Journal of Environmental Economics and Management 114 (2022) 102687

Contents lists available at ScienceDirect

Journal of Environmental Economics and Management

journal homepage: www.elsevier.com/locate/jeem

Note

Global carbon price asymmetry

Robert A. Ritz[1]

Energy Policy Research Group, Judge Business School, University of Cambridge, United Kingdom

ARTICLE INFO

JEL classification:
H23
L11
Q54

Keywords:
Carbon leakage
Carbon pricing
Imperfect competition
International trade
Second best

ABSTRACT

This paper studies a social planner who chooses countries' carbon prices so as to maximize global welfare. Product markets are characterized by firm heterogeneity, market power, and international trade. Because of the market-power distortion, the planner's optimal policy is second-best. The main insight is that optimal carbon prices may be highly asymmetric: zero in some countries and above the social cost of carbon in countries with relatively dirty production. This result obtains even though a uniform global carbon price is always successful at reducing countries' emissions. Competition policy that mitigates market power may enable stronger climate action.

1. Introduction

Carbon pricing is increasingly used as a key policy instrument to combat climate change. Yet carbon prices around the world remain low and uneven: above \$50 per ton of CO_2 in Europe's flagship cap-and-trade system—and even higher for some national carbon taxes—but much lower in most other jurisdictions (World Bank, 2021). This picture contrasts markedly with the Pigouvian ideal of a uniform global carbon price set at the social cost of carbon (SCC).

So far, carbon pricing has focused on power generation and emissions-intensive industrial sectors like aluminium, cement and steel. Three characteristics of these industries are striking. First, firms within each industry often have widely varying carbon intensities of production. This enhances the potential for market-based regulation to enhance abatement-cost efficiency. Second, emissions-intensive industries are often highly concentrated with long-standing concerns about the exercise of market power. This makes relevant the theory of the second best. Third, international trade is important as the scope of the product market in which regulated firms compete is often wider than that of the carbon price they face. This has led to concerns about leakage of emissions to less regulated jurisdictions.

This paper studies the optimal design of carbon prices in a model in which these three characteristics are crucial. The model considers a social planner who chooses countries' carbon prices so as to maximize global welfare. Because of a market-power distortion in the product market, the planner's optimal policy is second-best. The central trade-off is that a higher carbon price reduces a country's domestic emissions but also increases deadweight losses in the product market (due to pass-through of carbon costs to consumers) and leads to a degree of carbon leakage to the other country.[2] Thereby, the country with relatively clean firms is more vulnerable to carbon leakage as a policy-induced loss in production to the dirtier country translates into a larger increase in emissions.

E-mail address: rar36@cam.ac.uk.

[1] I am grateful to Joshua Linn (Editor) and two referees for their valuable feedback and to Lassi Ahlvik, Geoffroy Dolphin, Sam Fankhauser, Felix Grey, Chris Harris, Cameron Hepburn, Frank Jotzo and David Newbery for helpful comments on earlier versions of this paper and to Bowie Wong for excellent research assistance. All views expressed and any errors are mine.

[2] The leakage channel in the model arises from the market-share losses of more tightly regulated firms.

https://doi.org/10.1016/j.jeem.2022.102687
Received 17 December 2020
Available online 3 June 2022

The main insight is that second-best carbon prices can be extremely asymmetric across countries. Market power, on its own, pushes countries' optimal carbon prices downwards as the planner seeks to cushion the increase in consumer prices. The presence of international trade introduces a further effect: if carbon leakage for the country with relatively clean firms is sufficiently pronounced, its optimal carbon price is zero. This, in turn, limits deadweight losses in the product market and enables the planner to choose a higher carbon price for the dirtier country—which creates additional climate benefits as it reshuffles production to cleaner firms. As long as market power is not too pronounced, the dirtier country's optimal carbon price may lie above the SCC. This finding obtains even though a uniform global carbon price is always successful in reducing countries' emissions.

The result should not be overplayed given the model's very simple welfare function.[3] The more general point is that, while carbon prices around the world today are almost certainly far too low, failing to implement a global carbon price does not necessarily imply the wrong response to climate change. Moreover, competition policy to mitigate market power may enable stronger and more balanced climate action.

