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Review

State of the art in carbon taxes: a review of the global conclusions

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Abstract: Carbon taxes have been advocated as a key economic measure for the reduction of greenhouse gas emissions. The basis of this proposition, is the economic theory that applying a tax on carbon dioxide emissions is the "optimal" solution to addressing the market failure of externalities. In moving from theory to practice, the evidence from comprehensive global assessments, over the last three decades, covering actual policy experience and empirical study of policy effects, requires evolution and refinement of the theory. Carbon taxes are not adopted at the scale, coverage or price level necessary to effectively reduce emissions in line with the Paris Agreement. A persistent "implementation gap" has arisen, largely due to the political and social challenges that accompany taxation. Assessments of policy experience in key sectors of built environment, transport and industry, highlight the critical role of regulation, standards and technology among broader policy programmes. While a carbon tax can provide simplicity and scope, it is not sufficient on its own. Consistent with this finding, recent modelling innovations show that taxes can be employed as part of a portfolio of best practice policies and measures, for deep reduction of emissions. Portfolios can facilitate application of a lower, more "moderate" carbon tax, which enhances the social acceptability and political feasibility of the tax itself. When designing a tax, revenue recycling can help with policy resistance, delivering the "double dividend" of economic and climate gains, and addressing distributional considerations. A carbon tax may be useful to complement the broader portfolio of policies and measures accepted as necessary for long-term transition and transformation. It can offer support and prevent rebounds, but is not a substitute for the fundamental systems change that is at the core of addressing urgent sustainability crises.

Keywords: carbon tax; carbon pricing; greenhouse gas; climate change; mitigation; policy; green growth; regulation; transition; sustainable development

JEL Codes: H23, P48, Q01, Q38, Q50, Q54

Abbreviations: GHG: Greenhouse gas emissions; IPCC: Intergovernmental Panel on Climate Change; CO_2: carbon dioxide; COP: Conference of the Parties; UNFCCC: United Nations Framework Convention on Climate Change; US$/t$CO_2$e: United States dollars per tonne of carbon dioxide equivalent emissions; GCEC: Global Commission on the Economics of Climate Change; IMF: International Monetary Fund; DDPP: Deep Decarbonization Pathways Project

1. Introduction

The accepted conclusions of the science of climate change, that hardened particularly in the decade from 1980 to 1990, have now been followed by three decades of policy learning on practices to reduce greenhouse gas emissions (GHG). As the focus has moved from short-term emissions mitigation, to long-term transition and transformation, global policy development is evolving and accelerating. The Chilean presidency of the Conference of the Parties (COP), to the United Nations Framework Convention on Climate Change (UNFCCC), announced that 120 Parties are now working towards achieving net zero carbon dioxide emissions by 2050, as part of the "Climate Ambition Alliance" (World Bank, 2020). For the most significant greenhouse gas, carbon dioxide (CO_2), released predominantly during the combustion of fossil fuels—the economic measures have been central to the global policy discussion, with carbon taxes at its core.

As part of the discussion under the broad umbrella of economic measures in "carbon pricing", five initiatives can be gleaned: carbon taxes; emissions trading schemes; carbon crediting mechanisms; results-based climate finance and internal "shadow pricing"[1] (World Bank, 2020). The removal of harmful subsidies for the production and use of fossil fuels is widely regarded as a further essential step in implementing carbon pricing (Stiglitz and Stern, 2017; GCEC, 2018). In 1990, The Intergovernmental Panel on Climate Change First Assessment Report, specifically assessed the use of carbon taxes as a response strategy for the purpose of emissions mitigation (IPCC, 1990). The report suggested that taxes can potentially incentivise economically efficient emissions reduction, and generate revenues, but it also noted a number of key challenges that significantly hamper their use and effectiveness. The report highlighted that: (i) levels were not high enough to change behaviour, (ii) that there was general uncertainty on whether the tax would effectively reduce emissions, and (iii), that there were major practical difficulties in implementing a uniform tax at the global level[2]. Yet since this juncture, carbon taxes have remained a focal point for policy discussion on facilitating decarbonisation, and continue to play a key role in the "integrated assessment" modelling of the economics of reducing emissions (Rogelj et al., 2018).

A carbon tax is a form of tax levied on the content of carbon emissions embedded in fossil fuels, planet-warming emissions that are released upon combustion of coal, peat, oil and gas. Carbon dioxide emissions add further to the increasing stock in the atmosphere of this long-lived greenhouse gas. This process is the major driver of human-induced climate breakdown, resulting in significant costs to

[1]"Shadow pricing", is the assignment of a monetary value to an unpriced commodity, such as carbon emissions, in a cost-benefit analysis or in an impact assessment of an investment. It can used to "future-proof" public and private investment decisions. Mandatory disclosure of climate-related financial risks, are also often considered with the package of measures necessary to steer economies towards low-emissions development, and greener growth.

