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Analysis

Fossil Fuel Divestment and Portfolio Performance

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ABSTRACT

Fossil fuel divestment campaigns urge investors to sell their stakes in companies that supply coal, oil, or gas. However, avoiding investments in such companies might impose a cost on the investor in terms of foregone potentially profitable investments and reduced opportunities for portfolio diversification. We compare financial performance of investment portfolios with and without fossil fuel company stocks over the period 1927–2016. Contrary to theoretical expectations, we find that fossil fuel divestment does not seem to impair portfolio performance. These findings can be explained by the fact that, so far, fossil fuel company stocks do not outperform other stocks on a risk-adjusted basis and provide relatively limited diversification benefits. A more pronounced performance impact of divestment can be observed over short time frames and when applied to less diversified market indices.

1. Introduction

Divestment campaigns urge investors to sell their stakes in companies that supply coal, oil, or gas. Initiated at US universities, divestment has gained traction among foundations, pension funds, faith-based organizations, governments, and others.[1] The aim is to build support for legislation and technology that reduces Greenhouse Gas (GHG) emissions by cutting down financial support for and addressing the moral legitimacy of fossil fuel production and its use (Ansar et al., 2013; Ayling and Gunningham, 2017). As of September 2017, $5.53 trillion of institutions' Assets under Management (AuM) has been committed to divest from at least one type of fossil fuel.[2]

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; Gross, 2015; Van den Bergh and Botzen, 2015). Additionally, it links to debate about the role of finance in the transition towards a low-carbon economy (Busch and Hoffmann, 2007; Campiglio, 2016; Scholtens, 2017). 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, and therefore withdraw investments in publicly listed coal, oil, and gas companies (Ritchie and Dowlatabadi, 2014).

Conforming to the moral call to divest, however, can be costly and/or problematic for investors (see Ritchie and Dowlatabadi, 2015; Eurosif, 2016). Modern Portfolio Theory (Markowitz, 1952) suggests that constraining an investment portfolio would reduce opportunities for diversification and thereby impair financial performance. Fossil fuel companies indeed make up a large part of major benchmark indices. Yet, so far, the financial implications of fossil fuel divestment have not been systematically analyzed. Recently, reports have claimed that divestment comes with substantial costs (Cornell, 2015; Fischel, 2015), while others have suggested that it improves portfolio performance (Heaps et al., 2016). However, these reports apply ad hoc methods and measures, and focus on highly specific samples and study periods, which might explain their opposite conclusions. As divestment may reduce investment returns and thereby affect society at large, it is timely to rigorously study its impact on portfolio performance.

We construct US investment portfolios with and without fossil fuel company stocks, using industry classifications and the Carbon Underground 200 list. We investigate the differential in portfolio risk and performance of fossil-free and unconstrained portfolios by comparing the variance, the Sharpe and Sortino performance ratios, and four-factor adjusted alphas over the period 1927–2016. Our results suggest that fossil fuel divestment has not significantly impaired financial performance of investment portfolios.

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[1] http://gofossilfree.org/commitments/ (accessed: September 31, 2017).
[2] Ibid.

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This paper makes three contributions to the academic and societal debate about fossil fuel divestment. First, in the scarce literature on fossil fuel divestment we have not found a comprehensive systematic analysis of the financial dimension of divestment. Our analysis is firmly grounded in Modern Portfolio Theory and covers a broad market over an extensive time horizon. Furthermore, we employ various definitions of fossil fuel divestment and assess the sensitivity of our results to different study periods, investment indices, and model specifications. Secondly, we complement the Socially Responsible Investing (SRI) and screening literature (Humphrey and Tan, 2014; Lobe and Walkshäusl, 2016) by looking into an increasingly relevant application of screening: fossil fuel divestment. Lastly, we contribute to the debate about the implications of improved corporate carbon performance for financial performance. Generally, the literature has found that companies with lower (relative) carbon emissions have a superior financial performance (Busch and Lewandowski, 2017). On the investment side, a recent stream of literature investigates the carbon footprint of portfolios in an attempt to quantify the investor's exposure to 'carbon risk': the perceived financial risks associated with the transition from high- to low-carbon sources (Andersson et al., 2016; De Jong and Nguyen, 2016). Andersson et al. (2016) find that carbon footprint reductions of up to 50% are possible while keeping a minimal (negligible) tracking error. Our study takes the opposite perspective. Given the observed call to divest fossil fuel stocks, we assess financial costs (i.e., underperformance) when answering to it.

This paper proceeds as follows. Section 2 provides a theoretical framework for screening in relation to investment portfolio performance, and highlights our contribution to the literature. The methodology and data are described in Sections 3 and 4 respectively. Section 5 presents the results and discusses implications in light of the divestment and screening debate. Section 6 concludes.

2. Socially Responsible Investing and Diversification Costs

2.1. Theoretical Framework

Fossil fuel divestment can be regarded as a specific way of Socially Responsible Investing (SRI), namely exclusion (see Revelli and Viviani, 2015). Through SRI, investors aim to align ethical and financial concerns and consider the 'social damage' that their investment objects might cause (Dam and Scholtens, 2015). A common approach to achieve this is withholding investments in harmful or controversial activities (Eurosif, 2016; Global Sustainable Investment Alliance, 2016). The divestment campaigns frame fossil fuel production as such activity.

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 (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. We can define the 'diversification costs' following from divestment as the difference in risk-adjusted returns on a fossil-free portfolio and the unconstrained portfolio. Diversification costs are a function of the number of stocks in a portfolio and the correlation between stock returns (Markowitz, 1952). Hence, the largest diversification costs are expected from the exclusion of a large set of stocks which has a low correlation with other market investments.

Secondly, SRI implies that some investors' utility function may depend on non-financial attributes too. The divestment movement, in fact, treats stocks of fossil fuel companies as 'sin stocks', i.e. stocks of companies involved in controversial activities that investors commonly stay away from (see also Luo and Balvers, 2017; Hong and Kacperczyk, 2009). As with sin stocks, a reduction of demand for fossil fuel company stocks and excess demand for non-fossil stocks can be expected to reduce prices of the former category (underpricing) and increase prices of the latter (overpricing) (Dam and Scholtens, 2015; Fama and French, 2007; Heinkel et al., 2001). Investors would thus be willing to pay a higher price for non-fossil stocks and would expect a lower return on their investment for a given risk level. When fossil fuel company stocks are systematically screened, this differential should be detectable as risk-adjusted outperformance (positive alphas) of fossil fuel portfolios and underperformance (negative alphas) of fossil-free ones. As such, we expect additional outperformance (underperformance) of fossil fuel (fossil-free) portfolios in the period divestment takes place.

The prevalence of fossil fuel industry screening, however, seems low. Formally, the divestment movement started in 2011 (Ayling and Gunningham, 2017) and so far it appears that a relatively small share of total AuM applies exclusionary screens on the fossil fuel industry. Screening of the industry through other forms of SRI, such as green or thematic investments and best-in-class screening, does not seem to happen systematically on a large scale either. As a result, fossil fuel stocks are unlike some sin stocks, such as tobacco stocks, which have been structurally avoided by investors for long time frames. This suggests that demand for fossil-free company activity might best be taken as given (contrary to Luo and Balvers, 2017), even though the effects from a growing preference for fossil-free investments may become more important in the future.

