBJECTIVES, TARGETS, AND INSTRUMENTS

This paper focuses upon the choice of policy *instrument* to achieve a particular *target*. The target has, with any luck, been carefully designed to meet a sensible overarching policy *objective*.[5] This paper does not address the question of appropriate policy objectives, nor the justification for government intervention.[6] Nor does it address the design of targets. These questions are clearly important—choosing the correct instrument is pointless if the target itself is ill-advised. For instance, suppose the accepted policy objective is to improve the performance of children at mathematics. A corresponding target might be expressed in terms of results achieved on mathematics exams. Given this target, instruments might then be proposed to provide schools with the incentive to achieve mathematics results targets—a price might be put on good maths performance, or schools might be required to ensure that performance never falls below some specified quantity, with specified penalties for failure. Now, while the objective of improved mathematics competency is laudable (and would probably pass cost–benefit analysis at current levels of mathematical literacy), many would question the wisdom of setting exam performance targets. Without close auditing, exam targets may simply generate incentives to mark students leniently.

Setting targets frequently leads to gaming and unintended outcomes,[7] and results are likely to be unsatisfactory when targets do not map closely with the desired objective. Furthermore, the imposition of explicit incentives can crowd out intrinsic incentives that are already present.[8] Many in the health and education sectors, for instance, are motivated by helping other people. Regulation forcing a response to explicit prices—such as the tax and trading schemes beloved by economists—may crowd out such motivation.[9] Softer policy interventions that account for, and address, cultural and institutional factors may be more appropriate.

As such, policy analysis requires assessing the merits of the stated objectives (which may differ from the actual objectives) as well as the merits of the targets, before the detailed question of the appropriate instrument can be properly examined.[10] So, under the (non-trivial) assumption that the objectives and targets have been sensibly defined, we proceed to examine the choice between economic instruments and traditional command-and-control, before comparing price and quantity instruments in section IV.

III. ECONOMIC VS COMMAND-AND-CONTROL INSTRUMENTS

Economic instruments provide an explicit price signal to regulated firms and individuals. They include price-based instruments (e.g. taxes and subsidies) and quantity-based instruments (e.g. cap-and-trade schemes) where the price signal emerges from the quantity restriction coupled with a trading scheme. A key feature of economic instruments is that they exploit the capability of markets to aggregate information.

Economic instruments are especially useful when: (i) the appropriate response varies between differ-

[5] The stylized sequence of policy-making implied here—define objectives, set targets, choose instruments—does not, of course, always reflect practice. It may be easier to start with a focused discussion on the concrete measures to be adopted, before attempting to agree abstract objectives, even though the former conceptually follows the latter.

[6] Regulation is often justified by redistributional goals or the 'correction' of market failures such as the presence of positive externalities, negative externalities, or market power. An interesting policy question is whether the particular type of market failure influences (or should influence) the type of instrument chosen.

[7] For instance, a UK target that patients should be able to see a medical General Practitioner (GP) within 2 days appears to have resulted in GPs refusing to accept appointments more than 2 days in advance (Bevan and Hood, 2006). See also Bird *et al*. (2005).

[8] On general questions of school autonomy in the Finnish and British cases, see Webb *et al*. (1998).

[9] See Frey and Jegen (2001). The early theoretical debate came to prominence with Titmuss (1971) and Arrow (1972).

[10] Put simply, the economic theorist often assumes that the overarching objective of policy should be to maximize social welfare. In practice, of course, policy is not made based upon a social welfare function, but rather on a broader political welfare function that includes social welfare, but also captures considerations such as staying in power, achieving a social or economic programme that reflects their particular interests, and acquiring the support of (or at least placating) vociferous lobby groups in order to achieve the previous two objectives.

ent regulated firms; and (ii) there are information problems so the regulator does not have the necessary knowledge about firm costs. In climate policy, for example, government has highly imperfect information about the costs of reducing greenhouse-gas emissions, and it is likely that some sectors can reduce emissions much more cheaply than others. Economic instruments are likely to be preferable under these circumstances.

In contrast, command-and-control regulation requires firms or individuals to comply with specific standards, such as technology or performance standards. Command-and-control regulation should be preferred when the regulator has good-quality information, when the risk of government failure is low, and when the desired objective is best achieved by imposing similar requirements upon different firms and individuals. For instance, if the optimal level of a certain pollutant is unequivocally zero, then the appropriate instrument is simply a ban—there is little point in constructing a sophisticated trading scheme or tax.

IV. PRICE VS QUANTITY INSTRUMENTS

(i) Overview: The Duality of Prices and Quantities

Economists are familiar with the simple but essential symmetry between prices and quantities. Using a quantity instrument, whether by command-and-control regulation or by creation of a market, always imposes a corresponding (implicit) price.[11] Under idealized conditions, if the regulated quantity is allocated and then licences are traded, the resulting licence price will equal the optimum price instrument (e.g. a tax). A more generous quantity of licences is equivalent to setting a lower tax, and vice versa. As such, under idealized conditions, there is a one-to-one correspondence between price and quantity instruments.

(ii) Quantities

The most common form of regulation in many policy settings is command-and-control regulation by quantities. This includes quotas, targets, or specific commands, such as a regulation banning an activity (which is a quantity regulation where the quantity is zero). Food standards specify maximum (or minimum) quantities of certain chemical compounds. The Civil Aviation Authority imposes minimum air safety standards. Many environmental regulations specify upper limits (quantities) on pollution levels in effluent. Speed limits are another form of quantity regulation. More complicated quantity instruments may be a function of other measurable variables to be realized in the future.[12]

Some forms of quantity regulation occur by default. For instance, when public services are free at the point of use—as in the case of most roads and much health care—demand will often exceed supply, with the result that services are rationed. This rationing may be quite deliberate. According to Mattke (2000), limits on the number of hospital beds per specialty in the German regions are designed to create capacity constraints which force physicians to apply resources to patients with the greatest need.[13]

For some policy issues, the appropriate quantity may vary greatly between different individuals and/or firms. However, the information required to determine the optimum allocation of quantities is often unavailable. Under such conditions, as noted above, a quantity constraint with a trading scheme is preferable. When individuals or firms can exchange licences with one another, the licences are more

[11] This is true whether or not the price is directly revealed by a market that facilitates trading of the quantities. If the price is not directly revealed, it is a 'shadow' price. In the absence of a market these shadow prices may differ between regulated subjects according to their costs of compliance.

[12] Helfand (1991) provides an analysis of the economics of different types of quantity instruments in the context of different pollution standards. There is also a literature on targets that are expressed as a function of other variables to be realized in the future: see Aldy and Frankel (2004), McKitrick (2005), and Sue Wing *et al*. (2006) on the topic of emissions intensity targets. But Weitzman (1974) noted presciently that a 'contingency message', as he called it, is a 'complicated, specialized contract which is expensive to draw up and hard to understand'.