[2]Factors such as varying local price elasticities, tax structures and exchange rate fluctuations, were noted as making it "extremely difficult" to derive a uniform global tax that would limit or reduce emissions (IPCC, 1990).

current welfare, and puts future human and planetary wellbeing at risk of systemic failures, with even a small chance of catastrophic outcomes, as per Kolstad et al. (2014). In advocating the benefits of carbon taxes, the High-Level Commission on Carbon Prices noted that *"A well-designed carbon price is an indispensable part of a strategy for reducing emissions in an effective and cost-efficient way,*" (Stiglitz and Stern, 2017), and in theory it shifts the burden for damage back to those who cause it.

The origins of carbon taxes are in *Pigovian tax*, named after the economist Pigou, as a tax on the market activity that generates a "*disservice"*. This was later termed "*externalities*" by Coase (1960), as the social costs that are not reflected in the private market price. In theory, a Pigovian tax addresses the market failure by adding a levy onto the market price, to correct for the undesirable or inefficient market outcome, at a rate that reflects the social damage of the activity. The theory was taken up by economists such as Coase, Hayek, Ostrom and Baumol, generating theoretical debate on setting social costs, and most controversially in the case of the work of Coase (1960), the place of government intervention in markets[3]. The implementation of a carbon tax, to address the externality of the social damage caused by anthropogenic carbon dioxide emissions, has often been preferred in contemporary economic theory, as the "first-best" or "optimal" solution—the most economically efficient approach to reach ambitious climate targets (Bertram et al., 2015). Carbon taxes are not however without criticism. In political economy, the prioritisation of carbon taxes as an approach has been linked to a dominance of "climate capitalism" (Newell and Patterson, 2010), and to limited technocentric and economistic worldviews—arising from narrow monodisciplinary perspectives (Kirby and O'Mahony, 2018). In 2007, the conclusions of the IPCC fourth assessment report provided a significant challenge to placing a priority on carbon taxes, noting that carbon prices alone are insufficient, and that the necessary innovation requires government action (Barker et al., 2007).

This article is motivated by the observation that the literature providing evidence on actual experiences with carbon taxes are often split across a range of fields, and underappreciated in traditional economic settings. Similar to Klenert et al. (2018), who noted the narrow disciplinary limitations of reviews of carbon tax revenue recycling, a wide net is required to draw conclusions on the use, effectiveness and implications of carbon taxes. Consequently, this review places a particular emphasis on the successive global assessments of the IPCC, as already signed-off by global governments and appraised by voluminous expert review. This comprehensive synthesis literature, the gold standard in emissions mitigation, is further supported by reference to key practice literature, and the cutting edge empirical literature from models that explore the impacts of carbon taxes.

After the introduction in section 1, section 2 reviews the current status of carbon taxes globally, including general observations, and the conclusions from key sectors. Section 3 considers related issues, providing further context to considering and implementing a carbon tax: in the outcomes of recent modelling studies; evolution in the frames of analysis and policy for reducing emissions; and

[3]Coase work on *social costs* questioned Pigou's conclusions, and became deeply influential beyond economics, particularly in the ideological arguments of the US, on politics and law. Coase work was marshalled to provide ideological support against regulation, pejoratively termed "big government." This dogma rejected intervention, favouring reliance on the market to correct negative externalities, an approach that has since proven grossly inadequate to respond to sustainability crises. Coase was frustrated with the misunderstanding and misinterpretation of his work, even noting that regulation could on occasion improve efficiency. In his Nobel winning lecture, Coase (1991) was far more pragmatic in his claims, suggesting that the conclusions of the 1960 paper provided a stepping stone to critique of Pigovian taxes, and recommending that alternative institutional arrangements should be compared.

considerations relevant to the design of carbon taxes, and to options for the recycling of revenue. Section 4 discusses the findings of the review, and section 5 concludes.

2. Current status of carbon taxes globally

2.1. Implementation and general observations

While a globally applied tax may be suggested as the ideal, this is unlikely to be politically feasible, at least in the short term, and national and sub-national state implementation tend to be the channels of implementation. The World Bank "*State and Trends of Carbon Pricing 2020*" noted that there are currently 61 carbon pricing initiatives in place, or scheduled for implementation, consisting of 31 emissions trading systems and 30 carbon taxes (World Bank, 2020). Taken together, total carbon pricing covers 12 Giga Tonnes of CO_2 equivalent, or 22% of global greenhouse gas emissions, as illustrated in Figure 1. Half of all carbon prices are less than US$10 per tonne of CO_2 equivalent (US$/t$CO_2$e), with the IMF calculating that the global average carbon price is only US$2/t$CO_2$e (IMF, 2019). It is repeatedly noted that this price level, and coverage of emissions, are insufficient to drive the transformational change needed (GCEC, 2018; World Bank, 2020).

