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Arjan Trinks
Bert Scholtens
Machiel Mulder
Lammertjan Dam

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Research Institute SOM
Faculty of Economics & Business
University of Groningen

Visiting address:
Nettelbosje 2
9747 AE Groningen
The Netherlands

Postal address:
P.O. Box 800
9700 AV Groningen
The Netherlands

T +31 50 363 9090/3815

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Implicit Premiums in Renewable-Energy Support Schemes

Arjan Trinks
University of Groningen, Faculty of Economics and Business, Department of Economics, Economterics & Finance
p.j.trinks@rug.nl

Bert Scholtens
University of Groningen, Faculty of Economics and Business, Department of Economics, Economterics & Finance

Machiel Mulder
University of Groningen, Faculty of Economics and Business, Department of Economics, Economterics & Finance

Lammertjan Dam
University of Groningen, Faculty of Economics and Business, Department of Economics, Economterics & Finance

Divesting Fossil Fuels:
The Implications for Investment Portfolios

Arjan Trinks [a, *], Bert Scholtens [a, b], Machiel Mulder [a], Lammertjan Dam [a]

Abstract

Fossil fuel divestment campaigns urge investors to sell their stakes in companies that supply coal, oil, and gas. However, avoiding investments in such companies can be expected to impose a financial cost on the investor because of reduced opportunities for portfolio diversification. We compare the risk-adjusted return performance of investment portfolios with and without fossil fuel companies over the period 1927-2015. Contrary to theoretical expectations, we find that fossil-free investing does not seem to impair financial performance. These findings can be explained by the fact that fossil fuel company portfolios do not generate above-market performance and provide relatively limited diversification benefits. Significant performance impacts of a divestment strategy, however, are observed over short time frames and when applying divestment to less diversified investment portfolios.

Keywords: Fossil Fuel Divestment, Socially Responsible Investing, Portfolio Performance, Risk-adjusted returns, Market Capitalization, GARCH

JEL codes: G11, Q41

[a] Department of Economics, Econometrics & Finance, University of Groningen, PO Box 800, 9700 AV Groningen, The Netherlands

[b] Centre for Responsible Banking & Finance, School of Management, University of St. Andrews, The Gateway, North Haugh, St. Andrews, KY16 9RJ Scotland, UK

[*] Corresponding author. E-mail address: p.j.trinks@rug.nl (Arjan Trinks) Tel: +31 50 363 8139

1. Introduction

Recent divestment campaigns have been urging investors to sell their stakes in companies that supply coal, oil, and gas. Initiated at US universities, fossil fuel divestment campaigns have gained support from foundations, pension funds, faith-based groups, governmental organizations, educational institutions, and others. The movement's ultimate aim is to reduce Greenhouse Gas (GHG) emissions by cutting down financial support for and addressing the moral legitimacy of fossil fuel production and use (Ansar et al., 2013; Ayling and Gunningham, 2015). As of December 2016, about $5.5 trillion of institutions' Assets under Management has been committed to divest from at least one type of fossil fuel.[1]

The call for divestment closely relates to scientific and political debate about the need for global action to avert dangerous anthropogenic climate change (Arbuthnott and Dolter, 2013; DeCanio, 2009; Gross, 2015) and the associated societal costs and distribution thereof (DeCanio, 2009; Van den Bergh and Botzen, 2015). The divestment movement contends that investors should do their part by considering the ecological impacts of the activities they finance next to traditional risk-return measures (Ritchie and Dowlatabadi, 2014). As such, divestment requires investors to also consider the ethical merits of excluding publicly listed coal, oil, and gas companies (Ayling and Gunningham, 2015).[2]

Conforming to the moral call to divest, however, can be costly and/or problematic for investors (see Ritchie and Dowlatabadi, 2015). Fossil fuel companies make up a material part of major benchmark indexes. Despite popular claims about performance improvements following from divestment (Hunt et al., 2016; Heaps et al., 2016)[3], theoretical expectations are that constraining an investment portfolio would reduce opportunities for investment-portfolio diversification and consequently would impair financial performance. Our paper is the first to systematically investigate this financial dimension of divestment. Our analysis is firmly grounded in Modern Portfolio Theory and covers a broad market over an extensive

[1] http://gofossilfree.org/commitments/ (accessed: December 22, 2016).

[2] Parallel to this moral appeal, some reports predict strong declines in the stock prices of fossil fuel companies (Caldecott et al., 2014; Leaton, 2011; Leaton et al., 2013). They refer to Allen et al. (2009) and Meinshausen et al. (2009) who find that to keep the increase in global mean temperature below 2 °C, a commitment ratified in the Paris Agreement, up to 80% of current proven fossil fuel reserves must be left unused. McGlade and Ekins (2015) highlight the incommensurability of current and planned coal, oil, and gas production in different regions with the 2 °C limit. However, Griffin et al. (2015) do not find a corresponding strong negative impact of the above publications on US oil and gas firms' stock prices.

[3] See, for instance, http://fossilfreeindexes.com/2016/02/02/fossil-fuel-underperformance-short-term-phenomenon-or-secular-trend/ (accessed: February 17, 2016).

time horizon. As social norms and pressure to divest in the end likely affect society at large, it is momentous to rigorously study the potential costs of pursuing a divestment strategy.

We construct investment portfolios with and without fossil fuel companies using industry classifications and the Carbon Underground 200 list. We investigate the differential in portfolio risk and performance between fossil-free and unconstrained portfolios by comparing the variance, the Sharpe and Sortino performance ratios, and four-factor adjusted alphas over the period 1927-2015. Our results suggest that fossil fuel companies do not provide abnormal risk-adjusted returns and that avoiding investments in these companies does not significantly impair financial performance.

This paper proceeds as follows. Section 2 provides a theoretical framework and highlights our contribution to the literature. Section 3 and 4 provide the methodology and data respectively. Results are presented in Section 5. Section 6 concludes and discusses the implications in light of the divestment and screening discussion.

2. Socially responsible investing and diversification costs

Fossil fuel divestment can be regarded as a specific way of Socially Responsible Investing (SRI), namely exclusion (see Capelle-Blancard and Monjon, 2012; Revelli and Viviani, 2015). Through SRI, investors aim to align ethical and financial concerns and consider the 'social damage' that their investment objects cause (Dam and Scholtens, 2015). A common approach to achieve this is witholding investments in harmful or controversial activities (Eurosif, 2014; Global Sustainable Investment Alliance, 2012), such as fossil fuel production.

Modern Portfolio Theory (Markowitz, 1952; Roy, 1952; Tobin, 1958) implies that any constraint that reduces the investible universe will leave investors with a less efficient portfolio (Barnett and Salomon, 2006; Galema et al., 2008; Rudd, 1981). Divestment thus may impose an ineffiency, a cost, by increasing ideosyncratic (diversifiable) risk which is not (fully) compensated by higher returns. The associated 'diversification costs', the reduction in risk-adjusted returns, are a function of the number of stocks in a portfolio and the correlation between the stock returns (cf. Markowitz, 1952). Hence, we expect, first of all, that the exclusion of a large (small) set of stocks with a low (high) correlation with other market investments has larger (smaller) diversification costs (cf. Boutin-Dufresne and Savaria, 2004).

Secondly, however, standard asset pricing models may imperfectly capture the risk characteristics of the fossil fuel industry. For instance, high exposure of the industry to perceived (ir)responsibility or ‘sustainability’ risk as well as energy price risk may significantly affect stock returns, despite these factors are not being captured by standard asset pricing models (Cuñado and Pérez de Gracia, 2014; Driesprong et al., 2008; Sadorsky, 1999; Scholtens, 2014).

Thirdly, SRI implies that some investors’ utility functions may depend on non-financial attributes too.[4] The divestment debate, in fact, treats fossil fuel companies as controversial or ‘sin’ stocks (see Luo and Balvers, 2015; cf. Hong and Kacperczyk, 2009). A growing preference for fossil-free investment reduces aggregate demand for fossil fuel company stocks in favor of non-fossil ones, resulting in the former being underpriced (lying above the security market line) and the latter overpriced (lying below the security market line). This differential should be detectable as risk-adjusted abnormal returns (alphas) (Heinkel et al., 2001). The reduction in demand for fossil fuel stocks limits risk sharing among fossil fuel investors and makes them imperfectly diversified, which leads them to demand additional compensation for firm-specific risk, thereby increasing (decreasing) the required rate of return for fossil fuel (fossil-free) investments (Dam and Scholtens, 2015; Fama and French, 2007; Heinkel et al., 2001; Mackey et al., 2007; Merton, 1987). This demand mechanism effectively ‘prices’ social responsibility in capital markets. It implies that fossil-free investment produces risk-adjusted returns which are below those of unconstrained investments (cf. Hong and Kacperczyk, 2009; Trinks and Scholtens, 2015). The expected effects of this mechanism for the supply of social responsibility by firms in the energy sector resemble a ‘virtuous circle’ as the cost of equity financing reduces in responsibility (Revelli and Viviani, 2015). This could have an economic impact by incentivizing environmentally responsible firm behavior in case these costs are sufficiently large to warrant installing less carbon-intense technology. In other words, a decrease in the cost of capital potentially induces more investments in low-carbon technologies to become profitable.