[13] There is some evidence that rationing may improve resource allocation. For instance, Selker *et al*. (1987) found that reducing the number of coronary care units in New England reduced admittances to the units, but did not increase mortality. However, Cuyler and Meads (1992) report in the UK that implicit rationing also imposes costs by way of increased delay in treatment, and results in medical decisions based on the availability of resources rather than on clinical judgement.

likely to end up with those who value them most highly. Indeed, if there are large differences in valuations between individuals, and if licences are not legally tradable, then trade may occur on a black market.[14] Creating a legal scheme involves at least three elements: (i) an aggregate quantity is fixed; (ii) licences are allocated between individuals and firms; and (iii) a mechanism is established for enforcing compliance with the scheme.[15]

(iii) Prices

Price schemes can also operate to ensure the efficient allocation of activity between firms, and price instruments are indeed used to achieve some policy objectives. For instance, rather than set a total quantity of cigarettes that can be consumed in Britain in a given year, the government employs the more indirect approach of taxing tobacco, increasing the price of cigarette consumption, and reducing quantity consumed. Similarly, objectives in the labour market—such as the numbers of teachers, psychologists, nurses, etc.—are generally achieved by direct price adjustments. These days, when more soldiers are needed, military wages are increased, rather than citizens being compulsorily conscripted.

When conditions are uncertain—as they always are—price instruments do not guarantee that a particular quantity target will be achieved. Similarly, the use of a quantity instrument will not guarantee that a particular price target will be achieved.[16] However, as we will see, simply because a target is expressed as a price (quantity) does not mean that a price (quantity) instrument has to be employed to achieve it.

(iv) Hybrid Instruments

As Weitzman (1974) noted, there is ‘no good *a priori* reason for limiting attention to just [prices and quantities]’. There is a wide range of more complicated instruments, including a schedule of prices, or a ‘kinked’ function by way of a two-tiered price system. The only reason for the focus on pure price and quantity instruments is their simplicity, and for some policy problems, the benefits of simplicity may be outweighed by the costs of inefficiency.

A hybrid instrument—a tailored combination of price and quantity instruments—is a step up in complexity.[17] One important hybrid instrument is a trading scheme with a price ceiling or price floor. The government can implement a price ceiling by committing to sell licences at the ceiling price, and a price floor can be implemented by a commitment to buy licences at the floor price. As such, a hybrid instrument is neither a pure price nor a pure quantity instrument, but a mixture of both.

In any tradable-permit scheme, there will be a penalty for non-compliance. Often the penalty is proportional to the difference between actual performance and target (e.g. proportional to emissions in excess of an emissions target). Then, if payment of the penalty is an *alternative* to compliance, the penalty is effectively a price ceiling in a hybrid scheme (Jacoby and Ellerman, 2004). In contrast, if payment of the penalty does not amount to compliance—and the firm is still obliged to comply as soon as possible—then the scheme is not directly equivalent to a conventional hybrid scheme. For instance, although the European emissions-trading scheme (ETS) imposes penalties for non-compliance for Phase I and II of €40/tCO_2 and €100/tCO_2 respectively, excess emissions must also be offset in the following compliance period (European Commission, 2003). In contrast, the United Kingdom Renewables Obligation scheme is arguably a hybrid scheme, because firms can comply by simply paying the buy-out price.[18]

[14] See Kay (2004) for some (unattributed) estimates of the price of British taxi licences.

[15] For a review of compliance issues, see Heyes (1998).

[16] Often governments choose to set targets in terms of quantities rather than prices. Nevertheless, prices are sometimes the ultimate target. For instance, the objective of ‘affordable housing’ in the United Kingdom has been translated by the Deputy Prime Minister into a price target of £60,000 for a new home (DCLG, 2005).

[17] Hybrid instruments should be distinguished from the use of multiple instruments for the one problem (see section III(vi)). Hybrid instruments have recently generated a great deal of interest in the climate-change context, see, for example, Pizer (1997, 2002), Aldy *et al*. (2001), McKibbin and Wilcoxen (2002, 2004), and Jacoby and Ellerman (2004). The classic paper is Roberts and Spence (1976).

[18] This scheme is unusual for another reason: revenues from the price ceiling (the buy-out price) are recycled to those in compliance, thus creating the possibility that the market price could rise above the price ceiling.

(v) Multiple Instruments

Regulations are often directed at internalizing externalities, and the simple theory of externalities indicates that only one instrument is needed to internalize one externality. Nevertheless, policies often involve a plethora of different instruments, such as command-and-control regulation, subsidies, taxes, trading schemes, negotiated agreements, and information campaigns. In some instances, such as when there are multiple market failures, a 'package' of policy measures can make sense. However, in many instances, the use of multiple instruments to address a single problem almost certainly reflects an *ad hoc* policy-accretion process, driven by the multiplicity of national institutions (Helm, 2005). Multiple instruments may also reflect the temptation of politicians to 'fix everything'—both price and quantity—even when policy is generally best served by fixing one and letting the market determine the other. Multiple instruments are problematic when they are inconsistent with each other, and can result in perverse consequences if the interactions between different policies are not carefully considered.

V. INSTRUMENT COMPARISON

(i) Efficiency under Uncertainty

Under uncertainty, the duality of price and quantity instruments (see section III(i)) diverges.[19] In his classic paper, Weitzman (1974) demonstrated that when marginal costs of supplying a good—which could be health, education, transport, clean air, etc.—are uncertain, using a price instrument is more (less) efficient than a quantity instrument when the marginal benefits of that good are relatively flat (steep) compared with the marginal costs.[20] As a rough heuristic, this is because the instrument is intended to internalize the marginal benefit curve. A price instrument is horizontal (on the P–Q plane), so should be employed when the marginal benefit curve is relatively flat, while a quantity instrument is vertical and should be used when the marginal benefit curve is relatively steep. Figure 1 provides an illustration where the actual marginal costs of supplying the good are higher than originally expected. Here, the price instrument (tax, T), generates under-provision of the good ($Q_{tax} < Q^*$) leading to efficiency loss E_P, while the quantity instrument (trading scheme with cap Q_{trading}) leads to over-provision of the good ($Q_{\text{trading}} > Q^*$) with efficiency loss E_Q. As Figure 1 shows, the price instrument is preferable to the quantity instrument ($E_P < E_Q$) when the marginal benefit curve is relatively flat, and vice versa.

To illustrate, suppose the relevant good is the provision of prompt medical treatment. Suppose that more rapid medical treatment is costly, and that the marginal cost of more rapid treatment is uncertain, but is expected to increase quickly as delay is reduced (in the limit, the cost of instantaneous treatment is infinite). Suppose the marginal benefit of more rapid treatment is relatively constant—the medical condition is such that, without treatment, the patient's health will deteriorate gradually. In such circumstances, the Weitzman (1974) framework indicates that a price instrument is efficient—for this particular medical condition, the hospital should be paid a constant reward for each day of delay avoided (or have to pay a constant penalty for delay). In contrast, if the marginal benefit of rapid treatment falls very quickly (perhaps because after a threshold delay, d, the patient will die), then the hospital should face a quantity instrument of the form 'no patient shall face a delay of more than d days', with a strict penalty attached for failure.

