Carbon-Tax-Adjusted Value

David Blitz

Robeco Quantitative Investments

d.c.blitz@robeco.com

Tobias Hoogteijling

Robeco Quantitative Investments

t.hoogteijling@robeco.com

November 2021

Abstract

We examine the effects of incorporating a potential tax on carbon emissions into a value investment strategy. We show that in a portfolio optimization problem, a carbon tax at the stock level is mathematically equivalent to a carbon constraint at the portfolio level. Using this insight we derive a value-carbon efficient frontier that reflects the trade-off between a high value exposure and a low carbon footprint. Empirically we find that carbon taxes up to $100, corresponding to a portfolio carbon footprint reduction of about 50%, have little effect on the characteristics and the performance of the long side of a value strategy. Much more aggressive footprint reduction levels seem unreasonable, as they correspond to extremely high carbon tax levels and performance starts to decay.

The authors thank Matthias Hanauer, Pim van Vliet, Machiel Zwanenburg, and other colleagues at Robeco for valuable feedback on an earlier version of this paper. The views expressed in this paper are not necessarily shared by Robeco or its subsidiaries.

1. Introduction

Carbon emissions are a classic example of an externality. The production of almost every good and service comes with the emission of CO2, and the costs of these emissions are not borne by producers or consumers, but by society at large. This results in a Pareto suboptimal equilibrium, in which marginal costs of carbon emissions exceed marginal benefits and carbon-intensive goods and services are overproduced. The equally classic solution to this problem is imposing a Pigouvian tax, i.e. a tax that reflects the costs of the externality to society. Such taxes set the marginal costs of producers equal to the marginal costs for society, and thereby restore Pareto efficiency.

Carbon taxes (and other measures such as cap-and-trade systems) already exist in many countries, but their scope and impact are limited. With the commitment of governments around the world to combat climate change, the carbon emissions of the corporate sector will face increased scrutiny. Aggregate carbon emissions have been rising steadily over time and without government interference it is unlikely that there will be a sudden sharp reversal of this trend. In order to enforce a pathway to net zero emissions it therefore seems unavoidable that carbon emissions are going to be priced more heavily and more broadly in the foreseeable future, either directly or indirectly. In this paper we anticipate on these developments by examining the effects of incorporating a possible tax on carbon emissions into a value investment strategy.

The contribution of this paper is twofold. First, we show that in a portfolio optimization problem, a carbon tax *at the stock level* is mathematically equivalent to a carbon constraint *at the portfolio level*. In other words, for every carbon reduction target there exists a tax level per unit of CO2 emissions that leads to the *exact same portfolio weights*. This elegant equivalence implies that any level of decarbonization can be reached by imposing a corresponding carbon tax.

Second, we investigate how the long-term performance of a value investment strategy is influenced by a carbon tax. A value investor invests in stocks that offer a high fundamental value compared to their market value. However, value metrics are generally backward looking and ignore the underlying reasons why some stocks are priced more cheaply than others. If a potential future carbon tax is already discounted in current stock prices, then stocks with high emissions may appear underpriced, whilst actually being cheap for a reason. This deficiency can be rectified by making a carbon tax adjustment to traditional value metrics, to obtain a better assessment of true value and expected return in a rapidly changing world.

We find that a generic value strategy tends to have a high carbon footprint, implying that investors face a trade-off between high value exposure and low carbon footprint. All possible combinations of value exposure and carbon footprint together comprise a curve which we refer to as the *value-carbon efficient frontier*. Empirically, we find that the marginal costs of carbon footprint reduction in terms of value exposure grow exponentially. Starting from the base case value portfolio, halving the carbon footprint has an almost negligible impact on value exposure and return, but subsequent footprint reduction becomes more and more costly.

More specifically, we find that carbon taxes up to $100, corresponding to a portfolio carbon footprint reduction of about 50%, have little effect on the characteristics and the performance of the long side of a value strategy. Much more aggressive footprint reduction levels seem unreasonable, as they correspond to extremely high carbon tax levels and performance starts to suffer. The short side of a value strategy is affected more severely by carbon taxes, as the bottom portfolio effectively becomes a dumping ground for all the high carbon stocks.

The outline of the paper is as follows. We first discuss theoretical aspects, such as the rationale behind a carbon tax, and the equivalence between assuming a carbon tax and a constraint on the carbon footprint of an investment portfolio. We then proceed with describing our data and presenting our empirical results. Finally, we conclude.

2. Theoretical aspects

In this section we first discuss carbon taxes and the rationale behind carbon-tax-adjusted value metrics. We next show that making a carbon tax adjustment to the value definition is equivalent to imposing a carbon footprint reduction constraint on value investment portfolios.

2.1 Carbon taxes

Carbon emissions of firms are an example of what is called a negative externality in economics, because of their contribution to global climate change.[1] With the signing of the Paris climate agreement, governments around the world have committed themselves to a substantial reduction of carbon emissions. The question is not if this will have consequences for the corporate sector, but how big the consequences will be, especially for firms with high emissions. A policy instrument that is widely discussed nowadays is the introduction of a tax on carbon emissions. Pricing a negative externality in such a way is called a Pigouvian tax in economics (Pigou, 1920).

[1] Carbon dioxide is just one of the greenhouse gases associated with climate change. Throughout this paper we refer to carbon emissions, but the data we use also includes the emissions of other important greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O), which are converted to CO_2-equivalent figures.

Various taxes on carbon emissions already exist. A well-known example are excise duties on car petrol, which are levied in many countries. Carbon emissions can also be priced indirectly, by restricting the total amount of allowed emissions. An example of this is the Emissions Trading System in Europe, or EU ETS. However, it is important to realize that the scope and impact of these current forms of carbon taxation is limited. For instance, airline and shipping firms are typically exempt from the fuel taxes that consumers pay for their cars, and also the large carbon emissions of heavy industry are still largely untaxed. Governments may be reluctant to impose heavy carbon taxes out of fear that firms will simply move activities abroad, or because taxes may lead to higher prices for consumers. However, it seems unavoidable that sooner or later some form of carbon taxation will need to be introduced to curb emissions.

Traditional valuation metrics, such as price-to-earnings (P/E) ratios, do not yet reflect the costs of carbon emissions. In this paper we examine the impact of incorporating a hypothetical carbon tax in valuation ratios, in anticipation of likely future developments. Our paper is related to a recent stream of literature which modifies traditional valuation metrics by incorporating intangibles, such as knowledge capital, organizational capital, and brand value; see, e.g., Park (2019), Lev and Srivastava (2020), and Arnott et al. (2021). However, whereas those studies adjust firm values upwards by identifying unrecognized assets, carbon pricing results in downward adjustments because one accounts for unrecognized liabilities. Our paper is also similar in spirit to Pedersen, Fitzgibbons, and Pomorski (2021), who propose an ESG-adjusted CAPM. The main difference is that they derive an ESG-efficient frontier that stems from investor preferences, while we obtain a value-carbon efficient frontier that follows from pricing an externality. Further, we focus on the impact on a value investing strategy, and study the empirical shape of the value-carbon efficient frontier.

Carbon taxes are frequently discussed in the literature from a public economics perspective, for example Ulph & Ulph (1994), Hoel (1996), Metcalf (2009) and Marron and Toder (2014). There is no consensus in the literature on the social costs of carbon emissions and the corresponding optimal height of a carbon tax, but broadly a tax is considered between $1 and $100 per ton of CO2[2], a range also covered in this paper. Interestingly, also the carbon price in the EU Emissions Trading Scheme fluctuates approximately around these levels.[3] To the best of our knowledge, we are the first to study carbon taxes from a value investor perspective.