The movement of fossil fuel divestment, however, is only five years old and still relatively limited in size. The above effects related to social norms against fossil fuel investments thus seem to be virtually absent in long-term historical data. In this way, fossil fuel stocks are unlike sin stocks. We must take the demand for fossil-free firm activity as given (contrary to Luo and Balvers (2015)), even though the effects due to an additional preference for fossil-free investments will probably become more important in the future (cf. Ibikunle and Steffen, 2015). Nonetheless, portfolio diversification is not only constrained

[4] Fama and French (2007, p. 675) argue “[investors] get direct utility from their holdings of some assets, above and beyond the utility from general consumption that the payoffs on the assets provide.”

because of social norms but because of practical or behavioral reasons as well, suggesting there will be a compensation for idiosyncratic risk nevertheless (Boehme et al., 2009; Fu, 2009; Goyal and Santa-Clara, 2003; Malkiel and Xu, 1997). Accordingly, fossil fuel companies may receive additional returns because of their specific risks, such as high litigation and reputational risks (cf. Fabozzi et al., 2008) and industry and environmental challenges, such as the need for a radical transition to low- or zero-carbon alternatives (Ansar et al., 2013; Busch, 2007).

So far, the empirical SRI literature has found little to no negative impacts of ethical constraints on investment portfolio performance (Bello, 2005; Humphrey and Tan, 2014; Lobe and Walkshäusl, 2016; Trinks and Scholtens, 2015). Differences in findings might relate not only to the amount or market capitalization of the stocks excluded, but also to the correlations between excluded and remaining investment categories. Still, most of the environmental SRI literature has focused on the performance of specific environmentally responsible investment funds (Galema et al., 2008; Hoepner and Schopohl, 2016; Ibikunle and Steffen, 2015).

We complement this SRI and investment performance literature by systematically analyzing the risk and return characteristics of portfolios with and without fossil fuel stocks over an extensive study period. Our main interest lies with the size and significance of the diversification costs related to divesting fossil fuel companies. In other words, we are concerned with investigating whether excluding the fossil fuel industry makes the mean-variance frontier more flat or not and whether investment in this industry is needed to create a well-diversified portfolio. To this extent, we test whether divestment increases portfolio risk and impairs performance relative to the unconstrained market portfolio. Since diversification costs depend on size and risk-return characteristics, we first look into the variance and financial performance of publicly-listed fossil fuel companies. Next, we test whether portfolio performance is impaired by divestment. Our focus lies with the costs of divestment related to impaired diversification, abstracting from future policy and technology changes as well as any additional financial costs that divestment might impose, such as selection, transaction, and monitoring costs (see Bessembinder, 2016).

3. Methodology

3.1. Financial performance of the fossil fuel industry and fossil-free portfolios

The financial performance of fossil fuel company portfolios and the corresponding fossil-free market portfolios is evaluated using two well-documented measures of portfolio performance, namely the Sharpe and Sortino ratio, and by relating returns to risk factors via the Carhart four-factor model. As the two methods cover different portfolio-performance attributes it is common practice to combine them (Humphrey and Tan, 2014; Lobe and Walkshäusl, 2016). We start by considering the expected returns, total risk, and downside risk of fossil and fossil-free portfolios.

To test whether divestment comes with diversification costs (increased risk for a given return), we compare the total risk (variance) of constrained and unconstrained portfolios. We employ a standard F-test of equal variances as well as the Ledoit and Wolf (2011) test, which is robust to non-normal and serially correlated return data. Significant differences in portfolio variance would indicate reduced diversification. In the presence of imperfect investor diversification portfolio variance would be the appropriate measure to look at, as not only systematic risk component but idiosyncratic risk as well will be compensated.[5] We then evaluate portfolios' reward-to-risk performance using the Sharpe ratio (Sharpe, 1966) and the Sortino ratio (Sortino and Van der Meer, 1991). The Sharpe ratio relates the expected return on a portfolio in excess of the risk-free rate to the standard deviation of returns:

$$Sharpe_p = \frac{E(R_p)-R_f}{\sigma_p} \tag{1}$$

The Sortino ratio divides excess returns by downside risk:

$$Sortino_p = \frac{E(R_p)-R_f}{\sqrt{\frac{1}{T}\sum_{t=1}^{T}\iota^-(R_{p,t}-R_{MAR})^2}} \tag{2}$$

T is the total number of periods, ι^- is a dummy variable which takes the value 1 if $R_{p,t} \leq R_{MAR}$ and 0 if $R_{p,t} > R_{MAR}$, $R_{p,t}$ is the return on the portfolio in period t, and R_{MAR} stands for the Minimal Acceptable Rate of return, which we take to be the risk-free rate. Downside risk focuses on the probability of losses (negative returns), which might be a better reflection of investors preference for low levels of 'bad volatility' (Plantinga and De Groot, 2001; cf.

[5] Also note that we study the US market portfolio, which still includes unsystematic risk as it only imperfectly reflects the true market portfolio; it represents only a quarter of total value of common stocks outstanding globally, notwithstanding other non-common stock investable asset classes.

Nofsinger and Varma, 2014). In both the Sharpe ratio and the Sortino ratio the investor maximizes risk-adjusted return at the portfolio which displays the highest performance ratio. Significance of differences in Sharpe ratios is tested using the robust Ledoit and Wolf (2008) test recommended by recent related studies (Auer, 2016; Lobe and Walkshäusl, 2016) next to the standard Jobson-Korkie (1981) test corrected by Memmel (2003). The Ledoit and Wolf (2008) test is robust against non-normal and serially correlated return data. We use the circular blocks bootstrap procedure with 5,000 resamples, as recommended by Ledoit and Wolf (2008) and used in the recent literature (Lobe and Walkshäusl, 2016).

The Sharpe and Sortino ratio, however, assume perfect capital markets and do not allow for clean comparisons between portfolios due to (by definition) higher variability of subsamples and differences in exposure to systematic risk. Consequently, we will also have to evaluate the financial performance of fossil fuel company portfolios and divested portfolios by relating the returns in excess of the risk-free rate on each portfolio to well-documented risk factors. In line with related studies, we estimate the Carhart (1997) four-factor model:

$$R_{p,t} - R_{f,t} = \alpha_p + \beta_{p,m}(R_{m,t} - R_{f,t}) + \beta_{p,SMB} SMB_t + \beta_{p,HML} HML_t + \beta_{p,WML} WML_t + \varepsilon_{p,t} \quad (3)$$

The Carhart model relates the value-weighted excess return on an investment portfolio p in month t to four common determinants of risk. $R_{m,t} - R_{f,t}$, the market risk premium, is the return on a value-weighted market portfolio in excess of the risk-free rate. SMB_t (Small minus Big) is the return on a portfolio long in small cap stocks and short in large caps. The HML_t (High minus Low) factor, in a similar fashion, measures the return differential between high and low book-to-market stocks. WML_t (Winners minus Losers) represents the return on a portfolio long in stocks with the highest returns and short in those with the worst performance in previous 12 months. Lastly, α represents the variable of interest, namely the portfolio's abnormal return performance when controlling for the above four risk factors. US factor data are obtained from CRSP.

We analyze the impact of divestment by excluding stocks belonging to the fossil fuel industry from the unconstrained market portfolio. Differences in return performance between the unconstrained market portfolio and the same market portfolio screened for the fossil fuel company samples are tested using the long-short (zero-investment) approach (see Hong and Kacperczyk, 2009; Lobe and Walkshäusl, 2016), which regresses the returns of a portfolio with a long (positive) position in the fossil-free portfolio and a corresponding short (negative) position in the unconstrained portfolio on the four Carhart factors. The resulting alphas in these regressions provide the risk-adjusted return performance of the fossil-free market portfolio when benchmarked against the unconstrained market portfolio.

Diversification costs, the reduction in risk-adjusted returns, due to a divestment strategy may vary over time, as do our model's parameters. Therefore, we perform five- and one-year rolling window regressions and compare crisis and non-crisis periods. In addition, since investors in practice often rely on restricted market indexes, we rerun our analysis applying fossil-fuel screens to the S&P 500 and FTSE 100 indexes. Finally, we address volatility clustering and non-normality by employing a GARCH model and median regression.

Note that diversification costs may result from a reduced investment universe (number of stocks) and portfolio composition (type of stocks). We will have to consider disentagling both effects if and only if we would find significant effects of divestment. This can be done using the approach by Humphrey and Tan (2014), which simulates portfolios of similar size and as such distillates the portfolio composition effect.

4. Data

We construct portfolios with and without publicly listed fossil fuel companies. We extract data on all listed and delisted US common stocks from Center for Research in Security Prices (CRSP). Fossil fuel stocks are identified using Standard Industry Classification (SIC) codes (cf. Fama and French, 1997).[6] Using industry classifications is common practice in investment management and academic research (Hong and Kacperczyk, 2009; Humphrey and Tan, 2014). We follow the general approach of the divestment movement and focus on the supply (production) of fossil fuels. However, we acknowledge that in the future the movement might expand its scope to include demand, most notably energy conversion and consumption (Ansar et al., 2013). To accommodate differences in focus, we employ a narrow industry definition, which identifies companies involved in coal mining (SIC 12) and oil and gas extraction (SIC 13), as well as a broad industry definition, which also captures activities

[6] Our results are robust to complementing SIC codes with North American Industry Classication System (NAICS) codes. NAICS codes are available in CRSP only from 2004 onwards and add only a small number of stocks.

directly related to the supply of fossil fuels, such as oil and gas fiel machinery, mining services, and transportation. Table A.1 in Appendix A provides an overview of the codes used to identify companies involved in coal and oil and gas. The broader definition can be of interest to the investor who aims to avoid any major involvement with fossil fuel production as well as involvement by energy majors, which are often grouped in SIC 291. Our approach complements the SRI literature which has relied upon shorter time frames and less comprehensive industry classifications (e.g., Luo and Balvers, 2015), company-level exclusions (Trinks and Scholtens, 2015), or exclusions within particular SRI fund types (Ibikunle and Steffen, 2015).

