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Carbon Pricing: Effectiveness and Equity

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ABSTRACT

The 2015 Paris Agreement adopted the goal of limiting the rise in global mean temperature to 1.5–2 °C above pre-industrial levels. Carbon pricing can play a key role in meeting this objective. A cap-and-permit system, or alternatively a carbon tax indexed to a fixed emission-reduction trajectory, not only can spur cost-effective mitigation and cost-reducing innovation, but also, crucially, can ensure that emissions are held to the target level. The carbon prices needed to meet this constraint are likely to be considerably higher, however, than existing prices and conventional measures of the social cost of carbon. This poses issues of distributional equity and political sustainability that can be addressed by universal dividends funded by carbon revenues.

1. Introduction

'The weather,' observed nineteenth century essayist Charles Dudley Warner, 'is a matter about which a great deal is said and very little done.'[1] Today we are doing something *to* the weather, however: we are destabilizing it by emitting large quantities of greenhouse gases into the atmosphere. This, too, is a matter about which a great deal is being said, if still not all that much done.

An important contribution of economists to this conversation has been to make the case for carbon pricing. There are differing views, however, as to the appropriate carbon price, the design of carbon pricing policy, and the best uses of carbon revenues. This essay addresses these issues.

Section 2 reviews the case for carbon pricing. In addition to its instrumental value in providing incentives for cost-effective mitigation and cost-saving innovation, carbon pricing also may have intrinsic value if the policy is designed to advance the principle of universal co-ownership of gifts of nature. In addition, an important feature of carbon pricing that sets it apart from other policies is that the policy can be designed to guarantee fulfillment of emissions targets, such as a trajectory consistent with the Paris Agreement's objective of holding the rise in global mean temperature to 1.5–2 °C above pre-industrial levels.

Section 3 considers the appropriate price for carbon. Currently existing carbon prices generally fall below the 'social cost of carbon' (SCC) calculated from integrated assessment models that prescribe optimal emissions and price trajectories by weighing the benefits of mitigation against its costs. Conventional SCC measures, in turn, generally fall below the carbon prices that are likely to be required to meet the Paris goal. The divergence between the lower SCC and higher Paris-consistent prices reflects the difference between neoclassical efficiency and climate safety as normative criteria for policy making. In the efficiency criterion, economists determine the ends of climate policy. In the safety criterion, economists play a more modest role: they recommend cost-effective means to achieve ends set by climate scientists and international negotiators.

Section 4 turns to practical issues in the implementation of a carbon price. Uncertainty regarding the long-run price elasticity of demand for fossil fuels means that certainty in meeting targets requires that the price be determined by the quantity of emissions. This can be done via either a cap-and-permit system or an adjustable tax rate indexed to the quantity of emissions relative to targets. Implementing the price upstream, where fossil carbon first enters the economy, would minimize administrative costs. A cap-and-permit system does not require that permits be tradeable unless they are issued free of charge rather than auctioned. In the absence of an international agreement on a uniform price, carbon prices will vary across countries, and this variation can have desirable properties.

Section 5 discusses distributional impacts of carbon pricing and how these can be influenced by policy design. In many countries, such as the United States, the incidence of carbon pricing itself is regressive: higher fuel prices hit lower-income households harder than upper-income households as a percentage of their incomes. The magnitude of the fuel price increases required for carbon pricing to be effective in meeting emission targets, coupled with public sensitivity to fuel prices, could jeopardize the political sustainability of the policy. Carbon dividends –

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[1] A version of this quip is often attributed to Mark Twain, with whom Dudley co-authored the novel The Gilded Age: 'Everybody talks about the weather, but nobody does anything about it' (see https://quoteinvestigator.com/2010/04/23/everybody-talks-about-the-weather/).

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equal per capita payments from carbon revenue – can provide a way to address these distributional and political challenges. Section 6 offers some concluding remarks.

2. Why Price Carbon?

In the short run, a carbon price provides an incentive for households, firms, and governments to reduce emissions cost-effectively. In the long run, the prospect of continuing and rising carbon prices also provides an incentive for innovations to lower the cost of cutting emissions. These static and dynamic efficiency effects are independent of the policy's design, as long as the price signal is strong and persistent. Moreover, if designed with these goals in mind, carbon pricing can guarantee that emissions targets are met, and advance the normative principle of universal co-ownership of the gifts of nature.

2.1. Cost-effectiveness

The most widely cited reason for carbon pricing is to promote emissions reduction in a cost-effective fashion. The textbook logic is straightforward: faced with a price on carbon, economic agents will avail themselves of opportunities to abate emissions that are cheaper than paying the price. The marginal cost of abatement varies across techniques. Some options, like the installation of LED lighting or conversion to wind power in favorable locations, are relatively low cost; others, like carbon capture and sequestration at coal-burning plants, would be very expensive. A carbon price gives households, firms, and governments alike an incentive to pick the 'low-hanging fruit' – the most cost-effective ways – to reduce emissions.

Conventional regulations, somewhat derisively termed 'command-and-control' policies in many economics textbooks, are thought to be less efficient in that they do not necessarily minimize costs per ton of abatement. It is worth noting, however, that economic agents do not always behave as textbook models predict. Studies have reported that often there is scope for emissions reductions at *negative* cost – that is, unexploited opportunities that would be privately profitable even in the absence of a carbon price – arising, for example, from myopia and incomplete information.[2] This is one reason to include complementary instruments in the climate policy mix, rather than relying on price incentives to do the job alone.[3]

2.2. Incentives for Cost-saving Innovation

Marginal abatement costs shift over time. A further rationale for carbon prices is to strengthen incentives for research and development of technologies that will lower the cost of reducing emissions. Experience from past pollution-pricing policies suggest that these dynamic effects can be substantial. In the first decade of the sulfur dioxide cap-and-trade program for power plants in the United States, for example, technological changes occurred so rapidly that marginal abatement costs (and hence permit prices) fell to less than half of what most analysts had predicted (Burtraw, 2000). Similarly, there is evidence that the European Union's Emissions Trading System (EU ETS) for carbon emissions has increased patenting activity in low-carbon technologies (Calel and Dechezleprêtre, 2016).[4]

Of course, not all the returns to investment in research and development are privately appropriable, and this can be expected to cause underinvestment even in the presence of a carbon price. For this reason, complementary public policies are needed to promote cost-saving innovation.[5] Similarly, public investment is needed for public goods that cannot be provided by private-sector responses to the carbon price signal.