2. Model

Consider a global industry in which $n_k \geq 1$ firm(s) are based in country $k = i, j$. Country k's firms face a linear demand curve $p_k(X) = \alpha_k - X$ where $X \equiv X_i + X_j$ is total industry output ($X_k \equiv \sum_m x_k^m$ for $k = i, j$), and α_k is a measure of k's product quality.

Firm m from country k needs to produce $y_k^m = \xi_k x_k^m$ units to get x_k^m units of output to market, where $\xi_k \geq 1$ is a trade cost that takes an "iceberg" form. Its emissions are $e_k^m = z_k y_k^m - a_k^m$ where z_k is its baseline emissions intensity (emissions per unit of production) and a_k^m is abatement.

Faced with a carbon price τ_k in its country, firm m of k's profits are $\Pi_k^m = p_k(X)x_k^m - C_k^m(y_k^m, a_k^m; \tau_k)$, where its total costs $C_k^m(y_k^m, a_k^m; \tau_k) = c_k y_k^m + \tau_k e_k^m + \phi_k(a_k^m)$ consist of a production cost c_k per unit of y_k^m, carbon costs, and an abatement cost $\phi_k(a_k^m) = \frac{\gamma_k}{2}(a_k^m)^2$.

The product market features a generalized version of Cournot competition with a conduct parameter $\theta \in (0, 1]$. Formally, firms' equilibrium outputs $(\hat{x}_k^m)_{k=i,j}$ satisfy:

$$\hat{x}_k^m = \arg\max_{x_k^m \geq 0} \left\{ \left[p_k \left(\theta(x_k^m - \hat{x}_k^m) + \sum_m \hat{x}_i^m + \sum_m \hat{x}_j^m \right) x_k^m - C_k^m(y_k^m(x_k^m), a_k^m) \right] \right\} \tag{1}$$

Firm m in country k, in deviating its output by $(x_k^m - \hat{x}_k^m)$, conjectures that industry output will change by $\theta(x_k^m - \hat{x}_k^m)$ as a result. In this "conduct equilibrium" (Weyl and Fabinger, 2013), a lower θ corresponds to more intense rivalry while competition is imperfect with $\theta > 0$. The Cournot-Nash equilibrium occurs where $\theta = 1$.

The firm's first-order conditions for output and abatement are thus:

$$p_k - \theta x_k^m - c_k \xi_k + \gamma_k z_k \xi_k a_k^m = 0 \text{ and } -\gamma_k a_k^m + \tau_k = 0 \tag{2}$$

so a generalized version of marginal revenue equals the marginal cost of output while the marginal cost of abatement is equal to the carbon price. These conditions together imply:

$$p_k - \theta x_k^m = (c_k + \tau_k z_k)\xi_k. \tag{3}$$

Given separability of production and abatement costs, the product-market equilibrium does not depend on the extent of abatement. Let $X_k(\tau_i, \tau_j)$, $p_k(\tau_i, \tau_j)$, and $E_k(\tau_i, \tau_j)$ denote equilibrium outputs, prices and emissions (with $E \equiv E_i + E_j$).

Global welfare $W = U - \sum_k c_k \xi_k X_k - sE - \Phi$ reflects consumer utility $U = \sum_k \alpha_k X_k - \frac{1}{2}X^2$ (with $\frac{\partial U}{\partial X_k} = p_k$), production and trade costs, the global SCC s, and total abatement costs $\Phi \equiv \sum_k \sum_m \phi_k(a_k^m)$.[4] The social planner's problem is to $\max_{\tau_i, \tau_j} W(\tau_i, \tau_j)$ subject to the constraint that, at equilibrium, firms make non-negative profits, $\Pi_k^m \geq 0$. Assume that $W(0, 0) \geq 0$ so the market is socially viable without carbon pricing—and the planner therefore never shuts it down. A necessary condition is that consumers' willingness-to-pay exceeds social costs, $\min_k \{\alpha_k - (c_k + sz_k)\xi_k\} > 0$.

For conciseness, the main text focuses on the case with symmetric product qualities ($\alpha_i = \alpha_j = \alpha$) and non-carbon costs ($c_i = c_j = c$, $\xi_i = \xi_j = \xi$) and without abatement ($\gamma_i \to \infty$, $\gamma_j \to \infty$).