Second, consider the case of climate change. Suppose the marginal cost of reducing emissions increases quickly as we move from eliminating the cheap, 'low hanging fruit' on to more difficult sources of emissions (e.g. aviation transport). Suppose also that, because damages from climate change are a function of the stock of greenhouse gases in the atmosphere, they are only a weak function of emissions over short periods (e.g. 5 years),[21] so that the marginal benefit from abate-

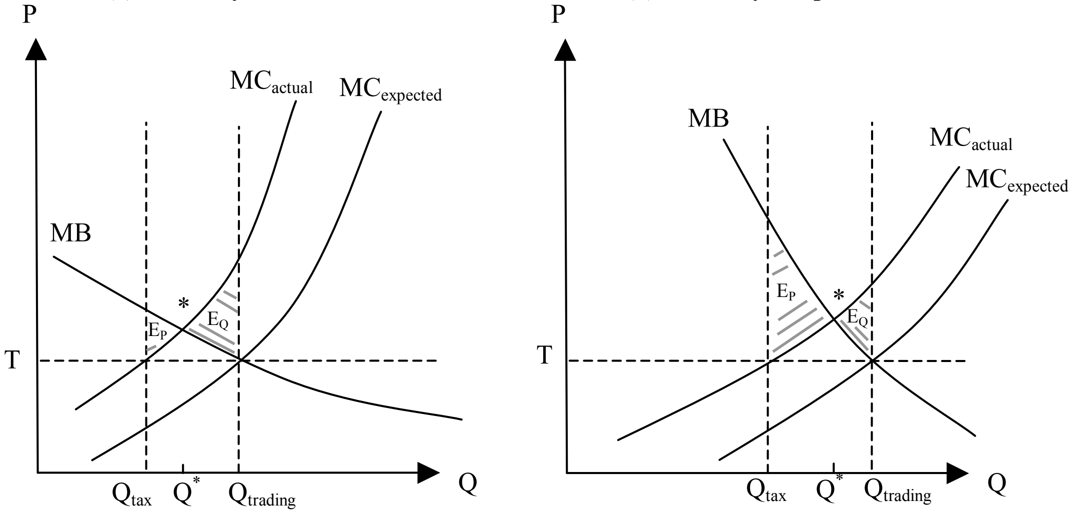
[19] Poole (1970) provides an early treatment of this divergence under uncertainty in the monetary policy context.

[20] Weitzman (1974) employs linear local approximations to the marginal cost and benefit functions. Most presentations follow Adar and Griffin (1976), who simply assume that the marginal cost and benefit functions are linear. See also Rose-Ackerman (1973), Fishelson (1976), and Roberts and Spence (1976).

[21] The assumption that the marginal damage curve is flat is less valid over longer timeframes. Hoel and Karp (2002) find that the preference for quotas increases as the relevant time horizon of policy is increased.

Figure 1
Simple Illustration of the Weitzman (1974) Result

(a) relatively flat MB curve **(b) relatively steep MB curve**



ment is relatively flat.[22] In such circumstances, a price instrument—a carbon tax—is the appropriate instrument to use (Hoel and Karp, 2001, 2002; Pizer, 2002). In contrast, if instead we are on the brink of a tipping point, such that emissions now do substantially less damage than emissions in 5 years' time, then an immediate restriction upon global emissions would be advisable.[23]

Note in both cases that it is not the *level* of the marginal cost curve that matters, but its *slope*.[24] It could be, for instance, that climate change is extremely dangerous in a manner that implies a high (but constant) marginal damage curve. A price instrument is still appropriate—the price should just be extremely high. [25]

Two further aspects of efficiency under uncertainty are relevant. First, Weitzman (1974) points out, and Stavins (1996) reminds us, that uncertainty in the marginal-benefit function is also relevant if it is correlated with marginal costs. Where the correlation is positive (negative), quantities (prices) are relatively more efficient. Second, Baldursson and von der Fehr (2004) show that if regulation is being imposed upon risk-averse firms, prices may be more efficient than tradable licences (*ceteris paribus*). This is because quantity regulation exposes firms to volatile licence prices, which is avoided by direct price regulation.[26] Risk aversion encourages a net buyer of licences to invest in technology that will reduce his or her need to buy licences. Conversely, risk aversion leads a net seller to under-invest in

[22] This is not to say that the damages from climate change are not high—they could be extremely high—only that they do not change rapidly as a function of additional emissions.

[23] Pizer (2002) finds that 'when damages rise from 1 per cent to 9 per cent as the mean global temperature rises from 3 to 4 degrees above historic levels, this is sufficient to encourage the use of quantity-based regulations over a 50-year policy horizon'.

[24] Weitzman (1974) examines the curvature of the cost and benefit functions, and employs local linear approximations to the marginal cost and benefit functions for simplicity. On the use of these approximations, see Malcomson (1978).

[25] The literature is not always clear here. For instance, McKibbin and Wilcoxen (2003) write that the 'trouble with a quantity-based approach like the Kyoto Protocol . . . is that it can be justified only under the most pessimistic assumptions about the dangers of climate change (a steep marginal benefit curve for abating emissions), or under the most optimistic assumptions about the cost of reducing emissions (a flat marginal cost curve)'. Pessimism about climate change certainly implies a high benefit-of-abatement curve—damages will be large—and possibly also a high marginal-benefit curve—damages will rise quickly as we emit more greenhouse gases, but pessimism does not necessarily imply a steep marginal-benefit curve.

[26] Of course, this depends upon the rule for tax adjustment—in practice, taxes are adjusted in budgets, which are an inherently political process, bringing its own uncertainties. Even if price regulation is credible, the flip side is that fixing prices creates quantity uncertainty.

such technology. The net effect is to reduce the trade in licences, and thereby reduce the efficiency of the instrument relative to price regulation.

In the case of climate change, price risk appears to reduce investment in long-term research and development into abatement technologies. Innovating firms already bear substantial technology development risk, and the addition of price risk reduces their incentive to innovate. This price risk might be decomposed into three components: (i) political risk; (ii) risk of (optimal) policy adjustments as a result of new climate science; and (iii) market risks, such as competitors producing superior abatement technology. The government should probably bear political risk, and it might even be in a better position to bear the climate science risk. Firms should probably bear the market risk. Given the public-goods nature of research and development, green innovations are probably already under-supplied. If the government shouldered all three risks by employing a price instrument, this might be viewed as an implicit (second-best) subsidy to internalize the external benefits of innovation.

(ii) Commitment, Credibility, and Flexibility

In many areas of public policy, uncertainties inevitably imply that policy will need to be adjusted over time in response to new technologies, new scientific information, and changed political realities. The discretion to adjust policy is therefore valuable. However, discretionary policy can also result in the following three problems.

(i) *The ratchet effect*. Discretionary policy results in an incentive for firms to distort decisions to influence future regulation, especially when firms have market power.[27]

(ii) *Credibility problems*. If policy needs to induce irreversible investment, a hold-up problem can arise: firms will not invest if the regulator has an incentive to adjust policy to achieve other objectives once their investment costs are sunk.[28]

(iii) *Inappropriate risk allocation*. Discretion imposes the risk on the private sector that policy will be adjusted (whether optimally or not). It may or may not be appropriate for the private sector to bear policy risk. If the risk is borne by the private sector, the required rate of return on investments reliant on a long-term revenue stream will be increased to reflect this.[29]

Obviously, credibly committing to future policy solves all three problems—the distortion in investment decisions by the ratchet effect, the hold-up problem, and it also reduces the required rate of return—but it also eliminates the flexibility to adjust policy as new information emerges. Determining the optimal trade-off between commitment and discretion involves balancing the benefits of flexibility with the three costs outlined above. We examine each of the costs in turn.

First, ratchet effects are most likely to occur when regulated firms can directly influence future targets. For instance, failing to comply with a target arguably signals to the regulator that compliance is costly, thereby lending support for the negotiation of a more lenient target in the following period. On the other hand, over-compliance signals that future targets should be tighter. These dynamic incentive problems are exacerbated by the use of grandfathered licences, if they create the incentive to underperform now to gain a higher licence allocation later.[30] In contrast, price instruments do not suffer from this problem.