[2] See e.g. Nordhaus (2007), Stern (2007), or Metcalf (2009).

[3] See e.g. https://ember-climate.org/data/carbon-price-viewer/

2.2 Carbon constraint and tax equivalence

A popular way to 'decarbonize' investment portfolios is by imposing a constraint which enforces the carbon footprint of the portfolio to be at least a certain percentage lower than that of a benchmark index or other reference portfolio. In this section we show that applying a carbon reduction constraint to a value strategy is equivalent to following a carbon-tax-adjusted value strategy. This equivalence means that a certain carbon footprint reduction percentage corresponds to applying a certain carbon tax level, and vice versa. This realization helps to better understand the implicit assumptions behind decarbonizing investment portfolios, and gives an economic interpretation to portfolio footprint reduction targets.

Following European benchmark regulation we scale the carbon emissions of a firm (CO2, in tons) by enterprise value (EV).[4] CO2/EV levels are reported in tons/million USD. We intentionally take a value metric that is also scaled by EV, namely the EBITDA/EV ratio, which has the added benefit of having a much stronger performance than the classic Book/Market ratio of Fama and French (1992); see, e.g. Loughran and Wellman (2011), Walkshäusl and Lobe (2015), and Blitz and Hanauer (2021). The optimization problem with a carbon footprint reduction constraint can then be written as

$$Max\ f(w) = \sum_i w_i \frac{EBITDA_i}{EV_i}$$

$$s.t. \sum_i w_i \frac{CO2_i}{EV_i} = CO2budget$$

$$\sum_i w_i = 1$$

$$l_i \leq w_i \leq u_i,$$

where w_i is the weight of stock i, and l_i and u_i are the lower and upper bounds on the weights of stock i. We assume that the CO2 budget constraint is binding, i.e. that the available budget is fully used, because a redundant (non-binding) constraint would be irrelevant. The optimization problem with a carbon tax t per unit of CO2 emissions can be written as follows:

[4] See Handbook of Climate Transition Benchmark, Paris-Aligned Benchmark and Benchmarks' ESG Disclosures; available at https://ec.europa.eu/info/files/192020-sustainable-finance-teg-benchmarks-handbook_en. Strictly speaking, we follow the regulation and scale carbon emissions with EVIC (24 month smoothed), which stands for Enterprise Value Including Cash. Since EV and EVIC are very closely related this has no material impact on results. Only to illustrate strict equivalence between a carbon tax and carbon constraint, we use EV excluding cash.

$$Max \sum_i w_i \frac{EBITDA_i - t * CO2_i}{EV_i}$$

$$s.t. \sum_i w_i = 1$$

$$l_i \leq w_i \leq u_i,$$

We rewrite the objective as

$$Max \sum_i w_i \frac{EBITDA_i}{EV_i} - h(w)$$

with $h(w) = t \sum_i w_i \frac{CO2_i}{EV_i}$. Let $\overline{w}$ denote an optimal solution and let $H = h(\overline{w})$. Then this is equivalent to optimizing

$$Max \sum_i w_i \frac{EBITDA_i}{EV_i}$$

under the additional constraint that $h(w) = H$:

$$Max\ g(w) = \sum_i w_i \frac{EBITDA_i}{EV_i}$$

$$s.t. \sum_i w_i \frac{CO2_i}{EV_i} = \frac{H}{t}$$

$$\sum_i w_i = 1$$

$$l_i \leq w_i \leq u_i,$$

which is the carbon-constrained optimization problem with a carbon budget of $\frac{H}{t}$.

The proof is as follows. Let $\overline{w}$ and w^* be an optimal solution for the first and second formulation respectively. Then by construction, $\overline{w}$ is also a feasible solution for the second formulation and w^* is a feasible solution for the first formulation. Further, we know that

$$f(\overline{w}) \geq f(w)\ \forall\ w$$

$$g(w^*) \geq g(w)\ \forall\ w,$$

implying

$$f(\overline{w}) \geq f(w^*)$$

$$g(w^*) \geq g(\overline{w}).$$

This means

$$\sum_i \overline{w}_i \frac{EBITDA_i}{EV_i} - h(\overline{w}) \ \geq \sum_i {w^*}_i \frac{EBITDA_i}{EV_i} - h(w^*)$$

$$\sum_i {w^*}_i \frac{EBITDA_i}{EV_i} \leq \sum_i \overline{w}_i \frac{EBITDA_i}{EV_i}.$$

Given that $h(\overline{w}) = h(w^*) = H$, we obtain

$$\sum_i \overline{w}_i \frac{EBITDA_i}{EV_i} - h(\overline{w}) = \sum_i {w^*}_i \frac{EBITDA_i}{EV_i} - h(w^*)$$

$$\sum_i {w^*}_i \frac{EBITDA_i}{EV_i} = \sum_i \overline{w}_i \frac{EBITDA_i}{EV_i},$$

or

$$f(\overline{w}) = f(w^*)$$

$$g(w^*) = g(\overline{w}),$$

which shows $\overline{w}$ is also an optimal solution in the second formulation and w^* is also an optimal solution in the first formulation.

There are two important caveats regarding the equivalence between a carbon reduction constraint and a carbon-tax-adjusted value metric. First, the exact equivalence no longer applies if different scaling measures are used for the carbon and value metrics, e.g. if EBITDA/EV is replaced with the book/market ratio, or if the carbon metric is scaled with firm revenues instead of enterprise value. Conceptually, however, there remains a clear resemblance between imposing a carbon reduction constraint and making a carbon tax adjustment to the value metric. The more strongly the two scaling measures are related, the more similar the effects of carbon reduction constraints and carbon taxes will be.

Second, exact equivalence at every given point in time does not imply exact equivalence throughout time, because of time variation in the carbon footprint of the base case value portfolio. Applying a carbon tax structurally reduces the attractiveness of firms with high carbon emissions, but a carbon footprint reduction constraint can become more or less binding depending on whether more or less high-footprint stocks make it to the top portfolio. Again, however, there remains a close resemblance between structurally imposing a carbon reduction constraint and structurally incorporating a carbon tax in the valuation metric.

3. Empirical analysis

In this section we first describe our data and methodology and then present our empirical results.

3.1 Data and methodology

Our sample consists of MSCI World constituent stocks at the end of every month from December 1985 to August 2021.[5] We exclude financials, since the EBITDA/EV measure is not defined for such stocks. We also exclude a small number of stocks for which carbon emissions data is missing. Return and fundamental data is sourced from Refinitiv. EBITDA stands for Earnings Before Interest, Taxes, Depreciation, and Amortization, and Enterprise Value (EV) is calculated as the market value of a firm's shares plus the book value of its debt minus cash. Following European benchmark regulation, we calculate the carbon footprint of a stock by dividing its carbon emissions (tons of CO2) by Enterprise Value. For the carbon emissions we take the combined scope 1 and 2 emissions from TruCost. We calculate carbon-tax-adjusted valuation ratios by subtracting an assumed carbon tax level times the carbon emissions of a firm from its raw EBITDA[6], and dividing the outcome by Enterprise Value.

It is important to realize that the cross-sectional distribution of the carbon data is highly skewed. This is illustrated in Exhibit 1, which shows the distribution at the end of our sample. A relatively small number of firms have very high carbon footprints, while the vast majority of stocks have much lower carbon footprints, which are almost negligible by comparison. The distribution of carbon footprints per sector is illustrated in Exhibit 2. The large carbon emitters are predominantly found in the energy, utility, and materials sectors. Also within sectors, however, the distribution of footprints is highly skewed.