3. Carbon prices and global emissions

The first results characterize basic properties of carbon pricing in an international context. The rate of carbon leakage associated with carbon pricing by country i is:

$$L_i^C \equiv \frac{dE_j(\tau_i, \tau_j)/d\tau_i}{-dE_i(\tau_i, \tau_j)/d\tau_i}. \tag{4}$$

This measures the fraction of i's emissions reduction that leaks to j. Similarly, output leakage $L_i^O \equiv (dX_j/d\tau_i)/(-dX_i/d\tau_i)$.

[3] The model is partial equilibrium without further distortions in factor markets or wider tax interactions. The social planner does not have additional policy instruments to directly address the market-power distortion.

[4] Product-market revenues are a transfer from consumers to firms and carbon-pricing revenues are a transfer from firms to governments.

Lemma 1. *An increase in country i's carbon price τ_i reduces its domestic production, $dX_i/d\tau_i < 0$ and its domestic emissions, $dE_i/d\tau_i < 0$, where:*
(a) the rate of output leakage $L_i^O = n_j/(n_j + \theta) > 0$;
(b) the rate of carbon leakage $L_i^C = (z_j/z_i)[n_j/(n_j + \theta)] > 0$;
(c) the rate of carbon cost pass-through $dp(\tau_i, \tau_j)/d\tau_i = \left[n_i/(n_i + n_j + \theta)\right] z_i\xi > 0$.

Output leakage is more pronounced with (i) more rivals in j engaging in "business stealing" from those in i as a result of the unilateral cost increase (higher n_j); and (ii) more competitive conduct (lower θ).

Carbon leakage equals output leakage scaled by the relative emissions intensity z_j/z_i. A higher carbon price by i increases in global emissions if its carbon leakage exceeds 100%. This is ruled out by symmetry but occurs if j's production is sufficiently more polluting.[5]

Carbon pricing reduces i's profit margin as less than 100% of its carbon cost is passed on to consumers; pass-through decreases with market power and with more rivals in j.

Global action "works" in the following sense:

Lemma 2. *An increase in a uniform global carbon price ($\tau_k = \tau$ for $k = i, j$):*
(a) reduces global emissions, $dE(\tau, \tau)/d\tau < 0$;
(b) reduces country k's emissions, $dE_k(\tau, \tau)/d\tau \leq 0$, if and only if $L_k^C \leq 1$.

A uniform tightening in carbon prices is always successful at reducing aggregate emissions—even if it may induce higher emissions by an individual country. Intuitively, if unilateral action by i has carbon leakage above 100%, then i's firms are significantly cleaner than j's so a higher global carbon price improves their competitiveness and they expand production and emissions.

4. Carbon prices and global welfare

Now consider the second-best carbon prices chosen by a social planner. At a global level, carbon pricing involves a trade-off between lower consumer utility and the potential for lower environmental damages. Letting $\hat{\alpha} \equiv (\alpha - c\xi)/\xi > 0$, the former dominates where:

Lemma 3. *If country i's rate of carbon leakage is sufficiently high,*

$$L_i^C \geq 1 - \frac{\theta}{(n_j + \theta)} \frac{\theta}{(n_i + n_j + \theta)} \frac{\hat{\alpha}/s}{z_i} \equiv \underline{L}_i^C,$$

then a zero carbon price is welfare-dominant, $W(0, \tau_j) \geq W(\tau_i, \tau_j)$ for all $\tau_i, \tau_j \geq 0$.

The result is immediate if $L_i^C > 1$. Then a "reverse leakage" argument applies: a reduction in i's carbon price raises its own emissions but this is outweighed by the induced reduction in j's emissions. As consumers also gain, global welfare rises. Given the linear-quadratic model structure, its leakage rate is a constant (Lemma 1) so this logic holds at any level of countries' carbon prices. Put simply, the extent of i's carbon leakage precludes effective climate action.

This conclusion applies as long as i's leakage rate is sufficiently high, $L_i^C \geq \underline{L}_i^C$, where $\underline{L}_i^C < 1$ because $\theta > 0$. The critical value $\underline{L}_i^C$ declines with the ratio $\hat{\alpha}/s$, which is a measure of the size of market-power distortion (via $\hat{\alpha}$) relative to the climate problem (via s). If the former is sufficiently important, $\underline{L}_i^C$ turns negative.