The High-Level Commission on Carbon Prices (Stiglitz and Stern, 2017) recommended that the global minimum price corridor towards the Paris temperature target is at least US$40–80/t$CO_2$e by 2020, and US$50–100/tCO_2e by 2030. Less than 5 percent of GHG emissions are currently covered by a carbon price within this range (World Bank, 2020). This recommended minimum carbon price corridor is in stark contrast to the actual average carbon price globally seen in Figure 2. It is important to emphasise, as noted by Stiglitz and Stern (2017), that studies have frequently proposed far higher carbon prices for consistency with long-term emissions targets, and that this minimum price corridor relies on more optimistic assumptions, such as on socio-economic development and the pace of technological change. The High-Level Commission noted that other policy measures are necessary, a conclusion also highlighted by the GCEC (2018). In keeping with this conclusion, de Coninck et al. (2018), in the IPCC 1.5 report, note that carbon prices may not suffice to trigger the low-carbon transition because of a persistent "*implementation gap",* between the aspirational carbon prices, and those that can practically be enforced.

In the IPCC Fifth Assessment Report Somanathan et al. (2014) provided general conclusions on carbon taxes, offering that they provide simplicity and scope, and are potentially more efficient than regulation, but that in practice they are not adopted as much as would be expected, and rarely at the higher levels considered "target-consistent". This comprehensive review concluded that lobbying from fossil fuel interests, high public visibility, risks to competitiveness and employment, as well as the distribution of costs and institutional path dependencies, are all challenges that hamper carbon taxes. They highlight that where market failures and psychological or institutional barriers prevent adoption, then regulations or other instruments may be efficient as a complement, or as stand-alone measures (Somanathan et al., 2014). They also highlighted that difficulties in implementing and increasing the explicit price of carbon—to levels that are actually target-consistent—increases the need for other policies and measures if emission are to be reduced.

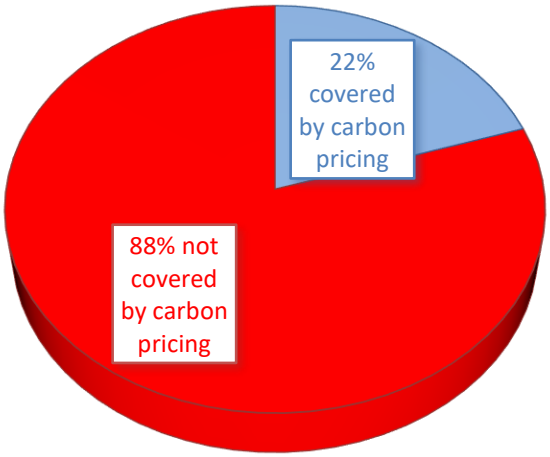

Figure 1. Percentage of global GHG in existing or scheduled carbon pricing schemes (World Bank, 2020).