INSERT EXHIBIT 1 AND 2 HERE

We first illustrate the equivalence between carbon-tax-adjusted value and a value portfolio optimized with a carbon budget constraint, by comparing the two approaches at the end of our sample period. For carbon-tax-adjusted value we sort stocks into five quintile portfolios based on their carbon-tax-adjusted EBITDA/EV ratios. For solving the optimization problem with a carbon budget constraint we use the SciPy linear programming functionality, where portfolio weights are restricted between 0 and 5/N, with N being the total number of available stocks. Without a carbon constraint this gives the standard top quintile value portfolio as the optimal outcome.

We next examine the long-term performance and characteristics of carbon-tax-adjusted value strategies. To this end we sort stocks into five quintile portfolios on their carbon-tax-adjusted EBITDA/EV ratios at the end of every month in our sample, and then

[5] Before 2001, we do not have access to MSCI World constituents, so we use FTSE developed as a proxy.
[6] This implies treating carbon emissions as a production cost. Strictly speaking, a carbon tax would not affect EBITDA, as EBITDA is gross of taxes.

compute the equally-weighted return of the five quintiles over the subsequent month.[7] On average, every quintile portfolio contains about 270 stocks.

As carbon emissions only recently started to get a lot of attention, not much historical carbon data is available. The carbon data from TruCost is only available to us for the last part of the sample.[8] For the earlier part, we resort to using (proprietary) simulated carbon data. Estimating historical carbon emissions is hard, because on the one hand economic activity was lower, associated with lower emissions, but on the other hand production processes were more (fossil) energy-intensive. Further, it is likely that a carbon tax would comove with emission levels. We circumvent this issue by simulating footprints based on a recent cross-sectional distribution of CO2/EV.[9] The data is bootstrapped using GICS-4 industry classifications, regions, market capitalization and random noise. The approach ensures that the simulated distributional characteristics, such as mean, dispersion, and skewness, are similar to the current distribution. Note that this implies stable levels of carbon footprint over time, but not necessarily a stable impact on the value strategy over time, because a value strategy has time-varying regional and industry exposures.

3.2 Results

The equivalence between a carbon tax and a carbon constraint is illustrated empirically in Exhibit 3 using data as of August 2021. We display the weighted average EBITDA/EV and CO2/EV levels of top quintile carbon-tax-adjusted value portfolios at different carbon tax levels and portfolios optimized with various carbon budgets (as a percentage of market carbon footprint). The dots representing optimal portfolios given a carbon tax and a carbon constraint lie exactly on the same curve, illustrating that the maximum exposure to EBITDA/EV given a certain carbon footprint can be achieved using either a tax or a portfolio constraint. This curve be seen as the *value-carbon efficient frontier*. The market portfolio is indicated in purple for reference purposes.

INSERT EXHIBIT 3 HERE

In the remainder of this section we examine the long-term performance and characteristics of carbon-tax-adjusted value portfolios. We start by reporting the average carbon footprint level of the top and bottom quintile portfolios of carbon-tax-adjusted value in Exhibit 4, for various levels of the assumed carbon tax. In the base case situation without a carbon tax, the top quintile portfolio exhibits an above-average carbon footprint

[7] Equal weighting can lead to inflated returns for broad universes containing illiquid small- and micro-caps, but we prevent this issue by using an investment universe that consists entirely of liquid large- and mid-cap stocks. In this case equal weighting is realistic and feasible.
[8] From June 2020 onwards
[9] January 2021

level, while the bottom quintile portfolio exhibits a below-average carbon footprint level. Thus, 'value' stocks tend to have a much higher average carbon footprint than 'growth' stocks. However, with a carbon tax the carbon footprint of the top quintile portfolio goes down, while the carbon footprint of the bottom portfolio goes up. It can be seen that the top and bottom portfolio have the same carbon footprint at a tax level of about $20.

INSERT EXHIBIT 4 HERE

Exhibit 5 shows the percentage reduction of the carbon footprint of the top quintile portfolio, measured either against the base case top quintile portfolio without a carbon tax, or the equally-weighted universe of all stocks. The largest effect of the carbon tax occurs in the $10 to $100 tax range. For the top quintile, a carbon tax of $10 leads to an 18% lower carbon footprint compared to the base case, a $50 tax leads to a 39% lower carbon footprint, and $100 leads to a 49% lower carbon footprint. As shown in the previous section, this reasoning can also be turned around, i.e. imposing a 49% carbon footprint reduction constraint is similar to assuming a $100 carbon tax. Carbon tax levels below $10 do not have much impact, but also carbon tax levels above $100 have an increasingly smaller impact on the portfolios. Getting beyond 60% carbon footprint reduction for the top quintile portfolio versus the base case requires progressively higher (and arguably unrealistic) carbon tax levels. For instance, a 70% carbon footprint reduction requires an assumed carbon tax of about $5,000. For the bottom quintile portfolio the carbon footprint explodes with carbon taxes above $10, as stocks with very high carbon footprints are effectively so heavily punished that they are forced into the bottom quintile.

INSERT EXHIBIT 5 HERE

Exhibit 6 shows that the amount of carbon reduction of the top quintile portfolio for a given carbon tax level is fairly stable over time. In particular, the impact of the carbon tax is not much bigger or smaller at the beginning of the sample than at the end, indicating that the use of simulated carbon data for a large part of the sample does not distort our results.

INSERT EXHIBIT 6 HERE

Exhibit 7 depicts the amount of carbon reduction versus the equally-weighted universe of all stocks over time. This reduction turns out to be less stable because the base case EBITDA/EV strategy already exhibits a strong time-varying carbon footprint compared to this benchmark. In fact, the base case EBITDA/EV top portfolio without a carbon tax almost always has a higher carbon footprint than the universe. It takes a carbon tax of about $50 to ensure that the carbon footprint of the top quintile portfolio is similar to the carbon footprint of the universe on average. In order to ensure that the top quintile always ends up with a lower carbon footprint than the universe, a substantially higher carbon tax of about $1,000 is required.

INSERT EXHIBIT 7 HERE

Exhibit 8 shows how much of the original EBITDA/EV exposure is left after selecting stocks on their carbon-tax-adjusted EBITDA/EV scores. We observe that the EBITDA/EV exposure of the top quintile is virtually unaffected for carbon taxes up to $50, and slowly begins to decay after that. Even at a carbon tax level of $1,000 a large part of the base case EBITDA/EV exposure still remains. The bottom quintile is affected more, starting to deteriorate already beyond a carbon tax level of $20, and having lost all of its EBITDA/EV exposure at the $1,000 tax level. These asymmetric results are in line with the previously observed asymmetric impact of carbon taxes on the carbon footprints of the top and bottom portfolios.

INSERT EXHIBIT 8 HERE

We next turn our attention to the impact of carbon taxes on returns. Exhibit 9 shows that the outperformance of the top quintile is effectively immune to carbon tax levels up to $100. At higher tax levels the performance begins to deteriorate, but it takes a carbon tax of over $20,000 to fully wipe out the top quintile outperformance. The bottom quintile performance deteriorates more rapidly, starting from a carbon tax level of $50, and already ending with zero performance at a tax level of $2,000. This asymmetric performance deterioration of the top and bottom quintiles is in line with the previously observed asymmetric deterioration of their EBITDA/EV characteristics, with the bottom quintile being affected more because it effectively becomes the dumping ground for all the stocks with high carbon footprints.