2.3. Carbon Pricing to Guarantee Achievement of Emission Targets

The single most compelling reason to include carbon pricing in the climate policy mix is to guarantee that emission reduction targets are met. As discussed in section 4, this can be ensured either by setting an emissions cap and issuing permits up to the quantity allowed by the cap, or by setting a carbon tax with a rate indexed to meeting the targets.

Other instruments can be valuable components of the policy mix, too. For example, feed-in tariffs for electric power and fuel economy standards for automobiles can accelerate innovation in these strategic sectors. Public investment in mass transit can reduce demand for fuel for private transportation. Regulations can advance efficiency and equity by ensuring greater emission reductions in 'hot spots,' locations where hazardous co-pollutants from fossil fuel combustion are concentrated, and by preventing the emergence of new ones.[6]

But the magnitude of impact of other policy instruments on total emissions inevitably will be uncertain. If they prove to be highly effective in reducing demand for fossil fuels, the result will be a lower carbon price; if they turn out to be sufficient on their own to meet emission goals, the carbon price could fall to zero. On the other hand, if impacts of other policies prove to be modest (for example, if energy efficiency investments lead to a substantial 'rebound effect' from increased demand in response to lower unit costs), the carbon price will be higher.[7] There is one, and only one, instrument in the climate policy mix that can guarantee with certainty that emission targets are met: a carbon price *driven by mandated reductions* in the use of fossil fuels.[8] If, for example, a government decides that the Paris goal requires it to cut emissions by 80% over 30 years, it could establish a cap that declines at a constant rate of 5.22%/yr during this period, and let the carbon price be determined by demand for permits as their supply declines accordingly.

2.4. From Open Access to Universal Property

Climate destabilization demonstrates the tragedy of open access (sometimes called 'the tragedy of the commons') at a global scale. Individual economic agents receive the full benefit of fossil fuel consumption but bear only a trivial fraction of its climatic cost, and as a result they make decisions that although privately reasonable are socially tragic. Open access is, by definition, the complete absence of property rights. Conversely, any arrangements that are put in place to prevent the tragedy involve the creation of property rights – in this case, rights to the limited capacity of the biosphere to absorb CO_2 emissions.

Property rights come in many shapes and sizes. These can include rights to use a resource, to exclude others from using it, to set rules for management of the resource, and to transfer these and other rights via inheritance or sale. Together, property rights constitute what legal scholars describe as a 'bundle of sticks.' Not all sticks necessarily are in the same hands, and some may not exist, open access being the extreme case where none exist.[9] Government regulations on carbon emissions

[2] See National Research Council (2010, pp. 69–73) and International Energy Agency (IEA) (2010), pp. 82–83, 529). For cautionary remarks on the measurement of marginal abatement costs, see Kesicki and Ekins (2011) and Murphy and Jaccard (2011).

[3] For discussion of reasons for insensitivity to price signals, see National Research Council (2010, pp. 96–104: 2011, pp. 109–114).

[4] For further discussion, see Baranzini et al. (2017).

[5] On the role of public-sector investment in innovation, see Mazzucato (2013).

[6] For discussion, see Boyce and Pastor (2013).

[7] For varying evidence as to the magnitude of rebound effects, see Gillingham et al. (2016), Wei and Liu (2017) and Friere-González (2017).

[8] Mandated reductions in emissions also provide a safeguard against the 'green paradox' – increased fossil fuel extraction in response to expectations regarding future climate policies – that could result from other policy instruments, including a carbon price not tied to quantity targets (Sinn, 2014; Jensen et al., 2015).

[9] For discussion, see Cole (2002).

create a property right – the right to manage – that is held by the state. Carbon pricing creates another: the right to receive income from selling use rights.

Who will receive this income is not a foregone conclusion. It depends on to whom this new right is assigned. It is state property if the proceeds from carbon permit auctions or a carbon tax treated as government revenue, but this only one option. If permits are allocated free-of-charge to compliance entities by means of a formula based on their historic emissions, and the firms can then sell and buy permits from each other (the policy known as 'cap-and-trade'), the income goes to firms that receive free allowances. These two options sometimes are combined, as in the EU ETS, where roughly half the permits are auctioned and the other half given away, with the state's share having risen over time.

A third option, discussed in Section 5, is to return the carbon revenue directly to the people in equal lump-sum payments, a policy known as 'cap-and-dividend' in the case of auctioned permits and 'fee-and-dividend' in the case of carbon taxes. In this case, the right to receive the income is neither strictly public nor strictly private as these categories are usually understood: unlike public property, it does not belong to the state; unlike private property, it cannot belong to firms. Instead it is universal property, held inalienably by all individuals.[10] The creation of universal property is not an intrinsic feature of carbon pricing. It can add intrinsic value to the policy, however, by affirming the normative view that nature's gifts should belong equally to all. This end-in-itself could complement carbon pricing's instrumental value as a means to protect the Earth's climate.

Given the amount of money that is potentially at stake, the assignment of rights to this natural asset is a question of political as well as philosophical importance. Comparing environmental permits to land in frontier societies, Ellerman (2005, p. 130) remarks, 'The initial allocation of these rights [to land] may have been coercive and unfair, but that ancient act is lost in the mists of history and no one really cares now.' Whether land rights are truly a settled issue throughout the world is an open question. Land redistribution played a central role in some of the great political upheavals of the 20th century, including the Chinese Revolution. In any event, the strife that often accompanied the initial creation of land rights should give pause to anyone inclined to regard allocation of carbon rights as a minor matter.

3. What Price Carbon?

Merely instituting a carbon price does not ensure that the policy goals outlined above will be met: the level of the price must be sufficient to the task. Carbon prices are commonly denominated in US dollars per metric ton of carbon dioxide (\$/mt CO_2).[11] Converting this into more familiar units, \$1/mt CO_2 is equivalent to roughly \$0.43 per barrel of oil, \$0.01 per gallon of gasoline, and €0.003 per litre of petrol.[12] Fig. 1 shows crude oil prices from 2000 to 2017, with the right-hand axis representing the impact of a carbon price normalized to zero at the average oil price for the year 2017. This provides one measure by which to gauge the carbon prices discussed in this section. For example, in 2017 a worldwide carbon price of about \$230/mt CO_2 would have increased the price of crude oil to the level reached at its market peak in July 2008.