Next to analyzing SIC industries, we consider the companies included in the Carbon Underground 200 (CU200), which is a list composed by Fossil Free Indexes LLC of the 100 largest coal and oil & gas companies based on their reported reserves. The list is often employed by advocates of divestment as a useful starting point[7] as it provides a straightforward method to identify the potential carbon content of one's investments (see Ritchie and Dowlatabadi, 2014).[8] The CU200 sample is constructed using the CU200 list as of July 2016[9] and identification is done through ISIN numbers (using ORBIS) and company names (manually). We do not explicitly consider other SRI strategies which can be used instead or alongside divestment. One such approach would be Divest-Invest, which replaces fossil fuel investments by low- or zero-carbon ones[10], using the recently developed Carbon Clean 200 (CC200), a list of the 200 largest stocks based on green energy revenues (Heaps et al., 2016), as a natural opposite of the CU200. Note, however, that our main analysis implicitly accounts for this Divest-Invest approach since the CU200-free CRSP market portfolio fully covers CC200 stocks.[11]

For each of the three identification methods (using the broad- and narrow-definition SIC codes as well as the CU200 list), we construct three fossil fuel portfolios, consisting of all companies involved in coal, oil and gas, or all fossil fuels. Hence, we end up with nine (3x3) fossil fuel company portfolios. Correspondingly, we construct nine fossil-free portfolios by

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[7] http://gofossilfree.org/top-200/ (accessed: August 8, 2016).

[8] Of course, other lists could also be considered, such as the 'filthy fifteen' of the largest and dirtiest US coal mining companies and coal-fired utilities (https://fossilfreefunds.org/filthy-15/) or the 90 'carbon majors' of the most carbon-intensive US firms (Heede, 2014).

[9] We thank Carbon Tracker Initiative for making this information publicly available at http://fossilfreeindexes.com/research/the-carbon-underground/ (accessed: August 2, 2016).

[10] See: http://divestinvest.org/ (accessed: September 27, 2016).

[11] Also note that, by construction, in fossil-free portfolios, weights of CC200 stocks and other remaining non-fossil stocks are increased proportionally to their market capitalization. This corresponds to the fact that divestment moves capital from the fossil fuel industry to other sectors (Ritchie and Dowlatabadi, 2014).

discarding from the CRSP market portfolio all stocks in the respective fossil fuel portfolios. Table 1 shows the amount of stocks in each sample. The results indicate that fossil-fuel screening, with the exception of screening for coal, could considerably reduce the number of investible assets. Also, it shows the important contribution of employing a broader range of industry codes than is commonly done in the literature (cf. Fama and French, 1997; Luo and Balvers, 2015).

From CRSP, we obtain monthly total returns, closing stock prices, and shares outstanding for NYSE, Amex, and Nasdaq stocks over the period 1927-2015. We follow the literature (see Lobe and Walkshäusl, 2016; Luo and Balvers, 2015) by focusing on companies with CRSP share codes of 10 or 11 and excluding companies with one-digit SIC codes of 6, belonging to the financial services industry. We delete stocks without return and market value of equity data or those with less than 60 months of returns or market values to allow for a sufficiently long price discovery process.

Table 1: Sample size of fossil and fossil-free portfolios

Sample	#stocks			
	Coal	Oil and gas	All fossil	All stocks
SIC broad definition	58	829	883	-
SIC narrow definition	44	584	628	-
CU200	23	47	68	-
CRSP market portfolio				12,141

This table shows the number of stocks of the nine fossil fuel company samples. The SIC narrow definition includes SIC 12 (coal) and 13 (oil and gas); the SIC broad definition adds SIC 3532, 5052, and 5082 (coal), and SIC 291, 3533, 46, 492, 517, 5541, 598, and 6792 (oil and gas). CU200 is the July 2016 list from Fossil Free Indexes LLC of the 100 largest coal and oil & gas companies based on their reported reserves (http://gofossilfree.org/top-200/). Note that the number of stocks represent the total number of stocks identified over the complete study period. The size of the portfolios at a particular time point is lower (e.g., in 2015, the year-average number of stocks in the market portfolio was 2,193).

5. Results

In this section, we first investigate the financial performance of the fossil fuel industry relative to the overall market index. We then report our findings for the effects of applying fossil fuel industry screens and discuss the implications for the divestment debate. Finally, we test and discuss the robustness of our findings.

5.1. Performance of fossil fuel investments

Table 2 presents the descriptive statistics and portfolio performance measures of the portfolios with and without stocks of companies involved in the supply of coal, oil, and gas. We observe market-conform average excess returns for coal stocks and above-market returns for oil and gas stocks. However, fossil fuel portfolios exhibit substantially higher risk than the market portfolio, both when measured in terms of standard deviation and downside risk. Notably, coal stocks face almost double the risk. As a consequence, the Sharpe and Sortino ratios are marginally lower for most fossil fuel portfolios as compared to the market portfolio. As shown in the last two columns of Table 2, the variance of fossil fuel portfolios is significantly higher than that of the market portfolio, while the Sharpe ratio is significantly lower only for the coal portfolio. Consequently, investments in the fossil fuel industry seem to offer market-like risk-adjusted returns, while, as expected, taken on their own do not provide sufficient diversification opportunities. The finding of higher returns and higher risk for fossil fuel investments is consistent with the hypothesized higher industry risk (cf. Cuñado and Pérez de Gracia, 2014; Fabozzi et al., 2008). Moreover, we notice that total risk decreases by more than 20% when moving from the narrow definition sample to the broad definition sample. In line with this move, Sharpe ratios increase. This finding informs the portfolio performance literature by showing that portfolio diversification benefits may still increase considerably in portfolios which already include a large number of stocks (cf. Evans and Archer, 1968; Statman, 1987), and by expanding the activity set covered by the portfolio.

Table 2: Descriptive statistics and performance ratios of fossil and fossil-free investment portfolios (1927-2015)

		Mean	StDev	DR	Sharpe	Sortino	ΔVar	ΔSharpe
CRSP	Market portfolio	0.65%	5.36%	3.54%	0.12	0.18	-	-
Fossil fuel portfolios								
SIC broad	Coal	0.59%	9.34%	5.93%	0.06	0.10	0.59%*** $^{\text{F, LW}}$	-0.0578** $^{\text{JK, LW}}$
	Oil and gas	0.72%	6.02%	3.84%	0.12	0.19	0.08%*** $^{\text{F, LW}}$	-0.0018*** $^{\text{JK}}$
	All fossil	0.72%	6.03%	3.85%	0.12	0.19	0.08%*** $^{\text{F, LW}}$	-0.0027
SIC narrow	Coal	0.61%	9.95%	6.32%	0.06	0.10	0.70%*** $^{\text{F, LW}}$	-0.0604** $^{\text{JK, LW}}$
	Oil and gas	0.74%	7.74%	4.92%	0.10	0.15	0.31%*** $^{\text{F, LW}}$	-0.0263* $^{\text{JK}}$
	All fossil	0.72%	7.68%	4.89%	0.09	0.15	0.30%*** $^{\text{F, LW}}$	-0.0281* $^{\text{JK}}$
CU200	Coal*	0.82%	8.44%	5.04%	0.10	0.16	0.43%*** $^{\text{F, LW}}$	-0.0243* $^{\text{LW}}$
	Oil and gas	0.95%	8.25%	4.85%	0.12	0.20	0.39%*** $^{\text{F, LW}}$	-0.0062
	All fossil	0.95%	8.23%	4.84%	0.12	0.20	0.39%*** $^{\text{F, LW}}$	-0.0065
Fossil-free portfolios								
SIC broad	Market excl. Coal	0.65%	5.35%	3.54%	0.12	0.18	0.00%	0.0001
	Market excl. Oil and gas	0.65%	5.43%	3.60%	0.12	0.18	0.01%	-0.0020
	Market excl. All fossil	0.65%	5.43%	3.60%	0.12	0.18	0.01%	-0.0019
SIC narrow	Market excl. Coal	0.65%	5.35%	3.54%	0.12	0.18	0.00%	0.0001
	Market excl. Oil and gas	0.65%	5.33%	3.53%	0.12	0.18	0.00%	0.0006
	Market excl. All fossil	0.65%	5.33%	3.53%	0.12	0.18	0.00%	0.0007

CU200	Market excl. Coal	0.63%	5.35%	3.54%	0.12	0.18	0.00%	0.0001
	Market excl. Oil and gas	0.65%	5.38%	3.56%	0.12	0.18	0.00%	-0.0009
	Market excl. All fossil	0.65%	5.38%	3.56%	0.12	0.18	0.00%	-0.0009

This table presents the mean, standard deviation, and downside risk (DR) of monthly excess returns of the fossil and fossil-free portfolios, as well as their Sharpe and Sortino ratios over the period 01/1927-12/2015. ΔVar is the difference between each portfolio's variance and the variance of the CRSP Market portfolio. *** p<0.01, ** p<0.05, * p<0.10, with F denoting the F-test for equality of variances and LW the robust Ledoit-Wolf (2011) alternative using the studentized time series bootstrapping procedure with 5,000 resamples. ΔSharpe is the difference between each portfolio's Sharpe ratio and that of the CRSP Market portfolio. JK denotes the Jobson-Korkie (1981) test of equal Sharpe ratios and LW the robust Ledoit-Wolf (2008) alternative using the studentized time series bootstrapping procedure with 5,000 resamples. The SIC narrow definition includes SIC 12 (coal) and 13 (oil and gas); the SIC broad definition adds SIC 3532, 5052, and 5082 (coal), and SIC 291, 3533, 46, 492, 517, 5541, 598, and 6792 (oil and gas). CU200 is the July 2016 list from Fossil Free Indexes LLC of the 100 largest coal and oil & gas companies based on their reported reserves (http://gofossilfree.org/top-200/).