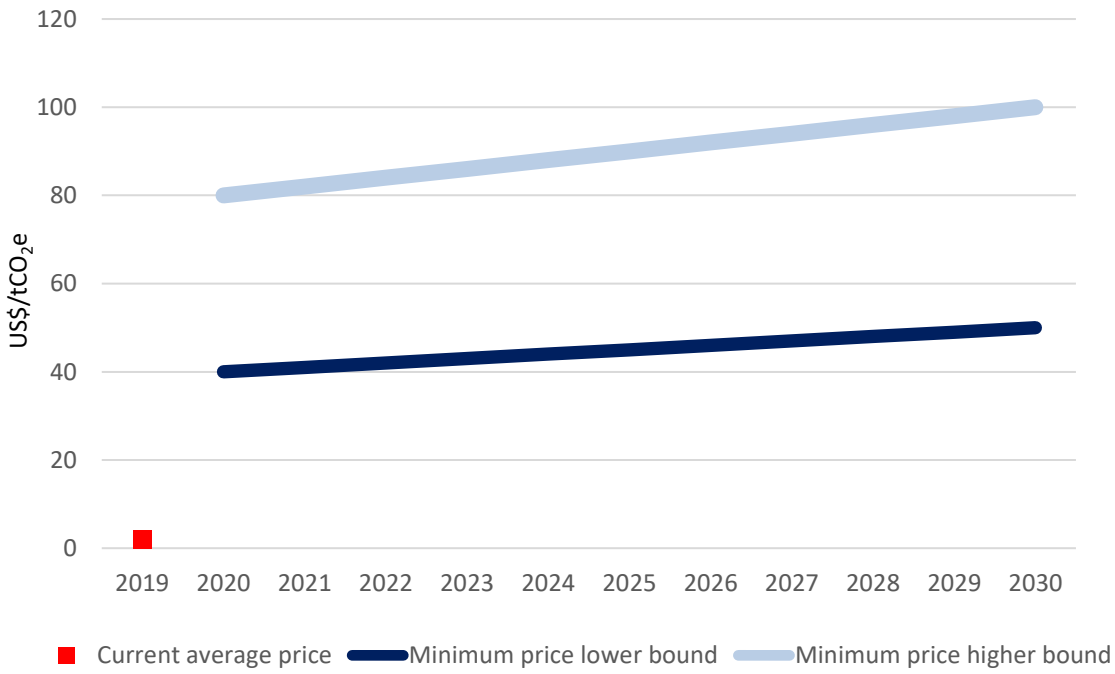

Figure 2. The current average carbon price (IMF, 2019), and recommended minimum carbon prices from 2020 to 2030 in Stiglitz and Stern (2017).

Figures 1 and 2 clearly illustrate that the gap in coverage and price level of existing carbon pricing schemes is less a corridor, and more a canyon, despite decades of initiatives to ramp up implementation. This gap increases in significance when noting that the coverage discussed includes the generous definition of both carbon taxes and emissions trading, in both existing and in planned schemes. In addition, the price corridor is at the lower -more attainable end of the range discussed in the literature.

2.2. Findings on carbon taxes from the key sectors

In contrast to the results of empirical studies that model future outcomes, the literature on existing global policy experiences shows that actual outcomes differ across the sectors, pointing to limitations in what carbon taxes achieve in practice. The conclusions of the IPCC reviews are useful here once more, in the context of the three key sectors for application of carbon pricing, the built environment, transport and electricity. For the built environment, Lucon et al. (2014) note that experience shows that pricing is less effective than programmes and regulation. In the case of transport, Sims et al. (2014) conclude that pricing is primarily useful to minimise the rebound, to offset the lower travel costs that arise from efficiency improvements. With electricity, Bruckner et al. (2014) note technology policies have proven successful in increasing the share of renewable energy technologies, and that carbon pricing can offer additional support in the long-term.

3. Carbon taxes in context: modelling results, policy evolution and designing a tax

3.1. The outcomes of modelling studies

The IPCC 1.5 report (Rogelj et al., 2018) point out it has been long argued that an explicit carbon pricing mechanism, by tax or cap-and-trade, can in theory achieve cost-effective emission reductions. Yet in addition to Somanathan et al. (2014) in the IPCC Fifth Assessment Report, it shows that the actual evidence has evolved. An emerging body of recent studies reviewed by Rogelj et al. (2018) include bottom-up approaches that focus on the interaction and performance of various policy mixes, including regulation, subsidies and standards. Among these, Kriegler et al. (2018) assume global implementation of a mix of best-practice policies, mostly regulatory initiatives in the electricity, industry, buildings, transport and agricultural sectors. This was combined with "moderate carbon pricing" in most world regions, between 5–20$2010/t$CO_2$ in 2025, and around 25$2010/t$CO_2$ in 2030. This produced early action mitigation pathways that reduced global CO_2 emissions by an additional 10 Giga tonnes of CO_2 equivalent in 2030, when compared to current policies. Chen et al. (2018) consider stricter "Minimum Energy Performance Standards" (MEPS) for the Chinese building sector, with a carbon tax, and concluded that more ambitious performance standards are central to triggering deep decarbonisation pathways.

Brown and Li (2018) analysed a 1.5 °C pathway specifically for the U.S. electricity sector. They analysed a mix of stringent energy efficiency policies, on the demand side, such as minimum performance standards and building codes. This was combined with a carbon tax that rises from 10$2010/t$CO_2$ in 2020 to 27$2010/t$CO_2$ in 2040. Brown and Li (2018) concluded that combining regulation with a carbon tax is actually more cost-effective than a carbon tax alone. The study of Bertram et al. (2015) considered a global policy mix that included a ban on new coal-based power plants, dedicated policies for renewable electricity and electric vehicles, and a moderate carbon price of 7$2010/t$CO_2$ in 2015. Bertram et al. (2015) found that this combination reduces efficiency losses compared with an optimal carbon pricing in 2030, and closes the gap on action to meet reduction targets when carbon prices are too low. Sonnenschein et al. (2018) implemented a bottom-up study, of stringent "minimum energy performance standards" for appliances, combined with carbon pricing. They showed that tightened standards can achieve ambitious efficiency improvements that may not be delivered by carbon prices alone, even at values of 100$2010/t$CO_2$ or higher. Another study noted by