Still, portfolio diversification is not only constrained because of social norms but because of practical or behavioral reasons as well, suggesting there could be a compensation for idiosyncratic risks next to systematic risks (Fu, 2009; Goyal and Santa-Clara, 2003). Accordingly, fossil fuel company stocks may receive additional returns due to high litigation and reputational risks (cf. Hong and Kacperczyk, 2009) and industry and environmental challenges, such as the need for a radical transition towards low- or zero-carbon sources (Ansar et al., 2013; Busch and Hoffmann, 2007). An important consideration in this respect is the appropriate pricing of carbon risk (Andersson et al., 2016; De Jong and Nguyen, 2016; Liesen et al., 2017). For example, a key concern is the risk that future stringent public policy will devalue or 'strand' fossil fuel reserves (Ansar et al., 2013). In fact, some reports advocate divestment based on a prediction of strong declines in the stock prices of fossil fuel companies (see Leaton, 2011 and subsequent reports).[3] Battiston et al. (2017) and Dietz et al. (2016) study the financial implications of various climate policy scenarios and arrive at material impacts.

Lastly, and relatedly, standard asset pricing models may imperfectly capture the risk characteristics of the fossil fuel industry. For instance, the industry's exposure to perceived (ir)responsibility or 'sustainability' risk as well as energy price risk may systematically affect stock returns, while these factors are not being captured by standard asset pricing models (Driesprong et al., 2008; Scholtens, 2014).

2.2. Empirical Literature

So far, the empirical SRI literature has found little to no negative impact of ethical constraints (screening) on portfolio performance (Bello, 2005; Humphrey and Tan, 2014; Lobe and Walkshäusl, 2016; Trinks and Scholtens, 2017). Financial implications of screening might relate not only to the amount or market capitalization of the stocks excluded, but also to the correlation between the returns on the excluded and remaining investment categories, and to whether excluded stocks show outperformance due to screening (see Section 2.1).

We complement the SRI and investment performance literature (see Revelli and Viviani, 2015) by systematically analyzing the risk and

[3] This work builds on findings by Allen et al. (2009) and Meinshausen et al. (2009) that in order 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 companies' stock prices.

return characteristics of portfolios with and without fossil fuel stocks over an extensive time period. Our main interest lies in the size and significance of the diversification costs following from a divestment strategy. To this end, we test for abnormal risk-adjusted return performance of fossil fuel portfolios and fossil-free portfolios. Our approach complements the reports of Cornell (2015), Fischel (2015) and Heaps et al. (2016) by applying a comprehensive systematic analysis grounded in Modern Portfolio Theory, and assessing the robustness of the results to different definitions of fossil fuel divestment, subperiods, stock indices, and model specifications. Our study contributes to the SRI literature which has relied upon much shorter time frames and less comprehensive industry classifications (e.g., Luo and Balvers, 2017), company-level exclusions (Trinks and Scholtens, 2017), and exclusions within particular investment funds (Hoepner and Schopohl, 2016; Ibikunle and Steffen, 2017). We abstract from any dynamic system-wide effects that divestment might have on future stock prices of fossil-fuel and high-carbon companies (cf. Battiston et al., 2017), as well as any additional financial costs that the implementation of divestment might impose, such as selection, transaction, and monitoring costs (see Bessembinder, 2016; cf. Cornell, 2015; Fischel, 2015), which will strongly depend on the investment type, size, and objectives.

3. Methodology

3.1. Financial Performance of the Fossil Fuel Industry and Fossil-Free Portfolios

The diversification costs of fossil fuel divestment are evaluated by comparing the risk-adjusted returns on fossil-free portfolios and the unconstrained portfolio. We employ two well-documented measures of portfolio performance, namely the Sharpe ratio and Sortino ratio, and relate 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). Since divestment implications will depend on the characteristics of fossil fuel stocks (see Section 2.2), we will first look into the performance of the fossil fuel industry before turning to the impact of divestment. We start by considering returns, total risk, and downside risk of fossil fuel portfolios and fossil-free portfolios.

Reduced diversification resulting from divestment would, first of all, be visible in significant differences in total risk (variance) of constrained portfolios compared to unconstrained portfolios. Moreover, in the presence of imperfect investor diversification, portfolio variance would be the appropriate measure to look at, as not only the systematic risk component but idiosyncratic risk as well is to be compensated. Therefore, we employ the Ledoit and Wolf (2011) test for equal variances, which is robust to non-normal and serially correlated return data, next to a standard F-test of equal variances. We then evaluate the reward-to-risk performance of fossil-free portfolios using the Sharpe ratio (Sharpe, 1966) and the Sortino ratio (Sortino and Van der Meer, 1991). The Sharpe ratio makes portfolio performance comparable by measuring the expected portfolio return per unit of risk:

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

The numerator, $E(R_p - R_f)$, measures the expected (mean) return on the portfolio in excess of the risk-free rate. The denominator, σ_p, is the standard deviation of portfolio returns, which is a measure of total risk. Theoretically, the unconstrained market portfolio has the highest achievable Sharpe ratio (Sharpe, 1966). By comparing the market portfolio with fossil-free portfolios, we assess whether fossil fuel divestment results in sub-optimal reward-to-risk performance.

The Sortino ratio divides expected (mean) excess return by downside risk:

$$Sortino_p = \frac{E(R_p - R_f)}{\sqrt{\frac{1}{T}\sum_{t=1}^{T}(Min(0,\ R_{p,t} - R_f))^2}} \tag{2}$$

Downside risk focuses on the probability of losses (negative excess returns), which might be a better reflection of investors' preference for low levels of 'bad volatility' (Sortino and Van der Meer, 1991). More generally, the Sortino ratio focuses on returns below a Minimal Acceptable Rate of return, R_{MAR}, which we take to be the risk-free rate. In both the Sharpe ratio and the Sortino ratio, the investor maximizes risk-adjusted return at the portfolio which displays the highest performance ratio. The significance of differences in Sharpe ratios is tested using the robust Ledoit and Wolf (2008) test, as in 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 5000 resamples, as recommended by Ledoit and Wolf (2008) and used in related literature (Lobe and Walkshäusl, 2016).

Additionally, we evaluate the financial performance of portfolios with and without fossil fuel company stocks by relating excess returns on each portfolio to well-documented (systematic) risk factors. In line with related studies (Humphrey and Tan, 2014; Lobe and Walkshäusl, 2016), we estimate the Carhart (1997) four-factor model:

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

The Carhart model relates the excess returns on an investment portfolio *p* in month *t*, which consists of stocks weighted by their market capitalization in the previous month, to four common determinants of risk (Carhart, 1997). $R_{m,\,t} - R_{f,\,t}$, the market risk premium, is the return on a 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 in the previous 12 months and short in those with the worst performance. α_p represents the coefficient of interest, namely the portfolio's abnormal return performance when controlling for the above four risk factors.

The impact of divestment on asset prices is tested using the long-short (zero-investment) approach (see Hong and Kacperczyk, 2009; Lobe and Walkshäusl, 2016), regressing the returns on a hypothetical portfolio with a long (positive) position in the fossil fuel company portfolio (a 'socially controversial' or 'sinful' portfolio) and a corresponding short (negative) position in the fossil-free portfolio (a 'socially responsible' portfolio) on the four Carhart factors (Eq. 3). The resulting alphas in these regressions provide a clean measure of the risk-adjusted returns on the fossil fuel industry when benchmarked against all remaining investment categories. Next, we test whether fossil fuel divestment impairs portfolio performance by regressing the excess returns on fossil-free portfolios on the Carhart factors (Eq. 3).

