VOLUME 34
NUMBER 2
SPRING 2022

# Journal of APPLIED CORPORATE FINANCE

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# The Financial Cost of Carbon

by Patrick Bolton, Columbia University and Imperial College; Zachery Halem, Lazard; and Marcin Kacperczyk, Imperial College*

In an ideal world, the financial cost of carbon (FCC) reflects the full social cost of carbon (SCC). The SCC is a familiar notion in climate change economics. It is an estimate of the future damages that are expected to be caused by the effects on climate change of emitting an additional ton of $CO_2$ in the atmosphere. Estimates of the SCC are based on integrated assessment models (IAMs), which are economic growth models augmented with an energy input, carbon emissions from production, the expected effect of these emissions on temperature increases (as best assessed by the climate science that underlies the climate change projections of the Intergovernmental Panel on Climate Change (IPCC)), and the expected feedback effect of this projected overheating of the planet on expected future economic productivity.

The SCC is envisioned by economists as a "shadow price of carbon": the price level (or tax) at which an extra ton of $CO_2$ emitted into the atmosphere would be charged in an efficient economy. In the presence of such a price, emitters of $CO_2$ will choose to emit only if the financial benefit exceeds the SCC. Economists have long argued that the key to solving the climate crisis is to introduce a global carbon tax equal to the SCC and otherwise let markets take care of themselves. The basic premise is that, when left to their own devices, markets achieve a reasonably efficient allocation of scarce goods and services, except for the carbon externality. Therefore, there is a simple fix to the climate crisis: a carbon tax. And in the thinking of economists, then, if we have a climate crisis, the cause will not be bad economics or science, but bad politics.

The rise of sustainable finance and responsible investment, and the new focus on environmental, social, and governance (ESG) impact factors, is partly a result of growing frustration with inadequate policy progress on climate change. It is difficult to pin down precisely when the ESG movement started—some commentators trace the first use of the term "ESG" to an IFC conference held in 2005.[3] But in less than 20 years, it has grown from a niche to $130 trillion of assets under management, representing an estimated 40% of global financial assets.[4]

But if the growth in responsible investment has been nothing short of phenomenal, there is conflicting evidence on what the impact of ESG has been so far. Our focus here is to contribute to the large and growing body of studies attempting to discern or reveal the links between stock returns, corporate valuations by financial markets, and corporate carbon emissions. We also present some new evidence

* We are especially grateful to Don Chew for his invaluable comments and advice. We also thank Peter Orszag for his comments, Abraham Axler, Quinn Pitcher for research support and Shenghan Yu, James Tea for help with data preparation and processing. Funding from the European Research Council (ERC) under the ERC Advanced Grant program (grant agreement No. 885552 *Investors and Climate Change*) for this research is gratefully acknowledged.

1 See, among many possible others, Gollier and Tirole (2015).

2 Although it had a somewhat different focus, the socially responsible investment (SRI) movement is the precursor to the ESG movement. The first environmental fund, Juniper, was launched in 1987 and by some estimates SRI-based investments represented around 15% of equity markets in 2005 (see Hong and Kacperczyk, 2009). Interestingly, the IFC conference held in 2005 was titled the "Who Cares Wins" conference, which contains the suggestion that ESG-based investments opened a pathway to doing well by doing good, an idea that has stuck and been a key element of the sales pitch for some ESG asset managers.

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4 This is the size of the Glasgow Financial Alliance for Net Zero (GFANZ) launched by Mark Carney at the COP26 in Scotland this past November 2021.

on the financial cost of carbon (FCC) that companies with higher carbon (generally greenhouse gas) emissions appear to have been paying for quite some time, and that appears to be steadily rising in tandem with projected SCC. We conclude by speculating that the FCC could rise even more sharply in the coming years, as the global economy shifts more and more towards net zero.

Our main argument here is that climate finance must be seen first and foremost as a response to a risk-management problem, a response by companies and their investors to the mounting financial risks associated with climate change and the transition to a net zero economy. As Robert Litterman wrote with great prescience in the wake of the Global Financial Crisis, when the notion of climate finance had barely been conceived,

> *Not pricing risk appropriately leads to disasters. Start by thinking about what would be the appropriate price for carbon emissions today. What should the price reflect? The price should reflect the risk created by carbon emissions, clearly…. Yet the situation we have today with respect to carbon emissions, is that not only are emissions currently not reflecting a premium, they are not even reflecting the expected discounted damages. How serious is it when a systematic risk is not priced appropriately? Recall that what caused the financial crisis was also a systematic risk that wasn't being priced. Not pricing systematic risk leads to too much risk being taken, and such a situation will eventually lead to a high probability of a global catastrophe.*[5]

For investors, taking account of climate risk exposure means essentially three things. First, prudent investors will seek to hedge climate change risk by reducing their exposure to it. Second, investors will demand compensation for holding this risk. Third, investors will engage with companies to exert pressure on them to reduce this risk if they are not adequately compensated for it. Reducing exposure to carbon transition risk—a form of divestment—can be justified purely based on effective, long-run value-maximizing risk management.

For companies, the main implication of climate-risk management by investors is that those with greater exposure to climate-change-related risk have a higher cost of capital, which means both lower price multiples on their projected earnings stream and higher hurdle rates on new investment—which, as we noted, should prompt their business and industry to shrink. The companies with greater carbon emissions will have to offer higher expected returns to their shareholders, other things equal, to compensate them for the higher exposure to carbon transition risk. In other words, the risk-management perspective that underlies climate finance establishes a positive link between carbon emissions and stock returns or, as cited above, a negative relation between price multiples and carbon emissions. And their lower valuations and higher investment hurdle rates should, especially with prodding from value-maximizing activist shareholders, exert pressure on managements to reduce their carbon transition risk exposure by committing to gradual decarbonizing of their operations and by disclosing their emissions.

## The Evidence to Date

Are these basic predictions borne out in the data? Before turning to the main findings of our study using the most recent and comprehensive available data, we discuss next a few influential recent studies that have reached what at least appear to be contradictory conclusions. As we argue below, some of the recent findings can be seen as offering out-of-sample evidence in support of the main results that we reported in our two studies published in the past two years.[6] Besides these two, the other studies linking stock returns to carbon emissions (or ESG) that we now discuss are the following:

(1) Cheema-Fox, LaPerla, Serafeim, Turkington, and Wang (2021);

(2) Pastor, Stambaugh, and Taylor (2021);

(3) Aswani, Raghunandan, and Rajgopal (2021); and

(4) Berk and Van Binsbergen (2022).