Rogelj et al. (2018) considered the reduction in the required price of carbon, that a combination policy mix might enable. Méjean et al. (2018) found that carbon prices in high energy-intensive pathways are 25–50% higher than in low energy-intensive pathways—which assume ambitious combination with regulatory instruments, economic incentives and voluntary initiatives.

The conclusion of Méjean et al. (2018) is consistent with the review of modelling studies in Mundaca et al. (2019), who pointed to lower energy intensity pathways as implicitly involving lower costs, and a better chance of meeting emissions targets. The problem articulated by Mundaca et al. (2019) is that current quantitative tools and progress indicators do not "see" many of the measures that this involves. This limitation means that the conclusions of current studies, that envisage high costs of mitigation, and/or high carbon prices, may be artefacts of how the studies themselves are constructed. This could occur where there are limited alternative scenario assumptions, or where models do not have systems change capabilities. It is critical to address these limitations of model-centric studies, as the unseen measures involve a far more rich panorama than improving technical energy efficiency and decarbonization alone (O'Mahony and Dufour, 2015; Kirby and O'Mahony, 2018). Model-centric studies often do not address change in fundamental drivers, or underlying processes, such as change in spatial patterns, or major shifts in transport modes, consumption patterns or human values. This is the realm of sustainable development pathways, and requires integrated qualitative/quantitative scenario analysis, rather than relying on quantitative modelling and analysis alone (O'Mahony, 2014; Morita et al., 2001).

3.2. The policy and analysis evolution, from cost-effectiveness to "systems thinking" and sustainable development paths

A seperate line of evidence that allows triangulation of these conclusions, is found in the literature assessing driving forces and emission scenarios. These are part of a wider literature that demonstrates that *sustainable development pathways* more generally are necessary to meet targets, reduce costs, increase feasibility and harness the benefits and opportunities -to maximise synergies and minimise tradeoffs (Sathaye et al., 2007; Fleurbaey et al. 2014). It is well accepted that these pathways are wider than climate-specific energy and emissions policy, and involve the "*systems thinking*" of sustainability science. Sustainable development pathways encompass the broad processes of development[4], and include actors across government, the private sector, NGO's and civil society, in "governance". Emissions mitigation has evolved significantly in the last twenty-five years, shifting from the economic lens of cost effectiveness, to wider systems thinking on sustainable development pathways, and the related processes of transition and transformation. Where development paths are pursued that are inherently less energy and emissions intensive, such as e.g. avoiding inefficient urban sprawl, it is implicit that the cost to mitigate remaining emissions are lower, as alluded to by Mundaca et al. (2019). This line of literature states that transition must begin with overall development, rather than with mitigation, and that the long-term low-carbon transition and transformation may not be possible without this approach. This literature, assessing development paths, driving forces and the wider range of policies and measures available to reduce emissions, supports a defining observation—that meeting

[4] Development paths are defined as a complex array of technological, economic, social, institutional, cultural, and biophysical characteristics that determines the interactions between human and natural systems, including consumption and production patterns in all countries, over time at a particular scale. See Sathaye et al. (2007).

the Paris Agreement commitments requires more than carbon taxes, or indeed economic measures. It also has major implications for the costs of reducing emissions in the long-term (Sathaye et al., 2007).

Related to this move towards systems thinking in conceiving policy, a related change has occurred in the evolution of policy objectives and evaluation criteria. It is no longer sufficient to consider just the cost-effectiveness of policies, it is necessary to consider four broad categories: economic, distributional/ fairness, environmental and institutional/political feasibility (Kolstad et al., 2014)[5]. This conclusion has intensified in recent years, and has led to emphasis on the importance of political, institutional, social and cultural factors in each individual national context. This wider perspective is not only relevant to the broad landscape of transition and transformation policy, and to policy and evaluation criteria, but it is specifically relevant to the design and implementation of carbon taxes, and is discussed below.