Finally, we assess the robustness of our results. 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 test whether the effect of divestment is more pronounced and negative in the period after the start of the first divestment campaigns in 2011, and cut our study period into various subperiods of 30, 15, 10, and 5 years. Analysis of subperiods also accounts for differences in investment horizons. In addition, since investors in practice often rely on restricted market indices, we rerun our analysis applying fossil fuel screens to the S&P 500 and FTSE 100 indices. Lastly, we address volatility clustering using a GARCH(1,1) model.

Note that diversification costs may result from a reduced investment universe (number of stocks) and portfolio composition (type of stocks). If there would be significant diversification costs, the two effects could

Table 1
Definition of fossil fuel company portfolios and market portfolio.

Source	Portfolio label	Definition	#Stocks
CRSP	Market	All stocks listed on NYSE, Amex, and Nasdaq excluding those with CRSP share codes other than 10 or 11 and those belonging to the financial services industry.	20,496
Fossil fuel portfolios			
SIC	Coal	SIC 12 (coal mining), 3532 (mining machinery)	84
	Oil and gas	SIC 13 (oil and gas extraction), 291 (petroleum refining), 3533 (oil and gas field machinery and equipment), 46 (pipelines, except natural gas), 492 (gas production and distribution)	1379
	All fossil fuels	SIC Coal ∪ SIC Oil and gas	1455
CU200	Coal	CU200 Coal list	13
	Oil and gas	CU200 Oil and gas list	31
	All fossil fuels	CU200 Coal ∪ CU200 Oil and gas	43
Fossil-free portfolios			
SIC	Coal	CRSP market portfolio excl. SIC Coal stocks	20,412
	Oil and gas	CRSP market portfolio excl. SIC Oil and gas stocks	19,117
	All fossil fuels	CRSP market portfolio excl. SIC All fossil fuels stocks	19,041
CU200	Coal	CRSP market portfolio excl. CU200 Coal stocks	20,483
	Oil and gas	CRSP market portfolio excl. CU200 Oil and gas stocks	20,465
	All fossil fuels	CRSP market portfolio excl. CU200 All fossil fuels stocks	20,453

This table shows the definition of the market portfolio, the six fossil fuel portfolios, and the six corresponding fossil-free portfolios, as well as the number of stocks in each portfolio. Portfolios consisting of coal, oil and gas, and all fossil fuel companies are identified using Standard Industry Classification (SIC) codes as well as the July 2016 Carbon Underground 200 (CU200) list from Fossil Free Indexes LLC, which includes the 100 largest coal companies and 100 largest oil and gas companies based on reported reserves (http://fossilfreeindexes.com/research/the-carbon-underground/). The Center for Research in Security Prices (CRSP) market portfolio includes all stocks listed on NYSE, Amex, and Nasdaq except those with CRSP share codes other than 10 or 11 and those belonging to the financial services industry.

be disentangled using the approach by Humphrey and Tan (2014), which simulates portfolios of equal size and as such quantifies the portfolio composition effect. However, such analysis is beyond the scope of this paper.

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 the Center for Research in Security Prices (CRSP). Fossil fuel company stocks are identified using two different approaches (see Table 1 for definitions). First, we use Standard Industry Classification (SIC) codes[4], which aligns with 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 companies that are closely linked to the supply (production) of fossil fuels (see, e.g., Ansar et al., 2013). This industry definition is sufficiently broad to capture differences in focus among divestment practitioners. Notably, divestment intuitively calls for the exclusion of energy majors, but these are often grouped in petroleum refining (SIC 291) and as such would have been ignored when using a narrower industry definition of SIC codes 12 and 13 (cf. Fama and French, 1997; Luo and Balvers, 2017). Moreover, a broad definition of divestment serves as an 'upper bound' to the potential impact of divestment, as the impact of excluding fewer stocks (based on a narrower definition of divestment) would be smaller.[5]

As a second definition, 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 companies and 100 largest oil and gas companies based on reported reserves. The list is often employed by advocates of divestment as a useful starting point[6] as it provides a straightforward method to identify the potential carbon content of one's investments (see Ritchie and Dowlatabadi, 2014). The CU200 sample is constructed using the CU200 list as of July 2016,[7] and companies are identified by International Securities Identification Number (ISIN) (using Orbis) and company name (manually). We do not explicitly consider other SRI strategies which can be used instead or alongside divestment. This is addressed by Schwarz (2015), among others. One approach would be Divest-Invest, which replaces fossil fuel investments by low- or zero-carbon ones. Investors could use 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 fully covers CC200 stocks and, by construction, in fossil-free portfolios, weights of CC200 stocks and other remaining non-fossil fuel stocks are increased proportionally to their market capitalization. Our analysis thus aligns with the fact that divestment moves capital away from the fossil fuel industry to other sectors (Ritchie and Dowlatabadi, 2014).

For each of the two identification approaches (using the industry definition and the CU200 list) we construct three fossil fuel portfolios, consisting of all US companies involved in coal, oil and gas, or all fossil fuels. Hence, we end up with six (2 × 3) fossil fuel company portfolios. Correspondingly, we construct six fossil-free portfolios by discarding from the CRSP market portfolio all stocks in the respective fossil fuel portfolios. From CRSP, we obtain monthly total returns (i.e., including dividends), closing stock prices, and shares outstanding for NYSE, Amex, and Nasdaq stocks over the period 1927–2016. Hence, we have 1080 monthly return observations for fossil-fuel and fossil-free portfolios. Note that the CU200 fossil fuel portfolio has a limited number of return observations because there are no CU200 oil and gas companies before 08/1955 and no CU200 coal companies before 02/1949 and at other early time frames. We follow the literature (Lobe and Walkshäusl, 2016; Luo and Balvers, 2017) by focusing on companies with CRSP share codes of 10 or 11 and excluding companies with one-digit SIC codes of 6, which belong to the financial services industry. US factor data are obtained from CRSP. By construction, the unconstrained

[4] Results are robust to complementing SIC codes with North American Industry Classication System (NAICS) codes. We use NAICS 2121, 213,113, and 333,131 for coal stocks, and NAICS 211, 213,111, 213,112, 2212, 23,712, 32,411, 333,132, and 486 for oil and gas company stocks. NAICS codes are available in CRSP only from 2004 onwards and do not contain many additional stocks.

[5] As a sensitivity analysis, we also apply a narrower definition of divestment, focusing on coal mining (SIC 12) and oil and gas extraction (SIC 13). Results, which are qualitatively similar, are available upon request at the corresponding author.

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

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

Table 2
Descriptive statistics of excess returns and performance ratios of fossil fuel portfolios and fossil-free portfolios (1927–2016).