Second, policy is often aimed at inducing irreversible investment. The most striking example is probably the need to stimulate low-carbon investment, but similar problems arise in utility regulation more generally, as well as in education and health. When the pay-off from irreversible investment depends upon future policy, and when the government faces different incentives *ex post* investment to those *ex ante*, the discretion to adjust policy creates a 'hold-up' problem. In the climate-change example, as Helm *et al*. (2003) argue, the regulator explicitly faces three competing objectives (energy prices,

[27] The basic ratchet effect is described by Freixas *et al*. (1985).

[28] See Kydland and Prescott (1977), Biglaiser *et al*. (1995), Kennedy and Laplante (1999), Karp and Zhang (2001), Moledina *et al*. (2003), Helm *et al*. (2004), Requate (2005), and Tarui and Polasky (2005*a*,*b*).

[29] See Helm *et al*. (2003) and Helm and Hepburn (2005).

[30] This problem does not arise if licences are grandfathered once and for all.

security of supply, and climate change), and may have an incentive to relax emission standards to achieve these other objectives once (irreversible) investment in low-carbon technology has occurred.

Third, for investments to be profitable often requires a revenue stream over a relatively long time horizon. As such, the benefits of flexibility must be balanced against the need to provide a fixed long-term policy regime (and price signal) to encourage investment. Under discretion, firms bear two risks that increase their required rate of return:[31]

- the optimal policy may change as new information emerges, or in response to innovations by other firms; and
- political reasons and changes in public preferences may prompt shifts in policy, which may be towards or away from the optimum.

It is not necessarily inefficient to impose these risks on firms and to increase the required rate of return. The risks must be allocated somewhere, so the question is where they are efficiently allocated. Efficiency probably requires the private sector to bear the risk of innovations by competitors. However, the government should probably bear policy risks arising from shifts in the political domain.

In sum, the time horizon of committed policy should be long enough to balance the costs and benefits discussed above. The time horizon must, however, be short enough to be credible, and a supposed 'commitment' which ignores the benefits of flexibility will not credible. In some policy areas, including climate policy, where the longest feasible commitment period may be too short to provide adequate incentives for long-term investment, the problem is finding a credible signal of future policy direction to firms. Credible signals are difficult to find, however, and by their very nature, they tend to be costly.

(iii) Implementation

Although there are differences in the implementation of price and quantity instruments, there is also a wide range of shared considerations. To start with, an examination of the costs and benefits of the policies is required to determine the appropriate tax rate or number of licences,[32] and a key insight is that 'generally speaking it is neither easier nor harder to name the right prices than the right quantities because in principle exactly the *same* information is needed to correctly specify either' (Weitzman, 1974). Both price and quantity instruments require more detailed regulation for their implementation. Both require careful attention to the incentives for compliance, including the specification of penalties for non-compliance and a monitoring and enforcement regime.[33] Just as a tradable licence scheme requires the careful definition of the property right, so too the formal incidence of a tax must be clearly specified.

That said, some quantity-based command-and-control regulation may be cheaper to implement and enforce than market-based instruments. For instance, although technology standards are (almost inevitably) less efficient than technology-neutral regulation, they have the countervailing advantage that enforcement is relatively straightforward. Rather than continuous measurement of firm performance, which can be costly, technology regulation can be enforced through simple spot checks that the appropriate equipment is installed.

Helm (2005) notes that the institutional burden of constructing a tradable-licence scheme can exceed that of a tax. In addition to the elements described above, a tradable-licence scheme requires a mechanism for the initial allocation of property rights, and a team to create and ensure the continuation of the market. Additional regulation is required to ensure that the market is competitive.

[31] It is common practice in the private sector to increase the discount rate to reflect risk. Strictly speaking, however, risk should be accounted for on the ledger, with the discount rate reflecting intertemporal considerations and the cost of capital.

[32] Although as Helm (2005) notes, it is remarkable that the use of cost–benefit analysis still appears to be the exception rather than the rule. See also Pearce (1998).

[33] Nordhaus (2005) argues that taxes have a compliance advantage over permits because 'tax cheating is a zero-sum game for the two parties [the treasury and the taxpayer], while emissions evasion is a positive sum game for the two parties [the buyer and seller]'. However, permits must eventually be surrendered to the regulator, and if permit-holders are liable for non-compliance ('buyer liability') the incentives are similar to tax, and the market would reflect the risk of non-compliance with appropriate price signals (Victor, 1999).

Other requirements for implementing and designing instruments (which do not necessarily guide the choice between prices and quantities) include: (i) agents have the *information* necessary to respond to the new incentives; (ii) agents have the *capacity* to respond to the incentives; and (iii) the *assumptions about behaviour* underlying the intervention are accurate.[34] The first two considerations may imply that the implementation of the price or quantity instrument should be accompanied by an information/education programme.

(iv) International Issues

Increasingly, national policy must be designed to mesh with policies at the supranational level, including EU directives and obligations under international treaties. The choice between a price or quantity instrument can be strongly influenced by supranational arrangements. For instance, if an EU directive imposes a quantity target with a large penalty for non-compliance, such as the Water Framework Directive, then the effective marginal benefit curve faced by the United Kingdom is discontinuous at the target. In such circumstances, provided the penalty is large enough, the Weitzman framework would recommend using quantity instruments at the national level.

Our analysis has so far presupposed the existence of a national regulator to enforce compliance with the policy instruments. However, certain policy problems are fundamentally international in nature, such that all nation states are better off if they can find a mechanism to support cooperation. Climate change is the canonical example—mitigation is a global public good, but free-rider problems make full participation and compliance in any agreement extremely difficult (Barrett, 2003). Under such circumstances, efficiency may have to give way to the need to encourage and sustain participation and compliance in an international agreement (Barrett and Stavins, 2003).

In the absence of a global regulator, the relevant question is whether price or quantity instruments yield differential incentives for participation and compliance. Barrett and Stavins (2003) identify three *positive* incentives for compliance and participation: explicit side payments, issue linkage, and the allocation of entitlements. Quantity schemes rely upon the allocation of entitlements (i.e. the initial distribution of licences) to encourage participation, while price schemes must employ explicit side payments.[35] There are clear advantages and disadvantages with both.[36] Harmonized taxes collected by national governments seem superficially fair—everyone is paying the same price—but the tricky questions of distributional effects are obscured, and must be dealt with indirectly with side payments. In contrast, negotiation over quantities places tricky distributional issues at the centre of the process, which again can be viewed as an advantage or a disadvantage. In both cases, however, negotiations are likely to be more successful if carefully linked in with other issues.

Barrett and Stavins (2003) also discuss three *negative* incentives supporting compliance and participation: reciprocal measures, financial penalties, and trade restrictions. The challenge here is that such incentives must be credible, and must be seen to be credible. This is problematic when punishment is itself a global public good, and therefore undersupplied. Again, it is not clear that there is a specific advantage to either price or quantity instruments. Indeed, for climate change, Barrett (2003) and Barrett and Stavins (2003) argue that it is so difficult to construct a participation- and compliance-compatible regime that a voluntary R&D protocol is the best feasible outcome. Certainly, given the difficulties of achieving cooperation on climate change, there are persuasive arguments for continuing to work with the policy regime already in place (Böhringer, 2003), rather than attempt to dismantle the institutional capabilities built over the last decade.