[10] An example of universal property is Alaska's Permanent Fund, which pays annual dividends to all state residents funded by oil revenues. For discussion of this innovative property type, see Barnes (2014).

[11] Less commonly, prices are expressed per metric ton of carbon (as opposed to CO_2). The conversion factor between the two, derived from the atomic weights of carbon and oxygen is \$1/mt C = \$3.67/mt CO_2. Following conventional usage of the term, 'carbon price' here refers to the price of CO_2.

[12] A useful source for equivalence calculations is the USEPA site https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references.

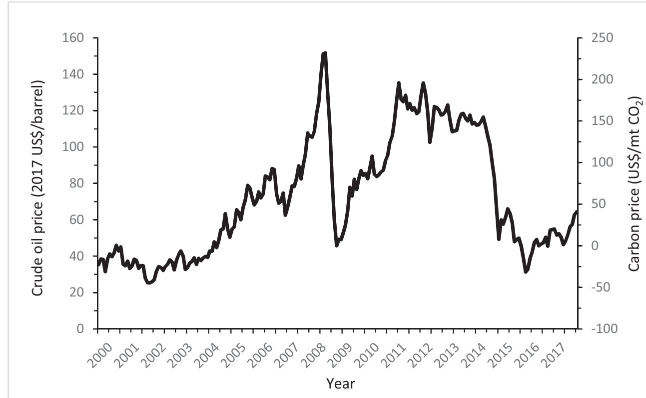

Fig. 1. Crude oil price, 2000–2017.
Sources: Crude oil prices at Brent, Europe (current US\$/barrel, monthly, not seasonally adjusted) from St. Louis Federal Reserve Bank: https://research.stlouisfed.org/useraccount/datalists/189721. Converted to constant 2017 dollars by GDP deflator from US Bureau of Economic Analysis: https://www.bea.gov/iTable/iTable.cfm?reqid=19&step=2#reqid=19&step=3&isuri=1&1910=x&0=-99&1921=survey&1903=42&1904=2000&1905=2018&1906=a&1911=0.

3.1. Actually Existing Carbon Prices

Carbon pricing initiatives around the world today cover approximately 8 gigatons of carbon dioxide emissions, equivalent to about 20% of global fossil fuel emissions and 15% of total CO_2-equivalent greenhouse gas emissions.[13] Prices ranged in 2017 from less than \$1/mt to \$140/mt, with roughly three-quarters of the total priced at less than \$10 (World Bank, 2017, pp. 10–11). In the world's two largest carbon pricing systems, the EU ETS and Japan's carbon tax, the prices were \$6 and \$3, respectively; in China's pilot ETS initiatives, the price ranged from < \$1 in Chongqing to \$8 in Beijing (World Bank, 2017, p. 14).

Most actually existing carbon prices are well below the levels recommended by climate policy analysts, whether on the basis of the efficiency criterion of neoclassical economics (see Section 3.2 below) or the safety criterion embodied in the Paris Agreement (see Section 3.3). Before turning to these, it is worth pausing to consider why existing prices are so low.

One plausible explanation is the political influence of groups with vested interests in continued use of fossil fuels. This can also help to explain why most of the world's emissions are not priced at all. Another indicator of this influence is the fact that many countries actively *subsidize* use of fossil fuels by means of policies that are tantamount to a negative carbon price. Direct fossil fuel subsidies by governments to consumers and producers worldwide amounted to \$333 billion/yr in 2015, according to a study by IMF researchers; by a broader measure that includes unpriced externalities, the study estimated the worldwide subsidy at \$5.3 trillion/yr (Coady et al., 2017).[14] By the narrower definition, the average global subsidy was equivalent to about \$10/mt CO_2, roughly five times more than the average global carbon price of \$2/mt CO_2.[15] In effect, then, the average net carbon price in the world today is *minus* \$8.

A second impediment may be unease among politicians and policy makers about public backlash from consumers faced with rising fuel costs. A telling example of political sensitivity on this score came during

[13] When China's national emissions trading system is implemented, the latter figure will rise to about 22% (World Bank, 2017, p. 27).

[14] For more on the magnitude of subsidies, see Kojima and Koplow (2015), McKitrick (2017) and Sovacool (2017).

[15] These averages are based on total world emissions (about 34 billion mt in 2015), including unsubsidized or unpriced emissions. Average global price carbon calculated from data in World Bank (2017, p. 29).

the 2008 U.S. presidential campaign, when candidates Hillary Clinton and John McCain, both of whom supported carbon cap-and-trade legislation, called for temporary suspension of the federal gasoline tax (then $0.184/gal) at a time of high prices in order to bring relief, in Clinton's words, to 'hard-pressed Americans who are trying to pay their gas bills' (Bosman, 2008).

3.2. The Social Cost of Carbon

Prescriptions for the 'right' carbon price necessarily rest on an ethical foundation. In neoclassical economics, where the reigning normative criterion is efficiency, the optimal price – termed the 'social cost of carbon' (SCC) – is one that maximizes the net present value of the benefits of emission reduction minus its cost. Apart from the technical difficulties involved in this application of cost-benefit analysis to climate change, it is important to note that different normative criteria can lead to quite different prescriptions, a point to which I return in Section 3.3.

The SCC is calculated from integrated assessment models (IAMs) that combine climate science and economics. The results are presented in a prescribed emissions trajectory and time path for carbon prices (the SCC), tied to each other by a presumed relationship between quantity and price. The difficulties in measuring the monetary benefits of emission reductions have been discussed extensively in the literature (see, for example, Azar, 1998; Ackerman et al., 2009; Pindyck, 2013, 2017; Van den Bergh and Botzen, 2014; Howard and Sterner, 2017). Among them are the following:

- *Climate damages:* The benefits of emission reductions are calculated from equations that express GDP losses as a function of global temperature increase. As Pindyck (2013, p. 870) remarks, these functions are 'completely made up, with no theoretical or empirical foundation.' Extrapolating from modest warming to unprecedented global temperature increases is especially problematic. As the Intergovernmental Panel on Climate Change, 2014, p. 79 observes, 'very little is known about the economic cost of warming above 3 °C relative to the current temperature level.' Yet IAMs 'treat high-temperature damages by an extremely casual extrapolation of whatever specification is assumed to be the low-temperature damages function' (Weitzman, 2009, p. 16). Moreover, total losses to world GDP may understate the severity of harm to vulnerable populations (Seneviratne et al., 2016; Karmalkar and Bradley, 2016).
- *Catastrophic risks:* The conventional treatment of risk in cost-benefit analysis, in which known probabilities are multiplied by known possible outcomes to calculate expected utility, is deeply problematic in the presence of catastrophic risks whose probability and magnitude are both unknown, as is the treatment of risk aversion and ambiguity aversion (Ingham and Ulph, 2005; Weitzman, 2007, 2009, 2011; Millnar et al., 2013; Ackerman, 2017).
- *Discount rates:* IAMs translate future damages into present values by means of a discount rate, a practice that assumes that the time-preference logic used by individual mortals in thinking about their personal futures should apply to how the present generation thinks about future generations. At a discount rate of 3%, for example, the present value of one million dollars in damages (in real terms) that will happen one century from now shrinks to about $50,000, and two centuries from now to less than $3000. Much as polar ice melts with climate change, future damages melt away with discounting.[16]
- *Co-pollutant impacts:* Along with CO_2, fossil fuel combustion releases multiple hazardous air pollutants, including sulfur dioxide, nitrogen oxides, and particulate matter. The benefits of reducing these emissions are excluded from the SCC despite evidence that their monetized value is comparable to or even greater than many estimates of climate damages (see, for example, Berk et al., 2006; Nemet et al., 2010; Shindell et al., 2016). The salience of air quality impacts is strengthened, moreover, by the fact that they are more proximate, spatially and temporarily, than climate impacts of carbon emissions.

'What do the models tell us?' asks Pindyck (2013) in a review of IAMs. His short answer: 'Very little.' The models used to compute the SCC, he concludes, are 'so deeply flawed as to be close to useless as tools for policy analysis' (Pindyck, 2013, pp. 861–2).

Further difficulties arise in measuring marginal abatement costs, which are compared to marginal damages in order to find the optimal carbon price. Not only are there uncertainties as to current marginal abatement costs, but the cost curves shift downward over time; indeed, a goal of many policies, including carbon pricing, is precisely to accelerate this shift. As in the case of damage functions, measurement is especially problematic in extrapolating outside the range of past experience.

Nevertheless, the SCC has played an important role in policy making. In the U.S., an Interagency Working Group on the Social Cost of Carbon was set up in 2010 to help comply with a presidential executive order that requires cost-benefit analysis of all 'significant' regulatory actions.[17] The Working Group used IAMs to compute SCC estimates that have been used in more than 40 regulatory impact analyses by the federal government (US Government Accountability Office, 2014). The average SCC for 2015 was $11 to $56/mt CO_2, depending on the discount rate, with a value of $105 used to test sensitivity to 'the potential for higher-than-average damages' (U.S. Environmental Protection Agency, 2015).[18] These official SCC estimates were taken to be 'binding' for policy evaluation by the director of the Office of Information and Regulatory Affairs in the Obama administration (Sunstein, 2014, p. 61). The Trump administration disbanded the Interagency Working Group in March 2017, but did not jettison the SCC altogether (Hess, 2017). Instead, in its regulatory impact analysis for the repeal of the Clean Power Plan, the U.S. Environmental Protection Agency (USEPA) increased the discount rate and excluded non-U.S. benefits of climate change mitigation, bringing the SCC down to $1–6/mt CO_2 (Mooney, 2017). In other words, the 'optimal' carbon price was redefined to one that would add $0.01–0.06 to the price of a gallon of gasoline.

3.3. Carbon Prices Based on the Paris Goal

An alternative way to decide upon the right carbon price is to base it on the cost of meeting emission targets consistent with the Paris goal of holding global mean temperature to 1.5–2 °C above its pre-industrial level. Here the normative criterion is safety, not neoclassical efficiency. Under this approach, economists do not serve as arbiters of the proper level of emissions reduction; instead they play the more modest role of advising on the most cost-effective means to achieve this end.[19]

The safety criterion is the foundation of much environmental law. The U.S. Clean Air Act, for instance, directs USEPA to set air quality standards for 'the protection of public health and welfare' while 'allowing an adequate margin of safety' – not to decide on standards by

[16] For a more extensive discussion of discount rates in the assessment of climate damages, see National Academies of Sciences, Engineering, and Medicine (2017), chapter 6.

[17] Executive Order 12866 issued by President Clinton on September 30, 1993. The original cost-benefit analysis mandate was issued by Executive Order 12291 issued by President Reagan on February 17, 1981.

[18] A meta-analysis by Van den Bergh and Botzen (2014) concluded that the appropriate lower bound of the SCC is $125/mt CO_2, higher than the upper-bound value prescribed by the Interagency Working Group. This contrast illustrates the sensitivity of SCC estimates to underlying assumptions not only on the discount rates but also on damage functions and the treatment of uncertainty and risk aversion.

[19] One way to characterize the difference between ecological economics and neoclassical economics is to say that the former treats some environmental limits as constraints rather than variables.

weighing marginal benefits against marginal costs.[20] The U.S. Supreme Court ruled unanimously in the case *Whitman v. American Trucking Associations* in 2001 that the Clean Air Act does not allow for exemptions based on compliance costs.[21] In the historic 5–4 decision that cleared the way for federal climate policies, the Court ruled in the case *Massachusetts* et al. *v. Environmental Protection Agency* in 2007 that the Clean Air Act gives USEPA the authority to regulate greenhouse gas emissions. When deemed 'significant' these regulations must pass through a cost-benefit screen, as mandated by presidential executive order, but the legal basis for U.S. climate policy therefore is safety.

Of course, there always will be some arbitrariness in delineating what qualifies as 'safe.' The 2 °C policy target, which can be traced to the early 1990s, was formally endorsed by UN Framework Convention on Climate Change in 2012 (Knutti et al., 2016). Two degrees has been criticized by some analysts (mostly scientists) as being too high, and by others (mostly economists) as being too low (Randalls, 2010). Dozens of nations, led by the Alliance of Small Island States and the least-developed countries, have advocated a more stringent 1.5 °C target (Rogelj et al., 2015). This led to the Paris Agreement's definition of the goal as 'holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C' (Schleussner et al., 2016). Today this goal serves as 'an easily understood, politically useful marker to communicate the urgency of the climate change problem and to drive action on a global scale' (Karmalkar and Bradley, 2016, p. 2).