We now try to make sense of the seemingly contradictory results of these studies.

The first of our two studies, published in 2021, looks at the relation between stock returns and carbon emissions of all U.S. listed companies for which there is data (provided by Trucost) on yearly carbon emissions. Our study begins in 2005, ends in 2018, and covers around 3000 listed companies. We find that both direct (scope 1) and indirect (scope 2 and 3) lagged carbon emissions have a positive association with stock returns after controlling for all other risk factors and companies' characteristics that expect to influence stock returns. In other words, companies with higher levels of carbon emissions, or higher growth rate in emissions, tend to have higher stock returns, holding other things equal.

We interpret these higher stock returns as expected compensation for bearing transition risk exposure demanded by investors—and we refer to the higher returns for higher emissions as the *carbon premium*. We find this premium to be "economically" as well as statistically significant, in the following sense: each one-standard-deviation increase in the level of

5 Litterman (2010).

6 Bolton and Kacperczyk (2021a and 2021b).

and change in cross-firm scope 1 emissions is associated, on average, with annualized increases in stock returns of 1.8% and 3.1%, respectively, during the period 2005-2018. And one-standard-deviation increases in the level and change of scope 3 emissions during the same period are associated with increases in stock returns of 4.0% and 3.8%, respectively, on an annual basis. Our finding surprised many commentators who either thought investors had not paid much attention to carbon transition risk until very recently (especially in the U.S.) or expected to find higher returns associated with green companies (those with lower GHG emissions) in confirmation of the doing-well-by-doing-good hypothesis.

In our follow-up study, we extended our analysis to the whole world in an attempt to identify the drivers of the carbon premium. Our chief candidates in this search were policy and regulatory risk, socio-economic risk, reputational risk, and technological risk. We found the presence of a carbon premium to be remarkably robust, and in evidence in almost all the 77 countries covered in our study (of nearly 15,000 companies from 2005 to 2019), representing more than 98% of listed companies (in terms of market capitalization) for which emissions data is available, and 80%-85% of the market value of all listed firms across the world. For the pooled sample of all 14,468 companies, a one-standard-deviation increase in scope 1 emissions was associated with a 13% lower market-to-book ratio, providing further confirmation of the presence of a carbon premium for listed companies across the world.

One important finding of both studies is that the carbon premium appears completely unrelated to emission intensity—which is the ratio of carbon emissions to sales revenue. This finding was somewhat surprising since many institutional investors are known to apply exclusionary screening filters to their portfolios, a form of divestment, based on the emission intensity of the company, but not on the level or growth rate of emissions.[7] Since the carbon premium is associated with the latter but not with carbon intensity, one important conclusion of our first study is that the higher returns associated with higher emissions are not driven by divestment per se, but rather by a general repricing of carbon transition risk exposure—an exposure that appears to be a direct function of the volume or size of emissions, not emission intensity. And such repricing is consistent with the tendency of both regulations limiting emissions and carbon pricing to target activities where the level of emissions is highest.

Another important finding of both studies is that the carbon premium is present in *all* industry sectors, not just the energy, utility, and transport sectors, where most divestment has occurred. This is to be expected given that all companies with large direct or indirect emissions are exposed to carbon transition risk.

These findings provide strong support for the general idea that companies with high carbon emissions have seen, and will continue to see, an increase in their cost of capital. The emergence of a carbon premium in the last decade is simply the reflection of financial markets at work, pricing risk to offer investors a higher return as compensation for bearing higher risk. Climate change has resulted in a new financial risk in recent years, so that it is to be expected that this risk would be reflected in returns. And as might also be expected, the first of our two studies, which focused on only U.S. companies, found no carbon premium in the 1990s when climate change risk was not perceived to be material; but as already noted, we found a marked increase of the carbon premium in the next two decades, especially in the wake of the socially and politically salient Paris Agreement.

## Conflicting Evidence

Nevertheless, a study published in the same year (2021) as our study of global corporations suggests the opposite. In that study, Alexander Cheema-Fox, Bridget LaPerla, George Serafeim, David Turkington, and Hui Wang estimate the returns of some 2,000 listed U.S. companies between 2013 and 2020, so that their sample overlaps considerably with that of our own study. Serafeim et al. estimate the returns of portfolios that are long on firms with lower carbon intensity and short on firms with higher carbon intensity, and they find positive returns in some sectors and negative returns in others. In an early related study, the same authors also reported finding that a portfolio long in low-carbon intensity sectors and short in high-carbon sectors delivered a positive and significant alpha of around 2% annually.

Serafeim et al. view both of these findings as confirming their hypothesis "that over time, market prices adjust as risks become more salient and as regulatory, technological, and physical risks manifest." Nevertheless, it's important to recognize that this working assumption and its exclusive focus on emission intensity—in other words, the design of their study—effectively prevents them from detecting any carbon premium that might be reflected in stock returns. Instead of capturing investors' perception and equilibrium pricing of carbon risk, their portfolio construction effectively limits their focus to the effects of differences in industry and technological characteristics that are correlated with, but do not directly contribute to, carbon intensity. In both of our studies, we stress the importance of recognizing and adjusting for cross-industry differences in carbon emissions when estimating

7 See Bolton and Kacperczyk (2021a).

the carbon premium. The fact that Serafeim et al.'s estimate of the carbon premium nearly doubles when they include industry-fixed effects is a clear sign that it is the differences among companies within an industry—and not differences across industries—that are driving their findings. And this is completely consistent with the findings of our studies, which as we said provide striking evidence of carbon premiums for companies with high emissions operating *in the same industry*, and these premiums are present in almost any industry you can name.

In another study published in 2021, Lubos Pastor, Robert Stambaugh, and Lucian Taylor use much the same approach as Serafeim et al. to identify what they call a "greenium"—a premium on stocks of green companies—rather than a carbon premium. Most of their analysis covers U.S.-listed companies during the period from November 2012 through the end of 2020. After classifying all stocks into "green" and "brown" categories based on their MSCI ESG rating, the authors report that a portfolio of green stocks generated much higher returns than a portfolio of brown stocks over this period.