* Return series starts from February 1949 (N=803).

To control for well-documented risk factors, we employ the Carhart four-factor model. Table 3 shows that over the 1927-2015 period portfolios consisting of fossil fuel companies, in particular coal companies, have generated slightly negative alphas. This demonstrates the substantial systematic risk associated with investments in the fossil fuel industry (in line with Cuñado and Pérez de Gracia (2014), Driesprong et al. (2008), Sadorsky (1999)), which more than offsets the above-market returns observed in this industry. In particular, the significant loadings on the Market, SMB, and HML risk factors indicate that the relatively high average excess returns on fossil fuel stocks can largely be explained as a compensation for their significant exposure to systematic risk factors.

From a pure financial perspective, however, the decision to divest should not be based on the performance of fossil fuel stocks in isolation, but rather it should be looked at how divesting fossil fuel stocks impacts the total portfolio of the investor. This is what we will do in the next subsection.

Table 3: Risk-adjusted return performance of fossil fuel portfolios (Carhart model, 1927-2015)

		Alpha	Rm_rf	SMB	HML	WML
SIC broad	Coal	-0.0024	1.0202***	0.4190***	0.3535***	-0.0696
		(0.0021)	(0.0465)	(0.1125)	(0.0980)	(0.0732)
	Oil and gas	-0.0000	0.9223***	-0.1958***	0.2890***	0.0888**
		(0.0011)	(0.0269)	(0.0424)	(0.0405)	(0.0356)
	All fossil	-0.0001	0.9248***	-0.1895***	0.2886***	0.0877**
		(0.0011)	(0.0268)	(0.0425)	(0.0406)	(0.0356)
SIC narrow	Coal	-0.0017	0.9905***	0.3928***	0.3016***	-0.0879
		(0.0024)	(0.0554)	(0.1192)	(0.1105)	(0.0799)
	Oil and gas	-0.0010	1.1038***	-0.0810	0.3458***	0.0120
		(0.0015)	(0.0339)	(0.0565)	(0.0498)	(0.0398)
	All fossil	-0.0011	1.0980***	-0.0589	0.3410***	0.0103
		(0.0014)	(0.0329)	(0.0555)	(0.0489)	(0.0396)
CU200	Coal*	-0.0003	1.0974***	0.2305**	0.2666***	-0.0365
		(0.0025)	(0.0678)	(0.0954)	(0.0969)	(0.0630)
	Oil and gas	0.0011	1.0376***	-0.2828***	0.5701***	0.0285
		(0.0018)	(0.0498)	(0.0780)	(0.0756)	(0.0670)
	All fossil	0.0010	1.0431***	-0.2759***	0.5621***	0.0253
		(0.0018)	(0.0496)	(0.0777)	(0.0752)	(0.0666)

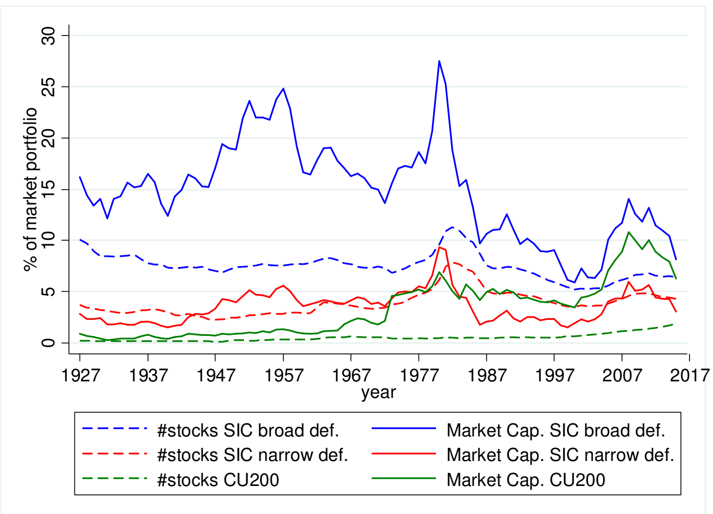
This table reports the results from regressing the excess returns of the nine capitalization-weighted fossil fuel portfolios on the Carhart (1997) US factors using OLS. Alpha is the intercept, indicating relative out- or underperformance. Rm_rf, SMB, HML, and WML are the coefficients on the Market, Size, Book-to-Market, and Momentum factors respectively. White standard errors appear in brackets. *** p<0.01, ** p<0.05, * p<0.10. The SIC narrow definition includes SIC 12 (coal) and 13 (oil and gas); the SIC broad definition adds SIC 3532, 5052, and 5082 (coal), and SIC 291, 3533, 46, 492, 517, 5541, 598, and 6792 (oil and gas). CU200 is the July 2016 list from Fossil Free Indexes LLC of the 100 largest coal and oil & gas companies based on their reported reserves (http://gofossilfree.org/top-200/).

* Return series starts from February 1949 (N=803).

5.2. Performance of fossil-free investments

We now turn to the impact of divesting fossil fuel stocks on investment portfolios. Figure 1 shows the year-average percentage share of the number and market capitalization of stocks which are excluded relative to total market portfolio. While on average the effects of screening are modest, there is considerable variation in the share the fossil fuel industry takes in the market portfolio in our sample period. Higher percentage shares, as witnessed in the 1980s for instance, could mean larger diversification costs related to a divestment strategy. This is relevant to the divestment debate, as implications of divestment could become more or less pronounced in future periods when the market share of fossil fuel stocks changes.

Figure 1: Year-average number of stocks and market capitalization of fossil fuel portfolios as a percentage of the market portfolio



As shown in the last two columns of Table 2, there is no significant differential between the variance nor the Sharpe ratio of fossil-free portfolios and the unconstrained market portfolio. Hence, there does not seem to be a significant reduction in diversification opportunities following from a divestment strategy. Table 5 shows the four-factor risk-adjusted return performance of fossil-free portfolios relative to the unconstrained market portfolio. We find no evidence of significant abnormal risk-adjusted returns for fossil-free portfolios over the whole study period, as indicated by the insignificant alphas.

Table 4: Risk-adjusted return performance of fossil-free market portfolios (Carhart model, 1927-2015)

		Alpha	Rm_rf	SMB	HML	WML
SIC broad	Coal	0.0000*	-0.0003***	-0.0005***	-0.0003*	-0.0001
		(0.0000)	(0.0001)	(0.0002)	(0.0002)	(0.0001)
	Oil and gas	0.0002	0.0005	0.0336***	-0.0348***	-0.0215***
		(0.0002)	(0.0053)	(0.0070)	(0.0069)	(0.0065)
	All fossil	0.0002	0.0000	0.0331***	-0.0352***	-0.0217***
		(0.0002)	(0.0053)	(0.0071)	(0.0069)	(0.0065)
SIC narrow	Coal	0.0000*	-0.0002**	-0.0004***	-0.0002	-0.0001
		(0.0000)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
	Oil and gas	0.0001	-0.0053***	0.0037*	-0.0070***	-0.0041**
		(0.0001)	(0.0014)	(0.0019)	(0.0018)	(0.0017)
	All fossil	0.0001	-0.0056***	0.0033*	-0.0071***	-0.0042**
		(0.0001)	(0.0015)	(0.0020)	(0.0019)	(0.0018)
CU200	Coal	0.0000	-0.0005**	0.0000	-0.0006***	-0.0003
		(0.0000)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
	Oil and gas	0.0000	0.0024**	0.0093***	-0.0139***	-0.0059***
		(0.0001)	(0.0012)	(0.0018)	(0.0016)	(0.0018)
	All fossil	0.0000	0.0021*	0.0095***	-0.0144***	-0.0064***
		(0.0001)	(0.0012)	(0.0018)	(0.0017)	(0.0018)

This table reports the results from regressing the excess returns on the zero-investment portfolio with a long position in the fossil-free market portfolio and a short position in the unconstrained market portfolio on the Carhart (1997) US factors using OLS. Alpha is the intercept, indicating relative out- or underperformance. Rm_rf, SMB, HML, and WML are the coefficients on the Market, Size, Book-to-Market, and Momentum factors respectively. White standard errors appear in brackets. *** p<0.01, ** p<0.05, * p<0.10. The SIC narrow definition includes SIC 12 (coal) and 13 (oil and gas); the SIC broad definition adds SIC 3532, 5052, and 5082 (coal), and SIC 291, 3533, 46, 492, 517, 5541, 598, and 6792 (oil and gas). CU200 is the July 2016 list from Fossil Free Indexes LLC of the 100 largest coal and oil & gas companies based on their reported reserves (http://gofossilfree.org/top-200/).

5.3. Sensitivity analyses

To test the robustness of our main results we consider rolling windows, crisis and non-crisis periods, divestment implications for the S&P 500 and the FTSE 100 indexes, and GARCH and median regression specifications. Details are available upon request at the corresponding author.

Rolling window results

First, we look into the stability of our results by performing five-year rolling window regressions. Figure B.1 in Appendix B shows that the out- or underperformance of the fossil fuel industry (SIC broad definition) varies substantially over time and strongly negatively correlates with the returns on the fossil-free portfolio.[12] Clearly, the most recent period is an extreme case, which is preceded by a period of fortune for fossil fuel investments. Though we generally find negative implications of divestment, we observe that an investment which is long in the fossil-free portfolio and short in the unconstrained portfolio generates significant positive alphas and Sharpe ratios significantly above the market portfolio during the mid-1980s and the period 2009-2015. However, the magnitude of this effect is quite modest (0.9-1.1% annual outperformance for these specific time frames). Moreover, the temporary nature of these alphas are clearly demonstrated by expanding our study period backwardly using one-year reverse-recursive rolling window regressions.

