JOURNAL OF INVESTMENT MANAGEMENT, Vol. 16, No. 1, (2018), pp. 59–69

JOIM
www.joim.com

CARBON FOOTPRINT AND PRODUCTIVITY: DOES THE "E" IN ESG CAPTURE EFFICIENCY AS WELL AS ENVIRONMENT?*

Gerald T. Garvey[a], *Mohanaraman Iyer*[a] *and Joanna Nash*[b]

This paper analyses the now-popular carbon ratio (emissions relative to sales) as a way to select stocks. We document that reduced carbon ratios are associated with stronger future profitability and positive stock returns in a global universe of stocks. But why? The prevailing view is that lower emissions reduces a firm's exposure to future greenhouse gas regulations or taxes, and the market is slow to appreciate this. However, we find strong effects in industries such as internet and commercial services where carbon taxes would have little direct effect. We show that there is a more fundamental connection between carbon emissions and overall productive efficiency. Most of a firm's activities, or inputs, result in some form of carbon emission due to direct energy consumption or indirect emissions (e.g., travel). We first show evidence that carbon emission works like an input to production along with the more traditional capital and labour. More importantly, firms that produce more than expected given their inputs tend to outperform in the future both in profitability and returns.

This paper analyses the now-popular carbon ratio (Scope 1 and 2 CO_2 emissions relative to sales) as a way to select stocks. We document that reduced carbon ratios are associated with stronger future profitability and stock returns in a global universe of stocks. But more importantly, why? The prevailing view is that lower emissions reduce exposure to future greenhouse gas regulations and taxes and the market has yet to fully incorporate these effects. However, our results apply to industries such as internet and commercial services where carbon emissions are too small to imply any strong effect from regulation. Furthermore, our sample is concentrated in recent years with declining energy prices and unfulfilled promises of Global Warming regulation.

*We thank Ron Guido for his comments and assistance.
[a]Blackrock, 400 Howard Street, San Francisco, CA 94104, USA. Tel: (415) 793-0208. E-mail: Gerald.garvey@ blackrock.com, Mohan.iyer@blackrock.com.
[b]Blackrock, Level 37, Chifley Tower, 2 Chifley Square, Sydney NSW 2000, Australia. E-mail: Joanna.nash@ blackrock.com

We emphasize a fundamental connection between carbon emissions and overall productive efficiency which does not depend on regulation or government action. Most of a firm's activities, or inputs, result in some form of carbon emission due to direct electricity consumption or indirect emissions (e.g., travel). Carbon emissions relative to sales, we argue, is a proxy for productive efficiency and/or effective pricing power. So an improved carbon footprint is associated with an ability to obtain more revenue from the same inputs, which in turn reflects improved efficiency in areas such as scheduling or inventory management, or more effective product pricing.

Our first set of tests show that carbon emissions are a productive input in a classical Total Factor Productivity setting (see, e.g., Solow, 1957). We start with firm revenue as our proxy for output, total operating assets as a proxy for capital, and headcount as a proxy for labour. We show in a simple Cobb–Douglas (1928) specification that these two proxies have strong explanatory power and readily interpretable coefficients. We then add carbon emissions to the regression and find that it has a significant positive incremental effect. The implications are (i) increased production generally involves carbon emissions as well as capital and labour, and more importantly (ii) firms that produce *more* than expected given their inputs are more productive.

We then show that these productivity results carry over to more traditional financial performance. Firms with improved carbon ratios have higher future return on assets (ROA) as well as risk-adjusted stock returns. These results continue to hold when we control for revenue growth. This control is important because while we think of revenue as merely a scalar, improved carbon ratios are inevitably a mix of revenue growth and emissions growth. We find qualitatively similar but modest effects for stock returns; stocks that have the strongest improvement in their carbon ratios appear to outperform those with deteriorating ratios by approximately 2.5% annually.

