Impact of Climate Change Hazard: Carbon Risk on Stock Returns and Asset Pricing

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Abstract

In this study, I extend the Fama and French five-factor asset pricing model with a sixth factor, namely, carbon risk, to investigate its impact on equity returns. To measure carbon risk, a new factor 'pollutant minus green,' is developed using the difference between the weighted average returns of pollutant and green firms across 51 developed and emerging countries across four categories—North America, Europe, Emerging Markets, and the Asia Pacific. The results reveal that North America, Europe, and Asia Pacific markets have a carbon risk premium that gets eliminated in small-cap firms. The carbon risk factor is further tested in left-hand side (LHS) test asset portfolios and found to be more pronounced with size-effect anomaly; specifically, small stock firms report greater declining average returns because of more exposure than the mega-cap stocks to carbon dioxide emissions. Furthermore, size-effect anomaly prevails with profitability and investment factors across firms. Therefore, high profitability, as well as high investment small firms, show a greater decline than the big stock firms in average returns when their carbon dioxide emissions increase. The asset pricing model evaluation is carried out through the Gibbons, Ross, and Shanken test. The six-factor model directed at capturing carbon risk patterns in average equity returns performs better than the three-factor and five-factor models of Fama and French (1993 and 2015) in the majority of categories under 3x3 sorting and compete with both Fama and French model under 2x4x4 sorted LHS portfolios. The finding of this study offers various useful applications for investors, policymakers, brokers, corporations, governmental pollution abatement institutions, and other stakeholders who wish to obtain carbon risk premium

Key words: Climate change risk, Asset pricing model, Fama and French Five Factor model, Carbon dioxide emissions, GRS method

1. Introduction

The world has been changing in terms of evolution and deregulation ever since the industrial revolution began in the late 1700s. On the one hand, nations have achieved remarkable economic progress and drastic improvements in living standards. On the other hand, substances hazardous to health have polluted the world's environment (Ritter, 2009). Before the industrial revolution, the pace of growth of the global economy was relatively slow with the gap in income between countries being small. For instance, in 1820, the cross-country income inequality was less than 15 percent; by 1950, that gap rose to well more than 50 percent. Similarly, the per capita income gap between the richest and the poorest country in 1820 was less than four times the latter; this gap shot up to 127 times the per capita income of the poorest countries in 1950 (Maddison, 2009).

The industrial revolution changed the economic map of the world. Consequently, a few Western industrialized countries became the main growth drivers and technological leaders, leaving the rest of the world behind. Attainment of the development goals led the world to a great divergence that became a turning point in ecosystems around the globe (Lin and Rosenblatt, 2012). The utilization of natural resources (fossil fuel) expanded rapidly during the early stages of industrialization, which caused an immediate change in the environment through hazardous emissions and pollutants. However, more than the harmful substances and pollutants, it was the attitude of the governing bodies of firms that damaged the climate more, as they assumed these substances were too expensive to dispose of (Dinda, 2004).

Thereafter, environmental degradation became the side effect of development. Environmental degradation embraces the depletion of three major natural resources (air, water, and soil) and demolition of the ecosystem, wildlife extinction, and pollution (Johnson et al., 1997). Fewer pro-environment actions and more pollution generating investments increased the level of GHGs, a leading source of climate change, in the atmosphere. The high degree of accumulation of hazardous gases poses a complex set of emerging risks and a series of negative outcomes to the planet. For instance, extreme weather conditions, increase in smog and haze, loss of plant and animal species, higher global temperature, glacial melting, and increase in sea levels (Nangombe et al., 2018). Consequently, climate change poses a grave threat to millions of people from different walks of life across the globe (Doherty et al., 2017; Hulme et al., 1999; Mora et al., 2018; Orimoloye et al., 2019).

Nonetheless, more than 90 percent of global climate change is due to harmful human actions (Bell, 2018). According to the Intergovernmental Panel on Climate Change, an intergovernmental body of the United Nations, “Climate change currently contributes to the global burden of disease and premature deaths.” Considering the severity of this issue, the United Nations has officially announced environmental degradation as one of the world’s top ten threats. To control GHG emissions and their harmful effects, various countries collaborated to set up the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 by signing an international agreement named the Kyoto Protocol (Lee et al., 2015; Smale et al., 2006).

Given the substantial emissions generated from manufacturing processes, the corporate sector is acknowledged as a key factor contributing to climate change (Sakhel, 2017). “More than half a trillion tons of carbon has been dumped in the atmosphere since the Industrial Revolution” (Paramati et al., 2017). Unsurprisingly, several questions have been raised and attention has also been given to how corporations have responded to mitigate this significant problem. Thus, rather than mere economic development, low carbon sustainable economic development has emerged as the key global challenge in the 21st century (Berrang-Ford et al., 2011; Nader, 2009).

According to the United Nations report, “The world's 3,000 largest companies are causing £1.4 trillion worth of environmental damage every year, these unaccounted environmental costs equate to an average of one-third of their profits. The actual environmental cost of firms' activities is likely to be even higher because the £1.4 trillion does not include damage caused by social impacts such as large-scale migration of people and other long-term effects of climate change.” Griffin (2017) revealed the alarming contribution of corporations to climate change that “Just 100 companies are responsible for 71 percent of global greenhouse gases emissions.” These statistics signal how serious the challenge is for the global economy and environment and raises the question about what can be done to mitigate this challenge.

About 50 years back Hardin (1968) termed “Global climate change is a tragedy of the commons.” The concept of “tragedy” denotes the anticipated depletion of free access to natural resources because of their common availability to the greatest number of beneficiaries. In other words, everyone mainly cares about his or her gain and rational choice by ignoring the common benefit that may produce irrational consequences for the rest. Given that corporations often remain a contributing cause and part of the problem, they are expected to do something about it, as it is pretty clear that businesses cannot save themselves by losing the planet (Lee and Kincaid, 2016).

A variety of measures have been proposed by countries to lessen the level of GHG emissions (Shafiei and Salim, 2014). Some of these measures aim to promote clean energy sources while other, especially those in many developed and emerging countries, levy "carbon tax" to reduce dependence on fossil fuels that generate carbon dioxide emissions as a negative byproduct (Intergovernmental Panel on Climate Change, 2007; Roelfsema et al., 2014; Winyuchakrit et al., 2011). In the same vein, some countries use emission standards mechanisms such as the "polluters pay principle" that imposes penalties when the maximum level of carbon emissions are exceeded (Burtraw and Sekar, 2014).

At the macro level, the minimum mitigation cost is approximately 1 percent of the world's gross domestic product (GDP), while the decline in firm value due to environmental damage could be more than 15 percent of the world's GDP (Aggarwal and Dow, 2012). The relationship between firm pro-environment initiatives and a firm's profitability level has been widely discussed in the extant literature. It is still a deep-rooted belief that emissions reduction incurs additional costs to corporations (Hogan and Jorgenson, 1991; Kaminski, 2003; Liu et al., 2016; Porter, 1991; Rajemi et al., 2010; Van Vuuren et al., 2007).

Nevertheless, climate change and climatic impacts influence both risks and opportunities for corporations. Their involvement in environmental management generates revenues and incurs costs. That participation remains voluntary as well as mandatory in response to increasing stakeholder pressure, environmental regulations, and to sustain their competitive advantage over rivals (Nishitani and Kokubu, 2012a). In this context, whether better environmental performance leads to better financial performance is an ongoing debate. However, the approach has changed from mere cost estimation to more revenue generation through the reduction of GHG emissions (Lewandowski, 2017). The higher risk of global warming can be translated into higher profits and greater returns by embracing these new opportunities (Lash and Wellington, 2007). Given the rapid global climate change, corporations are more prone to additional risk factors than just "market risk-premium," which requires them to undertake sustainability initiatives and various measures to reduce the ecological impact of their firms.