In line with our expectations, we further find the impact of divestment to depend on the type and proportion of stocks excluded during a specific time frame (Figure 1). An increase in the share of the fossil fuel industry positively relates to the financial impact of divestment. Additionally, the beta (loading on the Carhart market factor) of fossil fuel investments is fairly stable and close to one over the whole time period. Figure B.2 shows the development of beta over time for the SIC broad definition fossil fuel portfolio and the portfolio long in the portfolio excluding these stocks and short in the market portfolio. It suggests that periods in which divestment has significant return implications there are significantly positive shocks in the beta of the excluded stocks. The outperformance of fossil-free investments in the 1980s illustrates the effects from the type and proportion of the stocks excluded. The outperformance in this period corresponds with the fossil fuel industry's strong underperformance, the shock in its beta, and its significant share in the market.

Crisis vs. non-crisis periods

Next, we compare crisis- and non-crisis periods. Previous studies have found the performance of controversial sectors and screened portfolios to differ between economically good and bad times (see Nofsinger and Varma, 2014; Trinks and Scholtens, 2015). Nofsinger and Varma (2014) find that portfolios screening for controversial sectors do not outperform during crises (general economic downturns) while they significantly underperform the market during non-crisis periods. Accordingly, we might expect that fossil-free investments show (more) positive impacts during crises while performance would be impaired during non-crisis periods.

[12] Moreover, if we include (log) WTI oil price returns, outperformance becomes statistically insignificant, which further suggests that the outperformance of fossil-free portfolios in specific time frames can be attributed mainly to specific oil price shocks.

Using National Bureau of Economic Research (NBER) recession dates (cf. Nofsinger and Varma, 2014), we identify 15 crises lasting 196 months in total. As shown in Tables B.1 and B.2, we find no return differential between crisis and non-crisis periods for fossil and fossil-free investments. However, in crises corresponding to specific oil price shocks, alphas on fossil-free investments are significantly lower. These results confirm our general finding that the impact of divestment in specific time frames mainly relates to extraordinary performance of the divested category.

Divesting the S&P 500 and FTSE 100 indexes

In practice, investors often rely on restricted market indexes which imperfectly reflect the market portfolio. Most SRI funds use the S&P 500 as their benchmark (Humphrey and Tan, 2014). In the divestment discussion, the FTSE 100 is often considered next to the S&P 500[13], due to its high share of fossil energy firms (Leaton et al., 2013). For the S&P 500, we obtain historical constituents data from Compustat (1965-2016) and discard all stocks which are in each of our fossil fuel samples. This dataset is then merged with CRSP total return and market value data (as in Humphrey and Tan (2014)). For the FTSE 100, we retrieve historical constituents from Datastream (1996-2016) and couple these with SIC, NAICS, and NACE industry classifications (see Table A.1) data using ORBIS. Results, in Table B.3 are qualitatively similar to our main analysis. In line with our expectations, we find a more pronounced negative, but statistically insignificant, impact of divestment using the FTSE 100 index, as shown in Table B.4. Figure B.3 shows that about twice the proportion of stocks is excluded from the FTSE 100 (15% of the stocks with a market capitalization of 30% of the total index). We observe that the divested index generates a marginally lower Sharpe ratio (Figure B.4), while the downside risk is substantially lower, resulting in a much higher Sortino ratio (Figure B.5). Interestingly then, investors might have a strong preference for responsible (fossil-free) investments due to their safety despite their lower risk-adjusted returns, as suggested by Nofsinger and Varma (2014). In the specific period mid-2010/2011 to mid-2015/2016 we find (in Figure B.4) statistically and economically significant outperformance of fossil-free over the unconstrained index. However, the 'hanging belly' shape in the one-year recursive rolling window alphas (Figure B.6) illustrates that the impact of a divestment strategy has been generally negative while it turns insignificant when including recent time frames.

GARCH(1,1) regression

We address time-varying volatility (volatility clustering) present in our sample by using a GARCH(1,1) model. Results, included in Table B.5, remain qualitatively similar as OLS estimates. However, effects are less significant when employing a GARCH specification.

Median regression

Lastly, since our return data are not normally distributed (as is the case with most stock return series), we replace OLS with median regression analysis. Median regression is a type of quantile regression which fits the conditional median of the dependent variable as opposed to the mean in OLS (see Koenker and Hallock, 2001). Consistent with the literature, we perform median regressions using the Design Bootstrap procedure with 5,000 replications. Table B.6 shows that results slightly deviate from our main analysis. Coal stocks now show significant below-market median returns of -0.41%, -0.51%, -0.58% for the narrow definition, broad definition, and CU200 respectively. Results for fossil-free portfolios (Table B.7) are similar to those found in our main and sensitivity analyses. Only the portfolio which excludes the SIC broad definition coal stocks significantly outperforms the unconstrained market portfolio, but this effect economically insignificant (<0.01% monthly).

6. Discussion and conclusion

Fossil fuel divestment campaigns insist that investors must consider the impacts of the activities they finance on climate change, and consequently, they should sell their stakes in companies that supply coal, oil, and gas. We investigate whether fossil fuel divestment reduces opportunities for portfolio diversification and consequently impairs financial performance relative to the unconstrained market portfolio. Our main finding is that divested (fossil-free) portfolios do not significantly underperform the unconstrained market portfolio. A commitment to divesting fossil fuels thus does not seem to come at a significant cost. Furthermore, we find that holdings in fossil fuel companies generate higher mean returns, but, consistent with the theoretical and empirical literature, this can be explained as a compensation for higher exposure to systematic risk factors.

We complement the SRI and screening literature by systematically comparing portfolios with and without fossil fuel stocks over an extensive time frame and by analyzing the time-dependency of our results, the implications of divestment for the less diversified

S&P 500 and FTSE 100 indexes, and the effects when adopting GARCH and median regression specifications. We furthermore show that, contrary to standard portfolio theory, a constrained portfolio is not a sufficient condition for impaired performance.

Our findings are consistent with Bello (2005), Humphrey and Tan (2014), and Lobe and Walkshäusl (2016), but contrast with Hong and Kacperczyk (2009) and Trinks and Scholtens (2015) who find more pronounced outperformance of various controversial sectors and an underperformance of screened portfolios. In line with our expectations, diversification costs related to fossil fuel divestment are low because these costs increase, ceteris paribus, with the proportion of stocks excluded from the market portfolio and they decrease with the correlation between the unconstrained market portfolio and the fossil-free portfolio. The share of fossil fuel stocks is lower than the share of other main controversial sectors, and merely one investment category is avoided. Additionally, fossil fuel stocks have a beta close to one, meaning they are more or less substitutes, having relatively low diversification benefits, whereas for alcohol, tobacco, and gambling, beta is as low as 0.6 (see Trinks and Scholtens, 2015). Finally, the market-conform performance of the fossil fuel industry contrasts with the well-documented attractiveness of other controversial (Hong and Kacperczyk, 2009). Hence, the fossil fuel industry appears to be unlike various 'sin' industries not only because of the lack of a 'sin premium' (outperformance), but because of modest diversification benefits as well.

Nevertheless, a continued growth of investor commitment to fossil fuel divestment should be expected to significantly increase demand effects, inducing higher returns on fossil fuel investments and lower returns on fossil-free ones (Dam and Scholtens, 2015; Fama and French, 2007; Heinkel et al., 2001; Mackey et al., 2007; Merton, 1987). Additionally, more substantial effects of divestments are observed when considering less widely diversified investment portfolios (particularly the FTSE 100 index) and specific time frames. Our median regressions suggest that it may be financially wise to stay away from coal stocks as these potentially underperform the market over a long time span and divesting them at least does not seem to significantly hurt risk-adjusted returns. Finally, it should be noted that even small differences in portfolio returns can inflate quite significantly over longer time horizons, which might particularly concern institutional investors.

Our main results may seem as a welcome finding for proponents of divestment. Based on the period 1927-2015 and considering a portfolio of US common stocks, it seems that investors can safely divest the fossil fuel industry without significantly impairing portfolio performance. Absent any performance improvement, however, popular claims by some advocates of divestment, such as 350.org and Fossil Free Indexes, about the financial attractiveness of fossil-free investing[13] are unfounded. The divestment movement would thus benefit from shifting focus to its merits as a social and political tool to address climate change and away from cherry-picked historical outperformance.

A limitation of our study is that it is retrospective and as such does not guarantee that similar effects will obtain in the future. Our rolling window estimates show that impacts of divestment on portfolio performance may vary significantly across specific time periods. The divestment movement thus may prefer emphasizing long-term prospects and potential dangers of fossil-related investments rather than referring to historical outperformance, for which we find little evidence. Also, we abstract from any additional financial costs that divestment might impose, such as selection, transaction, and monitoring costs. Future studies could assess different responsible investing strategies next to simple exclusionary screens.