Section 1 below defines carbon emissions and summarizes past work in this area. Section 2 considers the relationship between carbon emissions and efficiency, and Section 3 looks at how this relates to company performance and stock returns. Finally, Section 4 concludes.

1 Background

1.1 What is being measured?

Carbon footprint represents the total set of greenhouse http://en.wikipedia.org/wiki/Greenhouse_gas gases caused by an organization, event, product, or person.[1] Greenhouse gas (GHG) emissions include carbon dioxide, methane, nitrous oxide, and related compounds, and are made comparable by converting to carbon dioxide equivalents where a tonne of carbon dioxide has a global warming potential of one.

The emissions reported are then broken down into three "Scopes". Scope 1 greenhouse gas emissions are the emissions released to the atmosphere as a direct result of an activity, or series of activities of the company. Scope 1 emissions are sometimes referred to as direct emissions. Examples are: emissions produced from manufacturing processes, such as from the manufacture of cement; emissions from the burning of diesel fuel in truck; fugitive emissions, such as methane emissions from coal mines, or production of electricity by burning coal. Scope 2 greenhouse gas emissions are released into the atmosphere from the indirect consumption of an energy commodity. For example, a power station burns coal to power its generators and in turn creates electricity. Burning the coal causes greenhouse emissions to be emitted. These gases are attributed to the power station as scope 1 emissions. If the electricity is then transmitted to a car factory and used there to power its machinery and lighting, the gases emitted as a result of generating the electricity are then attributed to the factory as scope 2 emissions.

Scope 3 greenhouse gas emissions are those beyond scope 2, generated in the wider economy. They occur as a consequence of the activities of a facility, but not from sources owned or controlled by that facility's business. Some examples are extraction and production of purchased materials, transportation of purchased fuels, use of sold products and services, and flying on a commercial airline by a person from another business.

Reporting of carbon emissions is in general voluntary. For companies with facilities over a certain size, some governments require the amount of carbon emissions to be reported for that facility, to the relevant authority, on an annual basis. This normally covers only scope 1 and 2 emissions as it is normally done at the facility level. Many companies as part of their annual sustainability reporting voluntarily report their carbon emissions. This data is provided in annual reports, sustainability reports, the carbon disclosure project[2] (CDP), or some combination of the above. Many companies follow the GHG accounting and reporting principles[3] which only require that companies report their scope 1 and 2 emissions and they can voluntarily report their scope 3 emissions. Data in relation to carbon credits or offsets need to be reported separately. Many third-party providers collect this carbon emissions data on an annual basis.

We use data from the MSCI ESG Manager database. This covers approximately 6400 firms globally and they collect scope 1, 2, and 3 emissions. We will focus on scope 1 and 2 emissions as the number of companies that report scope 3 is relatively small and we believe it is less able to be accurately measured by the companies. As noted by Koch and Bassen (2013), the data is skewed with a small number of large emitters and a large number of small emitters. There is also a large disparity between scope 1 and 2 emissions by company. Some have very large scope 1 and minimal scope 2 where the majority have large scope 2 and minimal scope 1. A histogram of the total breakdown of scope 1 and 2 emissions by company for 2015 is shown in Exhibits 1 and 2.

1.2 *Past research*

Previous work has largely focused on the link between carbon emissions and/or reporting of

Exhibit 1: Histogram of scope 1 emissions MSCI World universe, 2015.