In addressing the how-safe-is-safe question, scientists and international climate negotiators may be better placed than economists to decide. Moreover, unlike the neoclassical efficiency criterion, a safety standard does not pose the information problems of estimating marginal damages and abatement costs across the whole range of possibilities. For these reasons, some economists have chosen to frame their climate policy advice in terms of cost-effectiveness of the means of reducing emissions, rather than optimal choice of policy goals (see, for example, Van den Bergh, 2010; Söderholm, 2012; Aldy et al., 2016; Stiglitz and Stern, 2017; Bak et al., 2017).

Fig. 2 illustrates the potentially large differences between a price trajectory prescribed by an IAM and one based on a hard emissions target. The estimates come from a study by Nordhaus (2017a), who compares the SCC derived from DICE (the Dynamic Integrated Model of Climate and the Economy) to the price that he estimates would be required to limit global mean temperature increase to 2.5 °C.[22] The 'welfare-optimizing' SCC rises from \$37/mt CO_2 in 2020 to about \$100 in 2050. The temperature increase in this optimal trajectory would be 3.5 °C by the turn of the century, and rising thereafter.[23] The price required to achieve the 2.5 °C maximum starts more than six times higher at about \$230/mt CO_2 in 2020, rising to about \$1000 in 2050. The gap between these trajectories would be even wider if the temperature constraint was the 1.5–2 °C Paris target.

In practice, the cost of meeting the Paris goal (or any fixed emissions target) is unknowable, since it will depend on how abatement costs change over time. For example, if there are carbon price thresholds beyond which fossil fuels would be quickly replaced by alternative energy, extrapolation from cost curves based on lower levels of abatement may be unwarranted. On the other hand, it is possible that marginal abatement costs would rise more sharply as emissions are cut more deeply. This uncertainty is a reason to set the quantity of emissions and let prices adjust, rather than setting the price and hoping it will lead to the desired quantity of emissions.

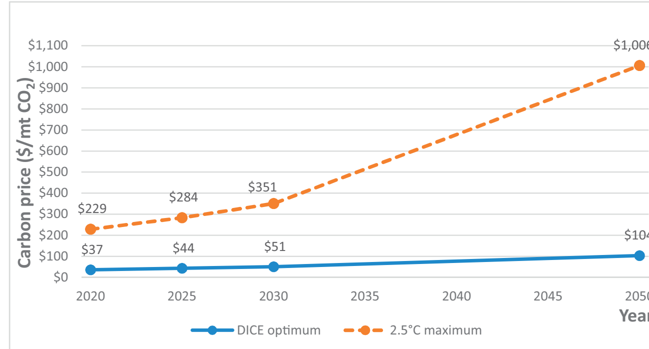

Fig. 2. Carbon price paths.
Note: Global CO_2 price in 2010 US dollars.
Source: Data from Nordhaus (2017a), Table 1.

4. How to Price Carbon

A carbon price can be implemented via a tax or a cap on emissions. The compliance entities that pay the tax or surrender a permit for each ton of emissions can be firms that bring fossil fuels into the economy or downstream users. Permits in a cap-and-permit system can be tradeable or non-tradeable, depending on whether they are allocated for free or auctioned. Carbon prices could vary across nations or be internationally uniform. This section considers these implementation issues.

4.1. Tax or Cap?

The reduction in supply of fossil fuels resulting from a mandated limit (a cap) on their use will lead to a rise in their prices; and the rise in prices will lead to a reduction in the quantity demanded. The magnitudes of these effects are less obvious, however, especially over time frames long enough to allow for technological and institutional changes. Hence the relationship between carbon prices and emission quantities cannot be known with certainty in advance.

Past experience may provide some guide as to what we can expect. A meta-analysis of empirical estimates of the price elasticity of energy demand, based a review of hundreds of studies published between 1990 and 2016, found an average short-run elasticity of −0.21 and an average long-run elasticity of −0.61 (Labandeira et al., 2017). That is, a 10% increase in energy prices resulted, on average, in a 2.1% decline in the quantity consumed in the short run and a 6.1% decline in the long run. This inelasticity reflects the reality that energy typically is a necessity rather than a luxury. The authors observe that price elasticities reported for recent years are closer to zero than earlier ones, and they speculate that this may reflect the depletion of less expensive abatement options in the wake of previous energy crises.

Different studies reported a wide range of elasticity estimates. In a sample of 959 estimates, long-run elasticities ranged from −1.81 to +0.15, with a mean of −0.52 and a standard deviation ± 0.39. These variations can be attributed to differences across energy products, locations, time, and estimation techniques. They also may reflect differences in public policies. Investment in public transportation, for example, makes it easier for consumers to curtail automobile use in response to higher fuel prices. Hence there is a considerable uncertainty as to price elasticities of demand, especially over the long run. Moreover, past experiences do not necessarily provide a reliable guide to future price responsiveness.

The centrality of the goal of reducing emissions, coupled with

[20] 42 U.S. Code § 7409 - National primary and secondary ambient air quality standards, section (b)(1).

[21] For discussion, see Mills (2002).

[22] Nordhaus dismisses the 2 °C target as 'infeasible.' In contrast, Millar et al. (2017) conclude that even a 1.5 °C target is technically achievable, albeit ambitious. A probabilistic forecast based on current mitigation policies by Raftery et al. (2017) estimates, however, that there is only a 1% chance that the Paris goal of 1.5–2 °C will be attained.

[23] Nordhaus (2017b), Fig. 4 and Table A-5). To put this number in perspective, the last time the Earth experienced mean temperatures 3.5 °C above pre-industrial levels was about 125,000 years ago, long before the advent of cave painting (about 40,000 years ago) or agriculture (about 10,000 years ago). Global sea levels were about 6 m higher than at present.

uncertainty as to the relationship between quantity and price, provides a compelling argument for setting the quantity trajectory and letting prices adjust, rather than vice versa. Hard quantity targets can be built into carbon pricing policy in either of two ways:

- The most straightforward way is to cap total emissions. The annual cap declines over time; each year the number of permits is set by the cap. During economic booms, when energy demand is high, the permit price will be higher than during recessions. If energy-saving technological change proceeds rapidly, their price will be lower than if it is slow. Regardless, the cap ensures that the target met.
- A second way to achieve this is by means of a carbon tax that adjusts automatically in response to differences between actual emissions and quantity targets. Switzerland has done this in its CO_2 levy on power plants. In proposing such a policy, which they call a Tax Adjustment Mechanism for Policy Pre-Commitment (TAMPP), Hafstead et al. (2017) observe that a rules-based approach (where targets and adjustments are specified in initial legislation) is more reliable than a discretionary approach (that would require new legislation for each change in the tax rate). They recommend adjusting the tax rate annually or biennially, with the extent of adjustment depending on the difference between actual emissions and targets. In addition to these sensible prescriptions for TAMPPing down emissions, it is important that the initial tax rate be sufficiently high, lest adjustments mandated as percentage of the current rate prove to be inadequate for reaching the targets.