In this study, I investigate the risk of carbon emissions for equity returns across 51 developed and emerging countries of the world that can be grouped into four categories, namely, North America, Europe, Emerging Markets, and the Asia Pacific. Firm-level carbon dioxide emissions are used to measure carbon risk and develop the carbon risk factor—pollutant firms minus green firms (PMG). Pollutant firms are firms that emit more carbon dioxide and green firms are those with less carbon dioxide emissions. To determine and scrutinize the carbon risk through the lens of the "factor-based asset pricing model," in this study, I incorporate carbon risk in test asset portfolios, that is, the left-hand side (LHS) portfolios, to examine the carbon risk related anomalies in average stock returns. Further, carbon risk is used as a factor on the right-hand side (RHS) to find whether it is priced or not through carbon risk premium and does the expansion of the asset pricing model explain the average returns due to the inclusion of carbon risk factor in the traditional five-factor model of Fama and French (2015).

2. Literature review

CAPM has been the foundation of virtually all asset pricing methodologies (Du Pisanie, 2018). The model was developed and theorized collectively but independently by a number of researchers, including Treynor (961), Sharpe (1964), Lintner (1965), Mossin (1966), and Black et al. (1972) over the period of a decade. However, the contributions of Ross (1978) through the arbitrage pricing theory and Fama and French (1993) with the introduction of the three-factor model sparked a paradigm shift in the area of asset pricing as a whole. Further, Carhart (1997) extended the model with a fourth factor of the momentum in the stock prices. More recently, Fama and French (2015) introduced a five-factor version to their previous three-factor model by using two added factors related to profitability and investment.

The asset pricing model has evolved over the last half-century. Nonetheless, in the 21st century, the challenges significantly more than the computation of simple asset returns through pricing the firm-specific and market-related risks. Currently, a corporation's risk array is incomplete without considering climate change, given its adverse environmental effects as climate change significantly affects the production and investment opportunities (Choiniere and Horowitz, 2005). As per the study of Balvers and Huang (2007), climate change-induced global warming is the main reason for the fluctuations in the investment opportunities; hence it should be the major risk factor that should be priced as productivity shock in the setting of the Merton model. Climate change is a global problem and must be included as a newly proposed risk in the standard asset pricing model. carbon dioxide in the atmosphere is an asset—although one with negative payoffs (Daniel et al., 2016).

In corporate finance, the price of an asset represents the accumulation of the discounted future benefits at zero time period (see, dividend discount model of Farrell, 1985). Similarly, the modern approach to asset pricing embraces the optimal price of carbon dioxide emissions, which is determined by discounting the marginal benefit of reduction in one additional ton of carbon dioxide emissions across the world in future years (Duffie, 2010; Hansen and Richard, 1987). The extant literature contains only a few studies explicitly testing the effect of climate change to identify mispriced financial assets. Andersson et al. (2016) explored the impacts of a hedging strategy for climate-related risk and mispricing of assets and found that before the implementation of climate change mitigation actions, the returns of hedged stocks and stocks without hedging earned the same returns; however, once climate change actions turn functional and carbon dioxide emissions get priced, the low carbon stock should start to outperform and mispricing moves in a particular direction.

However, Liesen (2015) illustrated differing results that firms reporting GHG emissions were found to be underpriced compared with those that did not report GHG emissions. The question, "Despite low returns, why should a firm invest in climate change mitigation projects?" has been dwelt upon by many researchers; in contrast to the traditional (CAPM) approach, which states that the returns depend on the correlation of risk factor between the returns of the market portfolio and returns of mitigation portfolio, Sandsmark and Vennemo (2007) found a joint determination between economic and environmental system and inferred environmental risk as an endogenous factor that may be mitigated by self-protection and self-insurance. Thus, environmental investments may be justified despite lower expected returns. Howarth (2003) strongly argued that the discrepancy between low returns on environmental investments and higher returns on non-environmental projects was due to the discount rate being identical for corporate stocks and climate stabilizing projects, although the former was dominated by a risk premium, whereas the latter would reduce the risk for the welfare of future generations.

Therefore, the author recommended using a rate equal to the annual return on the risk-free rate for discounting climate change mitigation projects. Further, Lind (1982) reasoned that: “The returns from energy research and development in the future may be negatively correlated with the returns to all other investments so that public investments, in this case, would have the effect of insurance. If we were to account for this insurance effect by altering the rate of discount, we should use a lower rate of a discount than the risk-free rate, not a higher one.” (p.70).

Pattberg (2012) called climate change an important business risk globally and that corporations were becoming more concerned about the undesirable effects of climate change on their operations and were implementing necessary measures to reduce their carbon emissions. On the part of investors, educating and motivating them to better handle and hedge the financial risk stemming as a result of climate change, is needed. The author further contended that despite no differences, companies are likely to be pressurized by climate change, while the level of climate change risk varied across companies, depending on the source of energy (fuel), energy intensity, geographic location, product mix, employed technology level, and firm-specific risk management capability. Stern (2007) estimated in The Stern Review that if carbon emissions were not reduced by at least 25 percent below current levels, then the global GDP is estimated to reduce by 5–10 percent from what it would have been otherwise. As a response to aggregate global level cost estimates, a large number of firms now disclose how climate change will affect their operations, productivity, and profits (Stanny and Ely, 2008).

Keeping in view that climate change is a business risk at national and international levels, this may not be different from the long-studied risk and return relationship model of asset pricing. The asset pricing model is still in the evaluation phase to explain the cross-section of expected returns. Recently, Bekaert et al. (2016) presented a list of 300 plus possible risk factors to explain the stock return variation and risk premiums, while the study of Brammer et al. (2006) examined the factor of corporate social performance and its relationship with stock returns. Further, Fama and French (2018) proposed the factor selection methodology. Braun et al. (2019) emphasized the consideration of sustainability dimensions as a risk factor due to its remarkable and quantifiable impact on stock performance. Ghirlanda et al. (2019) found significant alphas for a low carbon stock portfolio due to the decarbonization procedure.

2.1. Hypotheses Development

Whether stock markets integrate climate change hazards—the carbon risk—into their price fluctuations is one of the most important risk categories encountered by companies in this century (Tu and Hyafil, 2009). Various studies indicate the concerns about establishing an unequivocal relationship between asset pricing and climate risk. Concerns persist about climate-related physical and political risks not being suitably reflected in asset prices (Karydas and Xepapadeas, 2019). According to Chen and Silva (2012), climate risk is positively associated with the cost of capital, which may reduce stock returns. Two steps in asset pricing models can be identified to examine the role of carbon risk in stock prices. The first step includes the portfolio formation based on the book-to-market ratio, firm size, profitability, investment, and carbon risk to describe the variations in stock returns. The second step implies the formation of the RHS factors that explain the difference in average returns through risk premium because risk premium presents the additional compensation for bearing risk linked with the RHS factors.

Keeping in view the previous concerns about being pro-environment and its impact on firm profitability, in this study, I seek to test the impact of idiosyncratic risk (carbon dioxide emissions released by the corporation) on systematic risk (climate change). Following the popular notion that the business of business is business, or in other words, creating profit for shareholders (Friedman, 1970). Climate change has been a global issue in recent decades and enterprises are directly or indirectly exposed to it due to their pivotal role in both economic and social positions.

Asset pricing literature describes that the asset pricing equation contains two types of risks: one, the "*non-systematic* or *diversifiable*, *non-market* or *idiosyncratic* risk," that is, the residual term in the equation; two, the "*systematic* or *non-diversifiable* or *market* risk," represented by beta in the equation and this risk must be rewarded. The climate change risk also increases the systematic risk and should be priced (Cai and Lontzek, 2019; Lemoine, 2015; Sandsmark and Vennemo, 2007; Ziegler et al., 2011).

When asset pricing models capture the total variance in returns, the average absolute intercepts of all portfolios should be statistically indistinguishable from zero. Given that the time series regression intercepts are considered as pricing errors, therefore, these should be minimum, otherwise, the model will be misspecified as returns remain unexplained by risk factors.