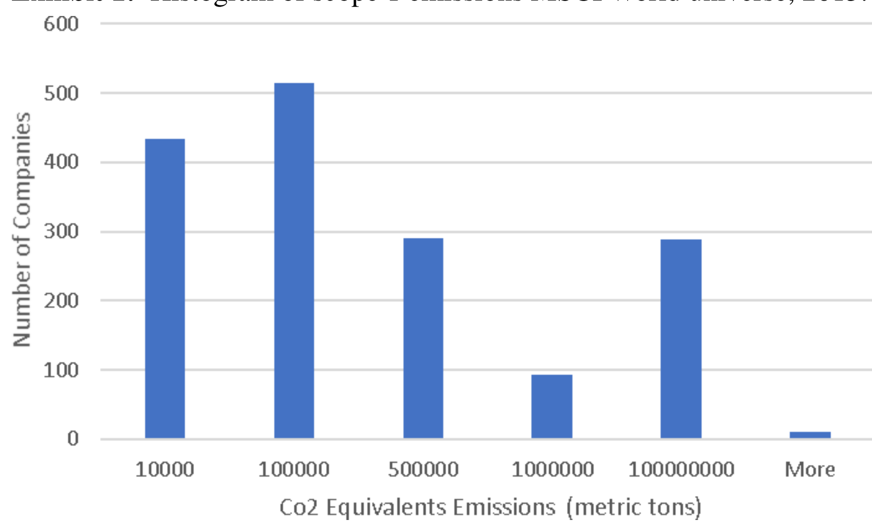
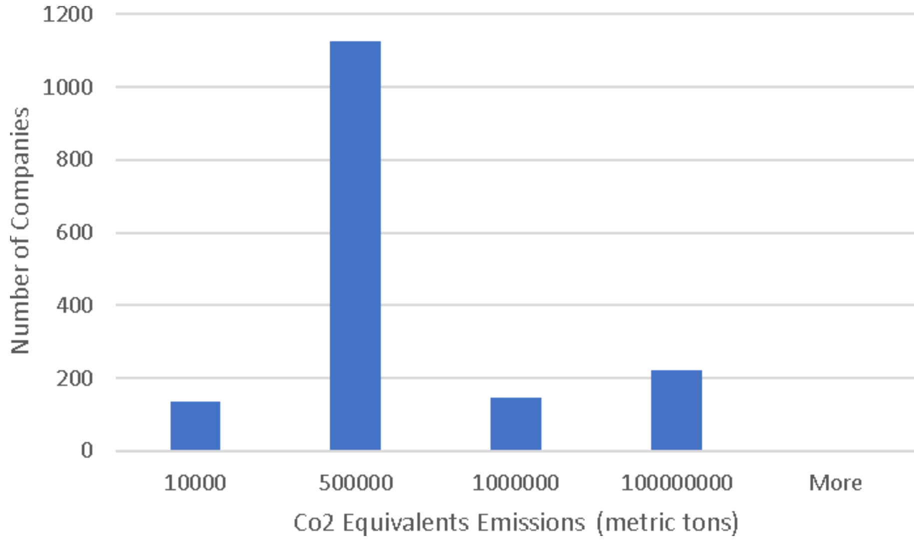


Exhibit 2: Histogram of scope 2 emissions MSCI World universe, 2015.



emissions and measures of return. Andersson *et al.* (2016) take a pure risk perspective and show that even if one is agnostic about the future performance of carbon emitters, the fact that emissions are so concentrated makes it possible to design low-emission portfolios with minimal tracking error. Other work has focussed more directly on expected profit and returns. Renner (2011) used data from the CDP 2009 questionnaire and found that participating in the CDP lead to a small positive abnormal return. Alvarez (2012) used data from 2007 and 2008 to see the effect on subsequent years return on assets (ROA) and return on equity (ROE). They found for most years except for ROA in 2007, it was not statistically significant. Ngwakwe and Msweli (2013) found a significant relationship between carbon reduction and increased dividend per share whilst Griffin *et al.* (2017) using a sample of companies from the SP500 found a negative relationship between higher company emissions and share value. Nishitani and Kokubu (2011) found that firms that reduce their GHG emission are more likely to increase firm value as measured by Tobin's Q and Ennis *et al.* (2012) argued that disclosure was to gain legitimacy amongst shareholders irrespective or performance and found that emissions data did not drive stock prices. Liesen *et al.* (2017) find that firms that more actively disclose their carbon emissions, and those with a high net income to emissions ratio tend to have stronger equity returns.