In both these policies, the carbon price would be driven by emission targets. Otherwise there can be no assurance that carbon pricing – or any other policy – will yield the desired emissions reduction.

4.2. Upstream or Downstream?

Carbon pricing is most easily instituted upstream at the ports, pipeline terminals, and mine heads where fossil fuels first enter the economy. For each ton of CO_2 that will be emitted when the fuel is burned, the supplier turns in one permit or pays the tax. In the U.S., such an upstream system would involve roughly 2000 collection points nationwide (U.S. Congressional Budget Office, 2001). If the compliance entities were final consumers of fossil fuels, the administrative costs would be far greater.

Existing carbon pricing systems often have midstream compliance entities – power plants, large industrial facilities, or fuel distributors – that are located between fossil fuel suppliers and final consumers. When these entities are few in number, the administrative costs are tractable. Typically, however, midstream systems are less comprehensive than an upstream system would be since they do not cover all sectors. An advantage of an upstream system is that it treats all fossil carbon equally, regardless of where it is burned.

A convenient feature of fossil fuels is that carbon emissions can be calculated from the carbon content of the fuels prior to their combustion, eliminating the need for end-of-pipe monitoring of CO_2 emissions. In this respect, carbon differs from conventional pollutants such as sulfur dioxide, where emissions per ton of fuel may vary depending on fuel quality and pollution control equipment. This feature of carbon makes it feasible to adopt an upstream pricing system.

Regardless of the compliance entities, the carbon price will be passed through to final consumers. When the cost of coal goes up as a result of carbon pricing, for example, the cost of electricity goes up accordingly. It is not the upstream or midstream compliance entities who ultimately pay the carbon price. This cost pass-through is a predictable and desirable feature of carbon pricing – it is not a 'bug' – since this is what sends the price signals for users to reduce their carbon footprints.

Prices to final users rise when the quantity of fossil fuels entering the economy is restricted, regardless of whether this results from a carbon pricing system. When OPEC restricts production, for example, oil prices rise. In this case, the extra money paid by consumers flows to the cartel. Similarly, if a country were to decide simply to 'keep the oil in the soil,' a slogan popular among climate activists, prices at the pump would rise. In this case, the extra money would flow to whoever continues to produce oil. Carbon pricing distinctive not only because it is motivated by the goal of climate protection, but also because it opens up other possibilities for allocation of the extra money that is paid by consumers (see Section 5).

4.3. To Trade or Not to Trade?

A cap-and-permit system is not necessarily a cap-and-trade system. Most permits – parking permits, for example, or driving permits, building permits, hunting and fishing permits – are not tradeable. There is no inherent reason why carbon permits ought to be different. The reason that 'cap-and-trade' became an important phrase in climate policy (so much so that it is sometimes mistakenly assumed to be synonymous with cap-and-permit) is that early pollution permit systems, such as the U.S. sulfur dioxide program for power plants and the EU ETS, gave the permits to firms free-of-charge by formulae based on historic emissions. For reasons of cost effectiveness free permits must be tradeable, allowing firms with higher abatement costs to purchase them from firms with lower abatement costs. If permits instead are auctioned, there is no need for trading, particularly when unused permits can be banked for use in subsequent periods.

Cap-and-trade has several drawbacks. First, it introduces possibilities for market manipulation and speculation. Second, it multiplies administrative costs. Third, it diverts some fraction of the money that users pay in higher fuel prices into trader profits, at the opportunity cost of other potential uses for these funds. Finally, the permit giveaways that make trading necessary mean that permit recipients receive windfall profits.

A variant of permit trading involves the creation of 'offsets,' whereby carbon polluters can pay for emissions reduction elsewhere (or carbon sequestration) as a substitute for surrendering a permit. However appealing offsets may be on cost-effectiveness grounds, they are beset by the practical difficulties of verification and additionality, and they can create perverse incentives for firms to increase baseline emissions in order to garner more payments.[24] Unless these problems can be effectively resolved, offsets risk turning the emission cap into a sieve. An alternative strategy is to pursue other policies for emissions reduction or sequestration independently, so that their impacts come on top of, rather than instead of, the reductions mandated by the cap.

4.4. A Uniform International Price?

In the absence of an international agreement there will not be a uniform world carbon price, whatever appeal uniformity may hold in theory (Weitzman, 2014; Aldy et al., 2016). Experience suggests that it is more likely that individual nations (or subnational units or regional bodies) will continue to establish carbon pricing policies independently with prices that vary across systems.

Apart from the practical difficulties of reaching any international agreement on a carbon price, different polities may have sensible reasons to prefer different prices. In effect, a uniform international price would allocate the Earth's remaining carbon space on the basis of ability to pay: high-income countries would be able to afford more space than low-income countries. The low-income countries may regard such an allocation as inconsistent with the United Nations Framework Convention on Climate Change (UNFCCC) provision that countries will reduce emissions according to their 'common but differentiated

[24] For discussion and proposals for potential remedies, see Bushnell (2010) and Bento et al. (2016).

responsibilities and respective capacities,' a formulation that implies that higher-income countries should do more, not less, to curb emissions.

The air quality benefits of reduced fossil fuel use may provide a further rationale for price differentiation (Boyce, 2018). Insofar as air quality hazards due to fossil fuel combustion are more severe in some low- and middle-income countries, they might prefer to have higher carbon prices.

In any case, prospects for carbon pricing need not hinge on joint international action. Air quality co-benefits alone may be sufficient for a country to decide to adopt it. And if the revenues from carbon pricing are returned to the public as dividends, the policy's net financial impact can be positive for the majority of each country's residents, as discussed in the next section.