To be sure, this finding might be—and, indeed, it has been and continues to be—interpreted as saying that there is no carbon premium; and the opposite is true, that there is a greenium reward in the form of above-market returns for investors holding low emitters and other green companies. But Pastor et al., to their credit, caution against such an interpretation, noting that such "outperformance likely reflects an unanticipated increase in environmental concerns." In other words, these returns are best viewed as reflecting a one-time market recognition and adjustment process; and as part of such a process, those returns are unlikely to be repeated in the future, and thus should not be viewed as a component of expected returns going forward.[8]

In yet another 2021 study, Jitendra Aswani, Aneesh Raghunandan, and Shiva Rajgopal provide a critical analysis of our 2021 study of U.S. companies cited above. The main concern of Aswani et al. is our study's reliance on *estimates* of carbon emissions (provided by the data vendor Trucost) instead of the actual emissions disclosed by the companies themselves. When they narrow their sample to U.S. companies that disclosed their emissions during the period 2005-2019, Aswani et al. find no relation between emissions and stock returns, and then conclude that our detected carbon premium must be entirely driven by biases in the Trucost estimate. But, as we have confirmed in our own more recent work, the carbon premium for companies that disclose their emissions, although smaller than that of our earlier sample, proved to be positive and highly statistically significant.[9] And as we pointed out in that study, a smaller carbon premium is to be expected if only because disclosure reduces uncertainty for investors, especially in the case of reported yearly growth in emissions, which cannot easily be predicted based on the level of past emissions.

What's more, Aswani et al.'s claim that our findings of a carbon premium are driven mainly by estimation biases in the Trucost data is also inconsistent with the parallel trends of both a rising carbon disclosure rate and a rising carbon premium. Despite the rise in the fraction of companies that disclose their emissions, the average carbon premium has increased. Also, although disclosure rates vary a lot across countries,[10] our recent work conclusively shows that the carbon premium is very similar across countries.[11]

Perhaps the most challenging of Aswani et al.'s criticisms is the possibility of a key missing variable—namely, a potential link between high emissions and high productivity and stock returns that, to the extent it could be demonstrated, would be misconstrued as evidence of a carbon risk premium. How can we be sure that the high stock returns of the high carbon emitters have not simply reflected the greater economic activity and operating efficiency of these companies?

As we have shown, the positive relation between stock returns and the level of emissions reported both in our study of U.S. companies, and in our study of global companies, also holds when returns are linked to *lagged* emissions and after controlling for firm size, sales growth, and ROE. Moreover, the strikingly negative relation between market-to-book ratios and carbon emissions reported by our 2021 study of global companies, *after controlling for current cash flows and analyst estimates of long-term earnings growth*, suggests that the carbon premium is unlikely to be driven by cash flow effects related to productivity.

Finally, we should mention one other recent study casting doubt on the social efficacy of divestitures as an ESG investment strategy. In their 2022 study, Jonathan Berk and Jules van Binsbergen hypothesize that ESG divestitures represent too limited a part of the potential market to influence the cost of capital of brown companies. They conclude from their analysis that ESG investors should concentrate on engagement rather than divestment.

8 Also, as other studies have pointed out (e.g., Yang 2019), ESG ratings are inconsistent across providers and aggregate different impact dimensions, which are not directly related to carbon transition risk.

9 Bolton and Kacperczyk (2021c).

10 Ibid.

11 Bolton and Kacperczyk (2021b).

*Table 1*
**Summary Statistics**

| Variable | Mean | Median | St. Dev. | Mean | Median | St. Dev. | Mean | Median | St. Dev. |
|---|---|---|---|---|---|---|---|---|---|
| | | Full | | | Europe | | | USA | |
| Carbon_level | 895683 | 8776 | 8294650 | 969674 | 8224 | 7154886 | 741006 | 8597 | 5491449 |
| Carbon_pctchg | 2.50 | 0.03 | 168.99 | 0.98 | 0.01 | 37.05 | 0.84 | 0.04 | 23.22 |
| Methane_level | 1840 | 0.62 | 39812 | 1597 | 0.45 | 20273 | 1535 | 0.62 | 17803 |
| Methane_pctchg | 253.34 | 0.03 | 47010.02 | 8.97 | 0.005 | 514.64 | 6.29 | 0.03 | 420.03 |
| Nitrous_level | 64 | 0.43 | 745 | 47.67 | 0.33 | 404.36 | 51 | 0.39 | 1125 |
| Nitrous_pctchg | 22.58 | 0.03 | 3063.94 | 5.15 | 0.01 | 257.74 | 32.61 | 0.03 | 2730.56 |
| Hfcs_level | 2.30 | 0.08 | 25.06 | 3.00 | 0.10 | 21.07 | 2.94 | 0.11 | 33.48 |
| Hfcs_pctchg | 1.41 | 0.03 | 71.37 | 1.0850 | 0.0153 | 31.1725 | 1.3291 | 0.0373 | 40.8213 |
| Log(p/e) | 2.9251 | 2.8484 | 0.7967 | 2.8868 | 2.8306 | 0.6966 | 3.0456 | 2.9489 | 0.8079 |
| Log(b/m) | -0.6362 | -0.5526 | 0.9973 | -0.7335 | -0.6687 | 0.9922 | -0.9529 | -0.8198 | 1.0130 |
| Log(cds) | 4.4220 | 4.4659 | 0.8818 | 4.4657 | 4.4427 | 0.7317 | 4.5373 | 4.5326 | 0.7883 |
| Return | 0.0102 | 0 | 0.6550 | 0.0089 | 0.0032 | 0.1469 | 0.0151 | 0.0084 | 0.2679 |
| Log(mktcap) | 6.79 | 6.73 | 1.71 | 7.13 | 7.03 | 1.80 | 7.34 | 7.28 | 1.87 |
| Leverage | 1181 | 48 | 202504 | 4659 | 55 | 454055 | 87 | 65 | 1722 |
| Momentum | 0.0068 | 0.0031 | 0.1915 | 0.0053 | 0.0043 | 0.0408 | 0.0085 | 0.0068 | 0.0741 |
| Investment/assets | -0.0869 | -0.0504 | 6.1931 | -0.0846 | -0.0538 | 1.0384 | -0.1311 | -0.0441 | 4.6874 |
| Log(ppe) | 11.78 | 11.92 | 2.45 | 11.72 | 12.02 | 2.78 | 11.8138 | 11.8811 | 2.5924 |
| Sales growth | 72.36 | 5.20 | 5288.08 | 99.79 | 4.38 | 4027.31 | 187.14 | 5.96 | 11542.84 |

Unfortunately, the authors offer no empirical support on the effects of engagement. Their analysis fails to recognize the importance of carbon transition risk, and of the ongoing impact of investors' perception of that risk—of its effect on the rising corporate cost of capital reflected in the companies' lower stock prices and PE multiples. Companies that persist in maintaining high carbon emissions are likely to be viewed by their existing and potential investors as increasingly out of step with national net zero commitments, exposing them to steadily increasing carbon transition risks.