INSERT EXHIBIT 9 HERE

The outperformance of the top quintile over time for different carbon tax levels is depicted in Exhibit 10. The performance of the base case EBITDA/EV strategy without a carbon tax adjustment is strong until about 2010, but levels off afterwards. This is in line with the known recent performance struggles of the value factor; see e.g. Arnott et al. (2021), Fama and French (2020), Israel, Laursen, and Richardson (2021), and Blitz and Hanauer (2021). For carbon taxes of $10 and $100 the cumulative performance development remains very similar, but for higher carbon taxes we observe clear deteriorations. Interestingly, the drop in performance with a tax of $1,000 is concentrated in the 2000-2008 period, during which the oil price rose from about $30 to over $175 per barrel. For the $10,000 carbon tax portfolio the performance is no longer recognizable as that of an EBITDA/EV strategy, because at such high tax levels the ranking of stocks is primarily determined by their carbon footprint levels instead of their EBITDA/EV characteristics.

INSERT EXHIBIT 10 HERE

3.3 Robustness tests

We perform two robustness checks. In the first one, we consider portfolio sorts which are neutral for regions (North-America, Europe, and Asia-Pacific) and GICS-1 sectors. This means that we create quintile portfolios within every regional sector separately and then aggregate these into overall quintile portfolios. In the second test, we consider the MSCI Emerging Markets universe, with data starting from the end of December 1995.

The carbon footprint of the region-sector neutral top and bottom value portfolio is shown in Exhibit 11. We observe the same patterns as in Figure 4. The top value portfolio has an above-average carbon footprint and the bottom portfolio has a below-average footprint. With a carbon tax of about $10, the carbon footprint of the top portfolio is reduced to the footprint of the bottom portfolio, and with a tax of about $50 it equals the footprint of the market.

INSERT EXHIBIT 11 HERE

The average EBITDA/EV and outperformance are shown in Exhibits 12 and 13. With taxes of up to $50, value exposure and outperformance remain virtually unchanged. This illustrates that the first decarbonization steps have negligible impact on a value strategy. With higher taxes, the value exposure and performance start to deteriorate.

INSERT EXHIBIT 12 AND 13 HERE

Results for emerging markets are shown in Exhibits 14, 15 and 16, and are very comparable to those for developed markets. The patterns are a bit less smooth, which is probably due to the smaller universe (about 135 stocks per quintile). The EBITDA/EV level of the top portfolio remains almost intact, even with a higher tax level of $200, although outperformance starts decreasing earlier.

INSERT EXHIBIT 14, 15 AND 16 HERE

4. Conclusion

We examined the effects of incorporating a potential tax on carbon emissions into a value investment strategy. We have established that in a portfolio optimization problem, a carbon tax for individual stocks is mathematically equivalent to a carbon constraint for the portfolio as a whole. Empirically, value exposure and carbon footprint are negatively related, such that investors face a trade-off between high value exposure and low carbon footprint. The optimal combinations of value exposure and carbon footprint together form the value-carbon efficient frontier.

Empirically we find that carbon taxes up to $100, corresponding to a portfolio carbon footprint reduction of about 50%, have little effect on the characteristics and the performance of the long side of an EBITDA/EV value strategy. This also seems to be about as far as one can reasonably get, because in order to go from a 50% to a 70% carbon footprint reduction one needs to increase the assumed carbon tax from $100 to about $5,000! At such extreme tax levels the impact on performance is also no longer negligible. The short side of the value strategy is affected more severely by carbon taxes, as the bottom portfolio effectively becomes a dumping ground for all the high carbon stocks.

References

Arnott, R. D., Harvey, C. R., Kalesnik, V., and Linnainmaa, J. T., 2021. "Reports of Value's Death May Be Greatly Exaggerated." *Financial Analysts Journal* 77 (1): 44-67.

Blitz, D., and Hanauer, M. X., 2021. "Resurrecting the Value Premium." *Journal of Portfolio Management* 47 (2): 63-81.

Fama, E. F., and French, K. R., 1992. "The Cross-Section of Expected Stock Returns." *Journal of Finance* 47 (2): 427-465.

Fama, E. F., and French, K. R., 2020. "The Value Premium." SSRN working paper, no. 3525096.

Hoel, M., 1996. "Should a Carbon Tax Be Differentiated Across Sectors?" *Journal of Public Economics* 59 (1), 17-32.

Israel, R., Laursen, K., and Richardson S. A., 2021. "Is (Systematic) Value Investing Dead?" *Journal of Portfolio Management* 47 (2): 38-62.

Lev, B., and Srivastava, A., 2020. "Explaining the Recent Failure of Value Investing." SSRN working paper, no. 3442539.

Loughran, T., and Wellman, J.W., 2011. "New Evidence on the Relation Between the Enterprise Multiple and Average Stock Returns." *Journal of Financial and Quantitative Analysis* 46 (6): 1629-1650.

Marron, D. B., and Toder, E. J., 2014. "Tax Policy Issues in Designing a Carbon Tax." *American Economic Review* 104 (5), 563-568.

Metcalf, G. E., 2009. "Designing a Carbon Tax to Reduce US Greenhouse Gas Emissions." *Review of Environmental Economics and Policy* 3 (1), 63-83.

Metcalf, G. E., and Weisbach, D., 2009. "The Design of a Carbon Tax." *Harvard Environmental Law Review* 33, 499-556.

Nordhaus, W. D., 2007. "To Tax or Not to Tax: Alternative Approaches to Slowing Global Warming." *Review of Environmental Economics and Policy* 1 (1), 26-44.

Park, H., 2019. "An Intangible-Adjusted Book-to-Market ratio Still Predicts Stock Returns." Critical Finance Review, forthcoming.

Pedersen, L. H., Fitzgibbons, S., and Pomorski, L., 2021. "Responsible Investing: The ESG-Efficient Frontier." *Journal of Financial Economics* 142 (2), 572-597.

Pigou, A. C., 1920. "The Economics of Welfare". Macmillan. *New York.*

Ulph, A., and Ulph, D., 1994. "The Optimal Time Path of a Carbon Tax." *Oxford Economic Papers* 46, 857-868.

Walkshäusl, C., and Lobe, S., 2015. "The Enterprise Multiple Investment Strategy: International Evidence." *Journal of Financial and Quantitative Analysis* 50 (4): 781-800.

Stern, N., and Stern, N. H., 2007. The Economics of Climate Change: The Stern Review. Cambridge University Press.

Exhibit 1: Cross-sectional distribution of carbon footprint (CO_2/EV in tons/million USD) levels as of August 2021