5. Distributional Impacts of Carbon Pricing

The sums generated through carbon pricing could be large, especially if the price is high enough to bring about emission reductions commensurate with the Paris goal of 1.5–2 °C warming. A simple calculation will illustrate the possible order of magnitude. CO_2 emissions from fossil fuel combustion in the U.S. currently amount to about 5.2 billion mt/yr. At $230/mt CO_2 (the 2020 carbon price in the 2.5 °C trajectory depicted in Fig. 2), carbon revenue could be in the neighborhood of $1 trillion/yr, the exact amount depending on the extent of the resulting impact on demand. Moreover, total revenue will increase as the cap tightens over time if the long-run demand for fossil fuel remains price-inelastic. Who pays and who receives the money will pose important distributional questions.

5.1. Transfers Versus Resource Costs

The higher prices paid for fossil fuels as a result of carbon pricing – a scarcity rent, hereafter termed 'carbon rent' – result in a transfer, not a resource cost. The carbon rent is not spent to abate emissions; it is the extra paid for fossil fuel use that is *not* abated. The money is not used to produce the fossil fuels, nor does it simply disappear. It is transferred.

The resource cost of reducing emissions via investments in energy efficiency or alternative energy may prove to be relatively modest. In an analysis of the 2009 Waxman-Markey bill, the U.S. Congressional Budget Office estimated that abatement costs in the year 2020 would amount to about $0.18/person/day (U.S. Congressional Budget Office, 2009).[25] Energy Secretary Steven Chu famously compared this to the cost of a postage stamp.[26] As emissions are reduced further over time, it is conceivable that abatement costs will decline rapidly enough so that total energy spending remains more or less constant as a fraction of national income.[27] Even if abatement costs rise, however, the carbon rent – the carbon price multiplied by the quantity of emissions not abated – will exceed the abatement cost until emissions have been cut radically.[28]

If carbon permits are given away free-of-charge to firms, the carbon rent transfer is received by the firms as windfall profits. Prices to end users rise as firms pass through the market value of the permits they surrender; using a permit to pollute means losing the revenue they would get from selling it.[29] If carbon permits are auctioned and the government retains the money (or retains the revenue from a carbon tax), the transfer flows to the government which can use it to fund government expenditures or cuts in other taxes. If carbon permits are auctioned (or carbon is taxed) and the money is distributed to the public as equal per-person dividends, the result is a net transfer from those with above-average carbon footprints to those with below-average carbon footprints.

5.2. Incidence of Carbon Pricing

Not everyone pays the same amount as a result of carbon pricing. Household carbon footprints vary with their direct consumption of fossil fuels and their indirect consumption via goods and services that use fossil fuels in their production or distribution. Those who consume more pay more, those who consume less pay less. Apart from households, governments are large final users of fossil fuels and they pay, too.[30]

Those households with the largest carbon footprints tend to be in the upper range of the income distribution. So, in absolute terms, they generally pay more than low- and middle-income households. Relative to their household income and expenditure, however, upper-income consumers generally pay less.[31] Fig. 3 shows the distributional incidence of a $200/mt CO_2 tax in the U.S. In the lowest household expenditure quintile, the tax would claim more than 12% of household expenditure; in the top quintile, less than 9%. The impact of the tax on household real incomes thus would be large and regressive.[32] It also would be quite visible.[33]

The reactions of consumers when faced by sharply increasing prices for fossil fuels could generate a backlash that jeopardizes the carbon pricing policy's political sustainability. Whether this happens may depend, however, on where the money goes.

5.3. Carbon Dividends: Net Impact on Vertical Inequality

If a substantial share of the carbon rent is rebated to the public as equal per-person dividends, the net impact of the carbon pricing policy turns progressive. This is illustrated in Fig. 4, which shows the impact of the $200/mt CO_2 tax when all the revenue is disbursed as dividends. The lowest quintile receives a positive transfer, net of the extra money they spend as a result of the carbon price, equivalent to 20% of their household expenditure. The top quintile sees a negative net transfer equivalent to 3% of theirs.

Carbon dividends are an example of a 'feebate': individuals pay fees in proportion to their use of a commonly owned resource, and the money is returned as equal rebates to all co-owners. In the case of carbon dividends, the common resource is the atmospheric carbon sink. The incentive for households to reduce their use of the resource – here,

[25] This estimate is obtained by dividing the CBO's estimated 'net annual economy-wide cost' of $22 billion/yr by the US population. In addition to resource costs of energy efficiency and alternative fuels, the CBO estimate includes costs for the purchase of international offsets and the production cost of domestic offsets.

[26] Chu testimony before the Senate Committee on Environment and Public Works, July 7, 2009.

[27] This outcome would be in keeping with Bashmakov's (2007) 'first law of energy transitions.' For discussion, see Grubb et al. (2014).

[28] To see why, let pre-policy emissions = E. Imagine a carbon price, P, that yields a 20% reduction in emissions. At this point, the marginal abatement cost = P. The average abatement cost, A, is less than P. The total resource cost, $0.2E * A$, is necessarily less than the carbon rent, $0.8E * P$. More generally, letting e = the percentage reduction in emissions, the carbon rent will exceed the resource cost as long as $P/A > e/(1 - e)$.

[29] Countervailing policies could limit or eliminate these windfall profits. For example, government regulators may prevent electric utilities from raising prices to consumers, albeit with the side effect of vitiating the price signal to end users of electricity. Governments also can tax windfall profits.

[30] In the U.S., for example, federal, state and local government account for roughly one-fourth of total fossil fuel use. An important issue in carbon pricing is whether, and if so, how, some of the carbon rent will be recycled to 'keep government whole' (Boyce and Riddle, 2008).

[31] This is true in industrialized countries where fossil fuels are a necessity rather than a luxury. In settings where fossil fuels are a luxury, perhaps including many low-income countries, the incidence of carbon pricing is progressive; see, for example, Brenner et al. (2007) and Datta (2010) on China and India, respectively.

[32] The measured extent of regressivity depends, among other things, on whether household income or expenditure is taken as the base for calculations (Hassett et al., 2009). It also may depend on whether inflation-indexed changes in government transfer payments are taken into account (Cronin et al., 2017).

[33] For evidence on the keen awareness of fuel prices among the U.S. public, see Ansolabehere et al. (2012).