The following hypotheses are proposed to be tested to meet the objective of this study:

H1: A carbon risk premium exists.

H2: Firm size impacts the carbon risk premium.

H3: Asset pricing anomalies related to carbon risk exist in the average returns of stocks.

H4: The incorporation of carbon risk factor (PMG) better explains the variations in the stock returns compared with the conventional asset pricing model (three-factor and five-factor models).

3. Data Sample, Data Description, Model Specification, Methodology, Factor Construction, and Formation of Test Portfolios

3.1. Data, Sample Description

The sample includes the stock returns and accounting data of the total data set of Thomson Reuters Asset4 ESG universe of companies, covering 7,000 plus publicly-traded companies from 51 developed and emerging countries around the world. I take into account corporate carbon dioxide emissions because they are the key contributor to climate change and the main target of policymakers to mitigate climate change (Griffin, 2017). Analyzing a firm's sensitivity to carbon dioxide emissions as well as how the inclusion of carbon dioxide emissions explains the cross-sectional stock returns and influences asset pricing, is critical. (Choi et al., 2018).

In line with Fama and French (2017), the sample is grouped into four categories where three categories represent regions and include almost the same number of countries, while the fourth category is that of emerging markets, comprising 28 economies around the world. The four categories are (i) North America, which includes Canada and the US (ii) Europe, which embraces Austria, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom. (iii) Emerging Markets, which includes Argentina, Bahrain, Brazil, Chile, China, Colombia, Czech Republic, Egypt, Greece, Hungary, India, Indonesia, Kuwait, Malaysia, Morocco, Mexico, Oman, Poland, Philippines, Peru, Qatar, Russian Federation, South Africa, South Korea, Saudi Arabia, Taiwan, Thailand, and the United Arab Emirates. (IV) The Asia Pacific, which covers Australia, Hong Kong, Israel, Japan, New Zealand, and Singapore. Furthermore, the global portfolios, which combines the four categories, is also examined. The dataset includes all the listed and delisted firms (to avoid the survivorship bias[1]) sourced from the ASSET4 ESG, a Thomson Reuters Datastream software (TDS) that captures information on sustainability and governance at the firm-level.

The sample period April 2006 to June 2020 is constrained by the data availability as all firms in the ASSET4 ESG are listed only from 2006. The monthly frequency data is collected from the Institute of Business Administration, Karachi. Following Ince and Porter (2006) and Hou et al. (2011), certain filters are incorporated. Table 3.1 reports the TDS mnemonics to filter the data to obtain a comprehensive and high-quality sample. To improve the power of tests, the well-diversified LHS portfolios are used in the regressions. Portfolio diversification increases the precision of the intercepts, which is the primary focus of the asset pricing tests. The choice of regions that is important for the power of tests is based on the plausible assumption of market integration.

To be included in the sample, a stock is required to have at least 24 months of returns and accounting data. Data include the number of shares outstanding, adjusted price (P), unadjusted price (UP), total assets for t−2 and t−1, total revenues, cost of goods sold, selling, general, and administrative expenses, interest expense for t−1, minority interest, market capitalization, market equity data for December of t−1 and June of t, and (positive) book equity data for t−1, and total assets data for t−2 and t−1. All the variables are denominated in the US dollar to avoid the exchange rate risk, make a cross-market comparison of asset pricing models, and have a meaningful integration of international stocks.

3.2. Factor Construction

In each region, the factors are constructed through the well-defined approach of Fama and French (1993, 2015, 2017). The market value of equity is the product of stock price and the number of outstanding shares. Book value of equity is defined as the stockholders' common book equity, plus the balance sheet deferred taxes and investment tax credit, if available, minus the book value of the preferred stock. OP is calculated as sales minus the cost of goods sold, selling, general, and administrative expenses, and interest expense divided by the sum of book equity and minority interest rate[1], and the investment factor refers to the annual growth rate of assets calculated as total assets at the end of June in year t−1 minus total assets at the end of June in year t−2, and dividing the result by total assets at the end of June in year t−2.

The sixth and new factor to be incorporated is the climate change hazard— carbon dioxide emissions by firms represent the CR in asset pricing equation—calculated as total carbon dioxide emissions by a firm at the end of June in the year t. Following Fama and French (1993, 2015, 2017), the undue weight on tiny stocks is handled through the New York Stock Exchange (NYSE) breakpoints for firm size and other variables. The size presents the market value of equity at the end of June in year t; to obtain the B/M ratio at the end of fiscal year t−1, market value at the end of June in year t is divided by book equity at the end of fiscal year t−1. The stocks are then sorted independently to construct the six portfolios based on size and B/M, at the end of each June of year t followed by value-weighted monthly stock returns from July of year t to June of year t+1.

[1] In August 2018, Fama and French revised the method for computing operating profitability, which now includes minority interest in the denominator. Therefore, the operating profitability ratio used to form portfolios in June of year t is annual revenues minus cost of goods sold, interest expense, and selling, general, and administrative expense divided by the sum of book equity and minority interest for the last fiscal year ending in t−1.
https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html

3.2.1. RHS factors

The RHS factors are portfolios constructed at the end of June in each year t, through 2x3 sorting on size, B/M, OP, investment, and climate change risk (PMG). In each category, stocks are sorted on market cap. In line with Fama and French (2017), for a category, the top 90 percent of market cap stocks are classified as big stocks while the bottom 10 percent are the small stocks. For North America, the top 90 percent array of big stocks roughly matches with the NYSE median used for big stocks in the study of Fama and French (1993). The breakpoints for B/M, OP, investment, and PMG are the 30^{th} and 70^{th} percentile of their respective variables for the big stocks of each region. The same breakpoints for each factor are used for the global portfolios. The dollar-denominated returns are computed from the perspective of the US investor, by using the one-month US Treasury bill rate[2] as the risk-free rate. The very first RHS factor, Mkt, is the region's value-weighted market portfolio minus the risk-free rate. Market portfolio for a region is the value-weighted market returns—value-weighted returns of each stock is divided by the total market cap of a region at the end of June in year t. For each region, the RHS explanatory factors are developed through 2x3 sorting that produces the six portfolios based on NYSE breakpoints. 2x3 sorting for size and B/M generates six portfolios—SG, SN, SV, BG, BN, and BV, where S and B indicate small or big and G, N, and V indicate growth, neutral, and value (bottom 30%, middle 40%, and top 30% of B/M), respectively. After independent sorting, I compute the value-weighted returns for each of the six portfolios from July of year t to June of t+1.

[2] All the returns are calculated from US Investor perspective so risk free rate the US treasury bill rate is taken from https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html

The table 3.1 presents the construction formula for the right hand side factors. The size factor small minus big (SMB) for each region is the equal-weight average of three constructing components of SMB, namely, SMB_BM, SMB_OP, and SMB_inv and calculated as SMB_bm = equally-weighted average of SG + SNbm + SV minus equally-weighted average of BG + BNbm + BV ; SMB_op = equally-weighted average of SG + SNop + SV minus equally-weighted average of BG + BNop + BV; SMB_inv = equally-weighted average of SG + SNinv + SV minus equally-weighted average of BG + BNinv + BV, and on the same pattern, the last constituent SMB_pmg would be calculated as SMB_pmg = equally-weighted average of SLC+ SNC+SHC minus equally-weighted average of BLC + BNC + BHC.