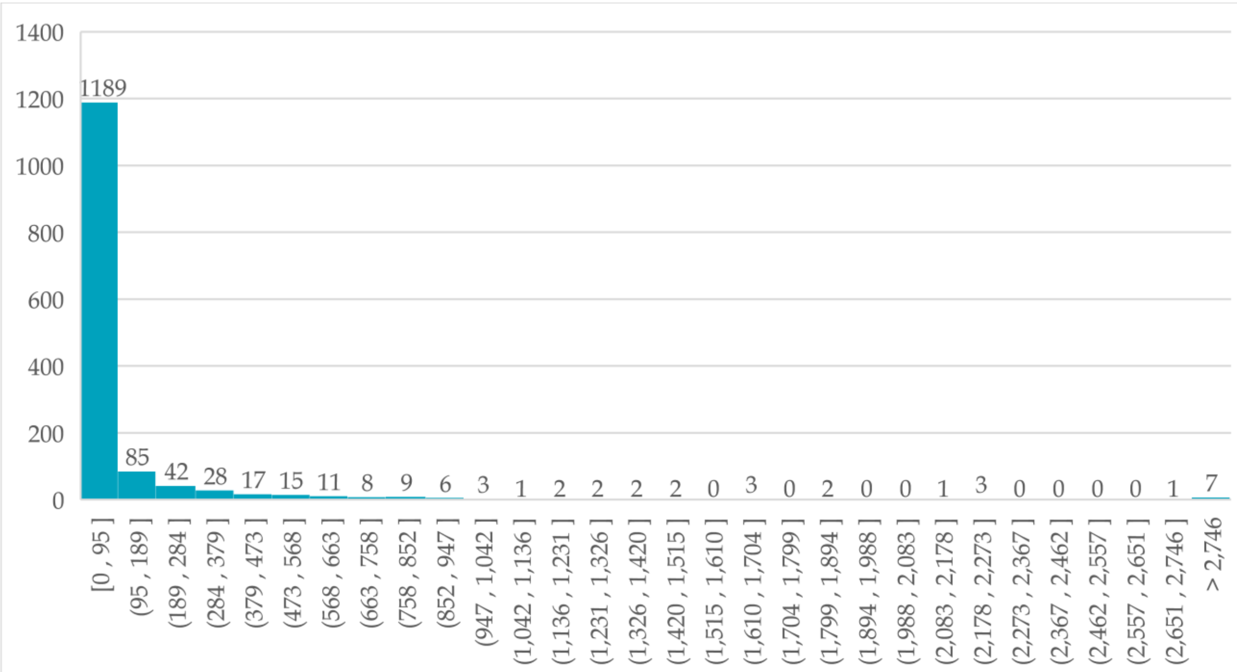

Exhibit 2: Cross-sectional distribution of carbon footprint (CO_2/EV) levels by sector, as of August 2021

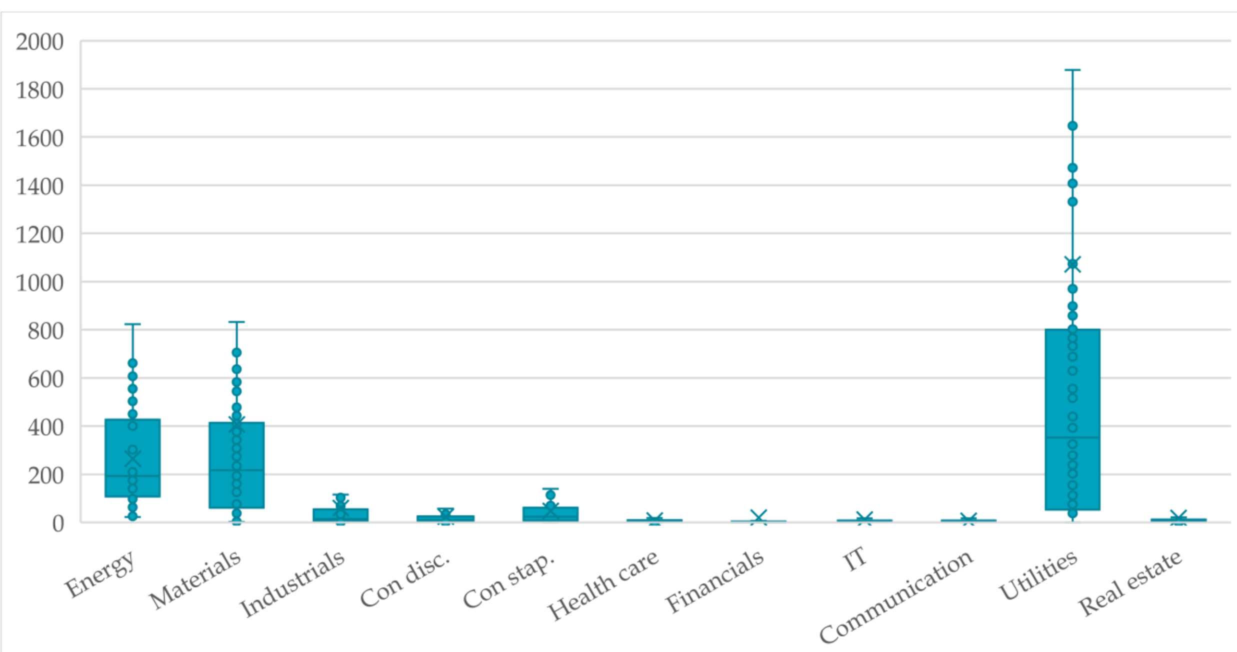

Exhibit 3: Simulated portfolio levels of EBITDA/EV for various levels of tax and carbon constraints

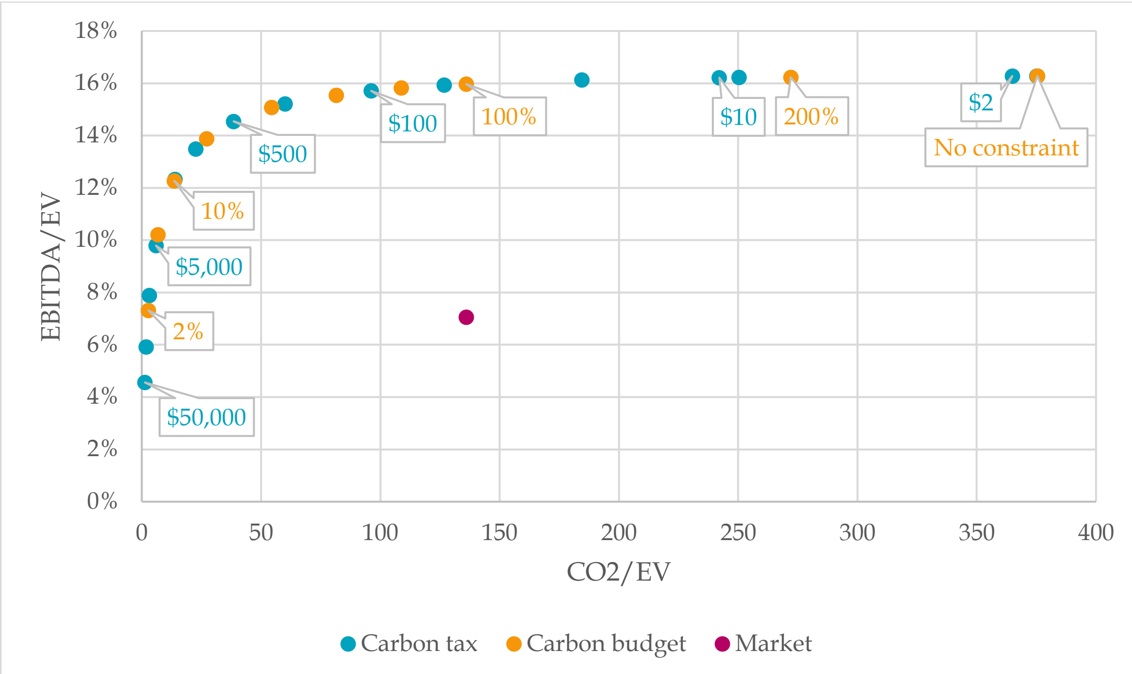

Exhibit 4: Average carbon footprint (CO2/EV) levels of carbon-tax-adjusted value (EBITDA/EV) top and bottom quintile portfolios