## Our New Study: GHG Emissions and P/E Ratios 2016-2020

We now turn to the discussion of the main findings of our study on how carbon transition risk has been reflected in the financial valuation of publicly traded companies in recent years, or what we refer to as "the financial cost of carbon." In our study we explore how corporate GHG emissions have affected the price-to-earnings (P/E) ratios of listed companies in Europe and the U.S. over the period 2016 to 2020. Our primary database is from S&P Global Trucost and combines annual information on firm-level GHG emissions with data on stock prices and returns, and corporate balance sheets. We also rely on Bloomberg financial data.

Our overall sample includes 16,995 global firms across the world, but the study focuses primarily on Europe and North America. To get a sense of the coverage of our data, we begin by providing basic summary statistics on corporate GHG emissions and several key firm characteristics.

Table 1 breaks down the distribution of GHG emissions across firms (both in levels of $CO_2$ equivalent emissions and their yearly rate of change) for carbon emissions ($CO_2$), methane emissions (CH4), nitrous oxide emissions (N2O), and hydrofluorocarbon emissions (HFCs). It is important to identify and try to distinguish among the different sources of GHG emissions because their impact on climate change differs—methane, for example, has an outsized effect on temperature rise in the short run but dissipates significantly quicker than carbon dioxide emissions, which can persist in the atmosphere for thousands of years—and the mitigation policies and technologies also diverge.

As shown in Table 1, both the median levels and percentage changes in overall emissions in Europe and the U.S. are quite similar. As expected, the average price-to-earnings ratio and market cap is higher for U.S. than European companies, 21 vs. 17.9 and $1.5 billion vs. $890 million, respectively. Their median leverage (debt-to-capital) ratios were 65% and 48%.

*Table 2*

**Descriptive Statistics**

| Market Cap | Count | % Disclosing |
|---|---|---|
| >$50bn | 312 | 94.9% |
| $10-50bn | 1,302 | 90.8% |
| $1-10bn | 5,859 | 74.8% |
| $<1bn | 8,092 | 19.4% |

| Region | Count | % Disclosing |
|---|---|---|
| Africa | 213 | -- |
| Asia-Pacific | 8,922 | -- |
| Europe | 2,455 | 28.6% |
| Latin America and Caribbean | 371 | -- |
| Middle East | 409 | -- |
| United States and Canada | 3,195 | 37.5% |

| Sector | Count |
|---|---|
| Communication Services | 756 |
| Consumer Discretionary | 2,111 |
| Consumer Staples | 1,013 |
| Energy | 600 |
| Financials | 1,705 |
| Health Care | 1,465 |
| Industrials | 2,788 |
| Information Technology | 2,050 |
| Materials | 1,527 |
| Real Estate | 1,102 |
| Utilities | 447 |

Table 2 reports the distribution of companies that disclose their GHG emissions by size (market cap), geographic location, and sector. The most striking observation is that almost 95% of the companies with market cap exceeding $50 billion disclose their emissions, and over 90% in the next size tranche ($10-50 billion) also report their emissions. One surprising result is that the fraction of companies that disclose their emissions is higher in North America (37.5%) than in Europe (28.6%). But this finding reflects the skewing of the size distribution of European companies towards smaller companies (under $1 billion) that do not disclose. In the coming years, all listed companies will likely be required to make GHG emission disclosures as securities regulators in different jurisdictions introduce new disclosure rules.

*Table 3*

**Pairwise Firm-Level Correlations across Greenhouse Gases**

Correlation of GHG (Global)

| | Carbon Dioxide Level | Methane Level | Nitrous Oxide Level | HFCs Level |
|---|---|---|---|---|
| Carbon Dioxide Level | 1 | | | |
| Methane Level | 0.8786 | 1 | | |
| Nitrous Oxide Level | 0.8946 | 0.8498 | 1 | |
| HFCs Level | 0.7565 | 0.6363 | 0.7316 | 1 |

Because this study is the first to examine equity and debt pricing of greenhouse gases other than carbon dioxide, we analyze the relationships between different gases at the individual company level. Ex ante, it was not clear to us whether we should expect companies to contribute equally to the footprint of each gas. To evaluate this claim, we ran the series of firm-level pairwise correlations in the levels of emissions (in tons of $CO_2$ equivalent) of different greenhouse gases whose findings are reported in Table 3. As can be seen in the table, the different GHG emissions are highly positively correlated.

## Our Key Findings

The main undertaking of our study was to determine the extent to which carbon transition risk exposure, as measured by the level of corporate GHG emissions, has been priced by financial markets in recent years (from 2016 to 2020) both in Europe and North America. We also considered separately carbon emissions from other GHG emissions, in particular methane emissions. Specifically, we related price-to-earnings ratios to the level of carbon emissions, controlling for other risk factors such as current and future return on equity, and adjusting for differences among industries and countries through the use of statistical methods such as country and industry fixed effects.

### 1. Equity Markets: The Carbon Discount Is Growing

As reported in Table 4, the main finding of the pooled regression report is that the level of carbon emissions has had a significantly and increasingly negative impact on price-to-earnings ratios. We interpret this finding as reflecting a price discount that investors are now requiring to bear the higher carbon transition risk exposure of their portfolio companies. Moreover, this finding is consistent with the results of our two earlier studies analyzing cost-of-capital premiums for global companies over a sample period 2005-2018. Instead of punishing high emitters with large, one-time adjustments, investors in recent years appear to have been steadily increasing the rate of discounting, especially for companies with high carbon emissions, as political and regulatory risk become ever more salient.