Hence the overall size factor SMB is an equally-weighted average of SMB_bm + SMB_op + SMB_inv + SMB_pmg, following Fama and French (2015), with an addition of the climate change risk factor. Consistently, SMB is the average of the returns on the 12 small stock portfolios of the four 2x3 sorts minus the average of the returns on the 12 big stock portfolios. The value factor is constructed through High Minus Low Small firms HMLS = SV−SG and High Minus Low Big firms HMLB = BV−BG, and HML is the average of HMLS and HMLB. The fourth and the profitability factor—robust minus weak (RMW) is the difference between two equally-weighted average components, one, the RMWr = equally-weighted average of SR+BR and the other, RMWw = equally-weighted average of SW+BW; thus, RMW = RMWr−RMWw. The fifth and the investment factor—conservative minus aggressive (CMA) is also constructed based on the same method, which is also the difference between two equally-weighted average components, one, the CMAc = equally-weighted average of SC+BC and the other, CMAa = equally-weighted average of SA+BA; thus, CMA = CMAc−CMAa. The last and a new addition to the two asset pricing equation is the climate change risk factor, which is also constructed in the same way. PMG is the difference between two equally-weighted average components, one, the PMGl = equally-weighted average of SLC+BLC, where SLC refers to small low carbon firms and BLC to big low carbon firms, and the other, PMGh = equally-weighted average of SHC+BHC; thus, PMG = PMGl−PMGh.

Table 3.1. Factor Construction Table

Factor	Formula
SMB_{BM}	$(SH + SN_{bm} + SL)/3 - (BH + BN_{bm} + BL)/3$
SMB_{OP}	$(SR + SN_{op} + SW)/3 - (BR + BN_{op} + BW)/3$
SMB_{Inv}	$(SC + SN_{inv} + SA)/3 - (BC + BN_{inv} + BA)/3$
SMB_{PMG}	$(SLC + SN_{pmg} + SHC)/3 - (BLC + BN_{pmg} + BHC)/3$
SMB	$(SMB_{BM} + SMB_{OP} + SMB_{Inv} + SMB_{PMG})/4$
HML	$(SH + SL)/2 - (BH + BL)/2$
RMW	$(SR + SW)/2 - (BR + BW)/2$
CMA	$(SC + SA)/2 - (BC + BA)/2$
PMG	$(SLC + SHC)/2 - (BLC + BHC)/2$

3.2.2. Summary statistics for RHS factor returns

Table 3.2 demonstrates the mean, standard deviation, and t values of RHS factors for each of the four categories. The emerging markets category has the lowest equity premium (the average Mkt returns) and is near zero (0.49% per month, t = 1.76). The rest of the categories show sufficient equity premium (Asia Pacific: 0.64%, t =1.91, Europe: 0.79%, t =2.02; and North America: 1.172%, t =3.9). Over the sample period June 2007 to February 2020, other than the Asia Pacific, the size premium is negative for all three categories. Thus, the largest size premium is 0.35% per month (t= 0.70) for Asia Pacific.

SMB is negative for the remaining three categories (North America: −0.59%, t = −1.30; Europe: −0.715%, t = −1.8; and Emerging Markets: −1.172%, t = 3.9). The value premium (average HML returns) is positive only North America (0.51%, t=1.19) and negative for emerging markets (−0.10%, t = −0.25), Asia Pacific, which has a slightly higher negative value of (−0.14%, t = −0.37) and Europe (−0.27%, t = 0.52). The profitability premium

Table 3.2 Summary statistics for factor returns: June 2007 – February 2020, 153 months

The table presents summary statistics of the RHS factors for each region: North America (NA), Europe, Emerging Markets and Asia Pacific denominated in US dollars. Portfolios are constructed at the end of June each year t through 2x3 sorting with the breakpoints of 30th and 70th percentiles lagged (fiscal year t-1). Mkt is return on a" "region's value-weight market portfolio minus the US one month T-bill rate" is followed by Mean and standard deviation for SMB, HML, RMW, CMA and PMG factors.

	Mkt	SMB	HML	RMW	CMA	PMG	Mkt	SMB	HML	RMW	CMA	PMG
	North America						Europe					
Mean	1.11	-0.59	0.51	-0.08	0.46	0.77	0.79	-0.71	-0.27	-0.26	0.80	0.65
Std Dev	3.70	5.58	5.28	4.82	3.49	4.03	4.82	4.90	6.15	4.6	4.29	3.54
t –Mean	4.80	-1.30	1.19	-0.20	1.64	2.35	2.02	-1.80	-0.52	-0.70	2.31	2.27
	Emerging Markets						Asia Pacific					
Mean	0.44	-1.17	-0.10	0.55	0.83	0.24	0.57	0.35	-0.13	-0.03	0.77	0.91
Std Dev	3.49	4.27	4.81	4.63	4.85	4.19	4.14	6.25	4.47	3.97	4.32	4.58
t –Mean	1.54	-3.39	-0.25	1.48	1.48	0.73	1.72	0.70	-0.37	-0.10	2.20	2.47

is positive only for emerging markets (0.55%, t =1.48), and negative for all other three categories (Europe: −0.26%, t = 0.70; Asia Pacific: −0.03, t = 0.10; North America has the lowest profitability premium of −0.08%, t = −0.2).

The investment premium (average CMA returns) is the highest for emerging markets (0.84%, t = 1.48), second-highest for Europe (0.80%, t = 2.31), followed by Asia Pacific (0.77%, t = 2.2), and North America (0.46%; t = 1.64). The sixth and additional factor that covers the premium against the most important global risk is the CR.

The first hypothesis of this study is related to the existence of premium on CR in equity returns across the four categories. As per the results, the CR premium is present across three categories; it is the highest in the Asia Pacific region (0.92% t = 2.47) followed by North America (0.77%, t =2.35), and Europe (0.65%, t= 2.27). Thus, for these three categories, the null hypothesis gets rejected against the alternative hypothesis, which postulates the existence of CR premium in equity returns. By contrast, emerging markets report the lowest and insignificant CR premium (0.25%, t = 0.73), implying that the null hypothesis is not rejected for emerging markets.

Table 3.3 presents the factors' average return results for small and big stocks. In line with Fama and French (2012), the value premium on small stocks is larger for only North America (1.15%, t = 1.49) while all remaining three categories display larger returns on big stocks. The profitability premium is larger and positive on small stocks for North America (0.01%, t = 0.01) and emerging markets (1.57%, t = 2.51) and negative for Asia Pacific (−0.17%, t = −0.27) and Europe (−0.73%, t = −1.10). The average values of investment premium CMA on big stocks are larger for North America (0.23%, t = 1.14) and Europe (0.34%, t = 1.44) and negative for emerging markets (−0.43%, t = −1.09) and Asia Pacific (−0.06%, t = −0.22). The most important impact to analyze here is the effect of firm size on CR premium. The second hypothesis of the study states that CR premium varies with firm size. Table 4 shows that firm size has a significant impact on the CR premium across three categories and there is no CR premium on small firms. These categories are Asia Pacific (−1.48%, t = −2.19), Europe (−1.28%, t = 2.54), North America (−1.25%, t = −2.05). By contrast, emerging markets do not report any market premium neither on big firms nor on small firms. In Europe, the CR premium values report very weak numbers, that is, when big numbers are subtracted from small numbers, still there is no CR premium. Therefore, I reject the second null hypothesis in favor of the alternative hypothesis that posits that firm size

Table 3.3 Small and Big components of factor returns

This table reports the equal weighted average returns for small and big stocks of HML, RMW, CMA and PMG factors. Value factor for small and big stocks is HMLS = SV – SG and HMLB = BV – BG. Profitability factor is RMWs = SV – SG and RMWB = BV – BG. Same pattern is repeated for Investment and Carbon risk factor (PMG).