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Appendix A. Industry classifications

Table A.1: Industry classifications of coal and oil and gas companies

Sample	SIC	NAICS	NACE
Narrow def. Coal	12 (coal mining)	2121 (coal mining)	05 (mining of coal and lignite)
Narrow def. Oil & gas	13 (oil and gas extraction)	211 (oil and gas extraction)	06 (extraction of crude petroleum)
Broad def. Coal	See SIC narrow def. 3532 (mining machinery) 5052 (coal and other minerals and ores) 5082 (construction and mining (except petroleum) machinery and equipment)	See NAICS narrow def. 213113 (support activities for coal mining) 333131 (mining machinery and equipment manufacturing) 423520 (coal and other mineral and ore merchant wholesalers)	See NACE narrow def. 0892 (extraction of peat) 0990 (support activities for other mining and quarrying) 1910 (manufacture of coke oven products)
Broad def. Oil & gas	See SIC narrow def. 291 (petroleum refining) 3533 (oil and gas field machinery and equipment) 46 (pipelines, except natural gas) 492 (gas production and distribution) 517 (petroleum and petroleum products) 5541 (gasoline service stations) 598 (fuel dealers) 6792 (oil rayalty traders)	See NAICS narrow def. 213111 (drilling oil and gas wells) 213112 (support activities for oil and gas operations) 2212 (natural gas distribution) 23712 (oil and gas pipeline and related structures construction) 32411 (petroleum refineries) 333132 (oil and gas field machinery and equipment manufacturing) 4247 (petroleum and petroleum products merchant wholesalers) 45431 (fuel dealers) 486 (pipeline transportation)	See NACE narrow def. 0910 (support activities for petroleum and natural gas extraction) 1920 (manufacture of refined petroleum products) 2011 (manufacture of industrial gases) 4671 (wholesale of solid, liquid and gaseous fuels and related products) 4950 (transport via pipeline)

Appendix B. Sensitivity analyses

Figure B.1: Five-year rolling window monthly alpha (alpha_LS) and Sharpe ratio (Sharpe_LS) differential between fossil-free and unconstrained market portfolio, and the alpha of the fossil fuel portfolio (alpha_Fossil)

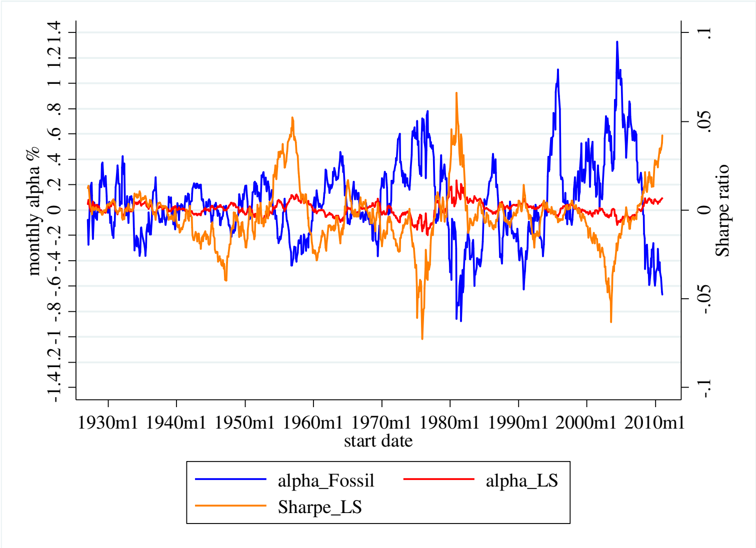

Figure B.2: Five-year rolling window beta of fossil fuel portfolio (beta_Fossil) and differential between fossil-free and unconstrained market portfolio (beta_LS)

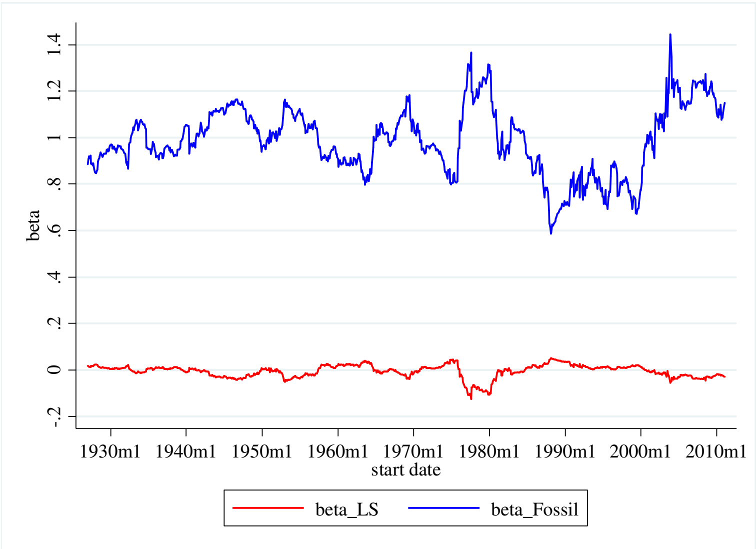

Table B.1: Crisis vs. non-crisis risk-adjusted return performance of fossil fuel portfolios (Carhart model, 1927-2015)

		Crisis	Alpha	Rm_rf	SMB	HML	WML
SIC broad	Coal	0.0006	-0.0025	1.0209***	0.4192***	0.3536***	-0.0692
		(0.0061)	(0.0022)	(0.0468)	(0.1125)	(0.0980)	(0.0731)
	Oil and gas	-0.0016	0.0003	0.9206***	-0.1963***	0.2888***	0.0879**
		(0.0031)	(0.0011)	(0.0267)	(0.0425)	(0.0405)	(0.0354)
	All fossil	-0.0015	0.0002	0.9231***	-0.1900***	0.2884***	0.0868**
		(0.0031)	(0.0011)	(0.0266)	(0.0426)	(0.0406)	(0.0355)
SIC narrow	Coal	-0.0007	-0.0016	0.9896***	0.3925***	0.3015***	-0.0884
		(0.0070)	(0.0025)	(0.0565)	(0.1192)	(0.1104)	(0.0798)
	Oil and gas	0.0003	-0.0010	1.1041***	-0.0809	0.3459***	0.0121
		(0.0043)	(0.0015)	(0.0340)	(0.0566)	(0.0498)	(0.0399)
	All fossil	0.0002	-0.0012	1.0982***	-0.0588	0.3410***	0.0104
		(0.0042)	(0.0015)	(0.0329)	(0.0556)	(0.0489)	(0.0397)
CU200	Coal*	0.0024	-0.0007	1.1001***	0.2309**	0.2678***	-0.0355
		(0.0099)	(0.0025)	(0.0702)	(0.0951)	(0.0967)	(0.0635)
	Oil and gas	-0.0008	0.0012	1.0367***	-0.2831***	0.5699***	0.0280
		(0.0060)	(0.0017)	(0.0508)	(0.0779)	(0.0758)	(0.0664)
	All fossil	-0.0008	0.0012	1.0422***	-0.2761***	0.5620***	0.0248
		(0.0059)	(0.0017)	(0.0505)	(0.0776)	(0.0755)	(0.0660)

This table reports the results from regressing the excess returns of the nine capitalization-weighted fossil fuel portfolios on the Carhart (1997) US factors using OLS. Crisis is a dummy taking the value 1 for the NBER crisis periods and 0 otherwise. Alpha is the intercept, indicating relative out- or underperformance. Rm_rf, SMB, HML, and WML are the coefficients on the Market, Size, Book-to-Market, and Momentum factors respectively. White standard errors appear in brackets. *** p<0.01, ** p<0.05, * p<0.10. The SIC narrow definition includes SIC 12 (coal) and 13 (oil and gas); the SIC broad definition adds SIC 3532, 5052, and 5082 (coal), and SIC 291, 3533, 46, 492, 517, 5541, 598, and 6792 (oil and gas). CU200 is the July 2016 list from Fossil Free Indexes LLC of the 100 largest coal and oil & gas companies based on their reported reserves (http://gofossilfree.org/top-200/).

* Return series starts from February 1949 (N=803).

Table B.2: Crisis vs. non-crisis risk-adjusted return performance of fossil-free market portfolios (Carhart model, 1927-2015)

		Crisis	Alpha	Rm_rf	SMB	HML	WML
SIC broad	Coal	0.0000	0.0000*	-0.0003***	-0.0005***	-0.0003*	-0.0001
		(0.0000)	(0.0001)	(0.0002)	(0.0002)	(0.0001)	(0.0001)
	Oil and gas	0.0003	0.0001	0.0008	0.0337***	-0.0348***	-0.0213***
		(0.0006)	(0.0052)	(0.0070)	(0.0069)	(0.0065)	(0.0065)
	All fossil	0.0003	0.0001	0.0004	0.0332***	-0.0352***	-0.0215***
		(0.0006)	(0.0053)	(0.0071)	(0.0069)	(0.0065)	(0.0065)
SIC narrow	Coal	0.0000	0.0000*	-0.0002**	-0.0004***	-0.0002	-0.0001
		(0.0000)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
	Oil and gas	0.0000	0.0001	-0.0053***	0.0037*	-0.0070***	-0.0041**
		(0.0002)	(0.0014)	(0.0019)	(0.0018)	(0.0017)	(0.0017)
	All fossil	0.0000	0.0001	-0.0055***	0.0033*	-0.0071***	-0.0042**
		(0.0002)	(0.0014)	(0.0020)	(0.0019)	(0.0018)	(0.0018)
CU200	Coal	0.0000	0.0000	-0.0005***	0.0000	-0.0006***	-0.0003
		(0.0000)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
	Oil and gas	0.0000	0.0000	0.0023**	0.0093***	-0.0139***	-0.0059***
		(0.0002)	(0.0012)	(0.0018)	(0.0016)	(0.0018)	(0.0018)
	All fossil	0.0000	0.0000	0.0021*	0.0094***	-0.0143***	-0.0061***
		(0.0002)	(0.0012)	(0.0019)	(0.0017)	(0.0019)	(0.0018)

This table reports the results from regressing the excess returns on the zero-investment portfolio with a long position in the fossil-free market portfolio and a short position in the unconstrained market portfolio on the Carhart (1997) US factors using OLS. Crisis is a dummy taking the value 1 for the NBER crisis periods and 0 otherwise. Alpha is the intercept, indicating relative out- or underperformance. Rm_rf, SMB, HML, and WML are the coefficients on the Market, Size, Book-to-Market, and Momentum factors respectively. White standard errors appear in brackets. *** p<0.01, ** p<0.05, * p<0.10. The SIC narrow definition includes SIC 12 (coal) and 13 (oil and gas); the SIC broad definition adds SIC 3532, 5052, and 5082 (coal), and SIC 291, 3533, 46, 492, 517, 5541, 598, and 6792 (oil and gas). CU200 is the July 2016 list from Fossil Free Indexes LLC of the 100 largest coal and oil & gas companies based on their reported reserves (http://gofossilfree.org/top-200/).