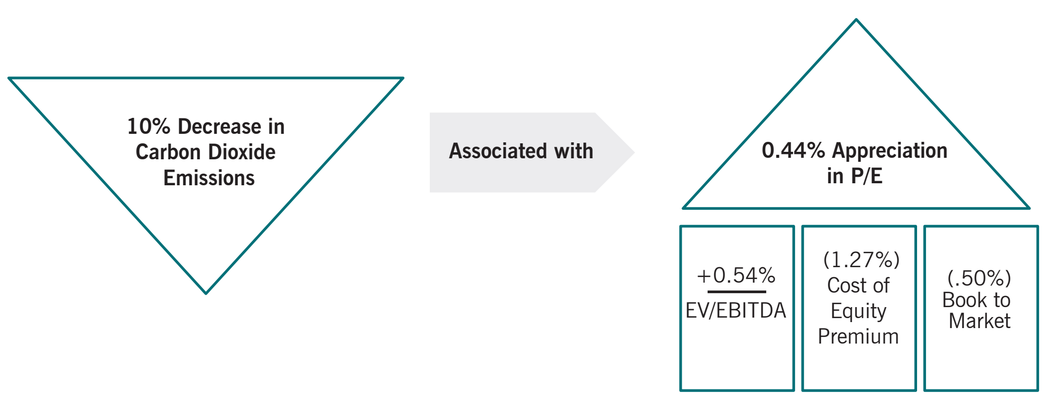
*Table 4*
**Global Carbon Discount with and without Industry Fixed Effects**

| Dependent Variable: Log P/E Ratio | (1) | (2) |
|---|---|---|
| Log Carbon Dioxide Emissions | -0.021*** | -0.044*** |
| | (0.002) | (0.003) |
| Return Momentum | 6.211*** | 5.788*** |
| | (0.417) | (0.296) |
| MSCI World Index Indicator | 0.007 | 0.073*** |
| | (0.014) | (0.013) |
| Return Volatility | -0.167 | -0.618*** |
| | (0.164) | (0.154) |
| ROE | -0.010*** | -0.009*** |
| | (0.001) | (0.001) |
| ROE (t+1) | -0.005*** | -0.003*** |
| | (0.001) | (0.001) |
| ROE (t+2) | -0.056*** | -0.048*** |
| | (0.004) | (0.004) |
| ROE (t+3) | 0.068*** | 0.051*** |
| | (0.004) | (0.003) |
| Constant | 3.093*** | 3.450*** |
| | (0.028) | (0.034) |
| | | |
| Yr/mo fixed effects | Yes | Yes |
| Country fixed effects | Yes | Yes |
| Industry fixed effects | No | Yes |
| Firm fixed effects | No | No |
| Observations | 368,395 | 368,395 |
| R-squared | 0.204 | 0.355 |

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

*Figure 1*
**Impact of a 10% Reduction in $CO_2$ Emissions**



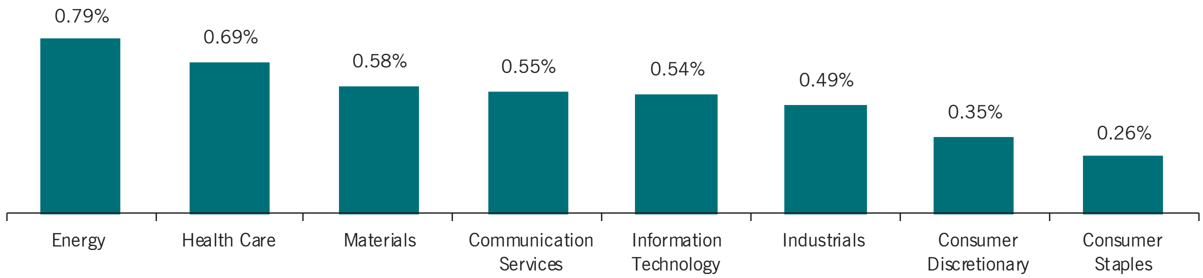

The main statistical conclusion of our study on the effects of carbon emissions can be summed up by a single number, the regression coefficient of -0.044. But to provide a better sense of the *economic* significance, we also show in the figure the expected effects of a 10% change in carbon emissions on a company's price-to-earnings ratio and other financial metrics. A 10% reduction in a company's carbon emissions would have resulted in a 0.44% increase, on average, in its price-earnings ratio, a 0.54% increase in its EV/EBITDA multiple, and a 0.50% increase in its market-to-book ratio.

Though a 0.44% valuation impact may not seem like much of a reward for or response to a 10% reduction in carbon emissions, there are three factors or considerations—the economic interpretation of the discount, the surrounding context of net-zero pledges and decarbonization frameworks, and the granular dispersion of discounts by sector, geography, and market cap—that can be used to show the practical import of our findings.

First, it is important to note that these discounts are intended to be viewed as a crude proxy for investors' growing awareness, but not a precise quantification, of climate risk. Thus, these values are both dynamic and elastic, depending as they do on the availability and veracity of firm-level climate data and beliefs about future regulatory intervention. With a push in the U.S. and EU for greater climate disclosure and visibility of corporate

*Figure 2*
**Significant Cross-Sector Variation in P/E Discount**

Illustrative association of a 10% reduction in carbon emissions with P/E appreciation for each sector. All values represent statistically significant results at a 95% confidence level. Real Estate & Utility Companies were excluded due to insignificant results. Financials excluded as P/E is not generally seen to be a material valuation metric for the sector.




| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **# Companies** | 601 | 1,465 | 1,528 | 756 | 2,049 | 2,788 | 2,111 | 1,013 |
| **Median Market Cap ($mm)** | $613 | $916 | $1,027 | $877 | $711 | $836 | $674 | $1,117 |
| **Avg. Yearly Emissions (Metric Tons $CO_2$)** | 3,874,024 | 28,649 | 2,779,840 | 25,046 | 30,206 | 514,874 | 98,204 | 180,991 |
| **Avg. Annual Change in Emissions** | ~31% | ~30% | ~20% | ~18% | ~18% | ~14% | ~10% | ~14% |
| **Median P/E** | 15x | 28x | 19x | 22x | 29x | 20x | 22x | 22x |
| **Illustrative P/E Appreciation** | 0.12x | 0.19x | 0.11x | 0.12x | 0.16x | 0.10x | 0.08x | 0.06x |

climate exposure, we expect the discounts to continue to grow over time.