We add to this literature by emphasizing a deeper link between carbon emissions and productive efficiency. This link has performance implications even in the absence of any regulatory action or change in investor preferences. Our performance tests focus on the change rather than on the level of emission efficiency and while our return effects are modest they may be more sustainable in the long term. First, we show that improvements in carbon efficiency strongly lead to future profitability even in industries with a small average carbon footprint. Second, most existing work focusses on the *level* of emissions. This is an appropriate metric for gauging exposure to major changes in regulation or investor recognition/preferences, but it is less likely to be valuable once the appreciation of carbon emissions is more widespread. Exactly this dynamic appears to have already played out in the "G" component of ESG, where Gompers *et al.* (2003) published a widely followed paper showing that firms with stronger governance outperformed between 1991 and 1999. Bebchuk *et al.* (2013) showed that the effect disappeared in the years following the publication of the study (2000–2008) and attribute the original results to a one-time appreciation of the virtues of governance.

2 Carbon output and efficiency

We present two suggestive cases and then show systematically that emissions are a systematic factor in production.

2.1 Cases

We begin with BT PLC, a British Multinational Telecommunications Services Company. One initiative that BT has implemented is the use of field force automation. Field force automation refers to the use of typically handheld PDAs, wireless devices or mobile phones to capture field sales or service information in real time. The captured data is transferred immediately to back end systems through wireless connectivity. This instant capture of information reduces time delays, avoids manual double entry data errors, and enhances field force productivity. From an operations perspective, availability of field information in near real time allows to plan delivery schedules, reduce inventory and monitor, and control the field workers. BT has been using these systems for a number of years which has helped it improved its responsiveness to customers as well as avoiding unnecessary travel. BT was able to provide a similar service to Northumbrian Water allowing them to reduce mileage by around 20%, improve productivity by 10% through optimal job allocation and reduction in travel times. This improved efficiency for BT also leads to a new revenue source. The change in emissions from each company was a way to capture these new efficiency innovations.

Mirvac is an Australian developer of both commercial and residential property. They aim to be net energy positive by 2030 via both reduction in consumption and by producing energy. An example of one of their initiatives is to install LED lightening with integrated sensors into the buildings they operate and own. For one shopping centre this involved an investment of \$350,000 with a saving of \$135,683 per year. Other measures they have implemented to improve energy savings is hot water timers which has led to a reduction in 31% of gas usage, whilst another project which changed the type of air conditioning unit used resulted in a reduction of 945 MWh of energy use over 12 months, 982 tonnes of carbon emissions, and \$135,000 in energy savings per year. Although these may seem like small individual initiatives they add up to a substantial savings for the company that is unlikely to be easily picked up in financial statements. By implementing these projects, Mirvac will be maintaining their output (same number of buildings they manage) but doing so in a more cost effective and efficient manner.

2.2 Systematic productivity estimates

We now ask whether these cases generalise in larger-sample statistics. We use a classic productivity framework based on the Cobb and Douglas (1928) production function: $Y_{jt} = a_j K_{jt}^{\alpha} L_{jt}^{\beta} M_{jt}^{\gamma}$, where Y_{jt} is firm j's output in period t, a_j is firm j's total factor productivity index, K_{jt} is the amount of capital it uses, L_{jt} is the amount of labour, and M_{jt} is the amount of materials and other variable inputs. This framework is appealing for practical uses as it is log-linear, with the estimated coefficients α, β, γ representing the marginal productivity of each input, and the sum $\alpha + \beta + \gamma$ represent average returns to scale (greater than 1 means increasing, less than 1 means decreasing, equal to 1 means constant). Another useful property for our current application is that company productivity, $\ln(a_j)$, can be expressed as the sum of the log of three productivity ratios: Y/K, the asset turnover ratio; Y/L the basic labour productivity metric[4]; and finally Y/M, the inverse of the carbon ratio. As asset turnover and revenue per head are already quite well known and unrelated to ESG, we focus on the carbon ratio.