3.3. Carbon tax design and revenue recycling

The discussion in the previous sections highlights that designing a carbon tax includes two important considerations: (i) the balance and relationship with the other emissions reduction measures that are necessary in parallel, and (ii), the rate at which it is implemented and increased. Another key consideration is the form of "revenue recycling", in how the revenue generated is used. The review of Somanathan et al. (2014) note that as an emissions tax involves a transfer from economic agents to the state, it involves private parties bearing the cost of reducing emissions, and that this can generate policy resistance from polluters. As exemptions may be economically inefficient, this can be overcome by designing the tax to avoid the transfer—through revenue recycling.

An important conclusion from the economic literature is that the conditions for an economic benefit, along with a climate benefit, a "*double dividend*", are well documented (de Coninck et al., 2018)[6]. Rogelj et al. (2018) highlight that the revenue recycling effect of carbon pricing can lower the costs of reducing emissions, by displacing other distortionary taxes, and also that lowering capital tax can yield greater savings in welfare costs. The optimal recycling scheme differs based on the structure of the economy (Lefèvre et al., 2018), but there are other considerations that also need recognition. Central to these are issues of social justice, not just *climate justice* and *climate ethics* globally[7], but also of energy justice for citizens subject to the carbon tax. A carbon tax can disproportionately affect those experiencing poverty, or on lower incomes, and designing a carbon pricing policy, in all cases, involves a balance between incentivising low-carbon behaviour, and mitigating the adverse distributional consequences of higher energy prices (de Coninck et al., 2018). These effects can be

[5]The IPCC AR 5 in Kolstad et al. (2014) expands on policy objectives and evaluation criteria to: economic objectives (economic efficiency, cost-effectiveness and transaction costs); distributional objectives (six distributional effects including environmental justice); environmental objectives (environmental effectiveness, co-benefits and carbon leakage); and institutional and political feasibility (administrative burden and political feasibility).

[6]See e.g. Goulder (1995) for more discussion of the double dividend.

[7]Issues of *climate justice* arise in the need to reduce emissions rapidly, to avoid the inequitable impacts of climate change, which already impact those least able to respond the most. They also arise in the need to provide assistance to adapt to the changes that will inevitably occur, due to historical emissions primarily from the industrialised nations. C*limate ethics* are also relevant, and encompass the intrinsic value of the natural world itself, rather than only addressing a partisan human-centred "anthropocentric" climate justice.

offset if revenues are redistributed through rebates to poor households, reduction of value-added taxes on basic products, or direct benefit transfers that enable poverty reduction.

A useful discussion in Klenert et al. (2018), proposes four main options for utilising revenue: (i) flowing directly to the exchequer; (ii) reducing income taxes; (iii) lump-sum quarterly transfers to households; and (iv) funding green investments. These were outlined in eight individual and hybrid options for revenue recycling and allocation across firms, households and the government budget. It noted that while exchequer revenue and reducing income taxes have tended to garner most attention, direct transfers and green investments are now receiving more analytical and policy focus internationally. The article provides hybrid insights from public finance theory, integrated assessment models, behavioural economics and political science, and reviewed practices in selected countries. Klenert et al. (2018) noted that while schemes differ widely, they could highlight two commonalities: firstly, that several important economic actors are compensated, and secondly, some form of transfer exists to compensate those especially hurt by higher carbon prices, such as rural or low-income households.

Klenert et al. (2018) concluded that analytical and numerical models of efficiency and productivity gains serve only as a benchmark, and that it is the social and political context that must take precedence for successful implementation. This inevitably involves engaging with the tradeoffs of economic efficiency and equity, where policymakers find an appropriate balance, in a broadly ideal approach. This process of delivering synergies and managing trade-offs requires more than theory, or narrowly defined optimal quantitative modelling studies. Failing to maximise synergies and manage tradeoffs is inherently a more costly approach, and makes reaching deep emissions reduction less feasible (Fleurbaey et al., 2014) The resulting higher emissions paths will miss opportunities for green growth and improvements in wellbeing and sustainability. Addressing this blindspot, requires a strategic policy process taking the different dimensions of the challenge together, to mainstream sustainability throughout the development path.

4. Discussion

In traditional economic settings, it is often assumed that carbon prices are the optimal route to reducing emissions (Bertram et al., 2015), or more specifically public finance theory holds this interpretation (Klenert et al., 2018). Yet decades of empirical study and actual policy experience do not support this as a hard principle or axiom. Table 1 provides a summary of the key conclusions from the global review. A carbon tax is not always the most efficient option, and it is usually more difficult to implement than regulation. In keeping with the conclusions of Barker et al. (2007), de Coninck et al. (2018) more recently deemed that pricing initiatives incentivise incremental change "…*but typically fail to provide the impetus for private actors to take the risk of engaging in the transformational changes that would be needed to limit warming to 1.5 °C*." This leads to the IPCC conclusion that pricing alone is insufficient, consistent with its fourth and fifth assessment reports, and with the consensus in the Stiglitz and Stern (2017) report, and in the Global Commission on the Economics of Climate Change (GCEC, 2018) update. It is now well established that a mix of policies and measures is required to reduce emissions in line with limiting global heating to 1.5 or 2 °C, as committed to in the Paris Agreement to the UNFCCC.