Second, to meet the stated objective in the Paris Agreement of limiting temperature rise to 2°C and, naturally, to adhere to a science-based target derived net zero pledge, corporations will have to achieve much more than a 10% emissions reduction. For example, the recent U.S. Department of Energy facilitated commitment calls for organizations to abate emissions by 50% by 2030. Thus, the investor-induced valuation impact for decarbonization is considerably larger in practice than the 10% benchmark.

Third, and most importantly, the discount is much larger in some sectors and for large companies. Sectors naturally possess different forms and magnitudes of climate risk given differences in their relative exposure. As shown in Figure 2, a 10% reduction in carbon emissions is associated with an increase in the P/E ratio of 0.79% in the energy sector, as compared to only 0.26% in the consumer staples sector. Thus, while all corporations are affected to some extent by the pricing of carbon transition risk, the carbon discount is largest in the highest-emitting sectors where investors perceive higher associated risks. We also note that the distribution of emissions across companies is much wider, and our findings indicate that otherwise similar companies with larger emission levels are priced with significantly smaller price multiples. As a general rule, our findings suggest that a one-standard deviation difference in emissions across companies generates price discounts or premiums of more than 10%.

Perhaps most important, we find that sectors with the largest annual increases in emissions are discounted the most heavily, suggesting that investors do revise their perceptions of transition risk downward if a company has been trending green historically. Take the case of the healthcare industry. Although not widely viewed as an emissions-intensive sector, healthcare companies account for 5% of national emissions in developed countries (especially in the U.S., which has the largest emitting health care sector of any industrialized nation). And the fact that this sector has the second highest discount (0.69%) in our study therefore doesn't come as surprise.

Finally, when we looked for possible effects of carbon emissions on the price-to-book ratios in the financial sector (since price-to-earnings ratios are sparsely used), we found a statistically significant effect for financial services and fintech companies, though not for banks. The respective price-to-book discount rate for large, middle, and small-cap non-bank financial companies were 1.62%, 1.04%, and 0.49%, respec-

*Table 5*
**Global Carbon Premium by Market Cap**

| Dependent Variable: Log P/E Ratio | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | MC > $50B | $50B > MC > $10B | $10B > MC > $1B | $1B > MC |
| Log Carbon Dioxide Emissions | -0.091*** | -0.058*** | -0.061*** | -0.064*** |
| | (0.022) | (0.007) | (0.005) | (0.006) |
| Return Momentum | 6.228*** | 7.640*** | 6.059*** | 4.697*** |
| | (0.878) | (0.519) | (0.316) | (0.262) |
| MSCI World Index Indicator | 0.022 | -0.019 | 0.005 | -0.105 |
| | (0.075) | (0.038) | (0.015) | (0.143) |
| Return Volatility | 0.012 | 0.551 | -0.224 | -0.084 |
| | (0.708) | (0.377) | (0.204) | (0.174) |
| ROE | -0.006*** | -0.008*** | -0.010*** | -0.010*** |
| | (0.002) | (0.001) | (0.001) | (0.001) |
| ROE (t+1) | 0.002 | 0.000 | -0.003*** | -0.006*** |
| | (0.001) | (0.001) | (0.001) | (0.001) |
| ROE (t+2) | -0.044*** | -0.058*** | -0.052*** | -0.037*** |
| | (0.012) | (0.008) | (0.005) | (0.004) |
| ROE (t+3) | 0.041*** | 0.057*** | 0.055*** | 0.041*** |
| | (0.011) | (0.008) | (0.005) | (0.004) |
| Constant | 3.973*** | 3.627*** | 3.664*** | 3.506*** |
| | (0.278) | (0.094) | (0.051) | (0.061) |
| | | | | |
| Yr/mo fixed effects | Yes | Yes | Yes | Yes |
| Country fixed effects | Yes | Yes | Yes | Yes |
| Industry fixed effects | Yes | Yes | Yes | Yes |
| Firm fixed effects | No | No | No | No |
| Observations | 9,812 | 48,069 | 197,261 | 113,252 |
| R-squared | 0.682 | 0.555 | 0.404 | 0.320 |
| Robust standard errors in parentheses | | | | |
| *** p<0.01, ** p<0.05, * p<0.1 | | | | |

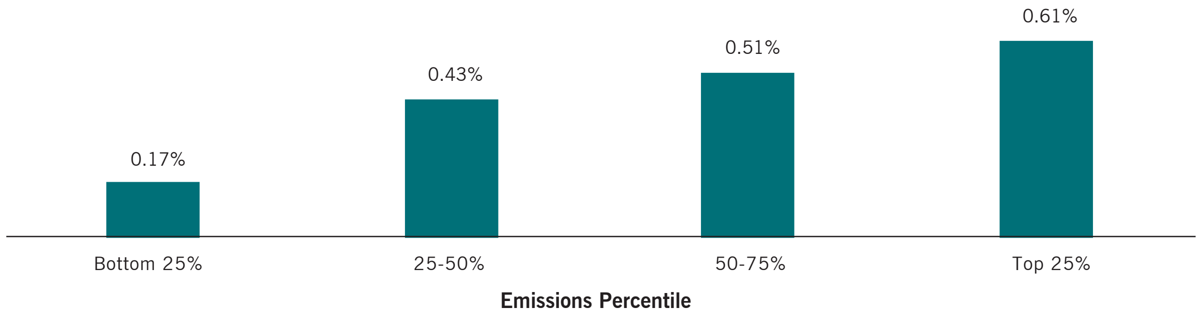
tively. Our failure to detect a price discount for banks likely reflects the focus of investor attention not on banks' emissions, but their financing of emissions.

We additionally explored how the carbon discount varies with firm size; and as reported in Table 5, we found that the largest companies tended to have the biggest discounts and therefore stand to benefit the most in terms of valuation impacts from emissions reductions (which is further pronounced at the sector level). We also found evidence of investors discounting companies in a "nonlinear" way: as can be seen in Figure 3, our findings suggest that brown companies with the highest emissions can expect to see the largest gains in price-earnings ratios from a 10% reduction in carbon emissions (0.61% for the top 25% emitters and 0.17% for the bottom 25% emitters).