Most early TFP estimates (Solow, 1957) were at the aggregate national level, and more recent work has used plant-level data (see Van Beveren, 2012, for an accessible update). Here we focus on the corporate level and use financial report data to proxy for the key variables. We proxy Y by sales, K by total assets, L by total employees, and M by carbon. Y, K, and L come from Worldscope and as mentioned above M comes from MSCI. None of the proxies are perfect: Sales is the product of price and output as there is no measure of individual companies' physical output; Total Assets reflects historical cost accounting and depreciation rules rather than true productive capacity (subtracting out cash and investments makes no difference), L is the raw headcount and does not account for differing labour quality (wage data is interesting but coverage is very uneven), and carbon is clearly only an indirect marker of variable inputs.

Despite these measurement issues, the regression is remarkably well behaved. We use data for the period 2011–2015 covering stocks in the MSCI World universe. After taking into consideration of missing data, primarily due to carbon and employee numbers, we end up with 7399 firm-years. Exhibit 3 shows the regression results for the original TFP regression and the TFP analysis which includes carbon.

Exhibit 3: Cobb–Douglas regression results for 2011–2015.

	ln(Sales)		ln(Sales)	
	Beta	*t*-stat.	Beta	*t*-stat.
Intercept	8.81	78.50	8.46	81.09
ln(Assets)	0.38	69.00	0.36	70.51
ln(Employees)	0.52	97.12	0.45	84.13
ln(Carbon)			0.12	35.37
R^2	0.79		0.82	

The R-squares are extremely high with significant coefficients for all variables. Of course, one reason is a variant of size effects, with assets, employees, and raw carbon all representing complementary versions of company scale. To abstract from size, we examine first differences so all variables are now annual percent changes. This is a stringent test as it requires the effect of increased carbon to be reflected immediately in sales in the same year; all variables are in fact slow-moving and there are sure to be both lead and lag effects. Nonetheless, Exhibit 4 shows that the qualitative results continue to hold.

We then looked to see if these results differed by sector. Using the Global Industry Classification Standard (GICS) we break the total market down into 11 sectors. We run the original regression in levels both with and without carbon. These results are presented in Exhibit 5 and 6.

Exhibit 4: Cobb–Douglas estimates in first differences for period 2011–2015.

	Δln(Sales)		Δln(Sales)	
	Coeffcient	*t*-stat.	Coefficient	*t*-stat.
Intercept	−0.01	−0.84	−0.01	−0.97
Δln(Assets)	0.35	62.79	0.35	62.68
Δln(Employees)	0.44	71.20	0.44	71.22
Δln(carbon)			0.02	1.65
R^2	0.72		0.72	

Exhibit 5: Total factor productivity by GICS sector 2011–2015.

		Consumer Discretionary	Consumer Staples	Energy	Financials	Health Care	Industrials	IT	Materials	Real Estate	Teleco Services	Utilities
Beta	Intercept	5.83	8.74	2.37	9.98	2.42	5.99	4.16	4.18	8.32	4.09	4.09
	Assets	0.59	0.40	0.69	0.34	0.74	0.53	0.64	0.66	0.44	0.68	0.62
	Employee	0.35	0.51	0.50	0.45	0.34	0.46	0.38	0.34	0.36	0.28	0.42
t-statistic	Intercept	21.02	21.07	2.92	33.15	5.23	19.69	13.43	5.72	8.03	6.86	5.61
	Assets	39.08	16.59	16.39	22.44	24.02	32.88	33.36	16.19	9.27	17.92	16.71
	Employee	28.39	25.71	15.63	27.57	10.64	31.61	21.78	9.36	17.13	7.30	15.45
R^2		0.859	0.898	0.850	0.784	0.875	0.810	0.923	0.676	0.642	0.942	0.858
No. obs		1162	543	379	1164	635	1238	746	601	387	192	347

Exhibit 6: Total factor productivity including carbon by GICS sector 2011–2015.