[34] For instance, policies on energy efficiency previously assumed, reasonably enough, that the future energy savings were one of the main drivers behind the uptake of energy efficiency. A recent study by Oxera (2006), however, finds otherwise. Key positive factors include positive recommendations from friends and family and awareness of labelling; key negative factors were disruption and capital expenditure.

[35] Endres and Finus (2002) show in a stylized two-country model that quotas are favoured over taxes when, along with other conditions, 'institutional restrictions' rule out side payments.

[36] The allocation of entitlements may amount to implicit side payments, raising negotiating difficulties that are magnified by the fact that the value of the entitlement is uncertain. See McKibbin and Wilcoxen (2002) on the advantages of resolving distributional issues by permit allocations, and Nordhaus (2005) on the disadvantages.

(v) Political Economy

The previous sections have largely focused on designing instruments to achieve efficient outcomes by correcting relative prices and inducing appropriate substitution effects. Such considerations are at the heart of the economic theory of instrument design. However, in practice, the instruments adopted depend more on political-economy considerations than on economic theory, and the political economy of instrument design is driven by income transfers, rather than substitution effects.

Price, quantity, and hybrid instruments can all be designed to transfer wealth from the private sector to the public revenue, or vice versa. Subsidies and taxes (both price instruments) obviously have opposite impacts on public finance. In theory, tax revenues can be returned to industry by hypothecation and recycling, but, in practice, this is difficult to achieve with any credibility. The public-finance impacts of quantity instruments are similar to taxes when tradable licences are sold to the private sector (by auction or otherwise) and the market is (roughly) perfectly competitive. In contrast, if licences are 'grandfathered' to incumbent operators for free (as in Phase 1 of the EU ETS), quantity trading is similar to a tax where the revenues are fully recycled. In sum, theoretical considerations suggest that the public-finance implications of price and quantity instruments need not differ.

In practice, however, taxes tend to generate more public revenue than quantity instruments. Even when all the relevant licences are auctioned, unless carefully designed, auctions may not raise the optimal amount of revenue (Klemperer, 2004). For instance, selling licences in a series of industry-specific auctions would leave the process particularly susceptible to manipulation. Moreover, grandfathered licences have the additional benefit, as far as incumbent firms are concerned, of raising rivals' costs. Helm (2005) notes that providing for a 'new entrants' reserve' does not entirely solve the problem, because the new instrument creates risks which operate as additional barriers to entry. Incumbents, unlike new entrants, typically have physical hedges against such risks. Given these factors, considerations of self-interest suggest that industry should be expected to lobby according to the following ranking: (i) subsidies; (ii) licences grandfathered to incumbents; (iii) auctioned licences; and then (iv) taxes.[37]

Nevertheless, the public interest would often be served by resisting this lobbying and raising revenue from instruments. This is particularly the case with instruments aimed at internalizing negative externalities, as has become clear from theoretical studies within environmental economics, which reveal at least five reasons to raise revenue from such instruments.[38]

First, raising revenue may generate a double dividend—the policy internalizes the negative externality, and the revenue raised can be recycled to offset other distortionary taxes.[39] Some policies—such as carbon pricing—produce a 'tax interaction effect' by increasing product prices and reducing real wages and labour supply.[40] The tax interaction effect, while an indirect effect, can be relatively large.[41] Nevertheless, policies that internalize a carbon price without raising revenue also suffer from the tax interaction effect, without benefiting from the revenue-recycling effect.[42] As such, climate policies that raise revenue are preferable to policies which do not.

Second, raising revenue avoids the distortion of dynamic incentives. For instance, if licences are

[37] A related point is the relative susceptibility of price and quantity instruments to regulatory capture, discussed by Helm (2006).

[38] Hepburn *et al*. (2006*b*) provide a review of the considerations for and against auctioning of European allowances in the EU ETS.

[39] A variety of different definitions of the double-dividend hypothesis are used in the literature, sometimes inconsistently. These definitions include 'weak', 'intermediate', and 'strong' forms. This terminology is avoided here because it is more confusing than it is helpful.

[40] See Bovenberg and de Mooij (1994), the critique by Fullerton (1997), and the reply by Bovenberg and de Mooij (1997). Also relevant are papers by Bovenberg and van der Ploeg (1994), Goulder (1995), Parry (1995), and Bovenberg and Goulder (1996).

[41] For climate-change policy, Parry (2003) notes that the tax-interaction effect dominates the revenue-recycling effect. This would be expected from optimal tax theory, which shows that broad taxes produce lower efficiency losses than narrow taxes (e.g. Diamond and Mirrlees, 1971). However, results appear to depend strongly upon assumptions about labour supply.

[42] Simple models, as in Parry *et al*. (1999) and Parry (2003), indicate that after accounting for the tax-interaction effect, grandfathered permits can generate striking welfare losses where auctioned permits produce gains. See also Goulder *et al*. (1997, 1999), and Fullerton and Metcalf (2001).

allocated for free, based on another variable (e.g. past emissions or output), firms have a dynamic incentive to increase that variable (e.g. increase emissions or output) now in order to be granted a larger licence allocation in the future. In contrast, this effect does not arise with taxes or auctioned permits.

Third, requiring payment from those who impose negative externalities on others probably reflects a fairer allocation of property rights. For instance, the polluter-pays principle starts from the premise that the right to a clean environment is owned by the public. If firms wish to pollute the environment, they must purchase the right to do so from the public.

Fourth, if licences are grandfathered to firms (or taxes recycled), the rents ultimately accrue to shareholders, who tend to be wealthier than the general population.[43] As such, grandfathered licences are a regressive instrument, transferring wealth from poor to rich. Even if the government finds it politically necessary to preserve firm profits, simulations suggest that no more than 50 per cent of licences, and probably a much smaller percentage, should be allocated for free (Bovenberg *et al*., 2005).[44] An exception applies to firms competing against imports which are not subject to similar policies.[45]

Fifth, firms and individuals behave using heuristics and 'rules of thumb' rather than by making calculations of optimality. Raising revenue directs attention to the policy problem, and is more likely to prompt an active response from firms. Furthermore, although firms should simply pass on a proportion of marginal costs to consumers, in practice prices will increase by a greater amount if firms also pay revenues to the government. Other things being equal, the demand response will be larger given a stronger price signal.

In sum, although economic theory provides several extremely good reasons—founded both on efficiency and equity—to raise revenue from the internalization of negative externalities, this frequently fails to occur for political economy reasons. Indeed, this point is more general. Economic theory has, justifiably, focused on providing guidance on instrument selection, under different conditions, to maximize social welfare. However, economists' theoretical prescriptions are rarely met in practice, for the simple reason that governments cannot design instruments without accounting for political realities (Pearce *et al*., 2006). A more accurate explanation of why particular instruments are adopted requires the specification and analysis of a political welfare function, capturing the fact that politicians also want to retain the support of various lobby groups in order to stay in power, and implement their pet social or economic programmes.[46] With this framework, it is not at all surprising that instrument selection is better explained by political economy and the income effect than by considerations of economic efficiency (Helm, 2005).

VI. APPLICATION TO CLIMATE POLICY

It is an understatement to say that climate policy is a difficult policy problem. It involves complex science and economics, and impacts across all countries over extraordinarily long time horizons. It is the greatest collective-action problem of our era (necessitating trust and negotiating skill) and international solutions may raise further problems of major financial and macroeconomic side-effects. There is clearly no room for pretence that climate policy simply requires a blithe application of the theory of instrument choice.