The global literature has evolved to conclude that a mix of measures can provide a more cost-effective approach, particularly in less energy intensive sustainable development pathways. This approach can also be used to set a more moderate target-consistent carbon price. This is significant, as it has proven practically

challenging to increase carbon taxes to the minimum levels considered necessary by the High-Level Commission on Carbon Prices (Stiglitz and Stern, 2017). Meeting the objective of deep emissions reductions first requires implementation of a range of nationally appropriate policies and measures, that can deliver a long-term process of transition and transformational change, in a sustainable development pathway (Fleurbaey et al., 2014). A carbon tax can be a complimentary approach to pursuing sustainable development paths, and implementing specific policies and measures such as regulations, standards and technology policies. This is borne out by actual policy experiences in the built environment, transport and electricity, where carbon taxes have been shown to offer a supporting role, and to prevent rebound.

The challenge of social acceptability and political feasibility continues to attend the development and implementation of carbon taxes, as they are highly visible economic instruments, attracting resistance from the vested interests of polluting firms, and from some citizens. The emergence of the *Gilet Jaunes* in France in 2018, and the collapse of carbon pricing in Australia under the Abbott government in 2014, are cautionary tales of the problems that can arise. However, implementing carbon taxes are a useful compliment. The combination of approaches offers the potential to assist the deepening of the required emissions reductions, and assisting in delivering the "double dividend" of economic benefits and emissions reduction. A combination of measures is also more socially acceptable, and politically feasible, as it requires lower carbon prices (Bertram et al., 2015).

In the study of Wakiyama and Zusman (2016) it was noted that stimulating emissions reductions, in the iron & steel, chemical, and machinery industries of Japan, requires policymakers to tailor the rates and revenue recycling provisions to an industry's unique features. In graduating to more broadly applicable conclusions, to design a tax, it is not only the rate or its increase that is important. The choice of the channel to direct revenues has major implications for how it is perceived by the public, its impact on equity considerations and on costs. Taken together, these are strategic policy considerations which require an appropriate balance to be struck, particularly with respect to more economically vulnerable groups. A widening of the lens beyond economic theory, or the cost-effectiveness at the traditional core of environmental economics, is now widely accepted as necessary for the reduction of emissions (Kolstad et al., 2014; Fleurbaey et al., 2014), and considering carbon taxes is no different (Klenert et al., 2018).

Yet, as established by the IPCC Fifth Assessment Report, addressing climate and ecological breakdown requires more than reducing greenhouse gas emissions, but requires reductions in material consumption, particularly the overconsumption of the wealthiest (Fleurbaey et al., 2014). When material consumption is recognised as a global mega-driver of a sharply deteriorating natural world, and the ecosystem services it provides, it becomes urgently necessary to develop approaches to address overconsumption. Shifting taxation to consumption, and also to emissions, can act as supporting economic measures, as part of the wider policy programmes that are necessary for transition and transformation onto sustainable paths.

Table 1. Summary of key conclusions from the review.

Topic	Review conclusion
Economic theory	*Seeking optimality* Can potentially achieve cost-effective emission reductions, as an "optimal" approach. See e.g. Somanathan et al. (2014) and Stiglitz and Stern (2017).
Current macro policy observations	*Coverage and price level* Not adopted at scale or price level required to deliver deep reductions (GCEC, 2018; World Bank, 2020), attributed to persistent social and political challenges (Somanathan et al., 2014). Similar challenges lead to the persistence of perverse subsidies for the production and consumption of fossil fuels, and other emissions intensive resources. *Economic efficiency* Not always the most "economically efficient" option. A carbon tax cannot fully address the underlying development path. Sustainable development paths are intrinsically of lower energy and emissions intensity, implicitly minimising the cost of emissions reduction. See Sathaye et al. (2007) and Fleurbaey et al. (2014).
Current sectoral policy observations	*Environmental Effectiveness* Reviews of key sectors of built environment (Lucon et al., 2014), transport (Sims et al., 2014) and electricity (Bruckner et al., 2014), conclude that other measures such as regulation, technology and standards are more effective.
Role in future transition and transformation	*Policy strategy* As an incremental approach it is not sufficient to deliver transition and transformation on its own (Barker et al., 2007; de Coninck et al., 2018). *Relationship with other policies and measures* Can be used as a supporting measure, and to help address rebounds, as part of the broader portfolio of policies and measures that is known to be required for deep emissions reduction (Rogelj et al., 2018; Mundaca et al., 2019).
Tax design and implementation	*Design considerations* Varies by country and sector, requiring consideration of specific national circumstances, and of climate ethics. Revenue recycling can assist with policy resistance, addressing distributional considerations and in achieving synergies (Klenert et al., 2018). *Price levels* A more moderate -lower- price level becomes possible, that is more socially acceptable and politically feasible, when using an appropriate portfolio of policies and measures. This requires a strategy that enables wider systems change, for lower emissions development pathways (Rogelj et al., 2018; Mundaca et al., 2019).