	HML S	HML B	HML S-B	RMW S	RMW B	RMW S-B	CMA S	CMA B	CMA S-B	PMG S	PMG B	PMG S-B
							North America					
Mean	1.15	-0.12	1.27	0.01	-0.17	0.17	-1.16	0.23	1.39	-1.25	-0.28	-0.97
Std Dev	9.50	3.04	9.37	8.93	2.21	8.73	6.12	2.49	6.21	7.51	2.38	2.38
t –Mean	1.49	-0.50	1.67	0.01	-0.93	0.23	-2.34	1.14	2.77	-2.05	-1.44	-1.56
							Europe					
Mean	-0.04	-0.51	0.48	-0.73	0.20	-0.93	-1.96	0.35	-2.30	-1.29	-0.01	-1.28
Std Dev	9.74	4.53	8.91	8.19	2.83	8.09	8.37	2.97	9.15	6.25	3.08	6.84
t –Mean	-0.04	-1.39	0.66	-1.10	0.88	-1.42	-2.89	1.44	-3.11	-2.54	0.04	-2.31
							Emerging Markets					
Mean	-0.33	0.12	-0.46	1.57	-0.46	2.03	-1.24	-0.44	-0.79	-0.10	-0.39	0.28
Std Dev	8.34	5.00	9.82	7.74	4.31	8.44	8.01	4.96	9.14	7.09	3.86	7.75
t –Mean	-0.49	0.31	-0.57	2.51	-1.33	2.90	-1.90	-1.09	-1.07	-0.19	-1.24	0.44
							Asia Pacific					
Mean	-0.14	-0.14	0.00	-0.17	0.10	-0.28	-1.48	-0.06	1.42	-1.48	-0.35	-1.12
Std Dev	8.32	3.14	8.84	7.85	1.90	8.21	7.85	3.33	8.40	8.72	2.05	8.748
t –Mean	-0.20	-0.54	0.00	-0.27	0.68	-0.42	-0.63	-0.22	2.09	-2.19	-2.09	-1.59

Table 3.4 Correlation matrices for the same factor in different regions

	NA	Europe	Emerging Markets	Asia Pacific	NA	Europe	Emerging Markets	Asia Pacific
			Mkt				**SMB**	
NA	1.00	0.71	0.71	0.78	1.00	0.36	0.05	0.50
Europe	0.71	1.00	0.71	0.77	0.36	1.00	0.18	0.23
Em-Markets	0.71	0.71	1.00	0.75	0.06	0.18	1.00	0.13
Asia Pacific	0.78	0.77	0.75	1.00	0.50	0.23	0.13	1.00
Global	0.96	0.93	0.83	0.87	0.75	0.57	0.29	0.67
			HML				**RMW**	
NA	1.00	0.35	0.22	0.07	1.00	0.04	0.05	0.00
Europe	0.35	1.00	0.13	0.18	0.04	1.00	0.06	0.03
Em-Markets	0.22	0.13	1.00	0.00	0.05	0.06	1.00	0.15
Asia Pacific	0.07	0.18	0.00	1.00	0.00	0.03	0.15	1.00
Global	0.46	0.71	0.29	0.32	0.29	0.22	0.26	0.24
			CMA				**PMG**	
NA	1.00	0.10	-0.02	0.09	1.00	0.19	0.09	0.24
Europe	0.10	1.00	-0.04	-0.07	0.18	1.00	0.13	0.26
Em-Markets	-0.02	-0.04	1.00	0.05	0.09	0.13	1.00	0.05
Asia Pacific	0.09	-0.07	0.05	1.00	0.24	0.26	0.05	1.00
Global	0.40	0.41	0.15	0.33	0.44	0.67	0.17	0.48

has an impact on the CR premium as the results provide sufficient evidence that small firms are more prone to CR compared with big firms.

Table 3.4 reports the correlation for each of the six factors. The results demonstrate that the correlation is high in the Mkt factor across the regions, consistent with the results of Fama and French (2017). North America and Europe are the most correlated regions with the coefficient of correlation being 0.972, and hence, are of special interest.

The correlation between North America and the Asia Pacific is 0.967 and Europe and the Asia Pacific is 0.957. The lowest correlation, of 0.948, is between Europe and emerging markets. Regarding the remaining five non-market factors, Europe and North America are the most correlated. Other than the PMG factor, SMB is 0.364, HML is 0.333, RMW is 0.088, CMA is 0.128, while the PMG factor reports the highest correction between the Asia Pacific and Europe (0.211) and the second-highest for North America and Europe (0.126). The investment factor CMA is the least correlated across the four categories, with the lowest and negative correlation being between the Asia Pacific and Europe (−0.041). The newly introduced PMG factor reports all positive correlations across the four regions, with the lowest and almost zero correlation being between the Asia Pacific and North America (0.008), followed by that between North America and emerging markets (0.071), emerging markets and Europe (0.076), and North America and Europe (0.126).

3.3. Test Portfolios

3.3.1. LHS Portfolios

To increase the power of the test through the precision of regression intercepts, diversified LHS portfolios are generated at the end of June in each year t. LHS portfolios are constructed based on two different sorting processes, one, the 3x3 sort and the other, the 2x4x4 sort. In the 3x3 sorting, nine portfolios are produced for each size–OP, size–Inv, size–B/M, and size–C_risk with the seven and 13 percentile breakpoints of the category's aggregate market cap. The 3x3 sorts breakpoints follow the same rules as 2x3 sorts except that 30–40–30 quintiles are used instead of 90% of the market cap for the allocation of big and small stocks in each category. Further 3x3 sorting is the independent intersection of size and OP, size and B/M, size and investment, and size and CR, the new addition.

Fama and French (2017) recommend more diversification of LHS portfolios because of the considerable correction among B/M, OP, and Inv, which ultimately affect the average returns. To disentangle the effects on average returns, the variables are sorted jointly on size, B/M, OP, and Inv. To avoid poor diversification, portfolios are sorted in

2x4x4 rather than 3x3x3x3 sorts. Under the 2x4x4 sorting, the first classification is based on size groups; big includes the top 90% and small the bottom 10% of a category's market cap, while the following classification is based on quartiles to create the four groups for each variable B/M, OP, Inv, and C_risk. The independent intersection of the 4x4 sorts process yields 32 portfolios on each variable for each category to use as LHS portfolios.

4. Empirical Results and Discussion

4.1. Factor Spanning Tests

The factor spanning test is used here to evaluate the extent of average returns that can be explained through regression intercepts and detect which factors are potentially redundant. Table 4.1 presents the regression results for each of the four categories, in which five factors explain the average returns on the sixth factor. It is interesting to observe whether the redundant factors are the same or different across each category. The intercept of regression presents the unexplained and leftover average premium by other factors (Barillas et al., 2020). A factor will be counted redundant and can be dropped from the RHS factor equation if it is an insignificant intercept close to zero, as the other factors would have captured its premium in the model (Fama & French, 2015). The market factor, Mkt, is not redundant for North America, Asia Pacific, and the global portfolios. North America has the highest significant and positive intercept (1.12% per month, t = 3.83), followed by Asia Pacific (0.58% per month, t = 1.73). However, Mkt slope is insignificant for Europe (0.55% per month, t = 1.39) and insignificant and smaller for emerging markets (0.41% per month, t = 1.51).

The size factor SMB is negative but significant for North America (−1.07% per month, t = −2.84), Europe (−0.86% per month, t = −2.56), and emerging markets (−1.04% per month, t = −3.08), while Asia Pacific (0.4% per month, t = 0.78) reports redundant size factor. The negative intercept SMB is mainly due to positive slopes of Mkt, HML, and CMA, which is more than sufficient to absorb the positive average SMB return.

Table 4.1 In each region five factors in every regression equation are used to explain the average returns on sixth factor: June 2007– February 2020, 153 months Mkt presents the value-weight return on the market portfolio of the stocks" of a region, minus the one-month Treasury bill rate; SMB (small minus big) is the size factor; HML (high minus low B/M) is the value factor; RMW (robust minus weak OP) is the profitability factor; and CMA (conservative minus aggressive Inv) is the investment factor and the last Carbon risk factor PMG (Pollutant minus Green). The following Right Hand Side (RHS) factors are constructed by sorting the size factor into two groups and rest of the factors into three groups.