Table B.3: Risk-adjusted return performance of fossil-free S&P 500 portfolios (Carhart model, 1927-2015)

		Alpha	Rm_rf	SMB	HML	WML
SIC broad	Coal	0.0000	-0.0002	0.0000	0.0000	-0.0001
		(0.0000)	(0.0001)	(0.0001)	(0.0002)	(0.0001)
	Oil and gas	0.0002	0.0024	0.0315***	-0.0212*	-0.0286***
		(0.0003)	(0.0085)	(0.0108)	(0.0123)	(0.0098)
	All fossil	0.0002	0.0022	0.0316***	-0.0211*	-0.0288***
		(0.0003)	(0.0085)	(0.0108)	(0.0123)	(0.0099)
SIC narrow	Coal	0.0000	-0.0002	0.0000	0.0000	-0.0001
		(0.0000)	(0.0001)	(0.0001)	(0.0002)	(0.0001)
	Oil and gas	0.0000	-0.0048*	0.0055	-0.0013	-0.0070**
		(0.0001)	(0.0027)	(0.0035)	(0.0040)	(0.0030)
	All fossil	0.0000	-0.0050*	0.0055	-0.0012	-0.0071**
		(0.0001)	(0.0028)	(0.0036)	(0.0040)	(0.0031)
CU200	Coal	0.0000**	-0.0001	-0.0006	-0.0018***	-0.0001
		(0.0000)	(0.0003)	(0.0004)	(0.0004)	(0.0002)
	Oil and gas	0.0000	0.0062**	0.0132***	-0.0138***	-0.0113***
		(0.0001)	(0.0031)	(0.0039)	(0.0049)	(0.0034)
	All fossil	0.0001	0.0062**	0.0127***	-0.0157***	-0.0114***
		(0.0001)	(0.0031)	(0.0040)	(0.0050)	(0.0034)

This table reports the results from regressing the excess returns on the zero-investment portfolio with a long position in the fossil-free S&P 500 portfolio and a short position in the unconstrained S&P 500 portfolio on the Carhart (1997) US factors using OLS. Alpha is the intercept, indicating relative out- or underperformance. Rm_rf, SMB, HML, and WML are the coefficients on the Market, Size, Book-to-Market, and Momentum factors respectively. White standard errors appear in brackets. *** p<0.01, ** p<0.05, * p<0.10. The SIC narrow definition includes SIC 12 (coal) and 13 (oil and gas); the SIC broad definition adds SIC 3532, 5052, and 5082 (coal), and SIC 291, 3533, 46, 492, 517, 5541, 598, and 6792 (oil and gas). CU200 is the July 2016 list from Fossil Free Indexes LLC of the 100 largest coal and oil & gas companies based on their reported reserves (http://gofossilfree.org/top-200/).

Table B.4: Risk-adjusted return performance of fossil-free FTSE 100 portfolios (Carhart model, 1927-2015)

		Alpha	Rm_rf	SMB	HML	WML
SIC/NAICS/NACE broad	All fossil	-0.0004	-0.0416	0.0810*	0.0411	0.0199
		(0.0013)	(0.0343)	(0.0418)	(0.0445)	(0.0309)

This table reports the results from regressing the excess returns on the zero-investment portfolio with a long position in the fossil-free FTSE 100 portfolio and a short position in the unconstrained FTSE 100 portfolio on the Carhart (1997) US factors using OLS. Results are robust to using the UK factors, as proposed by Gregory et al. (2013).[14] Alpha is the intercept, indicating relative out- or underperformance. Rm_rf, SMB, HML, and WML are the coefficients on the Market, Size, Book-to-Market, and Momentum factors respectively. White standard errors appear in brackets. *** p<0.01, ** p<0.05, * p<0.10. The SIC narrow definition includes SIC 12 (coal) and 13 (oil and gas) and corresponding NAICS and NACE codes; the SIC broad definition adds SIC 3532, 5052, and 5082 (coal), and SIC 291, 3533, 46, 492, 517, 5541, 598, and 6792 (oil and gas) and corresponding NAICS and NACE codes. CU200 is the July 2016 list from Fossil Free Indexes LLC of the 100 largest coal and oil & gas companies based on their reported reserves (http://gofossilfree.org/top-200/).

[14] UK factors are obtained from: http://business-school.exeter.ac.uk/research/centres/xfi/famafrench/files/ (Accessed: January 11, 2017).

Figure B.3: Year-average number of stocks and market capitalization of fossil fuel portfolios as a percentage of the total FTSE 100 index

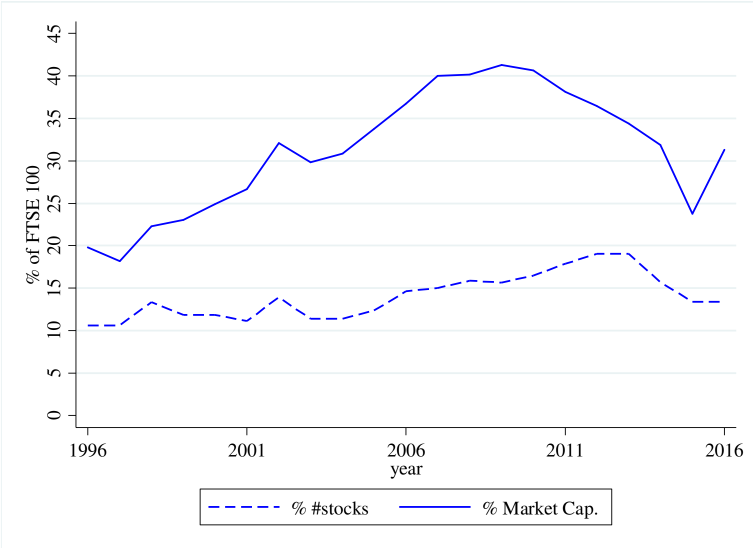

Figure B.4: Five-year rolling window monthly alpha (alpha_LS) and Sharpe ratio (Sharpe_LS) differential between fossil-free and unconstrained FTSE 100 index

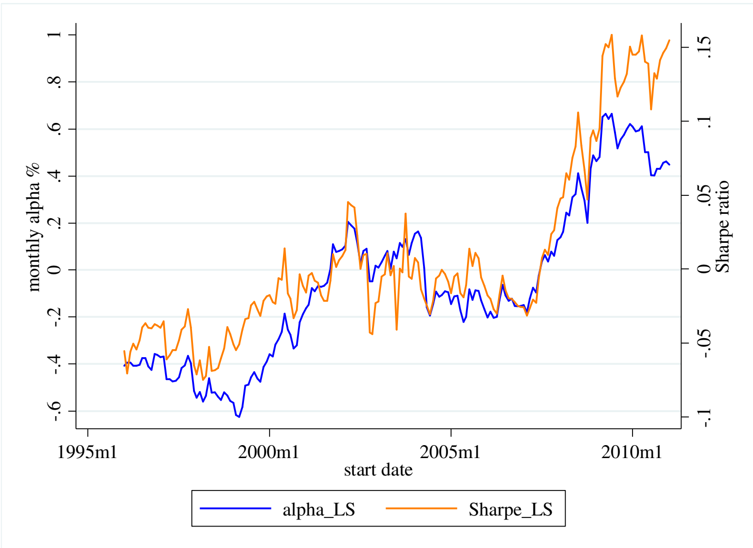

Figure B.5: Five-year rolling window differential in Sharpe ratio (Sharpe_LS) and Sortino ratio (Sortino_LS) between the fossil-free and the unconstrained FTSE 100 index

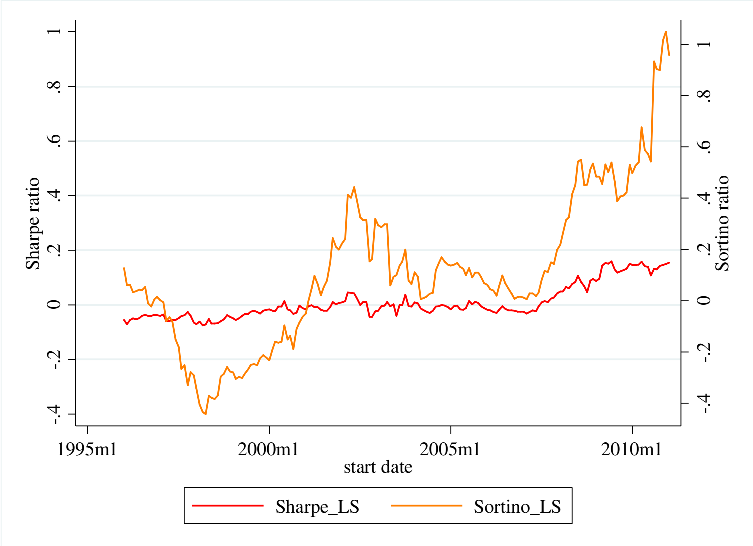

Figure B.6: One-year recursive rolling window monthly alpha differential between fossil-free and unconstrained FTSE 100 index