Nevertheless, basic economic theory has some extremely important and useful insights. Assuming that the agreed target is to limit the *flow of emissions* within a given time period, as under the Kyoto

[43] Parry (2003) points out that in the USA the top income quintile owns 60 per cent of all shares with the bottom owning less than 2 per cent. He cites a finding that reducing US carbon emissions by 15 per cent using grandfathered permits would reduce the income of the bottom quintile by $500 and increase that of the top quintile by $1,500.

[44] The essential reason for this is that, depending upon the market structure, firms will pass on a proportion of the marginal cost increase to consumers. As such, Vollebergh *et al*. (1997) recommend partial grandfathering and Bovenberg and Goulder (2000) examined the coal, oil, and gas industries in the United States and concluded that no more than 15 per cent of permits needed to be grandfathered for profit-neutrality. Smale *et al*. (2006) also find that the EU ETS will produce windfall profits in most participating sectors. Hepburn *et al*. (2006*a*) provide a relevant theoretical analysis.

[45] In the limit, fierce import competition would imply that firms are not able to pass through the marginal cost increase resulting from the emissions-trading scheme.

[46] See, for example, Grossman and Helpman (1994), Aidt (1998), and Aidt and Dutta (2004).

Protocol,[47] the crucial question is which instrument (or combination) should be employed? Commentators and academics have responded with a plethora of different approaches for consideration.[48] Nevertheless, a good starting point remains the choice between quantities (as under the Kyoto Protocol), prices (by way of an internationally harmonized carbon tax), or hybrid instruments.

In section V(i), the Weitzman (1974) framework was loosely applied to climate change with the conclusion that if the marginal cost of reducing emissions increases quickly and damages from climate change are relatively insensitive to emissions over short periods (e.g. 5 years),[49] then a price instrument is appropriate.[50] Indeed, unless we are certain that we are on the brink of a tipping point, a carbon tax appears superior to tradable quantities. To be clear, this is not to say that climate change is not an urgent or an extremely concerning problem, nor is it to claim that climate damages are unlikely to be high. The central claim behind the economic recommendation of a price instrument—which might optimally be set extremely high—is simply that damages do not change rapidly as a function of additional emissions over the next few years. If the member states were prepared to agree to commitment periods of several decades (notwithstanding the discussion on flexibility and commitment in section V(ii)), then quantity instruments become more attractive (Hoel and Karp, 2002), precisely because it is more likely such a tipping point would be crossed over that period.

However, as discussed in section V(iv), for international problems such as climate change, this economic theory can only serve as a starting point. The absence of a global regulator implies that the feasible set of negotiated solutions is highly constrained. Achieving international collective action is crucial to organizing an effective response to climate change, and this requires the gradual development of institutions, trust, and credibility over time. This is important, because trust and credibility will not be enhanced by large-scale, fundamental revisions to the direction of climate policy. As such, practical recommendations need to start from where we find ourselves, rather than where we might like to be. The institutions we have so far successfully developed are centred on quantity targets and timetables. This approach has hard-won momentum, and a degree of institutional lock-in. Financial institutions within the emissions-trading community, including some of the world's major banks and hedge funds, now have a vested interest in ensuring that emissions trading continues. Policy-makers have gained useful insights by 'learning by doing', as international emissions-trading schemes have been proposed, implemented, and iterated.

While such schemes are still far from perfect, the institutional switching costs of moving from a quantity-based to a price-based scheme, such as a harmonized tax, seem rather large. Substantial time and resources would need to be devoted to attempting to shift the current consensus away from targets and timetables. And there is no guarantee that a shift would be achieved, particularly given the environmental movement's resistance to leaving emissions uncapped, and industry resistance to additional taxes.[51] Even if the agreement to *negotiate* a tax scheme is reached, the time and resource costs required to sort out the devilish details and to implement the scheme should not be underestimated.

Accepting a quantity-based regime as the platform for future climate policy, section V(v) implies several immediate recommendations. First, maximizing social welfare implies that a large proportion of the allowances should be auctioned. Second, it should

[47] This is far from being the only possible target. We might aim to prevent global mean temperatures from increasing by more than a certain amount, such as 2°C, or prevent concentrations of greenhouse gases in the atmosphere from rising beyond a specific point, such as 500ppmv, or even set a target to limit cumulative anthropogenic emissions (over all time periods) to less than 1,000 GtC. Frame *et al*. (2006) suggest that this last target might be better specified.

[48] See, for example, the reviews in Philibert (2005), Aldy *et al*. (2003), and Bodansky (2004), the last providing summaries of over 40 different proposals.

[49] The assumption that the marginal damage curve is flat is less valid over longer timeframes. Hoel and Karp (2002) find that the preference for quotas increases as the relevant time horizon of policy is increased.

[50] For rigorous analyses that account for the stock pollutant nature of the problem, see Pizer (2002) and Hoel and Karp (2001, 2002).

[51] Aldy and Frankel (2004) state that 'for all the criticism the Kyoto Protocol has received, the most feasible approach in future policy efforts may be to build on this foundation'.

be expected that industry will lobby ferociously against any auctioning. Results from the European ETS appear to indicate that industry has won the first few rounds.[52]

Furthermore, the theory on commitment and flexibility (section V(ii)) is especially relevant to climate-policy setting. The costs imposed upon environmental innovators by retaining the flexibility to adjust climate policy are likely to be moderate to high. However, the benefits of the flexibility to respond to new climate science are difficult to estimate. As such, robust conclusions are unavailable. Nevertheless, while it is almost certain that the optimal commitment period is less than several decades (as this is the lifespan of most relevant plant), it seems unlikely that the optimal period is as short as 5 years. An analysis of longer commitment periods (e.g. 10 years and beyond) is clearly called for.[53]

Finally, accepting a quantity-based platform for future climate policy does not rule out the possibility of shifting to a more price-like system. An obvious starting point would be to create a hybrid instrument by adding a *price ceiling* and a *price floor*. If economists are correct about the marginal benefits curve, this would lead to substantial efficiency gains, while avoiding the costs of a major switch from current arrangements. Additionally, a price ceiling may enhance policy credibility, because it caps the costs of compliance and thus reduces the risk of a policy reversal if abatement costs turn out to be injuriously high. The price floor guarantees a certain minimum return on investment in low-carbon technologies, reducing the risk faced by innovating firms. Revenues derived from the sale of additional permits at the price ceiling might be recycled to induce greater participation in the scheme, to be applied to climate science, to support R&D into abatement technologies,[54] to fund adaptation, to fund the eventuality that the price floor is triggered, or to reduce other distortionary taxes.

The revenue needed to support a price floor, if not provided by revenue from the price ceiling,[55] could be provided by an initial auction of a proportion of the assigned amount units (AAUs), or from an existing (or newly established) international finance facility.

The key additional element of such a scheme is that, in addition to agreeing the next round of targets and timetables, relevant nation states would also need to agree upon the price ceiling and/or price floor,[56] in addition to a mechanism for implementing them.[57] Müller *et al*. (2001) express the view that achieving agreement on this would be a 'political nightmare'. This may well be correct, but without some mechanism to manage carbon prices,[58] it may be difficult to achieve broad participation in a future international agreement.

VII. APPLICATION TO TRANSPORT POLICY

Road use involves a variety of positive and negative externalities, including road-damage costs, congestion costs, safety hazards, greenhouse-gas emissions, local air pollution, and noise and light pollu-

[52] Hepburn *et al*. (2006*b*) suggest, however, that greater auctioning is highly likely as the scheme progresses.