Source	Portfolio label	N	Mean	Median	StDev	DR	Sharpe	Sortino	ΔVar	ΔSharpe
CRSP	Market portfolio	1080	0.65%	0.92%	5.35%	3.54%	0.1211	0.1827	–	–
Fossil fuel portfolios										
SIC	Coal	1080	0.61%	0.28%	10.17%	6.05%	0.0601	0.1011	–	–
	Oil and gas	1080	0.73%	0.67%	5.91%	3.77%	0.1241	0.1948	–	–
	All fossil fuels	1080	0.73%	0.69%	5.92%	3.78%	0.1229	0.1926	–	–
CU200	Coal	750	0.74%	0.38%	8.39%	5.03%	0.0880	0.1467	–	–
	Oil and gas	737	0.90%	0.70%	6.69%	3.88%	0.1345	0.2317	–	–
	All fossil fuels	815	0.89%	0.77%	6.92%	3.99%	0.1284	0.2224	–	–
Fossil-free portfolios										
SIC	Market excl. Coal	1080	0.65%	0.92%	5.34%	3.54%	0.1213	0.1830	−0.0004%	0.0002
	Market excl. Oil and gas	1080	0.64%	1.04%	5.45%	3.61%	0.1182	0.1785	0.0116%	−0.0029
	Market excl. All fossil fuels	1080	0.65%	1.03%	5.45%	3.61%	0.1184	0.1789	0.0111%	−0.0026
CU200	Market excl. Coal	1080	0.65%	0.93%	5.35%	3.54%	0.1211	0.1827	−0.0000%	0.0000
	Market excl. Oil and gas	1080	0.65%	0.95%	5.36%	3.55%	0.1206	0.1818	0.0011%	−0.0005
	Market excl. All fossil fuels	1080	0.65%	0.95%	5.36%	3.55%	0.1206	0.1818	0.0011%	−0.0005

This table presents the number of observations (N), mean, median, standard deviation, and downside risk (DR) of monthly excess returns (%) on the fossil fuel and fossil-free portfolios, as well as their Sharpe and Sortino ratios over the period 01/1927–12/2016. Downside risk is the standard deviation of negative excess returns. The Sharpe ratio is the portfolio's mean excess return per unit of total risk (standard deviation). The Sortino ratio is the portfolio's mean excess return per unit of downside risk. The Center for Research in Security Prices (CRSP) market portfolio includes all stocks listed on NYSE, Amex, and Nasdaq except those with CRSP share codes other than 10 or 11 and those belonging to the financial services industry. Fossil fuel portfolios are based on Standard Industry Classification (SIC) codes SIC 12, 3532 (coal) and SIC 13, 291, 3533, 46, and 492 (oil and gas), and the July 2016 Carbon Underground 200 (CU200) list from Fossil Free Indexes LLC of the 100 largest coal companies and 100 largest oil and gas companies based on reported reserves (http://fossilfreeindexes.com/research/the-carbon-underground/). 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 and Wolf (2011) alternative using the studentized time series bootstrapping procedure with 5000 resamples. ΔSharpe is the difference between each portfolio's Sharpe ratio and that of the unconstrained market portfolio. ^{JK} denotes the Jobson and Korkie (1981) test of equal Sharpe ratios and ^{LW} the robust Ledoit and Wolf (2008) alternative using the studentized time series bootstrapping procedure with 5000 resamples.

market portfolio is identical to the Fama-French US market factor.

Table 1 shows the definition of the market portfolio, the six fossil fuel portfolios, and the six corresponding fossil-free portfolios, as well as the number of stocks in each portfolio. Companies involved in fossil fuel supply (industry definition) comprise about 7% of the number of stocks in the market portfolio. Note that the number of stocks in each portfolio at a particular point in time is lower. For instance, in December 2016, the market portfolio contains 3041 stocks, of which 164 fossil fuel stocks based on the industry (SIC) definition. Table 1 suggests that fossil-fuel screening, with the exception of screening for coal, could considerably reduce the number of investible assets.

5. Results and Discussion

In this section, we first investigate the financial performance characteristics of the fossil fuel industry. We then report our findings for the effects of applying fossil fuel company 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 risk-return characteristics of the portfolios with and without fossil fuel stocks. We find higher returns and higher risk for fossil fuel stocks, which is consistent with the hypothesized higher industry risk (Driesprong et al., 2008; Ansar et al., 2013). For instance, excess returns on a portfolio consisting of coal, oil, and gas company stocks (industry definition) have averaged 0.73% per month at a total risk (standard deviation) of 5.92%, whereas the market portfolio has generated average excess returns of 0.65% at a lower total risk of 5.35%.

To evaluate the performance of the fossil fuel industry, we control for well-documented risk factors through the Carhart four-factor model (Eq. 3). Table 3 shows that, over the 1927–2016 period, fossil fuel portfolios have generated slightly positive but insignificant alphas when benchmarked against fossil-free portfolios. This demonstrates the substantial systematic risk associated with the fossil fuel industry (in line with Driesprong et al., 2008 and related studies), which offsets the above-market returns. 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. As shown by the coefficients on the SMB and HML factors in Table 3, fossil fuel stocks are mostly largecap value stocks, while fossil-free portfolios tend to be slightly smaller and more growth-oriented.

Clearly, the fossil fuel industry is unlike other controversial industries, such as alcohol, tobacco, and gambling, which do show significant outperformance (Hong and Kacperczyk, 2009; Trinks and Scholtens, 2017). It thus seems that divestment behavior has to become more prevalent in order to have any significant pricing impacts (cf. Heinkel et al., 2001), such that there will be outperformance of fossil fuel stocks. Furthermore, as the loading on the market factor in Table 3 is close to 0, there is only a small difference between the beta of the fossil fuel portfolio and the rest of the market. This means that fossil fuel stocks are more or less substitutes for the market index (which has a beta of 1) and as such provide limited diversification benefits. By contrast, betas of alcohol, tobacco, and gambling stocks are as low as 0.5 (see Trinks and Scholtens, 2017).

From a purely 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.

5.2. Performance of Fossil-Free Investments

We now turn to the impact of divesting fossil fuel stocks on investment portfolios. Fig. 1 shows the year-average percentage share of fossil fuel stocks in the market portfolio. On average, divestment has a modest impact in terms of the amount and value of stocks excluded. For comparison, the frequently studied alcohol, tobacco, and gambling sectors comprise about 2% of the market (Trinks and Scholtens, 2017). Note that there is considerable variation in the share the fossil fuel industry takes in the market portfolio over the years. Higher percentage

Table 3
Risk-adjusted return performance of fossil fuel portfolios (Carhart model, 1927–2016).