		Consumer Discretionary	Consumer Staples	Energy	Financials	Health Care	Industrials	IT	Materials	Real Estate	Teleco Services	Utilities
Beta	Intercept	5.92	8.84	8.12	9.94	2.46	6.27	4.30	4.97	7.98	5.02	4.24
	Assets	0.58	0.35	0.18	0.34	0.73	0.50	0.62	0.60	0.39	0.61	0.58
	Employee	0.32	0.43	0.54	0.41	0.33	0.45	0.36	0.34	0.33	0.26	0.40
	Carbon	0.04	0.14	0.40	0.06	0.02	0.03	0.04	0.05	0.15	0.09	0.06
t-statistic	Intercept	21.29	22.80	9.38	33.14	5.24	19.98	13.77	5.89	8.09	7.78	5.88
	Assets	36.84	15.05	3.14	22.09	22.72	28.29	31.67	11.21	8.51	13.67	15.03
	Employee	20.87	21.32	19.35	20.77	8.96	30.77	18.03	9.28	15.76	7.07	14.78
	Carbon	3.06	8.97	11.30	3.73	0.55	3.42	2.83	1.86	6.35	3.30	3.20
R^2		0.86	0.91	0.89	0.79	0.87	0.81	0.92	0.68	0.68	0.95	0.86
No. obs		1162	543	379	1164	635	1238	746	601	387	192	347

At a 10% significance level, all but three of these sectors have a significant marginal productivity of carbon. Many of the significant sectors are not heavy direct carbon emitters; consider Telecommunications, Consumer staples and Real Estate. This is consistent with our interpretation of carbon emissions as a marker for a broad class of input uses.

3 Carbon intensity and financial performance

3.1 *Profitability*

The productivity results are novel and illuminating, but are neither predictive nor related directly to financial performance. To move to a financial forecasting setting, we first ask whether the change in carbon ratio ($[M_t/Y_t] - [M_{t-1}/Y_{t-1}]$) predicts next year's return on assets (ROA) controlling for past ROA and well-known variables related to our key construct (level of sales, asset turnover, sales growth). Using data for companies in the MSCI World universe over the period 2011 to 2014 we find the following results in Exhibit 7.

The negative sign for carbon ratio indicates that a fall in the carbon ratio leads to an increase in profitability. We also find that asset turnover is associated with stronger future profitability, sales on its own is mildly negative, and past sales growth has no discernible effect.

To highlight our claim that carbon ratio is an indicator rather than a driver of fundamental efficiency, we repeat the analysis removing the most carbon-intensive industries. The results are shown in Exhibit 8. We can see that even with the large emitting industries removed, there is still a strong and significant relationship between companies that are improving their carbon ratio and ROA.

Exhibit 7: Carbon ratio and future profitability.

	Beta	*t*-stat.	Beta	*t*-stat.	Beta	*t*-stat.
Intercept	0.20	1.41	0.19	1.37	3.16	2.53
ROA(−1)	0.80	78.13	0.80	78.11	0.80	77.22
Sales/assets	0.76	5.70	0.77	5.72	0.84	6.11
Change Carbon	−0.54	−3.85	−0.53	−3.77	−0.53	−3.78
Sales Growth			0.07	0.63	0.05	0.44
ln(Sales(−1))					−0.31	−2.39

Exhibit 8: Carbon ratio and future profitability without utilities, energy and materials.

	Beta	*t*-stat.	Beta	*t*-stat.	Beta	*t*-stat.
Intercept	0.67	4.47	0.68	4.47	7.46	4.98
ROA(−1)	0.80	71.25	0.80	71.13	0.79	69.94
Sales/assets	0.49	3.39	0.48	3.35	0.60	4.09
ΔCarbon	−0.52	−2.62	−0.51	−2.60	−0.50	−2.56
Sales growth			0.02	0.30	0.16	1.98
ln(Sales(−1))					−0.30	−4.55

3.2 Stock returns

Finally we examine how carbon intensity affects subsequent returns. Using the stocks in the MSCI World universe, we sort the universe into terciles based on the change in their carbon ratio. Hence we are left with the three groups; those with the greatest improvement, those with the worst deterioration, and those in the middle. This ranking is updated as new data becomes available. Carbon emissions and sales are reported on an annual basis so the data for any company only changes once a year. We examine monthly returns from 2011–2015. The limited performance history is due to limitations in the number of companies reporting their carbon measures prior to 2011.