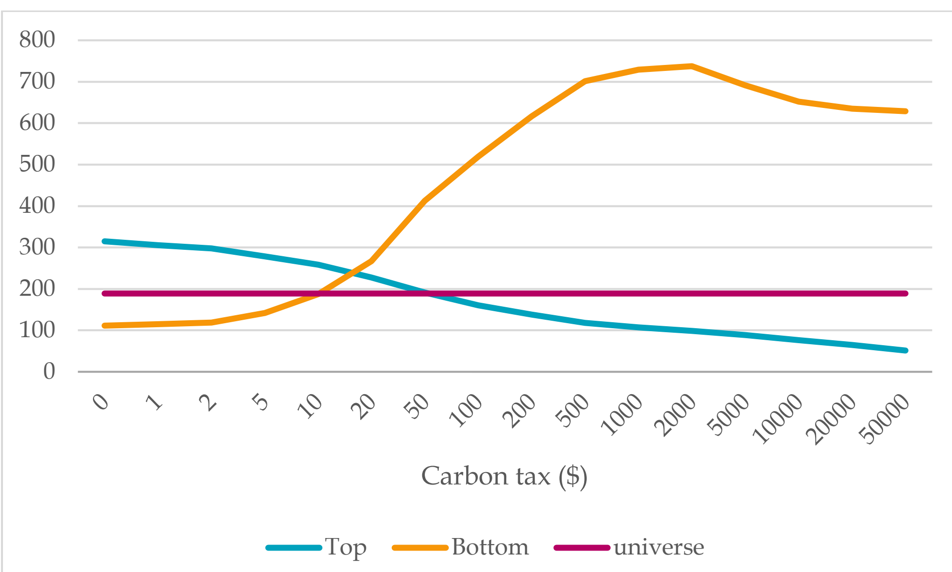

Exhibit 5: Average carbon footprint (CO_2/EV) reduction of carbon-tax-adjusted value (EBITDA/EV) top quintile portfolios versus base case value portfolio

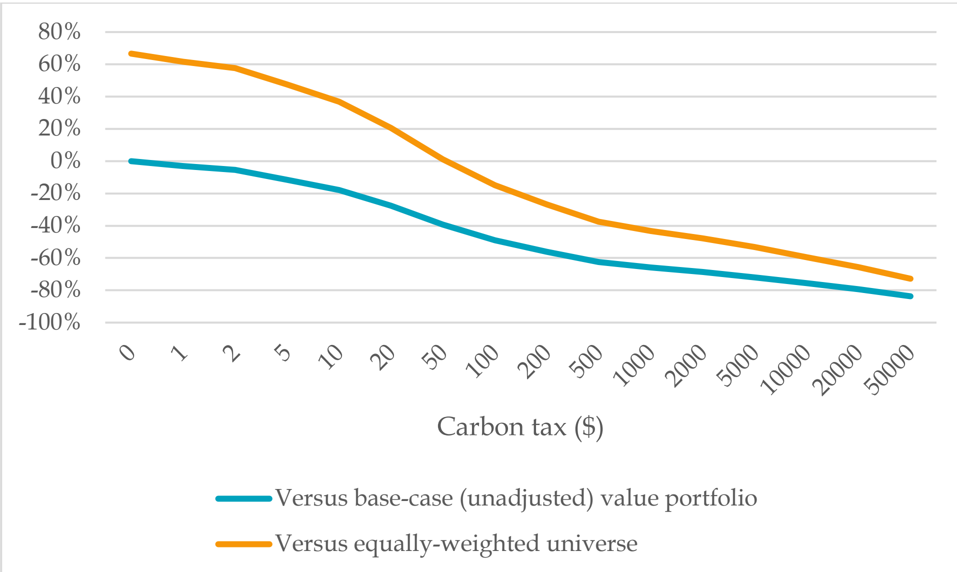

Exhibit 6: Carbon footprint (CO_2/EV) reduction of carbon-tax-adjusted value (EBITDA/EV) top quintile portfolios versus base case value portfolio over time

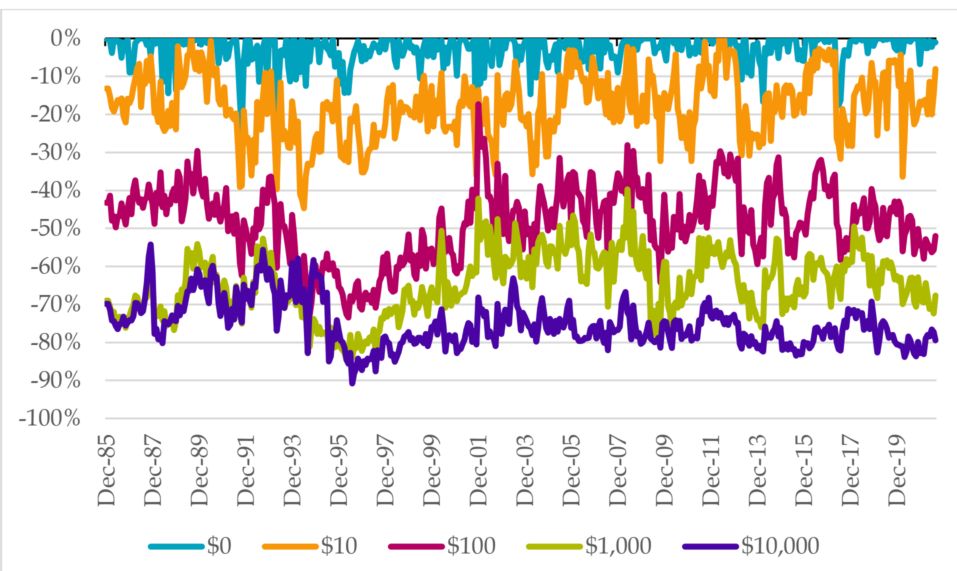

Exhibit 7: Carbon footprint (CO_2/EV) reduction of carbon-tax-adjusted value (EBITDA/EV) top quintile portfolios versus equally-weighted universe over time

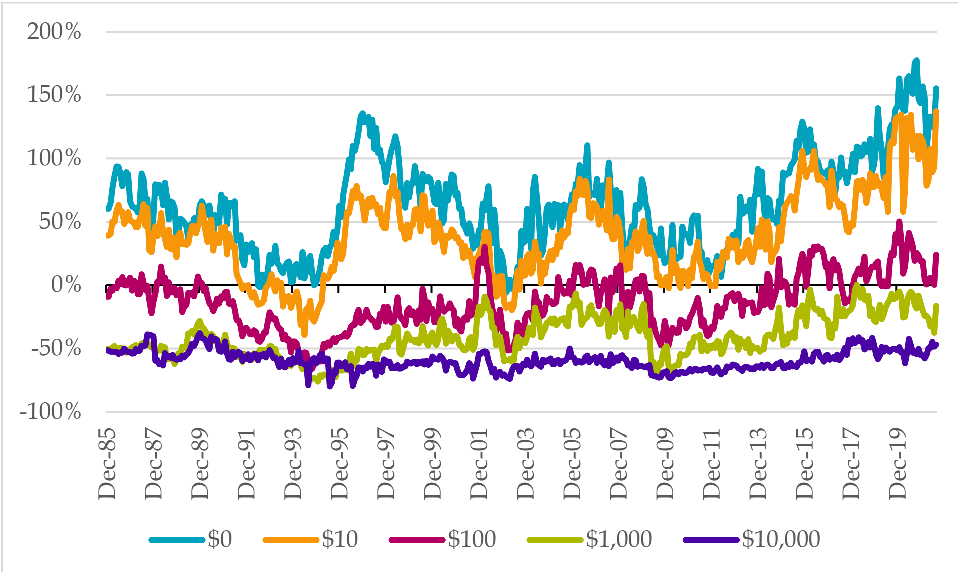

Exhibit 8: Average unadjusted value (EBITDA/EV) score of carbon-tax-adjusted value top and bottom quintile portfolios