[53] McKibbin and Wilcoxen (2002) propose renegotiating their permit price once every decade.

[54] See Barrett (2001, 2003). Note that a technology protocol could sit alongside a quantity-based instrument. Indeed, simple economic theory suggests pursuing both approaches—a carbon price internalizes the negative environmental externality, but it does not capture the positive externalities inherent in research and development.

[55] *Ex ante*, an asset-rich private finance entity may be willing to 'crop the tails' of the distribution of future prices. It could take on the financing requirement to support the price floor in return for the revenues (or a proportion) thereof if the price ceiling is triggered. Depending upon the level of the targets, the floor and ceiling, the private sector may be willing to take this risk.

[56] Pizer (2002) finds that the price ceiling should be set only marginally above the (otherwise) optimal carbon tax.

[57] The European ETS is not a hybrid scheme, because although there are penalties for non-compliance for Phases I and II of €40/tCO_2 and €100/tCO_2 respectively, excess emissions must also be offset in the following compliance period (European Commission, 2003). In contrast, the United Kingdom Renewable Obligation Certificate scheme arguably is a hybrid scheme given its buy-out price, although it is also unusual in the fact that revenues from the price ceiling (the buy-out price) are recycled to those in compliance, thus creating the possibility that the market price would rise above the price ceiling.

[58] Prices might be 'managed' without imposing absolute ceilings and floors. Hepburn *et al*. (2006*b*) discuss how auctions might be employed to this end. Newell *et al*. (2005) note that in a multi-period system with banking and borrowing, prices could be managed by agreeing that the stringency of targets in the next period automatically depend upon the revealed price in the current period.

tion.[59] The literature on most of these areas—particularly congestion—is detailed and long-standing. This section provides an overview of the merits of price and quantity instruments in addressing congestion, and discusses the notion of 'safety pricing'—replacing speed limits (quantities) with a schedule of prices to internalize safety externalities.

(i) Congestion Pricing

'I will begin with the proposition that in no other major area are pricing practices so irrational, so out of date, and so conducive to waste as in urban transportation.' (Vickrey, 1963)

Vickrey probably felt that transport policy was 'out of date' in 1963 because, several years earlier, he had advanced a perspicacious plan for road pricing in Washington, using electronic and photographic technology that would allow charging motorists without interrupting or slowing traffic (Vickrey, 1959). The scheme would be applied to 'the street and highway system as a whole, not just bits and pieces of it'. His calculations suggested that pricing would yield massive net benefits by reducing congestion, spreading peak hour traffic, making better use of the road network, and inducing optimal use of mass transit.[60] Furthermore, the revenue raised from user charges would pay for the capital expenditure of the scheme within the first year.

The plan was not implemented. One might conclude that it was simply ahead of its time, but toll roads were commonplace in Britain and the USA during most of the nineteenth century (Lindsey, 2006), perhaps influenced by the early insights of Adam Smith and the impressive contributions of French engineer/economists lead by Dupuit (1844).[61] Although the economic theorists continued to address questions of transport policy in the early twentieth century (Pigou, 1920; Knight, 1924), until the 1960s the planning of urban roads appears to have been left to engineers who paid little attention to pricing (Thomson, 1998).

For our purposes, the most interesting feature of the theory and practice of transport economics is that it has been focused on the use of *price* instruments, the London congestion charge being an obvious example (Santos and Fraser, 2006). Direct quantity restrictions, implemented by requiring a licence for particular road use, seem to be less often employed.[62] There are good practical reasons for this—creating a scheme of tradable road licences adds complexity and administrative costs. Nevertheless, if roads are priced to reflect congestion, it is interesting to ask whether the Weitzman framework[63] favours road-user charges or a system of tradable licences.[64]

For a given road at a given time, the marginal benefit of allowing an additional vehicle is a function of the inconvenience of using an alternative means of transport, shifting the time of travel, or forgoing the trip altogether. Standard linear demand curves are employed in the literature (e.g. Verhoef, 1999), and, indeed, one would expect the marginal benefits curve to be roughly flat or gradually downward sloping. In contrast, the marginal congestion cost of an additional vehicle is initially relatively low (additional vehicles have negligible congestion effects), but rises rather steeply as the road reaches capacity.[65]

[59] Newbery (1988) provides a review of the theory behind the estimation of the non-environmental externalities. Congestion and accident externalities are particularly important.

[60] The technology is increasingly sophisticated enough to allow real-time congestion charging, where prices would vary across the road network as a function of current flow rates. However, such a system is undeniably complex and infeasible until vehicles are equipped with central computers and global positioning system, such that the computer would propose a menu of route options to the driver (each with cost and expected time).

[61] Lindsey (2006) provides an excellent survey of the intellectual development of the idea of road pricing.

[62] Notable exceptions include Singapore, with a vehicle quota system where licences are auctioned (Santos *et al.*, 2004), Athens, where cars with odd (even) number plates can drive on odd (even) days only (Verhoef *et al.*, 1995), Mexico, São Paolo, and Rome. Quantity instruments are also employed for residential parking, and to regulate taxi licences.

[63] The other criteria discussed in section V are not examined here for reasons of brevity. This is not to suggest that they are not important.

[64] Recall that the Weitzman (1974) framework is relevant where the marginal cost and benefit curves are uncertain. Here, even if speed–flow relationships are able to be determined with precision for the road in question, uncertainties would arise because the marginal value of time is uncertain (and would also probably vary at different times of the day).

[65] See Newbery (1990). Indeed, the congestion costs approach infinity as flow approaches capacity (Morrison, 1986).

As such, for busy roads during peak hours, the marginal cost curve may be substantially more steeply sloped than the marginal benefits curve at the optimum vehicle density. If uncertainty is important, this suggests policy should employ a scheme of tradable licences to cap road use at the point before congestion becomes a major cost. If uncertainty is not important, policy can be fairly sure to hit the target with either instrument, and use of a price instrument may be preferable for other reasons (such as simplicity of implementation).

(ii) Speed and 'Safety Pricing'

Another important externality from road transport is the risk of fatal or non-fatal accidents to drivers, passengers, and pedestrians. The economic magnitude of accident risk might dwarf other road externalities (Newbery, 1988). The literature on pricing accident externalities has focused on the relationship between traffic flow and accidents (Newbery, 1990; Jones-Lee, 1990). Vehicle speeds are also an important variable (along with others) in determining accident risk, as is evident from the basic physical law that kinetic energy = ½ mass × velocity^2.[66] For this reason, a ubiquitous instrument of transport policy is a quantity constraint on speed. Current speed limits are clearly a very crude approximation to 'optimal' speed limits.[67] Although speed limits are unquestionably a quantity-focused instrument, it may be more accurate to describe them as hybrid instruments, where travel in excess of the speed limit is possible provided a fine is paid.[68] To our knowledge, speed objectives have not yet been targeted with pure price instruments (where prices vary in real time with vehicle speed), presumably because this is, at present, too technologically complicated and expensive.

However, in the coming decades, the technological limitations are likely to disappear. Vehicles increasingly have global positioning systems (GPS) and on-board computers to advise drivers (or even take decisions on their behalf). Future technology would allow road use to be charged per mile, with higher prices per mile for travel at very high (and possibly also very low[69]) speeds.[70] Indeed, Norwich Union already uses GPS technology to offer pay-as-you-drive insurance, where premiums are based on how often, where, and when the policy-holder drives. A profile of behaviour (e.g. speeds turning corners), and a measure of relative risk, can be constructed from this information. Such insurance policies are an important step towards internalizing driver's external safety costs. But such policies are optional, and drivers do not have price information in real time. Assuming that technological and administrative hurdles are overcome, would compulsory real-time 'safety pricing' or 'speed pricing' be a sensible idea?