Comparing carbon discounts for U.S. and European companies, we found that the P/E discounts are similar for large-cap companies (1.45% for the EU and 1.40% for the U.S.), but are significantly larger for smaller-cap U.S. companies than for their European counterparts (as can be seen in Figure 4). The larger difference in P/E discounts for smaller-cap companies could be attributable to the smaller fraction of U.S. small-cap companies disclosing their emissions and to the EU's tighter carbon emissions regulations, disclosure requirements, and carbon pricing.

But perhaps the most notable, certainly the most eye-catching, difference between U.S. and European carbon discounts is the one now being applied to large-market-cap European industrials. Whereas our findings show a fairly modest discount rate of 0.5% for U.S.-based industrials,

*Figure 3*
**Global Carbon Premium by Emissions Quartile**




| Emissions Quartile | Bottom 25% | 25-50% | 50-75% | Top 25% |
|---|---|---|---|---|
| Median P/E | 19x | 22x | 21x | 18x |
| Illustrative P/E Appreciation | 0.03x | 0.10x | 0.11x | 0.11x |

our estimate for large-cap European industrials is close to 18%! In other words, an EU industrial high emitter trading at a P/E multiple of, say, 17 times could expect to see its low-emissions competitors trading as high as 20 times earnings.

What could explain such a difference between U.S. and EU pricing? The industrials sector alone is responsible for over 20% of EU emissions, and many facilities in this sector are included under the EU ETS. This in turn suggests that there is an implied carbon price that has been steadily rising over our sample period (from under 10 euros per metric ton to a number currently around 80 euros) and that is expected to increasingly reduce net income. Hard-to-electrify industries such as iron and steel, refineries, cement, petrochemicals, and fertilizer today account for 70% of emissions covered under EU ETS, and thus market expectations of lower future earnings naturally show up as a larger carbon valuation discount.

We can also shed more light on this premium by focusing on the airline industry. Regardless of market cap, the European airline industry has a huge discount rate of around 30%, whereas the U.S. airline industry is still largely unaffected (with an estimated discount of just 0.6%). EU ETS is expected to cover about 99.5% of emissions of the European airline space (one of the most regulated segments) and has accounted for both a substantial reduction in emissions (17 million MT per year) while imposing a material cost on companies. U.S. regulation, by contrast, focuses solely on fuel-efficiency stipulations, which have been largely ineffective and poses a significantly smaller financial burden on the companies. These results suggest that airline stocks are highly sensitive to carbon pricing.

The energy sector has a large emissions carbon discount in both the U.S. and Europe, demonstrating that the energy transition is on investor's minds. Besides the obvious regulatory risks around energy, the growing attention to reputation risk and consumer preferences, given the prominence of debates around the transition to renewables, could be inducing high premiums around energy relative to other emissions-intensive sectors such as materials. Concrete production, for example, is a leading source of emissions, but it does not come with the same carbon valuation discount. (While it wouldn't be uncommon for a building developer to exhibit a strict preference for solar panels in a cost-agnostic environment, developers are rarely seen actively seeking out low-emission concrete.) Litigation risk, stemming in large part from the publication of fabricated information around environmental and societal impacts, has also become a factor.

Finally, year-over-year trends suggest that large-cap P/E impacts in Europe have been very sensitive to changes in the carbon price under EU ETS. The emissions premium for European large-cap stocks has increased since 2016, whereas the large-cap emission premium in the U.S. has fluctuated since 2016 and largely shrunk following a 2017 peak. The sensitivity of European emission premiums to regulation can be seen especially clearly from 2018 to 2019, when there was a roughly 140% increase in the cost of EU Carbon Permits, and the premiums of large-cap companies jumped from 1.01% to 2.75%.

*Figure 4*
**The P/E Discount in Europe and the U.S.**

Comparison of U.S. and European carbon premiums per market cap. All values represent statistically significant results at a 95% confidence level, Real Estate & Utility companies were excluded due to insignificant results.

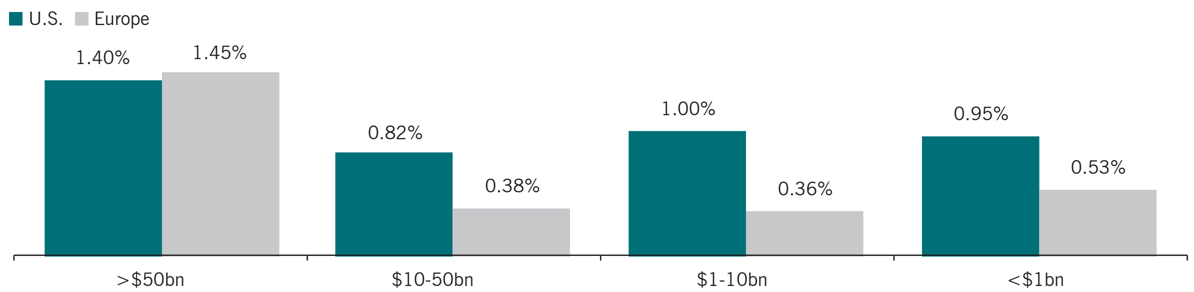



*Figure 5*
**Average CDS Spread % Increase for Small Caps (Under $1bn)**

Comparison of U.S. and European carbon premiums per market cap. All values represent statistically significant results at a 95% confidence level, Real Estate & Utility companies were excluded due to insignificant results.

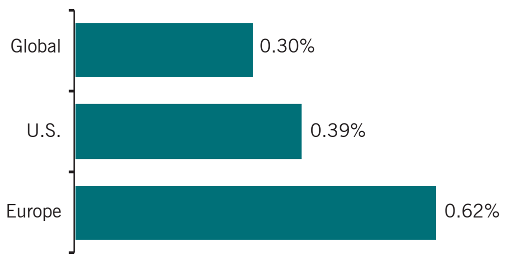



*Table 6*
**Deviations in Carbon Premiums between Large and Small Cap Companies**

| | Energy (U.S.) | Consumer Discretionary (U.S.) | Health Care (U.S.) | Energy (Europe) | Industrials (Europe) |
|---|---|---|---|---|---|
| >$50bn | 3.88% | 4.48% | 1.54% | 8.72% | 17.96% |
| <$1bn | 0.85% | 1.17% | 0.38% | 0.93% | 0.48% |

## 2. Debt Markets: A Small Market-Driven Premium on Debt for Small Caps

Does the carbon premium observed in stock markets extend to debt markets? Given the higher priority of debt as a senior claim, one might expect to see smaller if any discounts for climate risk. The pricing of debt is mostly about credit risk and, to the extent that carbon transition risk may result in losses that could lead to impairment of debt claims, the most exposed claims are the equity first-loss claims. Therefore, any carbon discount might be expected to show up first and foremost in equity values.