	SIC			*CU200*		
Portfolio:	Coal	Oil and gas	All fossil fuels	Coal	Oil and gas	All fossil fuels
Alpha	−0.0034	0.0003	0.0002	−0.0006	0.0024	0.0006
	(0.0023)	(0.0012)	(0.0012)	(0.0028)	(0.0019)	(0.0020)
MktRf	0.0675	−0.1053**	−0.1011**	−0.0476	−0.0295	0.0026
	(0.0597)	(0.0473)	(0.0472)	(0.0973)	(0.0737)	(0.0671)
SMB	0.4476***	−0.2372***	−0.2288***	−0.0518	−0.2777***	−0.2540***
	(0.1203)	(0.0543)	(0.0545)	(0.1146)	(0.1026)	(0.0933)
HML	0.6614***	0.2766***	0.2847***	0.5210***	0.5447***	0.6426***
	(0.1237)	(0.0704)	(0.0694)	(0.1901)	(0.1414)	(0.1376)
WML	−0.1573	0.1036*	0.1007*	−0.0281	0.0191	0.0090
	(0.1086)	(0.0612)	(0.0603)	(0.1011)	(0.0871)	(0.0807)
N	1080	1080	1080	750	737	815
R^2	0.1994	0.1019	0.1002	0.0411	0.1022	0.1091

This table reports the results from regressing the excess returns on zero-investment portfolios with a long position in the fossil fuel portfolio and a corresponding short position in the market portfolio excluding fossil fuel portfolio stocks on the Carhart (1997) US factors using OLS. Fossil fuel portfolios include stocks of companies with Standard Industry Classification (SIC) codes SIC 12 and 3532 (coal), and SIC 13, 291, 3533, 46, and 492 (oil and gas), and those belonging to the July 2016 Carbon Underground 200 (CU200) list from Fossil Free Indexes LLC of the 100 largest coal companies and 100 largest oil and gas companies based on reported reserves (http://fossilfreeindexes.com/research/the-carbon-underground/). The market portfolio includes all stocks listed on NYSE, Amex, and Nasdaq except those with Center for Research in Security Prices (CRSP) share codes other than 10 or 11 and those belonging to the financial services industry. Alpha is the intercept, indicating relative out- or underperformance. MktRf, SMB, HML, and WML are the coefficients on the Market, Size, Book-to-Market, and Momentum factors respectively. Newey and West (1987) heteroskedasticity and autocorrelation consistent (HAC) standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

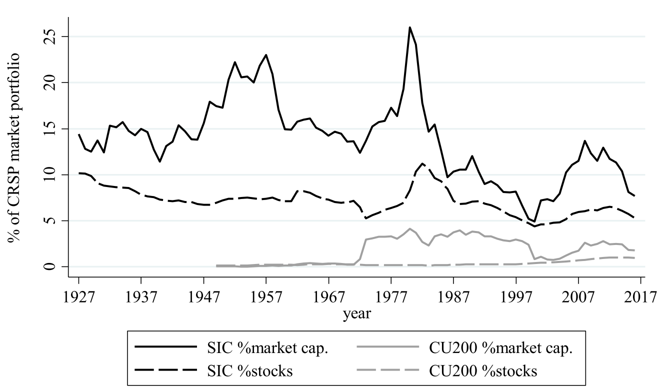

Fig. 1. Year-average percentage share of fossil fuel companies (SIC industry definition and CU200 list) in the CRSP market portfolio.
Source: Center for Research in Security Prices (CRSP), own calculations.

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 might become more or less pronounced in future periods when the market share of fossil fuel stocks could change. Additionally, note that divestment currently targets only the fossil fuel production industry, which means that divestment will induce a limited sector bias. However, in the future investors might expand the scope of divestment to better capture the interdependence of fossil fuel supply and economic activity (cf. Ritchie and Dowlatabadi, 2014). For instance, power generation and the use of fossil fuels by manufacturing industries might be accounted for. To this end, investors might decide to consider other lists, such as the 'filthy fifteen' of the largest and most carbon-intensive US coal mining companies and coal-fired utilities (https://fossilfreefunds.org/filthy-15/) or the 90 US 'carbon majors' identified by Heede (2014) to be responsible for two-thirds of historical GHG emissions. Applying a broader definition of fossil fuel divestment could induce a larger sector bias in investment portfolios.

To evaluate the diversification costs of divestment, we compare performance of the unconstrained market portfolio, which includes all non-financial common stocks listed on the NYSE, Amex, and Nasdaq, with that of portfolios which exclude fossil fuel company stocks from the market portfolio. As shown in the last two columns of Table 2, there tends to be some additional total risk (variance) and a lower Sharpe ratio of fossil-free portfolios compared to the unconstrained market portfolio. This finding complements the portfolio performance literature by showing that expanding the activity set covered by the portfolio might still increase diversification in a portfolio that includes a large number of stocks (cf. Evans and Archer, 1968; Statman, 1987). However, we find no evidence that the variance- and Sharpe ratio differential is significant. Hence, there does not seem to be a significant reduction in diversification opportunities following from a divestment strategy. Furthermore, as the fossil fuel industry is characterized by substantial input price risk (Driesprong et al., 2008), we might expect that excluding fossil fuels from investment portfolios would limit downside risk. Interestingly, however, we find downside risk to be slightly higher and Sortino ratios to be slightly lower for fossil-free portfolios. This contrasts with Nofsinger and Varma (2014), who find that socially responsible investments display lower downside risk.

To further investigate the performance impact of divestment, we compare four-factor risk-adjusted returns of fossil-free portfolios and the unconstrained market portfolio (Table 4). We generally find no evidence of significant abnormal risk-adjusted returns on fossil-free portfolios over the period 1927–2016, as indicated by the insignificant alphas. Only the portfolio that excludes coal stocks based on SIC codes shows a significant outperformance; however, the effect size is quite small (around 0.001% monthly). The absence of a material effect can be explained by the fact that fossil fuel stocks provide relatively limited portfolio diversification benefits (see Section 5.1), and coal stocks make up only 0.04–0.75% of the total number of stocks and 0.08–0.24% of the total market capitalization of the market portfolio. Note also that the share of fossil fuel stocks in the market portfolio has declined substantially in more recent time frames (see Fig. 1).

Our finding of no performance differential between fossil-free and unconstrained portfolios is in line with the portfolio literature on the effects of SRI and screening (Andersson et al., 2016; Bello, 2005; Humphrey and Tan, 2014; Lobe and Walkshäusl, 2016). Furthermore, our analysis suggests that it is important that conclusions about the implications of fossil fuel divestment for portfolio performance be based on a comprehensive sample and study period, as opposed to cherry-picked historical subperiods and indices (cf. Cornell, 2015; Fischel, 2015; Heaps et al., 2016).

Interestingly, we find that nearly all variation in the returns on

Table 4
Risk-adjusted return performance of fossil-free portfolios (Carhart model, 1927–2016).

	SIC			*CU200*		
Portfolio:	Coal	Oil and gas	All fossil fuels	Coal	Oil and gas	All fossil fuels
Alpha	0.0000**	0.0001	0.0001	0.0000	−0.0000	−0.0000
	(0.0000)	(0.0002)	(0.0002)	(0.0000)	(0.0000)	(0.0000)
MktRf	0.9996***	1.0047***	1.0042***	0.9999***	1.0016***	1.0015***
	(0.0002)	(0.0078)	(0.0079)	(0.0001)	(0.0008)	(0.0009)
SMB	−0.0007***	0.0320***	0.0312***	0.0001	0.0037***	0.0038***
	(0.0002)	(0.0071)	(0.0072)	(0.0001)	(0.0011)	(0.0011)
HML	−0.0013***	−0.0226**	−0.0241***	−0.0001	−0.0051***	−0.0053***
	(0.0004)	(0.0090)	(0.0090)	(0.0001)	(0.0012)	(0.0013)
WML	0.0003	−0.0216**	−0.0213**	−0.0002	−0.0007	−0.0009
	(0.0003)	(0.0098)	(0.0098)	(0.0001)	(0.0011)	(0.0011)
N	1080	1080	1080	1080	1080	1080
R^2	1.0000	0.9889	0.9887	1.0000	0.9997	0.9997