	Coefficients							t-Statistics							
	Int	**Mkt**	**SMB**	**HML**	**RMW**	**CMA**	**PMG**	**Int**	**Mkt**	**SMB**	**HML**	**RMW**	**CMA**	**PMG**	**R2**
North America															
Mkt	1.127		0.232	0.106	0.116	0.016	0.087	3.83		3.71	1.44	1.66	0.18	1.07	0.129
SMB	-1.073	0.369		0.311	-0.230	0.246	-0.284	-2.84	3.71		3.45	-2.64	2.16	-2.83	0.389
HML	0.621	0.131	0.241		-0.392	0.371	-0.414	1.84	1.44	3.45		-5.49	3.84	-4.93	0.472
RMW	-0.176	0.158	-0.197	-0.434		0.503	-0.270	-0.49	1.66	-2.64	-5.49		5.11	-2.92	0.324
CMA	0.240	0.013	0.125	0.245	0.300		0.238	0.87	0.18	2.16	3.84	5.11		3.36	0.230
PMG	0.579	0.089	-0.182	-0.343	-0.202	0.299		1.88	1.07	-2.83	-4.93	-2.92	3.36		0.273
Europe															
Mkt	0.552		-0.187	0.334	0.101	0.110	0.205	1.39		-1.99	0.082	1.09	1.09	1.94	0.147
SMB	-0.869	-0.141		0.387	0.049	0.350	0.156	-2.56	-1.99		5.73	0.62	4.24	1.70	0.389
HML	-0.460	0.305	0.471		-0.489	0.205	-0.015	-1.21	4.08	5.73		-6.19	2.16	-0.15	0.523
RMW	-0.495	0.079	0.052	-0.423		0.033	0.099	-1.40	1.09	0.62	-6.19		0.37	1.05	0.263
CMA	1.149	0.073	0.311	0.149	0.028		-0.205	3.69	1.09	4.24	2.16	0.37		-2.39	0.287
PMG	0.806	0.121	0.123	-0.009	0.074	-0.182		2.68	1.94	1.70	-0.15	1.05	-2.39		0.070
Emerging Markets															
Mkt	0.410		-0.113	0.266	-0.199	0.025	0.039	1.51		-1.76	4.80	-3.43	0.45	0.58	0.806
SMB	-1.042	-0.183		0.126	-0.199	0.149	-0.207	-3.08	-1.76		1.68	-2.65	2.12	-2.45	0.101
HML	-0.085	0.511	0.149		0.067	-0.061	-0.198	-0.22	4.80	1.68		0.80	-0.79	-2.14	0.189
RMW	0.349	-0.373	-0.229	0.065		0.082	0.144	0.93	-3.43	-2.65	0.80		1.07	1.57	0.146
CMA	0.908	0.055	0.199	-0.069	0.094		0.319	2.29	0.45	2.12	-0.79	1.07		3.32	0.103
PMG	-0.262		-0.189	-0.153	0.114	0.219		-0.78	0.58	-2.45	-2.14	1.57	3.32		0.173
		0.058													
Asia Pacific															
Mkt	0.589		0.164	-0.147	-0.108	-0.007	-0.095	1.73		3.06	-1.78	-1.15	-0.09	-1.06	0.091
SMB	0.400	0.366		0.032	-0.189	-0.015	-0.267	0.78	3.06		0.25	-1.35	-0.13	-2.02	0.232
HML	0.379	-0.144	0.014		-0.207	0.018	-0.499	1.12	-1.78	0.25		-2.26	0.23	-6.33	0.232
RMW	0.507	-0.083	-0.065	-0.162		-0.175	-0.389	1.70	-1.15	-1.35	-2.26		-2.57	-5.40	0.236
CMA	0.658	-0.008	-0.007	0.020	-0.246		0.126	1.86	-0.09	-0.13	0.23	-2.57		1.35	0.091
PMG	0.851	-0.079	-0.101	-0.429	-0.426	0.098		2.77	-1.06	-2.02	-6.33	-5.40	1.35		0.372

The main factor to be sought for redundancy is the value factor, HML. Other than North America (0.62% per month, t = 1.84), the value factor is redundant for the remaining three regions, namely Europe (−0.46% per month, t = −1.21), emerging markets (−0.08% per month, t = −0.22), and Asia Pacific (0.37% per month, t =1.12).

The profitability factor RMW is the most redundant factor of the study—only one category, Asia Pacific, is positive and significant but with weak values (0.50% per month, t = 1.70)—while it is insignificant for the remaining three categories of North America (−0.17% per month, t = −0.49), Europe (−0.49% per month, t = −1.40), and emerging markets (0.34% per month, t = 0.93).

The investment factor CMA is positive for all categories and redundant only in North America (0.24% per month, t = 0.87). The intercept in the CMA regressions for Europe, emerging markets, Asia Pacific, and the global portfolios are 1.14% per month (t= 3.69), 0.90% per month (t = 2.29), 0.90% per month (t = 2.29), and (0.65% per month (t = 1.86), respectively.

The CR factor PMG is found to be positive and significant for all categories other than emerging markets, where it is redundant with average returns of −0.26% per month and t value of −0.78. This shows that the PMG factor can improve the description of average return in this factor spanning tests. The PMG regression intercepts for North America is 0.57% per month (t = 1.88), Europe is 0.80% (t = 2.68), and Asia Pacific is 0.85% (t = 2.77).

In sum, the factor spanning test results found that Mkt, CMA, and PMG are promising factors that majorly explain the average returns. In line with Fama and French (2017), SMB and HML factors are reported redundant in overall global portfolios and the Asia Pacific. Finally, the investment factor, RMW, seems redundant everywhere except the Asia Pacific.

4.2. Asset Pricing Tests

The central theme of this study is to test the performance of asset pricing models. Given that a new factor, the CR premium (PMG), is introduced that extends the five-factor model to the six-factor model, examining the performance comparison becomes fundamental. A model will be considered best if the regression intercepts for a set of double-sort portfolios is indistinguishable from zero. The intercepts are estimated using the GRS F-statistic proposed by (Gibbons, Ross, & Shanken, 1989) to test the null hypothesis that the slope of all regressions is jointly equal to zero.

Moreover, GRS helps analyze the relative performance of the asset pricing model. To evaluate the performance of competing models, the zero or close to zero-sum of intercepts serves as a reference point to compute the dispersion of unexplained part of LHS average returns relative to the dispersion of LHS average returns. This assures that the model captures most of the variation in the average returns on the portfolios. To pass the GRS test, F-statistics should be close to 1.0, which leads to the decision where the null hypothesis is not rejected.

The null hypothesis of the GRS model is expressed as the following equation

$H_0 : \alpha_i \ = 0 \ i = 1, \ldots,$ N,

Here, α_i is the sum of LHS portfolios intercepts, the LHS portfolios are the value-weighted average returns on portfolio i minus risk-free rate defined as $\bar{r}_i$. The dispersion is computed by the ratio of unexplained dispersion Aa_i^2 on LHS portfolios to total dispersion on LHS portfolios, that is, $\frac{Aa_i^2}{A\bar{r}_i^2}$. Further, GRS computations include the unexplained dispersion attributed to sampling error, $\frac{As^2(a_i)}{Aa_i^2}$, where, $As^2(a_i)$ denotes the average of the squared sample standard errors of a_i and Aa_i^2 is the average squared intercept. A good model shows a low value of $\frac{Aa_i^2}{A\bar{r}_i^2}$, the ratio of unexplained dispersion to total dispersion, and high value of $\frac{As^2(a_i)}{Aa_i^2}$, the ratio of sampling error to unexplained dispersion.

The GRS test results in Table 4.2 demonstrate that the five- and six-factor models are rejected for North America, while the three-factor model, which explains the average returns better than the other two models, is accepted. The GRS results are similar for emerging markets, favoring the three-factor model but with significant values, thereby leading to the rejection of near to zero cumulative intercepts, which is against the passing criteria of GRS test statistics. However, for the Asia Pacific, the six-factor model outperforms the three- and five-factor models by better explaining the average returns, although the level of significance does not support the GRS results in its favor. The GRS test results for Europe for size–B/M–OP sorts rejects the three- and five-factor models while accepting the six-factor model that better explains the average returns and does not reject the null hypothesis of zero intercepts.