We explored the effects of carbon transition risk on debt pricing by linking credit default swap (CDS) spreads to our measures of corporate carbon emissions. Our expectation was that, to the extent credit investors take account of climate risk, the companies with the highest emissions are likely to be associated with higher CDS spreads, other things equal.

As summarized in Figure 5, our findings did not include any significant impact of carbon emissions on CDS spreads for larger companies, which is sensible since it is extremely unlikely that a robust large-market-cap firm would default as a result of regulation incidence or a natural disaster. Nevertheless, for small caps (under $1 billion), we found a small statistically significant effect, suggesting some credit investor sensitivity to climate risk.

## 3. Other Greenhouse Gases Have Small, but Likely to Become Larger Effects

Finally, we also explored whether other greenhouse gases than carbon are assessed as a financial risk by investors. These gases, in particular methane, have become prominent in recent policy debates, especially at the COP26 in Glasgow. Methane emissions have been shown to contribute more directly than carbon emissions to global warming in the short run (by a factor of 84 over 20 years), but only lasts in the atmosphere for slightly over a decade. But given the priority of avoiding an average temperature rise of more than $1.5^0$ Celsius by 2050, it is becoming more urgent to slow down temperature rise by curbing methane emissions.

To what extent has this policy shift towards methane in recent years materialized as a risk for investors? As we

*Table 7*

**Global Premium of Methane, Nitrous Oxide, and HFCs**

| Dependent Variable: Log P/E Ratio | (1) | (2) | (3) |
|---|---|---|---|
| | | | |
| Log Methane Emissions | -0.008* | | |
| | (0.004) | | |
| Log Nitrous Oxide Emissions | | 0.004 | |
| | | (0.004) | |
| Log HFCs Emissions | | | -0.013*** |
| | | | (0.004) |
| Return Momentum | 5.811*** | 5.792*** | 5.830*** |
| | (0.294) | (0.296) | (0.296) |
| MSCI World Index Indicator | 0.048*** | 0.038*** | 0.067*** |
| | (0.012) | (0.012) | (0.012) |
| Return Volatility | -0.534*** | -0.541*** | -0.624*** |
| | (0.155) | (0.154) | (0.155) |
| ROE | -0.009*** | -0.009*** | -0.009*** |
| | (0.001) | (0.001) | (0.001) |
| ROE (t+1) | -0.003*** | -0.003*** | -0.003*** |
| | (0.001) | (0.001) | (0.001) |
| ROE (t+2) | -0.049*** | -0.049*** | -0.048*** |
| | (0.004) | (0.004) | (0.004) |
| ROE (t+3) | 0.052*** | 0.052*** | 0.051*** |
| | (0.003) | (0.003) | (0.003) |
| Constant | 3.029*** | 3.012*** | 2.948*** |
| | (0.018) | (0.018) | (0.018) |
| | | | |
| Yr/mo fixed effects | Yes | Yes | Yes |
| Country fixed effects | Yes | Yes | Yes |
| Industry fixed effects | Yes | Yes | Yes |
| Firm fixed effects | No | No | No |
| Observations | 363,512 | 364,207 | 365,301 |
| R-squared | 0.352 | 0.351 | 0.353 |
| Robust standard errors in parentheses | | | |
| *** p<0.01, ** p<0.05, * p<0.1 | | | |

report in Table 7, we do see a very small effect for methane emissions, and a slightly stronger effect for HFCs (a more potent GHG used in cooling and refrigeration). This is not too surprising given the lack of investor awareness and general public attention to these other greenhouse gases over the last five years. Additionally, a large quantity of methane emissions come from natural gas leaks, which can be remediated through repairing energy infrastructure. In fact, the UN's recent methane report demonstrates that 80% of measures in oil and gas facilities to reduce methane emissions would impose no financial burden or even induce a financial gain (by capturing more gas through abated leakage).[12] However, we expect that the recent agreements around COP26 to curb methane emissions may give rise to higher future P/E discounts for agriculture companies in particular, which possess a greater technological challenge to curb methane emissions from livestock.

## Conclusion

Financial markets have begun to respond to climate change and the transition to Net Zero in the way one would expect. Driven by investor beliefs about the impact of climate change on corporations, markets are beginning to price a new and increasing aggregate risk. This pricing is reflected in the price-to-earnings discounts for companies that stand out in the size of their carbon emissions. We find that the extent of the price-earnings discount varies significantly by sector and across firm size, with larger companies experiencing the larger discounts. Although the pricing of carbon transition risk is similar generally in the U.S. and in Europe, we find significantly higher discounts applied to EU industries directly covered by EU ETS.

We also find evidence of a small price discount on corporate debt of mainly smaller issuers, in the form of CDS spreads rising slightly with carbon emissions. Finally, we find that the risk associated with the energy transition is reflected in exposures not just to carbon emissions but also to other GHG emissions, albeit to a much smaller extent. And when we combine these findings with those of earlier studies, what emerges is a clearer pattern of investors' growing recognition and pricing of transition risk.

Our findings confirm earlier evidence of a carbon return premium in the 2010s and provide more support for the hypothesis that investors increasingly perceive carbon emissions to be a relevant risk and require compensation for exposure to this risk.

12 See United Nations Environment Programme and Climate and Clean Air Coalition (2021). Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions. Nairobi: United Nations Environment Programme.

All in all, then, companies with high carbon emissions are faced with a rising financial cost of carbon (FCC). The valuation discount being applied to companies with high emissions and in the early stages of decarbonization should work to encourage such companies to progress further along the decarbonization path, which our results suggest can bring large economic benefits.

Whether this FCC is currently too low, given the perceived size of the carbon transition risk, and so providing potential arbitrage opportunities, is difficult to say. We do, however, expect the price-to-earnings discount associated with GHG emissions to continue to grow as transition risk intensifies.

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***Journal of Applied Corporate Finance*** (ISSN 1078-1196 [print], ISSN 1745-6622 [online]) is published quarterly per year by Wiley Subscription Services, Inc., a Wiley Company, 111 River St., Hoboken, NJ 07030-5774 USA.

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