This table reports the results from regressing the excess returns on the market portfolio excluding fossil fuel portfolio stocks on the Carhart (1997) US factors using OLS. The market portfolio includes all stocks listed on NYSE, Amex, and Nasdaq except those with Center for Research in Security Prices (CRSP) share codes other than 10 or 11 and those belonging to the financial services industry. Fossil fuel portfolios include stocks of companies with Standard Industry Classification (SIC) codes SIC 12 and 3532 (coal), and SIC 13, 291, 3533, 46, and 492 (oil and gas), and those belonging to the July 2016 Carbon Underground 200 (CU200) list from Fossil Free Indexes LLC of the 100 largest coal companies and 100 largest oil and gas companies based on reported reserves (http://fossilfreeindexes.com/research/the-carbon-underground/). Alpha is the intercept, indicating relative out- or underperformance. MktRf, SMB, HML, and WML are the coefficients on the Market, Size, Book-to-Market, and Momentum factors respectively. Newey and West (1987) heteroskedasticity and autocorrelation consistent (HAC) standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

fossil-free portfolios is captured by the market factor. The R-squared in Table 4 is very close to 1 for coal-free portfolios, while it is slightly lower for oil and gas-free portfolios. This corresponds to the findings of Andersson et al. (2016) that investors may substantially reduce the carbon footprint of portfolios by divesting the fossil fuel industry, coal stocks in particular, at a minimal tracking error.

5.3. Sensitivity Analyses

To test the robustness of our main results, we consider the effect of divestment in the period following the first divestment campaigns, other subperiods, the S&P 500 and FTSE 100 indices, and applying a GARCH(1,1) regression specification. All underlying results tables are available upon request at the corresponding author.

5.3.1. Impact of Divestment Campaigns (2011–2016)

First, we test whether the effect of divestment on portfolio performance has been more pronounced in the period following the first divestment campaigns. Wide-spread divestment of fossil fuel company stocks would lead fossil fuel portfolios to outperform fossil-free ones (Dam and Scholtens, 2015; Heinkel et al., 2001). To find out, we extend regression Eq. 3 with a time dummy, $Divestment_t$, which takes on the value 1 in the period from the start of the first divestment campaigns (2011–2016) and 0 for the period before (1927–2010).

Contrary to our expectations, we find a significant underperformance of coal and CU200 stocks and outperformance of coal-free portfolios during the period since the start of the first divestment campaigns (2011–2016), as indicated by the loadings on the Divestment dummy in Table A.1 and Table A.2 (Appendix). However, it should be noted that this underperformance is only observed for a relatively short time period that coincides with significant declines in fossil fuel prices. We employ two additional tests (not reported) to further investigate the findings. First, because standard asset pricing models may not fully capture the impact of energy price risk on stock prices (Driesprong et al., 2008; Scholtens, 2014), particularly those of fossil fuel companies in recent years, we include Western Texas Intermediate (WTI) spot Cushing price ($/barrel) log returns as an additional pricing factor in Eq. 3 (in line with Driesprong et al., 2008; Scholtens and Yurtsever, 2012). As a robustness check, we use the WTI three-month futures price as an alternative oil price measure. When we account for movements in the oil price, negative alphas on fossil fuel stocks disappear. This suggests that the underperformance of fossil fuel portfolios during 2011–2016 can be attributed mainly to the negative oil price shock in that time period (cf. Scholtens and Yurtsever, 2012). Secondly, including a time dummy in Eq. 3 assumes that divestment has a sudden impact on stock prices, whereas demand effects (Dam and Scholtens, 2015; Heinkel et al., 2001) may materialize gradually as more and more investors apply divestment while market equilibrium has yet to be established. We therefore compare Dividend-Price (D/P) ratios of fossil fuel portfolios with those of the market portfolio in the period 2011–2016. We obtain annual D/P ratios from CRSP total return data including and excluding dividends, following Cochrane (2008, p.1541). We do not find a substantial rise in D/P ratios of fossil fuel portfolios relative to those of the market. This suggests that the only explanation for the absence of four-factor outperformance of fossil fuel investments during 2011–2016 is that the market for divestment is not (currently) large enough to induce substantial price effects, and market equilibrium has yet to be reached. In line with Lobe and Walkshäusl (2016), our findings can thus best be explained by a lack of persistent influence of SRI investors on asset prices.

5.3.2. Subperiods

To assess the stability of our results over time, we cut the study period into various subperiods of 30, 15, 10, and 5 years. Table A.3 lists the performance of portfolios with and without fossil fuels (industry definition) over 15-year time frames. Results for other time frames and portfolios are qualitatively similar and available upon request from the corresponding author. The performance (alpha) of the fossil fuel industry clearly varies over time, while there is no clear out- or underperformance of fossil-free portfolios. On average, Sharpe ratios are lower for divested portfolios. Interestingly, we observe positive alphas for fossil fuel portfolios in the most recent 15 years. This underlines our finding that the period of underperformance following recent divestment campaigns is an exceptional case which is preceded by a period of good fortune for fossil fuel investments.

In line with expectations, we further observe that the impact of divestment relates to the proportion of stocks excluded during specific time frames. With the decline in the share of the fossil fuel industry in the market portfolio in the past 30 years has come a relatively low impact of divestment on Sharpe ratios. The outperformance of fossil-free investments in the 1980s informally 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 substantial share in the market.

5.3.3. Divesting the S&P 500 and FTSE 100 Indices

In practice, investors often rely on restricted market indices 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, due to its high share of fossil energy companies (Leaton, 2011). Therefore, we consider the impact of divestment when applied to the less diversified S&P 500 and FTSE 100 market indices. For the S&P 500, we obtain historical constituents data from Compustat (1964–2016) and discard all stocks which are in each of the six 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 combine these with industry classifications by SIC (see Table 1) and the Statistical Classification of Economic Activities in the European Community (NACE)[8] using Orbis. We use the US factors in the S&P 500 regressions and the UK factors (Gregory et al., 2013)[9] in the FTSE 100 regressions.

Results for the S&P 500 (Tables A.4–A.6) and FTSE 100 (Tables A.7–A.9) show that, consistent with expectations, the impact of divestment is more pronounced for portfolios that are less diversified, particularly for the FTSE 100. Fig. A.1 shows that compared to the US market index about twice the proportion of stocks is excluded from the FTSE 100 (about 10% of the stocks with a market capitalization of 25% in the index). Nevertheless, results are qualitatively similar to the main analysis, with divested portfolios generally having Sharpe ratios slightly below those of the unconstrained index (Tables A.4 and A.7) and insignificant four-factor alphas (Tables A.6 and A.9). These findings are well in line with studies applying other sector screens to the S&P 500 (Humphrey and Tan, 2014). Note that differences in sample periods (1964–2016 for the S&P 500 and 1996–2016 for the FTSE 100) may influence findings. Finally, note that the R-squared in the regression of the returns of fossil-free portfolios on the Carhart factors (Tables A.6 and A.9) diverges more heavily from 1 compared to the main analysis based on the CRSP market portfolio. This means that divestment could induce substantial tracking error when applied to a more constrained market index, such as the FTSE 100 (cf. Andersson et al., 2016).

5.3.4. GARCH(1,1) Regression

We further address time-varying volatility (volatility clustering) present in our sample directly by modeling volatility as a GARCH(1,1) process. Results for the GARCH(1,1) model, included in Tables A.10 and A.11, remain qualitatively similar to the OLS estimates.