Table 4.2

Statistical summary to explain the monthly excess returns on the (2x4x4) sorts for Size-B/M-OP portfolios, Size-BM-Inv portfolios, Size-OP-Inv portfolios, Size-BM-CR portfolios, Size-OP-CR portfolios and Size-Inv-CR portfolios. GRS statistics are shown for three, five and six factor model for four regions including; North America, Europe, Emerging Markets and Asia Pacific: June 2007 to February 2020. Sampling error to unexplained dispersion $\frac{As^2(a_i)}{Aa_i^2}$, ratio of unexplained dispersion to total dispersion $\frac{Aa_i^2}{A\bar{r}_i^2}$ and average adjusted R2 of the nine regressions.

Model factors	GRS	p(GRS)	$\frac{As^2(a_i)}{Aa_i^2}$	$\frac{Aa_i^2}{A\bar{r}_i^2}$	AR^2	GRS	p(GRS)	$\frac{As^2(a_i)}{Aa_i^2}$	$\frac{Aa_i^2}{A\bar{r}_i^2}$	AR^2
Panel A: 32 Size BM OP portfolios										
			North America					**Europe**		
Mkt SMB HML	0.722	0.855	0.342	0.290	0.645	1.226	0.215	0.373	0.427	0.612
Mkt SMB HML RMW CMA	0.823	0.732	0.333	0.351	0.670	1.148	0.292	0.384	0.342	0.620
Mkt SMB HML RMW CMA PMG	0.751	0.823	0.330	0.429	0.682	1.150	0.290	0.390	0.305	0.626
			Emerging Markets					**Asia Pacific**		
Mkt SMB HML	2.312	0.000	0.461	0.453	0.390	1.695	0.022	0.270	0.390	0.691
Mkt SMB HML RMW CMA	2.742	0.000	0.460	0.521	0.428	1.676	0.024	0.280	0.380	0.695
Mkt SMB HML RMW CMA PMG	2.725	0.000	0.450	0.511	0.448	1.519	0.056	0.280	0.370	0.696
Panel B: 32 Size BM Inv portfolios										
			North America					**Europe**		
Mkt SMB HML	1.282	0.170	0.324	0.256	0.649	1.402	0.099	0.367	0.344	0.612
Mkt SMB HML RMW CMA	1.580	0.041	0.320	0.281	0.670	1.369	0.115	0.379	0.347	0.618
Mkt SMB HML RMW CMA PMG	1.446	0.081	0.313	0.325	0.685	1.365	0.118	0.386	0.310	0.623
			Emerging Markets					**Asia Pacific**		
Mkt SMB HML	1.138	0.302	0.413	0.355	0.438	1.519	0.057	0.280	0.371	0.697
Mkt SMB HML RMW CMA	1.151	0.288	0.408	0.373	0.470	1.370	0.114	0.282	0.306	0.665
Mkt SMB HML RMW CMA PMG	1.167	0.272	0.404	0.375	0.483	1.367	0.117	0.289	0.296	0.673
Panel C: 32 Size OP Inv portfolios										
			North America					**Europe**		
Mkt SMB HML	1.496	0.062	0.333	0.241	0.638	1.140	0.299	0.370	0.339	0.610
Mkt SMB HML RMW CMA	1.582	0.040	0.330	0.278	0.658	0.991	0.489	0.380	0.300	0.619
Mkt SMB HML RMW CMA PMG	1.453	0.078	0.320	0.312	0.670	1.039	0.424	0.387	0.230	0.624
			Emerging Markets					**Asia Pacific**		
Mkt SMB HML	1.260	0.186	0.402	0.325	0.447	1.126	0.315	0.273	0.245	0.677
Mkt SMB HML RMW CMA	1.339	0.132	0.400	0.365	0.481	1.131	0.310	0.272	0.242	0.685
Mkt SMB HML RMW CMA PMG	1.355	0.124	0.392	0.366	0.492	1.297	0.160	0.270	0.255	0.688

Table 4.2 continued

Model factors	GRS	p(GRS)	$\frac{As^2(a_i)}{Aa_i^2}$	$\frac{Aa_i^2}{A\bar{r}_i^2}$	AR^2	GRS	p(GRS)	$\frac{As^2(a_i)}{Aa_i^2}$	$\frac{Aa_i^2}{A\bar{r}_i^2}$	AR^2
Panel D: 32 Size Inv ER portfolios			**North America**				**Europe**			
Mkt SMB HML	1.339	0.132	0.335	0.313	0.654	1.348	0.127	0.355	0.335	0.625
Mkt SMB HML RMW CMA	1.319	0.145	0.330	0.325	0.670	1.147	0.293	0.368	0.320	0.629
Mkt SMB HML RMW CMA PMG	1.223	0.218	0.325	0.370	0.686	1.003	0.474	0.374	0.287	0.636
			Emerging Markets				**Asia Pacific**			
Mkt SMB HML	1.897	0.007	0.404	0.351	0.446	2.059	0.002	0.286	0.326	0.655
Mkt SMB HML RMW CMA	1.861	0.008	0.401	0.384	0.472	1.952	0.005	0.287	0.319	0.665
Mkt SMB HML RMW CMA PMG	1.868	0.008	0.392	0.396	0.487	1.752	0.016	0.292	0.298	0.670
Panel E: 32 Size BM ER portfolios			**North America**					**Europe**		
Mkt SMB HML	1.730	0.018	0.342	0.387	0.655	2.427	0.000	0.349	0.385	0.638
Mkt SMB HML RMW CMA	1.711	0.020	0.334	0.437	0.679	2.261	0.000	0.361	0.364	0.642
Mkt SMB HML RMW CMA PMG	1.575	0.042	0.328	0.508	0.697	1.971	0.005	0.367	0.319	0.647
			Emerging Markets					**Asia Pacific**		
Mkt SMB HML	1.490	0.064	0.428	0.406	0.417	2.007	0.003	0.260	0.397	0.717
Mkt SMB HML RMW CMA	1.791	0.013	0.423	0.441	0.452	1.912	0.006	0.260	0.386	0.720
Mkt SMB HML RMW CMA PMG	2.041	0.003	0.418	0.453	0.469	1.643	0.029	0.268	0.345	0.723
Panel F: 32 Size OP ER portfolios			**North America**					**Europe**		
Mkt SMB HML	1.609	0.035	0.331	0.328	0.663	1.537	0.051	0.344	0.322	0.637
Mkt SMB HML RMW CMA	1.647	0.029	0.324	0.354	0.683	1.75	0.017	0.356	0.311	0.639
Mkt SMB HML RMW CMA PMG	1.515	0.057	0.318	0.389	0.702	1.488	0.066	0.362	0.246	0.646
			Emerging Markets					**Asia Pacific**		
Mkt SMB HML	1.318	0.145	0.432	0.395	0.402	1.993	0.004	0.256	0.396	0.707
Mkt SMB HML RMW CMA	1.331	0.137	0.428	0.481	0.435	1.916	0.006	0.259	0.384	0.709
Mkt SMB HML RMW CMA PMG	1.493	0.064	0.420	0.482	0.456	1.754	0.016	0.264	0.344	0.714

5. Conclusion

Taking the accounting variables and stock returns data of 51 countries around the globe, I constructed four categories of international markets, namely, North America, Europe, emerging markets, and the Asia Pacific I followed the methodology of Fama and French (2017), who included 23 countries and classified them into four regions, where Japan was a separate region. All these 23 countries were included in this study and a new category of emerging markets was designed to cover the markets of emerging countries. This, the four categories were (1) North America, containing two countries (the US and Canada) same as Fama and French (2017). (2) Europe, comprising Austria, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom. This study has three differences compared with Fama and French (2017), who included 16 countries in Europe, unlike this study, which includes 15 countries; the two countries—Belgium and Greece—are included in emerging markets while the country not considered by Fama and French (2017), namely, Luxemburg is included in Europe in this study. (3) The Asia Pacific included only four countries (Australia, New Zealand, Hong Kong, and Singapore) in the sample of Fama and French (2017), while my sample of Asia Pacific not only included all these four countries but also Japan and Israel. Moreover, the new category introduced in this study, the emerging markets, contained countries, namely, Argentina, Bahrain, Brazil, Chile, China, Colombia, Czech Republic, Egypt, Greece, Hungary, India, Indonesia, Kuwait, Malaysia, Morocco, Mexico, Oman, Poland, the Philippines, Peru, Qatar, Russian Federation, South Africa, South Korea, Saudi Arabia, Taiwan, Thailand, and the United Arab Emirates.