The main interest of the paper lies in global carbon price asymmetry, so suppose that i's firms are cleaner with $z_i/z_j < 1$. The problem is then resolved by the three industry characteristics described in the introduction:

Lemma 4. *Suppose that country i's carbon price $\tau_i = 0$. Then an interior solution $\tau_j^* > 0$ for country j that maximizes $W(0, \tau_j)$ satisfies:*

$$\frac{\tau_j^*}{s} = 1 - \underbrace{\frac{\theta}{n_j}\left(\frac{\hat{\alpha}/s - z_j}{z_j}\right)}_{\text{market power}} + \underbrace{\frac{n_i}{n_j}\left[1 + \left(\frac{n_i + n_j + \theta}{\theta}\right)\left(1 - \frac{z_i}{z_j}\right)\right]}_{\text{international competition \& firm heterogeneity}}.$$

The first deviation of τ_j^* from the SCC is driven by market power. The standard result for a second-best domestic emissions tax is nested where $\tau_j^*\big|_{n_i=0} = [s - (\theta/n_j)\left(\hat{\alpha}/z_j - s\right)] < s$ (recalling $\min_k \left\{\alpha - (c + sz_k)\xi\right\} > 0$). With perfect competition, $\tau_j^*\big|_{n_i=0,\theta=0} = s$ is Pigouvian.

The second deviation from the SCC instead pushes τ_j^* upwards—driven by firm heterogeneity and cross-border competition. An increase in j's carbon price shifts production to i's cleaner firms. This has two implications. First, output leakage to i limits the contraction in industry output due to j's carbon price, mitigating the incremental product-market distortion. Second, the contraction

[5] Large intra-industry heterogeneity is borne out in practice (Lyubich et al., 2018). Babiker (2005) finds carbon leakage rates up to 130% in a general-equilibrium model with similar ingredients to the present model.

in industry output leads to a greater reduction in global emissions precisely because i's firms are cleaner. These factors limit deadweight losses and amplify environmental benefits, pushing upwards j's optimal carbon price.

A related observation is that the social planner regards countries' carbon prices as strategic substitutes.[6] A higher carbon price by j raises the product price and so exacerbates the market-power distortion. This sharpens the planner's trade-off against emissions cuts by i, and reduces the welfare gain from i's own carbon price.

The main result shows how this international-competition effect can dominate the planner's calculus and yield extreme asymmetry in global carbon prices:

Proposition 1. *Suppose that country i's firms are sufficiently cleaner than j's, with*

$$\frac{z_i}{z_j} \leq 1 - \frac{\theta n_j}{\left[(n_i+\theta)(n_i+n_j+\theta)+n_j(n_j+\theta)\right]} \equiv \delta < 1.$$

Then, for the range of parameter values given by

$$\frac{\hat{\alpha}}{s} \in \left[\Psi, \Psi + \frac{n_i}{\theta}\frac{n_j}{\theta}(z_j - z_i)\right] \text{ where } \Psi \equiv \left(1+\frac{n_i}{\theta}\right)\left[z_j + \frac{n_i}{\theta}(z_j - z_i)\right],$$

welfare-optimal carbon prices are $\tau_i^* = 0$ while $\tau_j^* \geq s$.

Proposition 1 establishes in equilibrium the logic underlying Lemmas 3 and 4. The range on $\hat{\alpha}/s$ ensures that the market-power distortion is small enough for τ_j^* to exceed the SCC by Lemma 4 but also large enough for j's firms to remain profitable. The condition $z_i/z_j \leq \delta$ ensures that indeed $\tau_i^* = 0$ because i's leakage is sufficiently pronounced as per Lemma 3.

Illustrations. Fig. 1 illustrates how Proposition 1 applies to a significant "chunk" of the parameter space. It sets $s = 50$, $z_j = 1$, and $n_i/\theta = n_j/\theta = 6$—corresponding, e.g., to a relatively concentrated market $n_i = n_j = 3$ and competition "halfway" between perfect and Cournot ($\theta = \frac{1}{2}$). The result holds notably where i is much cleaner and $\hat{\alpha}/s$ is not too large.