In summary, we are confident of our findings as they seem to hold across time, in alternative and smaller investment portfolios (indices), and when using alternative regression model specifications.

6. Conclusion

Fossil fuel divestment campaigns insist that investors must sell their stakes in companies that supply coal, oil, or gas. We investigate whether such divestment would have had a material impact on portfolio performance. For various categories of fossil fuel companies and market indices we find that divested (fossil-free) portfolios would not have significantly underperformed the unconstrained market portfolio over a comprehensive time frame. These findings are in line with the literature on the effects of SRI and screening (Humphrey and Tan, 2014; Lobe and Walkshäusl, 2016), which usually focus on much smaller industries.

The absence of diversification costs from divestment can be explained by the fact that fossil fuel company stocks have thus far not outperformed other stocks on a risk-adjusted basis and only provide relatively limited diversification benefits. We find that fossil fuel stocks are more or less substitutes for the market index (which has a beta of 1), which contradicts the findings by Fischel (2015), and that the current focus on fossil fuel production induces only limited sector bias in divested portfolios. Our analysis suggests that it is important to systematically analyze the implications of fossil fuel divestment for portfolio performance based on standard methods in the finance literature, using a comprehensive sample and study period, and assessing the robustness of results (cf. Cornell, 2015; Fischel, 2015; Heaps et al., 2016). Notably, we find the underperformance of fossil fuel stocks in the most recent period (2011–2016) to be attributable to the negative oil price shock in that period. The divestment movement may thus benefit from shifting focus from financial arguments to its potential merits as a tool to address climate change. However, the environmental benefits (carbon emissions reductions) caused by divestment are contestable and have not been systematically analyzed yet.

A limitation of our study is that it is retrospective and static. As such, the effect of divestment on prices and expected returns remains to be seen. Continued growth of investor commitment to divestment may be expected to lower demand and prices for fossil fuel investments relative to fossil-free ones, inducing higher returns on the former and lower returns on the latter category (Dam and Scholtens, 2015; Heinkel et al., 2001). The effect on the returns of fossil fuel and fossil-free investment thus ultimately depends on investors' willingness-to-accept the controversial character of their investments in fossil fuel stocks. Moreover, a broader scope of fossil fuel divestment, which considers the interconnectedness between fossil fuel supply and economic activity (see Ritchie and Dowlatabadi, 2014), might result in more pronounced implications for portfolio performance (cf. Battiston et al., 2017). Future research could apply our portfolio approach to assess the system-wide impacts of divestment on prices of a broader range of fossil fuel intensive industries. At the same time, investors might apply less restrictive approaches to reduce the carbon footprint of their investment portfolios, and thereby limit diversification costs (Andersson et al., 2016). A second limitation is that we abstract from any additional financial costs that divestment might impose, such as selection, transaction, and monitoring costs. The size of these costs should be assessed on a case by case basis, as they will strongly depend on the investment type, size, and objectives.

In all, our study calls for a careful consideration of the pro's and con's of divestment as a tool to address climate change. This study has focused on the financial dimension of fossil fuel divestment. We feel that future study is especially needed on the environmental and social outcomes associated with divestment and other responsible investing strategies.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2017.11.036.

[8] We use NACE 05, 0892, 0990, and 1910 for coal, and NACE 06, 0910, 1920, 2011, and 4950 for oil and gas.

[9] http://business-school.exeter.ac.uk/research/centres/xfi/famafrench/files/ (accessed: September 20, 2017). Results are robust to using the Fama-French European factors.

References

Allen, M.R., Frame, D.J., Huntingford, C., Jones, C.D., Lowe, J.A., Meinshausen, M., Meinshausen, N., 2009. Warming caused by cumulative carbon emissions towards the trillionth tonne. Nature 458 (7242), 1163–1166.

Andersson, M., Bolton, P., Samama, F., 2016. Hedging climate risk. Financ. Anal. J. 72 (3), 13–32.

Ansar, A., Caldecott, B., Tilbury, J., 2013. Stranded Assets and the Fossil Fuel Divestment Campaign: What Does Divestment Mean for the Valuation of Fossil Fuel Assets? Smith School of Enterprise and the Environment, University of Oxford.

Arbuthnott, K.D., Dolter, B., 2013. Escalation of commitment to fossil fuels. Ecol. Econ. 89, 7–13.

Auer, B.R., 2016. Do socially responsible investment policies add or destroy European stock portfolio value? J. Bus. Ethics 135 (2), 381–397.

Ayling, J., Gunningham, N., 2017. Non-state governance and climate policy: the fossil fuel divestment movement. Clim. Pol. 17 (2), 131–149.

Battiston, S., Mandel, A., Monasterolo, I., Schütze, F., Visentin, G., 2017. A climate stress-test of the financial system. Nat. Clim. Chang. 7 (4), 283–288.

Bello, Z.Y., 2005. Socially responsible investing and portfolio diversification. J. Financ. Res. 28 (1), 41–57.

Bessembinder, H., 2016. Frictional Costs of Fossil Fuel Divestment. Unpublished results. https://ssrn.com/abstract=2789878 (accessed: July 11, 2017).

Bollerslev, T., Wooldridge, J.M., 1992. Quasi-maximum likelihood estimation and inference in dynamic models with time-varying covariances. Econ. Rev. 11 (2), 143–172.

Busch, T., Hoffmann, V.H., 2007. Emerging carbon constraints for corporate risk management. Ecol. Econ. 62 (3), 518–528.

Busch, T., Lewandowski, S., 2017. Corporate carbon and financial performance: a meta-analysis. J. Ind. Ecol. 1–15. http://dx.doi.org/10.1111/jiec.12591.

Campiglio, E., 2016. Beyond carbon pricing: the role of banking and monetary policy in financing the transition to a low-carbon economy. Ecol. Econ. 121, 220–230.

Carhart, M.M., 1997. On persistence in mutual fund performance. J. Financ. 52 (1), 57–82.

Cochrane, J.H., 2008. The dog that did not bark: a defense of return predictability. Rev. Financ. Stud. 21 (4), 1533–1575.

Cornell, B., 2015. The Divestment Penalty: Estimating the Costs of Fossil Fuel Divestment to Select University Endowments. doi: https://doi.org/10.2139/ssrn.2655603 (accessed: July 11, 2017).

Dam, L., Scholtens, B., 2015. Toward a theory of responsible investing: on the economic foundations of corporate social responsibility. Resour. Energy Econ. 41, 103–121.

De Jong, M., Nguyen, A., 2016. Weathered for climate risk: a bond investment proposition. Financ. Anal. J. 72 (3), 34–39.

Dietz, S., Bowen, A., Dixon, C., Gradwell, P., 2016. Climate value at risk' of global financial assets. Nat. Clim. Chang. 6 (7), 676–679.

Driesprong, G., Jacobsen, B., Maat, B., 2008. Striking oil: another puzzle? J. Financ. Econ. 89 (2), 307–327.

Eurosif, 2016. European SRI Study. http://www.eurosif.org/sri-study-2016/ (accessed: July 3, 2017).

Evans, J.L., Archer, S.H., 1968. Diversification and the reduction of dispersion: an empirical analysis. J. Financ. 23 (5), 761–767.