Methodology part provided the construction details of asset pricing factors, following the standards of Fama and French (1993, 2015, 2017) along with the addition of the new risk factor to Fama and French's five-factor model, the CR factor (PMG). Methodology part further presented the summary statistics of all six factors and their respective size impacts. All four categories showed positive and significant premium on average market returns (equity premium). The average market premiums were largest in North America followed by Europe and the Asia Pacific. The higher equity premium can be attributed to a low risk-free rate (as the US one month T-bill was used here as the risk-free rate). Further, it was shown that the equity premium was associated with the risk-free rate puzzle (Mehra & Prescott, 1985; Weil, 1989). None of the categories reported size (SMB) premium in equity returns; these results were in line with those in Fama and French (2012, 2017; Gregory et al., 2013).

The value (HML) premium was statistically insignificant for all four categories. These results rejected the well-documented value premium anomaly, which states value stocks (stocks with high B/M ratios) earn higher average returns than the growth stocks (stocks with low B/M ratios). Current results confirmed the value stock across the four categories were not risker than growth stocks; thus, there was no extra compensation for bearing extra risk. When decomposing value premium on the small and big stocks separately, only one category, North America, reported positive and significant HML returns that show when big stocks in North America are separated from small stocks, then higher returns are offered when big stocks earn any compensation without bearing any risk. No profitability (RMW) premium was present in any of the categories, which verified that higher profitability did not lead to higher returns in any of the four categories. Thus, profitability was not priced as per the current results. The results changed only for small stocks of emerging markets, where micro-cap stocks reported profitability premium. Hence, size mattered for the RMW factor premium in emerging markets only, while for the other three categories, RMW was indifferent to firm size.

Investment factor was priced in Europe and the Asia Pacific, while in North America, it also offered a premium but with marginal statistical significance at the 10% level. Emerging markets lacked investment premium. The main focus of this study, the CR factor, was found to be priced in North America, Europe, and the Asia Pacific, whereas emerging markets did not report any premium for bearing CR. Further, the firm size played a critical role in the determination of CR premium because firm size segregation was a reason to lose the risk premium. In all the three categories of North America, Europe, and the Asia Pacific, small stocks did not show any significant evidence of CR premium. This proves small firms are more prone to CR premium and need to take more steps to mitigate climate change risk.

To upsurge the power of asset pricing tests, the LHS portfolios were generated at the end of June in each year t. Base on two different sorting processes, one the 3x3 sort, and the other, the 2x4x4 sort. According to the results of the 3x3 sorting criteria, size-effect anomalies were found in the LHS portfolios of CR. In the markets of North America and Europe, the average excess returns fell as firm size and CO2 emissions increased. For the biggest carbon emitter, that is, North America, these results put high pressure on big firms to account for their carbon emissions as it negatively affects their cross-sectional stock returns. Similar results were found in the Asia Pacific, while emerging markets revealed different results, showing that big firms earn more returns with increases in CR.

Three more triple sorted 2x4x4 LHS portfolio categories (size–B/M–CR, size–OP–CR, and size–Inv–CR) were added in the study to clearly identify the role of CR in the asset pricing model. The size–B/M–CR sorts reported size-effect and reverse of value-effect anomalies across the four categories, which led to a decline in the average excess returns with an increase in the level of CO2 emissions by firms. The profitability of firms was also affected by CR. Thus, no size-effect anomaly was present as with the increase in CR, the average stock returns fall and the firms with lower profitability are affected more. Hence, it can be concluded that the less profitable firms take extra care of carbon dioxide emissions as it further reduces their stock returns, and this characteristic is observed across all four categories.

The size–Inv–CR sorts reported size-effect and the CR anomalies at different levels of investment across the four categories. The small-cap firms were more prone to CR with increasing level of investment, implying that when small-cap firms take investment decision, they have to be mindful of their CO2 emissions to increase the firm value and stock returns because, with a higher level of CO2 emissions, more investment can lead to lower returns. Similar patterns were found in the mega-caps, who also need to take cognizance of their investment decisions in the situation of higher carbon emissions to avoid declining returns.

The main results reported in results and discussion part extended the asset pricing literature by incorporating a new risk factor, namely, CR, in the asset pricing models. At first, using the factor spanning test, I tested the power of regression intercepts to explain the average returns (six for each region), where the five-factor explained the return on the sixth factor across four categories of North America, Europe, emerging markets, and the Asia Pacific. As the factors to explain average returns keep increasing and are tested gradually, it is important to distinguish between essential and redundant factors to be included in the asset pricing model. The size factor SMB was found to be negatively significant in three categories—North America, Europe, and emerging markets—while it was redundant in the Asia Pacific. The negative intercept SMB in the three regions was mainly due to positive slopes of Mkt, HML, and CMA which more than sufficed to absorb the positive average SMB return.

As per previous studies of Fama and French (1993, 2015, 2017), the main factor to test for redundancy is the HML value factor that was observed to be redundant in the markets of all the four categories other than North America. This implied that in three categories, all the factors other than HML could better explain the average returns. In addition to the value factor, the profitability factor RMW was found to be redundant in North America, Europe, and emerging markets, while the Asia Pacific reported positive significance. The investment factor CMA was positive for all the four categories and redundant only in North America. The main contributive factor of this study, the CR factor PMG, was reported as a factor that played an essential role in describing the average returns in three categories. However, in emerging markets, the CR factor was reported to be negative and insignificant, and hence, was regarded as redundant in explaining the average returns.

To assess the performance of the six-factor model (five-factor model with the addition of the CR factor, PMG) vis-à-vis the three-factor and the five-factor model proposed by Fama and French (1993, 2015), I used the GRS test on the two sets of the LHS test portfolios. Particularly, the 3x3 and 2x4x4 that were sorted based on size, B/M, OP, investment, and CR in North America, Europe, emerging markets, and the Asia Pacific. The GRS test results were fairly encouraging and in favor of the six-factor model proposed in this study. The results suggest that the CR factor (PMG) is useful for explaining the cross-sectional average returns. The findings lead to the assumption that the PMG factor improves the GRS results and proved that the corporate carbon emissions are a risk encountered by firms in the form of lower profits and for investors in the shape of declining returns and to the whole world in the form of environmental pollution and global warming.

This study presents a robust contribution to the asset pricing and climate finance literature. The methodology used to develop the CR factor (PMG) can be used to expand the asset pricing model and the set of test asset portfolios. To the best of my knowledge, none of the studies have incorporated only corporate CO2 emissions—the most significant contributor to climate change—to develop the factor in the asset pricing model. Moreover, the results show that the explaining power of return variation through the factor model improves with the addition of the CR factor. A strong size factor anomaly is present as CR does not appear to be priced in small-sized firms and small-cap firms are more prone to the negative impacts of CR than mega-cap firms. Further, the adverse effect of CR due to the size-effect anomaly prevails in B/M, OP, and investment portfolios. The results of this study are useful for investors, policymakers, brokers, corporations, governmental pollution abatement institutions, and those wishing to obtain CR premium.

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