For example, if i's firms are modestly cleaner with $z_i = 0.9$, Proposition 1's condition $\frac{z_i}{z_j} \leq \delta = \frac{127}{133}$ is met. With $\hat{\alpha} = 600$, Lemma 4 gives $\tau_j^* = 73\frac{1}{3}$—almost 50% above the SCC. If instead $\hat{\alpha} = 560$, $\tau_j^* = 80$ makes j's firms just indifferent about being active ($\Pi_j^* = 0$) while $\tau_j^* \geq s$ as long as $\hat{\alpha} \leq 740$. For these parameter values, $L_i^C = .952$ and $L_j^C = .771$ by Lemma 1, confirming that global action "works" as per Lemma 2.[7]

Extensions. Proposition 1's insight obtains in the generalized model (see Appendix) with heterogeneity in product qualities and non-carbon costs, plus abatement by firms. These heterogeneities have an ambiguous impact: if j has a lower-quality product or higher costs, this strengthens the planner's case for setting a relatively higher carbon price (and vice versa). Abatement pushes optimal carbon prices towards the SCC so the result is less likely—but still applies over a significant parameter range.

5. Conclusions and related literature

The finding of extreme global asymmetry in equilibrium carbon prices—with $\tau_i^* = 0$ but simultaneously $\tau_j^* \geq s$—differs from prior literature in several respects. First, a classic literature (Buchanan, 1969; Requate, 2006) studies local environmental policy with imperfect competition where the planner chooses a single *domestic* emissions price. This second-best emissions price is typically less than Pigouvian, with $\tau_i^* <$ social marginal damage. By contrast, this paper has studied global welfare with multiple carbon prices.

Second, the literature on international climate policy (e.g., Babiker, 2005; Fowlie et al., 2016 typically examines models where a unilateral actor/coalition (e.g., OECD) pursues carbon pricing, often with $\tau_j^* < s$, while other countries (e.g., non-OECD) *exogenously* have $\tau_i \equiv 0$.[8] For example, Fowlie et al. (2016) also focus on impacts of market power and international trade but from the perspective of domestic US welfare. By contrast, this paper has studied a global planner where all carbon prices are endogenous and extreme asymmetry with $\tau_i^* = 0$, $\tau_j^* \geq s$ is optimal.[9]

Third, it is known that cross-country differences in marginal abatement costs can be optimal due to equity concerns—a less rich country may have a higher marginal utility of income—and restrictions on financial transfers (Chichilnisky and Heal, 1994). By contrast, this paper has obtained an extreme version of non-uniform pricing in a model without equity concerns.

Future research could incorporate this paper's approach—global-welfare maximization with imperfect competition and endogenous carbon prices—into detailed simulation models that are calibrated to global market data. This may help understand the extent to which observed asymmetries in carbon prices around the world represent second-best policy; the present analysis suggests that more carbon-intensive countries should have (much) higher carbon prices.

---

6 Global welfare, $W(\tau_i,\tau_j) = U(\tau_i,\tau_j) - \sum_k c\xi X_k(\tau_i,\tau_j) - sE(\tau_i,\tau_j)$ is submodular in countries' carbon prices:

$$\frac{d}{d\tau_j}\left[\frac{dW(\tau_i,\tau_j)}{d\tau_i}\right] = \frac{d}{d\tau_j}\left[\sum_k \left[p(\tau_i,\tau_j) - c\xi\right]\frac{dX_k}{d\tau_i} - s\frac{dE_i}{d\tau_i}(1-L_i^C)\right] = \frac{dp}{d\tau_j}\frac{dX}{d\tau_i} < 0,$$

since $dX_k/d\tau_i$, $dE_i/d\tau_i$ and L_i^C are all constants, $dp/d\tau_j > 0$, and $dX/d\tau_i < 0$ (Lemma 1).

7 First-best would be restored with a global carbon price $\tau^* = s$ plus a discriminatory output subsidy of $(\theta/n_i)[\alpha - (c + sz_i)\xi]$ to i's cleaner firms that pushes j out of the market. Here, the planner attempts to mimic this policy by instead skewing carbon pricing towards the dirtier country.

8 When climate action is exogenously restricted to a subset of countries, it is second-best to set lower carbon prices for sectors with internationally-traded products—unless corrective trade tariffs are available (Hoel, 1996).

9 While results with $\tau_i^* \neq \tau_j^*$ are not surprising, the extent of the equilibrium asymmetry shown in this paper seems much less obvious.