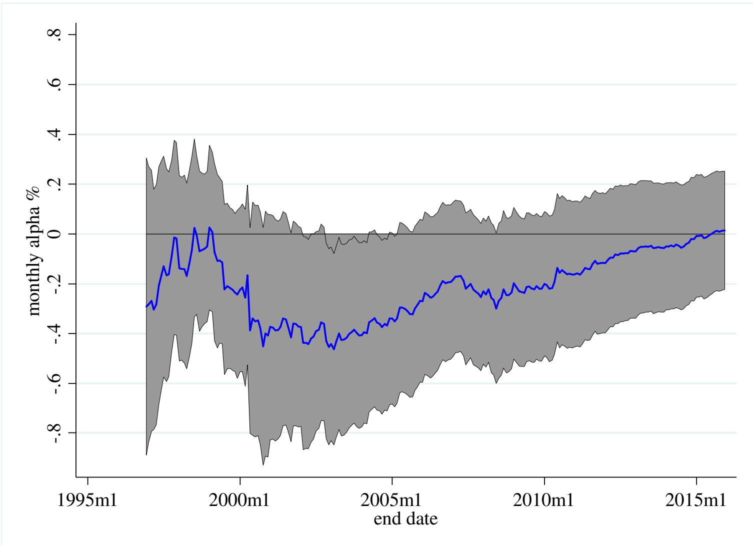

Table B.5: Risk-adjusted return performance of fossil-free portfolios (Carhart model with GARCH(1,1) specification, 1927-2015)

		Mean specification: $R_{p,t} - R_{f,t} = \alpha_p + \beta_{p,m}(R_{m,t} - R_{f,t}) + \beta_{p,SMB}SMB_t + \beta_{p,HML}HML_t + \beta_{p,WML}WML_t + \varepsilon_{p,t}$					***Variance specification:*** $h_t = \alpha_0 + a_1\epsilon_{t-1}^2 + a_2h_{t-1}^2$		
		Alpha	Rm_rf	SMB	HML	WML	a_0	a_1	a_2
SIC narrow	Coal	0.000	0.000	-0.000***	-0.000***	0.000**	0.000***	0.169***	0.806***
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.020)	(0.020)
	Oil & gas	0.000	-0.001	0.004***	-0.008***	-0.000	0.000***	0.193***	0.816***
		(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.021)	(0.017)
	All fossil	0.000	-0.001	0.003***	-0.009***	0.000	0.000***	0.195***	0.814***
		(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)	(0.021)	(0.017)
SIC broad	Coal	0.000	0.000	-0.001***	-0.000***	0.000**	0.000***	0.151***	0.833***
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.018)	(0.017)
	Oil & gas	0.000	0.010***	0.024***	-0.051***	-0.003	0.000***	0.169***	0.789***
		(0.000)	(0.003)	(0.004)	(0.004)	(0.003)	(0.000)	(0.023)	(0.029)
	All fossil	0.000	0.0010***	0.023***	-0.052***	-0.002	0.000***	0.173***	0.783***
		(0.000)	(0.003)	(0.004)	(0.004)	(0.003)	(0.000)	(0.024)	(0.030)

CU200	Coal*	0.000	-0.001***	-0.001***	-0.003***	-0.000	0.000*	0.201***	0.763***
		(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.013)	(0.054)
	Oil & gas	-0.000	0.000	0.000	-0.005***	-0.001**	0.000***	0.140***	0.874***
		(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.015)	(0.013)
	All fossil	-0.000	0.000	0.000	-0.005***	-0.001**	0.000***	0.147***	0.869***
		(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.016)	(0.013)

This table reports the Maximum Likelihood coefficient estimates of the GARCH(1,1) Carhart (1997) regressions of the monthly excess returns of the nine capitalization-weighted zero-investment portfolios with a long position in the fossil-free portfolio and a short position in the unconstrained market portfolio on the US factors from 1927-2015. Alpha is the intercept, indicating relative out- or underperformance. Rm_rf, SMB, HML, and WML are the coefficients on the Market, Size, Book-to-Market, and Momentum factors respectively. Standard errors appear in brackets. *** p<0.01, ** p<0.05, * p<0.10. The SIC narrow definition includes SIC 12 (coal) and 13 (oil and gas); the SIC broad definition adds SIC 3532, 5052, and 5082 (coal), and SIC 291, 3533, 46, 492, 517, 5541, 598, and 6792 (oil and gas). CU200 is the July 2016 list from Fossil Free Indexes LLC of the 100 largest coal and oil & gas companies based on their reported reserves (http://gofossilfree.org/top-200/).

* Return series starts from 1997 (n=228).

Table B.6: Risk-adjusted return performance of fossil fuel portfolios (Carhart model with Median regression specification, 1927-2015)

		Alpha	Rm_rf	SMB	HML	WML
SIC broad	Coal	-0.0051***	0.9742***	0.3947***	0.2974***	-0.0262
		(0.0018)	(0.0379)	(0.0703)	(0.0638)	(0.0581)
	Oil and gas	-0.0005	0.9548***	-0.2522***	0.3099***	0.1055**
		(0.0012)	(0.0286)	(0.0485)	(0.0445)	(0.0419)
	All fossil	-0.0001	0.9511***	-0.2488***	0.3081***	0.0950**
		(0.0012)	(0.0289)	(0.0467)	(0.0454)	(0.0418)
SIC narrow	Coal	-0.0043**	0.9036***	0.3700***	0.2378***	-0.0615
		(0.002)	(0.0522)	(0.0782)	(0.0875)	(0.0658)
	Oil and gas	-0.0011	1.0975***	-0.0995	0.3081***	-0.0516
		(0.0015)	(0.0393)	(0.0807)	(0.0719)	(0.0439)
	All fossil	-0.0009	1.0952***	-0.0796	0.3186***	-0.0577
		(0.0014)	(0.0398)	(0.0732)	(0.0648)	(0.0436)
CU200	Coal*	-0.0058**	1.0656***	0.1784	0.1472	-0.0442
		(0.0026)	(0.0921)	(0.1589)	(0.1552)	(0.0774)
	Oil and gas	-0.0025	0.9720***	-0.1917***	0.4890***	0.033
		(0.0019)	(0.054)	(0.0613)	(0.069)	(0.0741)
	All fossil	-0.0021	0.9909***	-0.2145***	0.4766***	0.0349
		(0.0018)	(0.0506)	(0.0613)	(0.0626)	(0.0632)

This table reports the results from regressing the excess returns of the nine capitalization-weighted fossil fuel portfolios on the Carhart (1997) US factors using median regression. Alpha is the intercept, indicating relative out- or underperformance. Rm_rf, SMB, HML, and WML are the coefficients on the Market, Size, Book-to-Market, and Momentum factors respectively. Standard errors appear in brackets. *** p<0.01, ** p<0.05, * p<0.10. The SIC narrow definition includes SIC 12 (coal) and 13 (oil and gas); the SIC broad definition adds SIC 3532, 5052, and 5082 (coal), and SIC 291, 3533, 46, 492, 517, 5541, 598, and 6792 (oil and gas). CU200 is the July 2016 list from Fossil Free Indexes LLC of the 100 largest coal and oil & gas companies based on their reported reserves (http://gofossilfree.org/top-200/).

* Return series starts from February 1949 (N=803).

Table B.7: Risk-adjusted return performance of fossil-free market portfolios (Carhart model with Median regression specification, 1927-2015)

		Alpha	Rm_rf	SMB	HML	WML
SIC broad	Coal	0.0000**	0.0000	-0.0005***	-0.0004***	0.0001
		(0.0000)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
	Oil and gas	0.0001	0.0034	0.0325***	-0.0404***	-0.0132**
		(0.0002)	(0.0041)	(0.0087)	(0.0068)	(0.0058)
	All fossil	0.0001	0.0026	0.0312***	-0.0393***	-0.0137**
		(0.0002)	(0.0042)	(0.0083)	(0.0070)	(0.0060)
SIC narrow	Coal	0.0000*	0.0001*	-0.0004***	-0.0003***	0.0001
		(0.0000)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
	Oil and gas	0.0000	-0.0023**	0.0016	-0.0069***	0.0000
		(0.0000)	(0.0010)	(0.0016)	(0.0017)	(0.0012)
	All fossil	0.0000	-0.0023**	0.0014	-0.0072***	0.0004
		(0.0000)	(0.0010)	(0.0017)	(0.0016)	(0.0013)
CU200	Coal	0.0000*	0.0000	0.0000	0.0000	0.0000
		(0.0000)	(0.0000)	(0.0001)	(0.0000)	(0.0000)
	Oil and gas	0.0000	0.0014*	0.0044***	-0.0082***	-0.0017
		(0.0000)	(0.0008)	(0.0014)	(0.0013)	(0.0012)
	All fossil	0.0000	0.0014*	0.0045***	-0.0081***	-0.0013
		(0.0000)	(0.0008)	(0.0014)	(0.0014)	(0.0013)

This table reports the results from regressing the excess returns on the zero-investment portfolio with a long position in the fossil-free market portfolio and a short position in the unconstrained market portfolio on the Carhart (1997) US factors using median regression. Alpha is the intercept, indicating relative out- or underperformance. Rm_rf, SMB, HML, and WML are the coefficients on the Market, Size, Book-to-Market, and Momentum factors respectively. White standard errors appear in brackets. *** p<0.01, ** p<0.05, * p<0.10. The SIC narrow definition includes SIC 12 (coal) and 13 (oil and gas); the SIC broad definition adds SIC 3532, 5052, and 5082 (coal), and SIC 291, 3533, 46, 492, 517, 5541, 598, and 6792 (oil and gas). CU200 is the July 2016 list from Fossil Free Indexes LLC of the 100 largest coal and oil & gas companies based on their reported reserves (http://gofossilfree.org/top-200/).

List of research reports

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