Nonetheless, it is also crucial to recognise that economic measures such as taxation are useful additions, but are not enough in themselves. The challenging history of carbon taxes in recent decades is clear evidence of the need for a more comprehensive portfolio of measures, that go beyond the incremental. This must be encompassed in a strategic policy framework, that also includes the regulatory and technology measures, which are less impeded by social and political difficulties. The IPCC have observed that the change in approach this involves is about addressing underlying systems, and developing policy synergies and managing tradeoffs. Consistent with this accepted conclusion, the European Environment Agency State and Outlook 2020 recently made their key overarching policy observation, that the unfolding

sustainability crises, and the lack of progress through incrementalism, demands urgent implementation of systemic solutions. The EEA stated the unambiguous conclusion that: "…*we do not only have to do more; we also have to do things differently. Over the next decade, we are going to need very different answers to the world's environmental and climate challenges than the ones we have provided over the past 40 years*" (EEA, 2019). Given inadequate progress, this is cannot be reduced to a platform to amend the design and implementation of carbon taxes, it demands fundamental change to policy practice, and to the related framing of the systemic challenges policy is seeking to address.

5. Conclusion

This article set out to review the current state of the art in carbon taxes globally. While some economists have advocated carbon taxes as the "first-best" policy choice, the economic theory that getting the price right facilitates leaving the market to provide the most efficient solutions, the weight of empirical analysis, and actual policy experience does not support this conclusion. In a crisis, an incremental response such as carbon pricing is not sufficient. Comprehensive reviews such as those of the recent IPCC reports provide ample clarity, continuing an evolution that remains in agreement with the early findings of the First Assessment Report in 1990 (IPCC, 1990). Correcting for the market failures of the negative externalities of climate change is not a simple matter of increasing a carbon tax, and expecting rational actors to respond to the price signal. The rapid transformation that is urgently needed to eliminate greenhouse gas emissions requires far more than a strident adherence to the early theories of Pigou, or indeed Coase.

Decades of empirical study and actual policy experience demonstrate that carbon taxes are a useful compliment to the other policies and measures that are required for emissions reductions. If deep emissions reductions are to be achieved, then a portfolio of policies and measures are necessary, and carbon pricing can offer further support and prevent rebounds. This is not only consistent with achieving deep emissions reduction in the long-term, but with securing social acceptability, political feasibility and with delivering the cost-effective emissions reductions of lower intensity pathways. The implementation of a carbon tax has been proposed as one of the key measures for emissions reduction, due to simplicity and scope. It also offers an opportunity for a potential "double dividend" of climate benefit and economic gains. However, its visibility and attraction to lobbying by vested interests consistently leads to problems in raising it to the higher levels deemed necessary. Recent analysis suggests that a more moderate carbon tax may be both more politically feasible, and more socially acceptable, and can be consistent with both low-carbon transition and achieving least-cost.

Achieving ideal outcomes, that maximise synergies and manage trade-offs, necessitates a wide portfolio of measures, that strategically initiate a sustainable development path. Implementing a carbon tax can assist in steering the development path towards low emissions outcomes, offering benefits to welfare by re-directing the economy into the opportunities of more resilient green growth. A carbon tax can be designed to address the distributional considerations of equity and fairness, particularly through the channels of revenue recycling. Nevertheless, while a carbon tax is a useful complement, it is not sufficient on its own. It cannot be relied upon as the sole, or indeed the priority means of responding to the sustainability crises now unfolding. There is now an urgent need for systemic transition and transformation as highlighted by the IPCC assessments, and the EEA (2019), among others. Crucially, the answer to these challenges is not primarily "more" or "better" carbon pricing. The

answer lies in determining which broader measures can deliver a managed transition and transformation to sustainability, and how carbon taxes might be implemented in support of this strategic approach.

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Conflict of interest

The author declares no conflicts of interest in this paper.

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