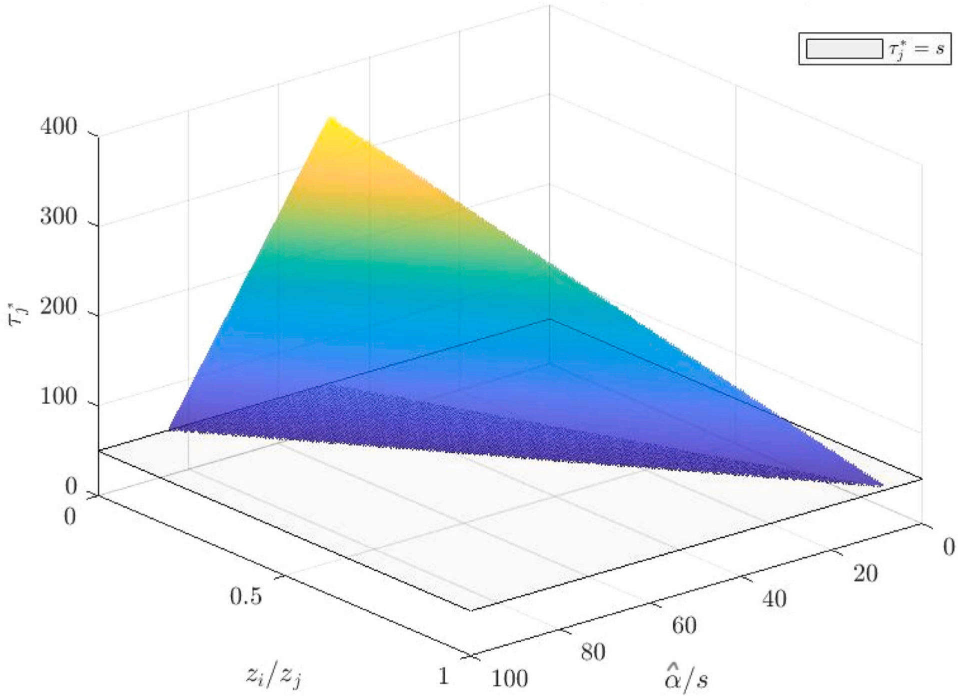

Fig. 1. Parameter region for Proposition 1's result $\tau_i^* = 0$ and $\tau_j^* \geq s$. Notes: Fixes $s = 50$, $n_i/\theta = n_j/\theta = 6$, $z_j = 1$; varies z_i and $\hat{\alpha} \equiv (\alpha - c\xi)/\xi$.

Declaration of competing interest

One or more of the authors of this paper have disclosed potential or pertinent conflicts of interest, which may include receipt of payment, either direct or indirect, institutional support, or association with an entity in the biomedical field which may be perceived to have potential conflict of interest with this work. For full disclosure statements refer to https://doi.org/10.1016/j.jeem.2022.102687. I serve on the academic advisory panels at the Competition & Markets Authority (the UK's competition and antitrust body) and at Ofgem (the regulator for electricity and natural gas markets in Great Britain). I am also a principal at Vivid Economics (an economics consultancy).

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jeem.2022.102687.

References

Babiker, Mustafa H., 2005. Climate change policy, market structure, and carbon leakage. J. Int. Econ. 65, 421–445.
Buchanan, James, 1969. External diseconomies, corrective taxes, and market structure. Amer. Econ. Rev. 59, 174–177.
Chichilnisky, Graciela, Heal, Geoffrey, 1994. Who should abate carbon emissions? An international viewpoint. Econom. Lett. 44, 443–449.
Fowlie, Meredith, Reguant, Mar, Ryan, Stephen P., 2016. Market-based emissions regulation and industry dynamics. J. Polit. Econ. 124, 249–302.
Hoel, Michael, 1996. Should a carbon tax be differentiated across sectors? J. Public Econ. 59, 17–32.
Lyubich, Eva, Shapiro, Joseph S., Walker, Reed, 2018. Regulating mismeasured pollution: Implications of firm heterogeneity for environmental policy. In: American Economic Association: Papers & Proceedings, vol. 108, pp. 136–142.
Requate, Till, 2006. Environmental policy under imperfect competition: A survey. In: Tietenberg, Tom, Folmer, Henk (Eds.), International Yearbook of Environmental and Resource Economics 2006/2007. Edward Elgar, Cheltenham: UK.
Weyl, E. Glen, Fabinger, Michal, 2013. Pass-through as an economic tool: Principles of incidence under imperfect competition. J. Polit. Econ. 121, 528–583.
World Bank, 2021. State and Trends of Carbon Pricing 2021. World Bank Group, Washington DC: USA.