Exhibit 9 summarizes the returns to going long the companies with the strongest improvements and shorting the companies with the largest deterioration in their carbon ratio. We first report the raw return difference and then control for Fama–French factors market, size, and value.[5] The return spread is at about 2% annually and with only 60 monthly observations the significance is modest. The results strengthen somewhat after controlling for Fama–French factors, with a tilt towards large and expensive stocks. Finally, we add a sales growth factor to account for any returns to the carbon ratio purely driven by the change in sales. We compute this factor in the same way as our carbon ration change; the returns to the highest minus the lowest tercile of sales growth. We experimented with a sales level factor but it is already subsumed by the Fama–French size factor.

Exhibit 10 repeats the analysis after excluding the most carbon-intensive industries. The point estimates of return are actually somewhat higher, annualizing at 2.5%. Significance levels on all variables, including Fama-French factor loadings, fall because we have fewer stocks in the long and short portfolios so there is more firm-specific volatility.

Exhibit 9: Returns to low minus high portfolios by change of carbon ratio.

	Beta	*t*-stat.	Beta	*t*-stat.	Beta	*t*-stat.
Intercept	0.002	1.753	0.002	1.786	0.002	1.722
MKT			0.000	−0.332	0.000	−0.332
SMB			−0.002	−2.273	−0.002	−2.385
HML			−0.002	−3.960	−0.002	−3.059
Sales growth					0.016	0.196

Exhibit 10: Returns to low minus high portfolios excluding utilities, energy and materials.

	Beta	*t*-stat.	Beta	*t*-stat.	Beta	*t*-stat.
Intercept	0.002	1.635	0.002	1.551	0.002	1.723
MKT			0.000	−0.599	0.000	0.195
SMB			−0.001	−1.176	0.000	−0.312
HML			−0.001	−1.253	−0.002	−2.708
Sales growth					−0.243	−3.212

Exhibit 11: Cumulative total returns by tercile of carbon ratio improvement.

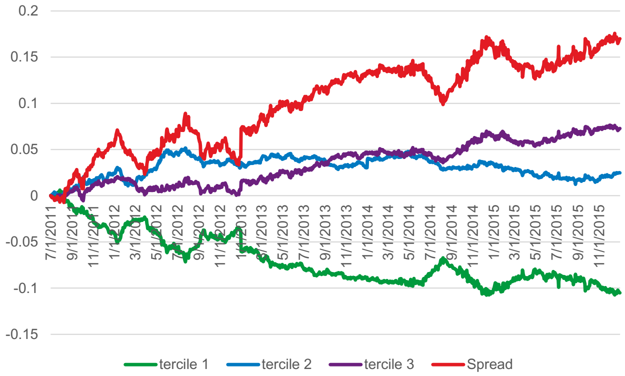


Exhibit 11 plots the total returns to each tercile as well as the tercile spread. The return differences are quite consistent and are monotonic by tercile.

4 Conclusion

Carbon emissions are an environmental concern in part because they are so deeply linked to so many productive activities. We find that firms are able to emit less primarily by being more efficient. This efficiency translates into stronger future financial performance at both the firm level when we consider ROA measures and to investors when looking at the returns that can be achieved by investing in those companies that have the largest improvements in their emissions. Our results hold across multiple techniques but in many cases are quite modest. One reason could be the lack of consistent standards for measuring and reporting emissions. Our approach suggests that environmental effects are a useful gauge of efficiency as well as social concern. This realisation should motivate better disclosure but also more serious attempts at third-party measurement of firms' environmental footprints.