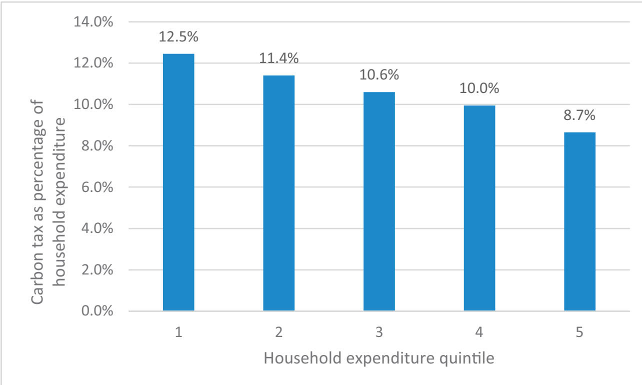

Fig. 3. Incidence of $200/t CO_2 tax in U.S.
Note: Based on consumer expenditure survey data for 2012–2014.
Source: Calculated from data presented in Fremstad and Paul (2017), Table 10.

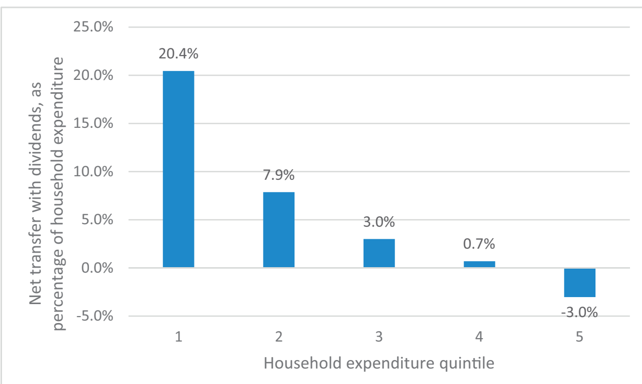

Fig. 4. Net incidence of $200/t CO2 tax coupled with dividends in U.S.
Source: Calculated from data presented in Fremstad and Paul (2017), Table 10.

their carbon footprints – is not diminished by rebates since their individual use only affects what they pay, not what they receive.

Upper-income households, who typically have the largest carbon footprints, generally would pay more than they get back. Lower-income households, who typically have the smallest carbon footprints, would get back more than they pay. Middle-income households would roughly break even, thus being protected from adverse impacts on their net incomes. The result of the policy is a decrease in vertical inequality.

It is possible to divide the carbon revenue between dividends and other uses, such as public investment (for examples, see Burtraw and Sekar, 2014). This would alter the magnitude of the distributional effects depicted in Fig. 4, but their progressive net impact would persist as long as the fraction going to dividends remains sufficiently large.[34]

5.4. Carbon Dividends: Net Impact on Horizontal Inequality

Although a carbon dividend policy would be progressive in its net impact on the vertical distribution of income, there can be significant variations within any given household income stratum. Continuing with the U.S. example, Fig. 5 shows the percentage of households in each quintile that would receive positive net transfers. In the poorest quintile, seven of eight households come out ahead – the dividends they receive would exceed what they pay as the result of carbon pricing – while in the top quintile, 72% pay more than they get back.

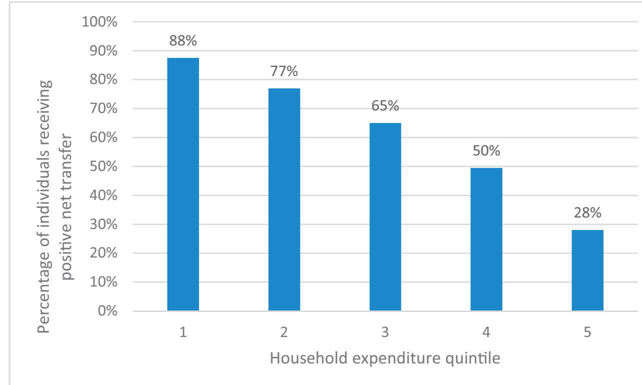

Fig. 5. Percentage of individuals receiving positive net transfers from $200/t CO2 tax coupled with dividends in U.S.
Source: Calculated from data presented in Fremstad and Paul (2017), Table 10.

The reasons for these horizontal variations may include circumstances that are largely beyond the control of households, such as rural-urban differences in vehicle use or regional differences in heating and air conditioning needs. On grounds of equity as well political acceptability, therefore, policy makers may wish to take such horizontal inequalities into account in allocating some fraction of the carbon rent.[35]

6. Conclusions

Carbon pricing is a key instrument in climate policy, since it can be tied to emission targets so as to guarantee that they are met. This feature sets it apart from other policy instruments. Carbon pricing creates incentives for cost-effective emission reductions in the short run and cost-reducing innovation in the long run. It can complement the use of other policy instruments, such as regulations and public investment. These can reduce the required carbon price if deployed skillfully. But just because emissions are legal within an existing regulatory framework does not mean they should be free.

Owing to uncertainty about the precise relationship between carbon prices and the quantity of emissions, especially over multi-year time frames that allow for technological change, the only way to ensure the effectiveness of carbon pricing in meeting emission targets is to bind the price to quantitative targets by means of an emissions cap or by indexing a carbon tax to the level of emissions relative to the target.

It is possible, indeed likely, that the resulting carbon prices will be high enough to have major impacts on the fossil fuel prices. If and when happens, the distributional impacts of the policy can be expected to emerge as an important issue. The net distributional impact will depend crucially on the allocation of the carbon rent, the extra money paid by end users as a result of the carbon price. Rather than transferring this money to firms (as in a cap-and-trade system with free permits) or to the government (as would happen if permit auction or carbon tax revenue goes to the treasury), part or all of the carbon rent could be returned to the public via equal per capita dividends. Carbon dividends would be consistent with the ethical premise that the gifts of nature belong to all in common and equal measure. The dividend option is attractive on equity grounds, and by protecting real incomes for the majority of people it could help to maintain public support for effective climate policy in the face of rising fossil fuel prices.

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[34] An alternative way to tap carbon rent for public investment is to make dividends taxable as income. The distributional impact of taxable dividends would be more progressive than funding equivalent public investment directly by carbon revenue, since the latter is tantamount to a regressive tax. See Boyce and Riddle (2008) for discussion.

[35] For further discussion, see Boyce and Riddle (2011) and Cronin et al. (2017).

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