Let us start with the Weitzman (1974) framework, which necessitates understanding how external safety costs vary with speed. Speed limits would be optimal if the risk of an accident were zero at any speed below the speed limit, and constant (at the level of the expected fine) above the speed limit. This is clearly not so—accident risk is a (potentially complicated) non-linear function of speed, so, clearly, a non-linear pricing schedule would better reflect expected increases in safety hazard with speed (with a suitable risk-aversion parameter).

[66] While the physics is indisputable, one must watch for counter-intuitive results in transport policy. Parry and Bento (2002) note that heavy traffic might reduce accidents, if drivers are more careful. An analogous result might apply to vehicle speed. Also, it appears that increasing speed limits on some roads may save lives if this liberates resources to be directed elsewhere. Lave (1985) and Lave and Elias (1994) show that increasing speed limits on United States rural inter-state highways from 55mph to 65mph allowed a shift in safety prevention efforts, reducing overall fatality rates. Kweon and Kockelman (2005) provide a review.

[67] Verhoef and Rouwendal (2003) derive optimal speed limits (and tolls) in a model of highway congestion, concluding that *minimum* rather than maximum speed limits are appropriate to reduce density (for a given flow) and hence accident risk.

[68] Speed limits could be viewed as hybrid instruments if (i) the payment of the fine does not involve slowing down; and (ii) several fines do not result in driving licence confiscation. Speed cameras are closer to being a hybrid scheme than being pulled over by the police, because the latter results in a (potentially substantial) reduction in the average speed of the journey.

[69] Richiardi (2005) notes the conventional wisdom that the probability of accidents during lane changes depend upon the speed differential between lanes, so discouraging slow driving might improve safety. It may also make sense for other reasons; Rouwendal *et al*. (2002) find that the optimal congestion toll is higher for slow vehicles than fast vehicles.

[70] Of course, it is not always feasible for drivers to pay more to travel more rapidly. For instance, differential vehicle speeds are impossible under dense traffic conditions in single-lane roads. But the possibility arises on multi-lane roads, parallel roads, and on roads with lower-density traffic flow.

So, once technology allows, the theoretically efficient approach to internalizing safety externalities would be to employ the best science to determine an appropriate pricing schedule for different speeds. But efficiency is not the only relevant criterion for instrument choice, and it will be obvious that the 'safety pricing' proposal raises a variety of problems.

First, drivers have heterogeneous preferences. Different time valuations and speed preferences imply that 'safety pricing' would increase surplus, allowing drivers to travel more quickly when, for instance, they are running late (provided they pay the costs). But drivers also have different risk preferences—highly risk-averse drivers will lose from speed pricing, while risk-loving drivers will gain.

Second, the technology that enables government monitoring of road use and speeds might be considered an intrusion of privacy. Nevertheless, mobile phones reveal similar information about our movements, and they have been readily adopted by consumers.

Third, highly differentiated pricing schemes are often argued to be confusing to drivers (Nash and Sansom, 2001). This could be a serious problem unless vehicle technology is such that the on-board computer can do most of the processing, offering the driver a menu of two or three different routes, with corresponding prices and estimated arrival times.

Fourth, the criminal law would still need to be invoked to prevent speeds which impose unacceptable risk on others. For instance, even a sharp increase prices (e.g. to £100,000 per mile for travel at 100mph outside a primary school) would not be publicly acceptable. First, while small risks to life are inevitable (and can be priced), pricing more substantial risks to life, or even life itself, may be viewed as being ethically obnoxious. Second, if high speeds are only regulated with extremely high prices, this effectively allows the wealthy to inflict risk upon others.

Finally, safety pricing would have to overcome the general public resistance to road pricing, which has prevented many sensible schemes from being implemented over the past few decades (Harrington *et al*., 2001).

These difficulties suggest that the concept of 'safety pricing', while an intriguing idea, is unlikely to be implemented, especially when more simple policies may achieve similar results. Nevertheless, it may warrant further research before wide-scale adoption of new vehicle technology makes it feasible in practice. The most likely initial application of the idea would be on motorways, where drivers could pay to travel faster, probably in a dedicated lane. Application to urban roads would probably face much greater hurdles. Irrespective of the merits, the notion of 'speed pricing' rather than 'speed limits' provides an illustration of the possibilities of thinking carefully about the choice between prices and quantities in regulation.

VIII. CONCLUSION

As citizens' demands upon policy-makers increase, designing policy that maximizes net social benefits will become more important. As the focus on efficiency sharpens, the use of economic instruments will become more appealing. Economic insights on instrument choice are likely to be more widely applied than at present. Although economic considerations are not always paramount,[71] a large variety of policy problems—road congestion, hospital waiting times, climate-change policy, educational outcomes—would benefit from the systematic application of economic theories of regulation, including theories pertaining to the sensible choice of objectives and targets, in addition to the theory of instrument choice presented here. Problems of decision-making under uncertainty, credible commitment and flexibility, implementation, and political economy arise in almost all settings, and increasingly international issues are also often relevant to national policy-makers. Economic theory has something to contribute in each of these areas.

[71] For instance, the decision to replace military conscription (effectively a quantity instrument) with an all-volunteer military force (effectively a price instrument) had little to do with the relative slopes of the marginal cost and benefit curves, and much more to do with philosophical reasons, as discussed by Galston (2003).

There are at least six key lessons for policy-makers from the theory of instrument choice. First, whenever government faces information problems, and the costs of response vary between regulated entities, economic instruments are likely to be preferable to command-and-control regulation. Second, under uncertainty, price instruments are more efficient than quantity instruments when the marginal benefit curve is flat relative to the marginal costs curve, but correlated uncertainty can reverse this preference. Third, for longer-term policy challenges, perverse dynamic incentives (ratchet effects), hold-up problems, and the allocation of risk should be considered in making the (inevitable) trade-off between commitment and flexibility. Fourth, all instruments require enforcement and some instruments (e.g. technology standards) may be simpler and cheaper to enforce than others. Fifth, instruments must be designed to mesh in with policies at the supranational level, and incentives for participation and compliance are crucial at the international level. Finally, and perhaps most importantly, political economic considerations appear to constrain the feasible set of instruments—industry has a strong preference for instruments that transfer income towards (or at least not away from) its shareholders and that enhance market power.

Political factors are more important than economic considerations in explaining why particular instruments are employed for particular problems. Helm (2006) provides a useful summary of regulatory capture in this context. To assume that politicians can maximize a representative social welfare function, rather than a 'political welfare function', is simply naïve, even if such an assumption was plausible in Platonic times.[72] However, as Pearce *et al*. (2006) put it, 'explaining the gap between actual and theoretical design is not to justify the gap'. Moreover, as citizens' legitimate demands for better public outcomes increase, so the social (and even political) argument for using economic theory to improve instrument choice will become more powerful.

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[72] Russell (1946, Book 1, Part 2, ch. 14, final page) suggests that Plato's republic may have actually been intended to be founded. He notes that this 'was not so fantastic or impossible as it might naturally seem to us. Many of its provisions, including some that we should have thought quite impracticable, were actually realized at Sparta.'

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