Notes

1 Wikipedia
2 www.cdp.net
3 http://www.ghgprotocol.org/files/ghgp/public/ghg-protocol-revised.pdf
4 See for example, http://www.investopedia.com/terms/a/assetturnover.asp, http://www.investopedia.com/terms/r/revenueperemployee.asp
5 Data from http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html

References

Alvarez, I. (2012). "Impact of CO_2 Emission Variation on Firm Performance," *Business Strategy and the Environment* **21**, 435–454.

Andersson, M., Bolron, P., and Samama, F. (2016). "Hedging Climate Risk," *Financial Analysts Journal* **72**, 13–32.

Bebchuk, L. A., Cohen, A., and Wang, C. C. Y. (2103). "Learning and the Disappearing Association Between Governance and Returns," *Journal of Financial Economics* **108**, 323–348.

Cobb, C. W. and Douglas, P. H. (1928). "A Theory of Production," *American Economic Review* **18**, 139–165.

Derwall, J., Guenster, N., Bauer, R., and Koedijk, K. (2005). "The Eco-Efficiency Premium Puzzle," *Financial Analysts Journal* **61**, 51–63.

ET Index, (2015). "The Emerging Importance of Carbon Emission-Intensities and Scope 3 (Supply Chain) Emissions in Equity Returns," Special Report.

Ennis, C., Kottwitz, J., Lin, H., and Markusen, S. (2012). "Exploring the Relationship between Carbon Disclosure and Performance in FTSE Companies," Working Paper.

Gompers, P., Ishii, J., and Metrick, A. (2003). "Corporate Governance and Equity Prices," *Quarterly Journal of Economics* **118**, 107–153.

Griffin, P. A., Lont, D. H., and Sun, Y. (2017). "The Relevance to Investors of Greenhouse Gas Emission Disclosures," *Contemporary Accounting Research* **34**, 1265–1297.

Koch, A. and Bassen, A. (2013). "Valuing the Carbon Exposure of European Utilities: The Role of Fuel Mix, Permit Allocation, and Replacement Investments," *Energy Economics* **36**, 431–443.

Liesen, A., Figge, F., Hoepner, A., and Patten, D. M. (2017). "Climate Change and Asset Prices: Are Corporate Carbon Disclosure and Performance Priced Appropriately?," *Journal of Business Finance and Accounting* **44**, 35–62.

Ngwakwe, C. and Msweli, P. (2013). "On Carbon Emission Reduction and Firm Performance: Example from 3M Company," *Environmental Economics* **4**, 54–66.

Nishitani, K. and Kokubu, K. (2012). "Why Does the Reduction of Greenhouse Gas Emissions Enhance Firm Value? The Case of Japanese Manufacturing Firms," *Business Strategy and the Environment* **21**, 517–529.

Renner, A. (2011). "Does Carbon-Conscious Behaviour Drive Firm Performance?," Dissertation, University Erlangen Nuremberg.

Solow, R. W. (1957). "Technical Change and the Aggregate Production Function," *Review of Economics and Statistics* **39**, 312–320.

Taken To Task (2016). "How to Deal with Worries about Stranded Assets," The Economist, special report, November 24. https://www.economist.com/news/special-report/21710632-oil-companies-need-heed-investors-concerns-how-deal-worries-about-stranded.

Task Force on Climate-Related Financial Disclosures (2016). "Recommendations of the Task Force on Climate-Related Financial Disclosures," December 14. Available as https://www.fsb-tcfd.org/wp-content/uploads/2016/12/TCFD-Recommendations-Report-A4-14-Dec-2016.pdf.

Zeigler, A., Busch, T. and Hoffmann, V. H. (2011). "Disclosed Corporate Responses to Climate Change and Stock Performance: An International Empirical Analysis," *Energy Economics* **33**, 1283–1294.

Keywords: Greenhouse gas; carbon footprint; efficiency; productivity