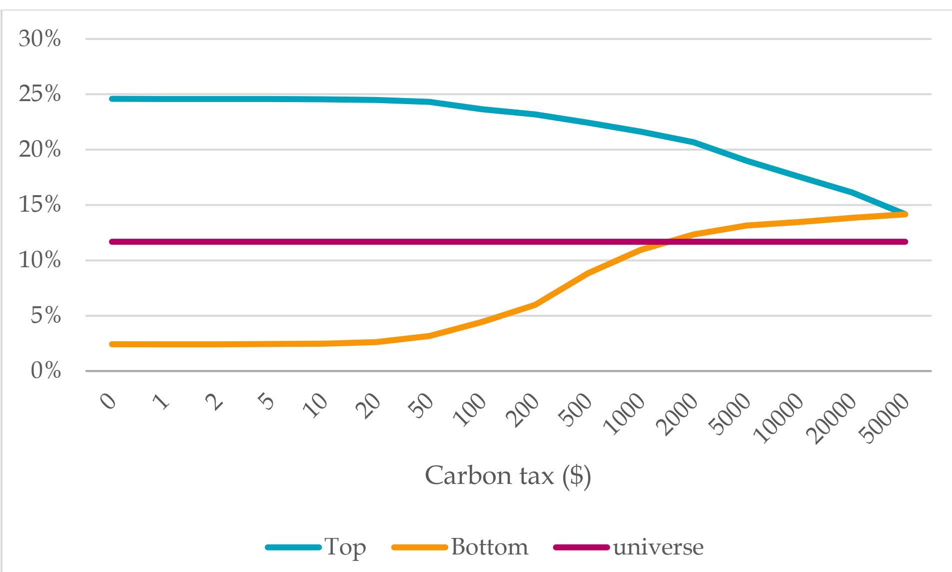

Exhibit 9: Average outperformance versus equally-weighted universe of carbon-tax-adjusted value (EBITDA/EV) top and bottom quintile portfolios

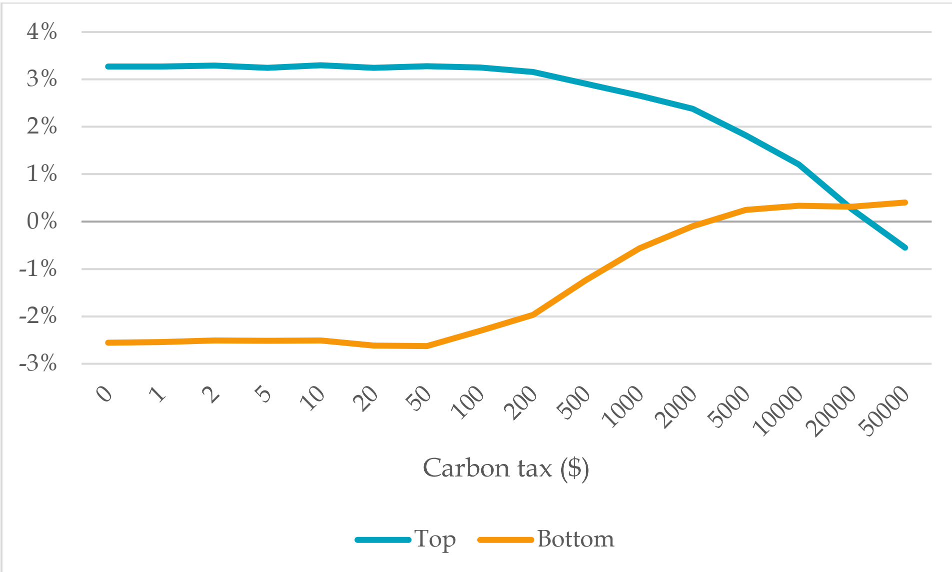

Exhibit 10: Cumulative outperformance of carbon-tax-adjusted value (EBITDA/EV) top quintile portfolios versus equally-weighted universe over time

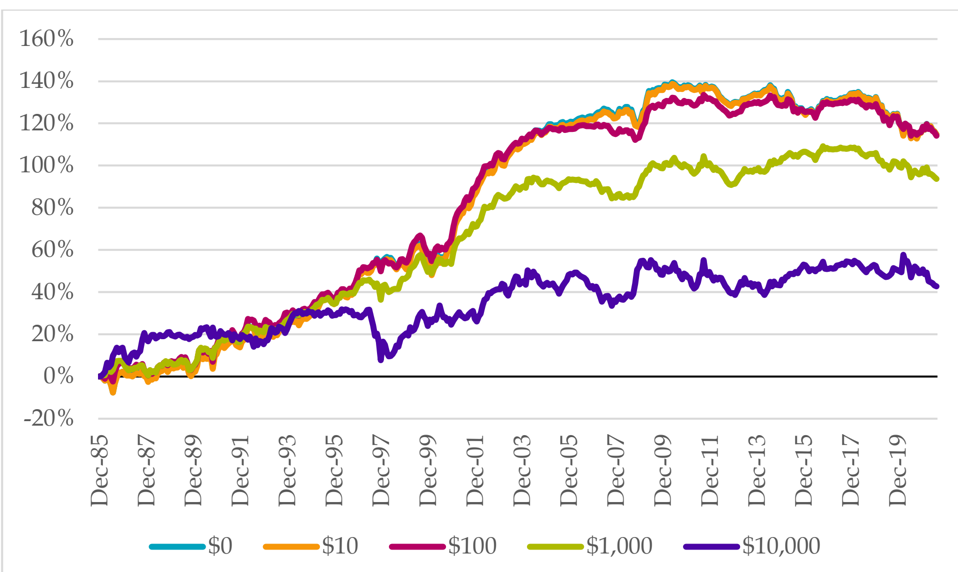

Exhibit 11: Average carbon footprint (CO_2/EV) levels of carbon-tax-adjusted value (EBITDA/EV) top and bottom quintile portfolios (region-sector neutral)

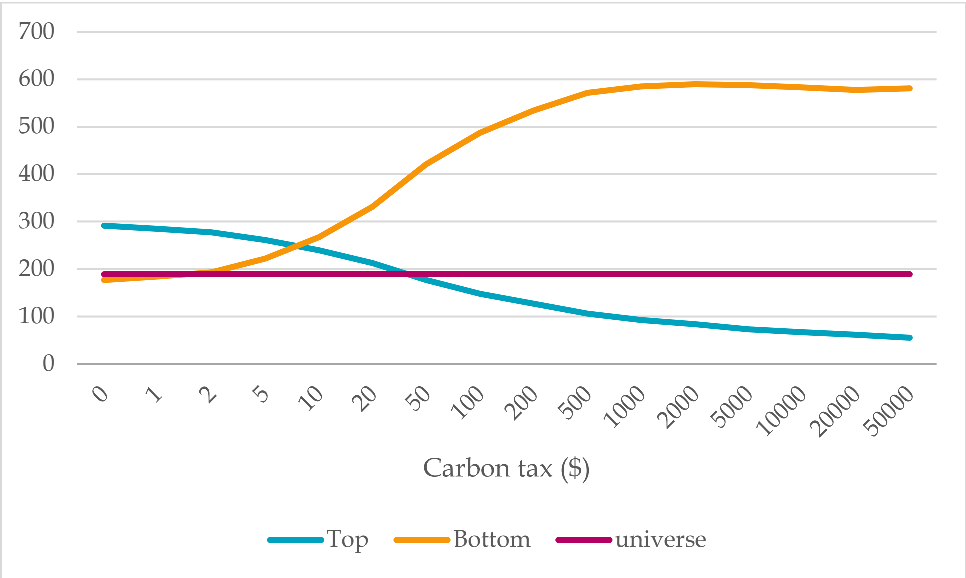

Exhibit 12: Average unadjusted value (EBITDA/EV) score of carbon-tax-adjusted value top and bottom quintile portfolios (region-sector neutral)