Fama, E.F., French, K.R., 1997. Industry costs of equity. J. Financ. Econ. 43 (2), 153–193.

Fama, E.F., French, K.R., 2007. Disagreement, tastes, and asset prices. J. Financ. Econ. 83 (3), 667–689.

Fischel, D.R., 2015. Fossil Fuel Divestment: A Costly and Ineffective Investment Strategy. http://divestmentfacts.com/pdf/Fischel_Report.pdf (accessed: July 11, 2017).

Fu, F., 2009. Idiosyncratic risk and the cross-section of expected stock returns. J. Financ. Econ. 91 (1), 24–37.

Galema, R., Scholtens, B., Plantinga, A., 2008. The stocks at stake: return and risk in socially responsible investment. J. Bank. Financ. 32 (12), 2646–2654.

Global Sustainable Investment Alliance, 2016. Global Sustainable Investment Review. http://www.gsi-alliance.org/members-resources/trends-report-2016/ (accessed: July 3, 2017).

Goyal, A., Santa-Clara, P., 2003. Idiosyncratic risk matters. J. Financ. 58 (3), 975–1007.

Gregory, A., Tharyan, R., Christidis, A., 2013. Constructing and testing alternative versions of the Fama–French and Carhart models in the UK. J. Bus. Finance Account. 40 (1–2), 172–214.

Griffin, P.A., Jaffe, A.M., Lont, D.H., Dominguez-Faus, R., 2015. Science and the stock market: Investors' recognition of unburnable carbon. Energy Econ. 52 (PA), 1–12.

Gross, M., 2015. Twenty-five years of climate change failure. Curr. Biol. 25 (8), R307–R310.

Heaps, T., Yow, M., Behar, A., 2016. Carbon Clean 200: Investing in a Clean Energy Future. Corporate Knights and As You Sow. http://www.clean200.org/ (accessed: September 29, 2017).

Heede, R., 2014. Tracing anthropogenic carbon dioxide and methane emissions to fossil fuel and cement producers, 1854–2010. Clim. Chang. 122 (1), 229–241.

Heinkel, R., Kraus, A., Zechner, J., 2001. The effect of green investment on corporate behavior. J. Financ. Quant. Anal. 36 (4), 431–449.

Hoepner, A.G., Schopohl, L., 2016. On the price of morals in markets: an empirical study of the Swedish AP-funds and the Norwegian government pension fund. J. Bus. Ethics 1–28. http://dx.doi.org/10.1007/s10551-016-3261-0.

Hong, H., Kacperczyk, M., 2009. The price of sin: the effects of social norms on markets. J. Financ. Econ. 93 (1), 15–36.

Humphrey, J.E., Tan, D.T., 2014. Does it really hurt to be responsible? J. Bus. Ethics 122 (3), 375–386.

Ibikunle, G., Steffen, T., 2017. European green mutual fund performance: a comparative analysis with their conventional and black peers. J. Bus. Ethics 1–19. http://dx.doi.org/10.1007/s10551-015-2850-7.

Jobson, J.D., Korkie, B.M., 1981. Performance hypothesis testing with the Sharpe and Treynor measures. J. Financ. 36 (4), 889–908.

Leaton, J., 2011. Unburnable Carbon – Are the world's Financial Markets Carrying a Carbon Bubble? Carbon Tracker Initiative, London, UK. http://www.carbontracker.org/report/carbon-bubble/ (accessed: July 17, 2017).

Ledoit, O., Wolf, M., 2008. Robust performance hypothesis testing with the Sharpe ratio. J. Empir. Financ. 15 (5), 850–859.

Ledoit, O., Wolf, M., 2011. Robust performances hypothesis testing with the variance. Wilmott 2011 (55), 86–89.

Liesen, A., Figge, F., Hoepner, A., Patten, D.M., 2017. Climate change and asset prices: are corporate carbon disclosure and performance priced appropriately? J. Bus. Finance Account. 44 (1 & 2), 35–62.

Lobe, S., Walkshäusl, C., 2016. Vice versus virtue investing around the world. Rev. Manag. Sci. 10 (2), 303–344.

Luo, H.A., Balvers, R.J., 2017. Social screens and systematic investor boycott risk. J. Financ. Quant. Anal. 52 (1), 365–399.

Markowitz, H., 1952. Portfolio selection. J. Financ. 7 (1), 77–91.

McGlade, C., Ekins, P., 2015. The geographical distribution of fossil fuels unused when limiting global warming to 2 °C. Nature 517 (7533), 187–190.

Meinshausen, M., Meinshausen, N., Hare, W., Raper, S.C., Frieler, K., Knutti, R., Frame, D., Allen, M.R., 2009. Greenhouse-gas emission targets for limiting global warming to 2 °C. Nature 458 (7242), 1158–1162.

Memmel, C., 2003. Performance hypothesis testing with the Sharpe ratio. Finance Lett. 1 (1), 21–23.

Newey, W.K., West, K.D., 1987. A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix. Econometrica 55 (3), 703–708.

Nofsinger, J., Varma, A., 2014. Socially responsible funds and market crises. J. Bank. Financ. 48, 180–193.

Revelli, C., Viviani, J., 2015. Financial performance of socially responsible investing (SRI): what have we learned? A meta-analysis. Bus. Ethics Eur. Rev. 24 (2), 158–185.

Ritchie, J., Dowlatabadi, H., 2014. Understanding the shadow impacts of investment and divestment decisions: adapting economic input–output models to calculate biophysical factors of financial returns. Ecol. Econ. 106, 132–140.

Ritchie, J., Dowlatabadi, H., 2015. Divest from the carbon bubble? Reviewing the implications and limitations of fossil fuel divestment for institutional investors. Rev. Econ. Finance 5, 59–80.

Roy, A.D., 1952. Safety first and the holding of assets. Econometrica 20 (3), 431–449.

Rudd, A., 1981. Social responsibility and portfolio performance. Calif. Manag. Rev. 23 (4), 55–61.

Scholtens, B., 2014. Indicators of responsible investing. Ecol. Indic. 36, 382–385.

Scholtens, B., 2017. Why finance should care about ecology. Trends Ecol. Evol. 32 (7), 500–505.

Scholtens, B., Yurtsever, C., 2012. Oil price shocks and European industries. Energy Econ. 34 (4), 1187–1195.

Schwarz, R., 2015. Reinvesting after divesting: a few fossil-fuel-free options. J. Environ. Invest. 6 (1), 42–46.

Sharpe, W.F., 1966. Mutual fund performance. J. Bus. 39 (1), 119–138.

Sortino, F.A., Van der Meer, R., 1991. Downside risk. J. Portf. Manag. 17 (4), 27–31.

Statman, M., 1987. How many stocks make a diversified portfolio? J. Financ. Quant. Anal. 22 (3), 353–363.

Tobin, J., 1958. Liquidity preference as behavior towards risk. Rev. Econ. Stud. 25 (1), 65–86.

Trinks, P.J., Scholtens, B., 2017. The opportunity cost of negative screening in socially responsible investing. J. Bus. Ethics 140 (2), 193–208.

Van den Bergh, J.C.J.M., Botzen, W.J.W., 2015. Monetary valuation of the social cost of CO_2 emissions: a critical survey. Ecol. Econ. 114, 33–46.