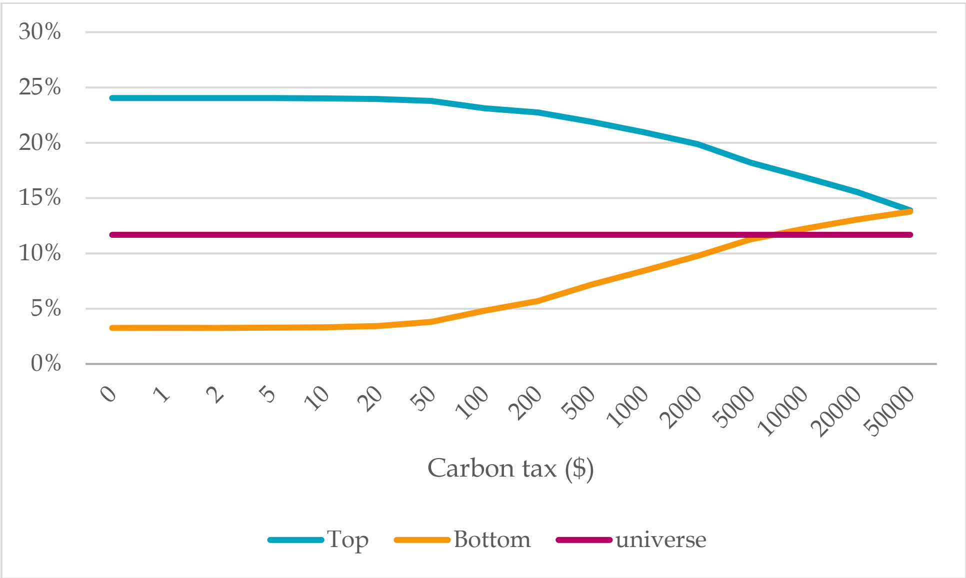

Exhibit 13: Average outperformance versus equally-weighted universe of carbon-tax-adjusted value (EBITDA/EV) top and bottom quintile portfolios (region-sector neutral)

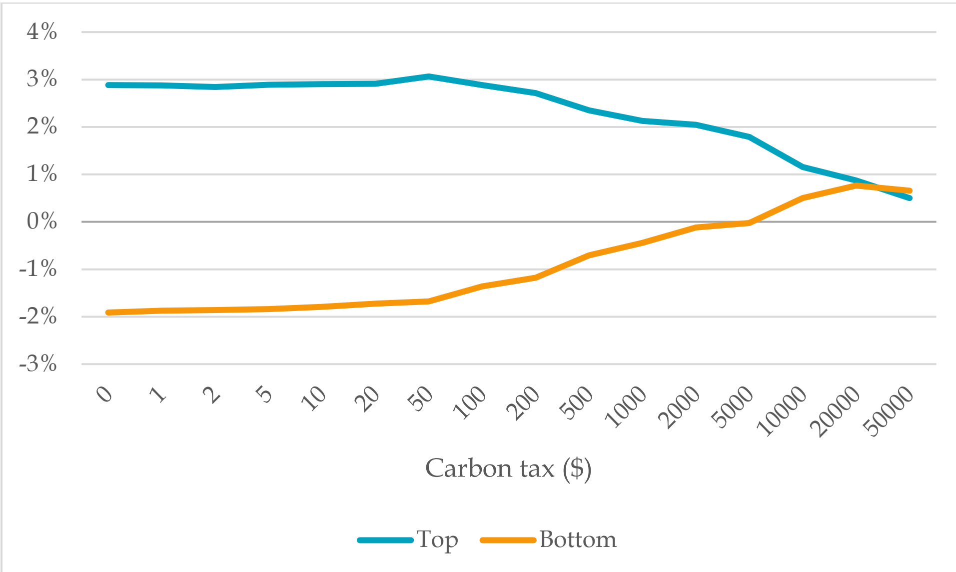

Exhibit 14: Average carbon footprint (CO2/EV) levels of carbon-tax-adjusted value (EBITDA/EV) top and bottom quintile portfolios (Emerging Markets)

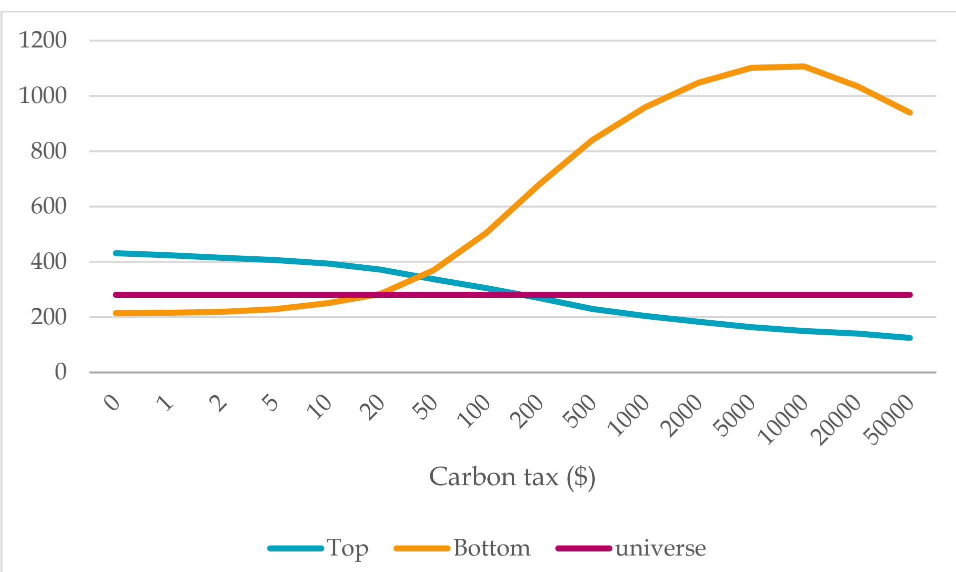

Exhibit 15: Average unadjusted value (EBITDA/EV) score of carbon-tax-adjusted value top and bottom quintile portfolios (Emerging Markets)

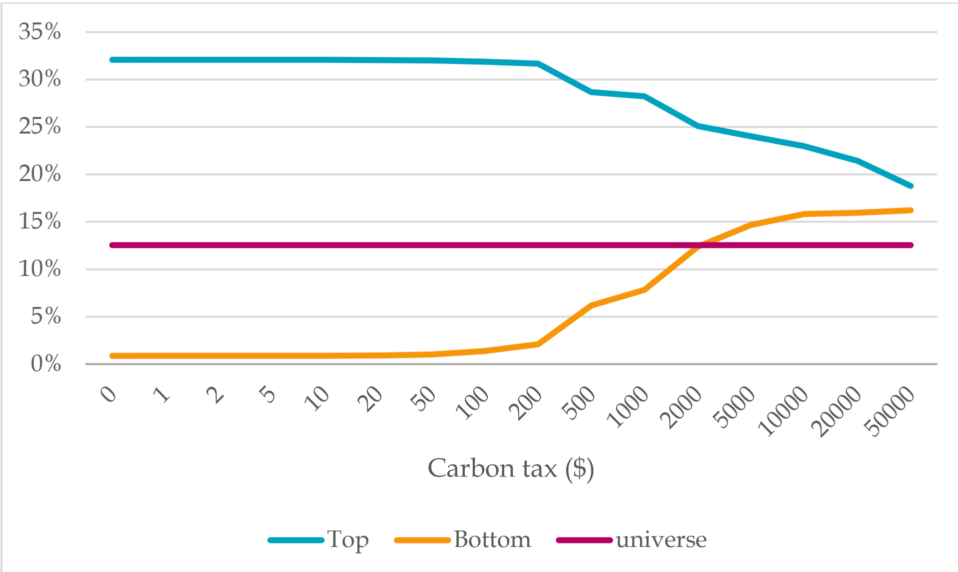

Exhibit 16: Average outperformance versus equally-weighted universe of carbon-tax-adjusted value (EBITDA/EV) top and bottom quintile portfolios (Emerging Markets)