NGFS Occasional Paper

Case Studies of Environmental Risk Analysis Methodologies

SEPTEMBER 2020

Central Banks and Supervisors
Network for Greening the Financial System

Editors

Ma Jun (Special Advisor to PBC Governor; Chair of the NGFS workstream “Supervision”; Director of Research Center for Green Finance Development at Tsinghua University)

Ben Caldecott (Director, Oxford Sustainable Finance Programme & Associate Professor, University of Oxford; COP26 Strategy Advisor for Finance, Cabinet Office, UK Government)

Ulrich Volz (Director of the SOAS Centre for Sustainable Finance & Reader in Economics, SOAS, University of London; Senior Research Fellow at the German Development Institute)

Disclaimer

With the exception of chapter 1, the views and opinions expressed in this volume are those of the authors alone and do not reflect those of the Central Banks and Supervisors Network for Greening the Financial System (NGFS) or the editors.

Table of Contents

Chapter 34 CARIMA – A Capital Market-Based Approach to Quantifying and Managing Transition Risks

By

University of Augsburg and VfU[1,2]

Abstract

The impact of uncertainty associated with the ongoing transition towards a green and in particular low-carbon economy affects virtually all financial market participants. If the transition process accelerates compared to current expectations, the values of carbon-based firms are likely to decline, while the values of low-carbon firms will tend to benefit from this development. On the other hand, if the transition process decelerates unexpectedly, the reverse could happen.

The central goal of CARIMA is to quantify exactly those types of risks as well as opportunities for firm values via a capital-market based approach. Using a factor model, carbon risks are simply “extracted” from the historical returns of global stock prices using the Carbon Risk Factor BMG (Brown-Minus-Green) return time-series.

The CARIMA concept is essentially directed towards key players in the financial industry, such as portfolio managers, who want to take carbon risks in their asset management process into account. CARIMA also addresses further stakeholder groups, such as firms, regulatory authorities, politicians, and finally scientists.

Keywords: carbon risk, carbon beta, climate finance, economic transition, asset pricing, factor models, carbon risk management

1 Introduction

The research project Carbon Risk Management (CARIMA), funded by the German Federal Ministry of Education and Research (BMBF), aims to quantify the existing risks and opportunities for the values of financial assets and respective portfolios in light of climate change and the transition towards a green economy, since values of firms, in many cases, also depend on the expected developments of this transition process. If the transition process accelerates compared to current expectations, the values of carbon-based (“brown”) firms are likely to decline, while the values of low-carbon (“green”) firms will tend to benefit from this development. On the other hand, if the transition process decelerates unexpectedly, the reverse could happen.

---

[1] This chapter is written by Maximilian Görgen, Research Assistant, Chair of Finance and Banking, Faculty of Business Administration and Economics, University of Augsburg, email: maximilian.goergen@wiwi.uni-augsburg.de; Marco Wilkens, Professor/ Chair holder, Chair of Finance and Banking, Faculty of Business Administration and Economics, University of Augsburg, email: marco.wilkens@wiwi.uni-augsburg.de; Henrik Ohlsen, Managing Director, Verein für Umweltmanagement und Nachhaltigkeit in Finanzinstituten e.V. (VfU), email: ohlsen@vfu.de.

[2] The project Carbon Risk Management (CARIMA; funding code: 01LA1601) is sponsored by the German Federal Ministry of Education and Research.

A key challenge for policy is to plan and shape the transition process of the economy in such a way that it results in the lowest possible uncertainties for firm values and thus avoids unnecessary welfare losses that will affect not only the firms, but also society as a whole. An unstructured transition towards a green and low-carbon economy that does not consider such losses would have unforeseen consequences. It is therefore vital that the risks arising from the uncertainty associated with the transition process be as transparent, quantifiable, and manageable as possible.

The impact of uncertainty associated with the transition process affects virtually all financial market participants, as the risks for firm values are directly reflected in the risks for all financial assets issued by firms, such as stocks, corporate bonds, loans, and hybrid financial assets. Since all these financial assets are in turn an integral part of a vast array of portfolios including investment funds, pension funds, pensions offices, life insurances, and portfolios by private investors, such portfolios are exposed to these risks as well.

It is therefore a key challenge for investors and financial intermediaries to assess how well firms can or cannot adapt to the transition process and to take this into account in their investment decisions. An important challenge for central banks and supervisors is to understand the impact of the transition process on the financial institutions they monitor and the overall stability of financial markets.

Risks threatening the existence of firms are particularly worrisome. These ultimately affect not only shareholders or lenders, but also employees, suppliers, and consumers. The transition process of the economy must not lead to unnecessary frictions due to an inappropriate handling of the associated risks of the transition process, as these risks ultimately determine the welfare of all people.

The central goal of CARIMA is to quantify exactly those types of risks as well as opportunities for firm values − the so-called "carbon risks", also often referred to as "transition risks". A rational handling of these carbon risks is necessary to achieve the Paris Agreement's target to keep global warming well below 2°C while avoiding unnecessary socioeconomic losses.

As far as we are aware, CARIMA is currently the only concept to derive such a risk measure based on a capital market-based approach. Compared to other approaches, a crucial advantage of CARIMA is that when applying the CARIMA approach using the freely available Carbon Risk Factor BMG (Brown-Minus-Green), there is no need for detailed fundamental climate change-relevant information about firms, which is often difficult and expensive to obtain or, in the case of many small caps, may not even be available.

The two-year project carried out by the two peer project partners, the University of Augsburg and the Verein für Umweltmanagement und Nachhaltigkeit in Finanzinstituten e.V. (VfU), ended in August 2019. The CARIMA concept was presented to financial practitioners at a rollout-conference and many other workshops and conferences. The CARIMA handbook as well as its related Excel tool and the Working Paper "Carbon Risk" (Görgen et al., 2019) describe the general approach and contain the key results of the project. The corresponding files can be accessed and downloaded free of charge from the project website.[3]

The CARIMA concept is essentially directed towards key players in the financial industry, such as professional portfolio managers, who want to take carbon risks in their asset management

[3] See https://carima-project.de/en/

process into account. In addition, CARIMA also addresses further stakeholder groups, such as firms, regulatory authorities, politicians, and finally scientists.

2 CARIMA – a capital market-based approach

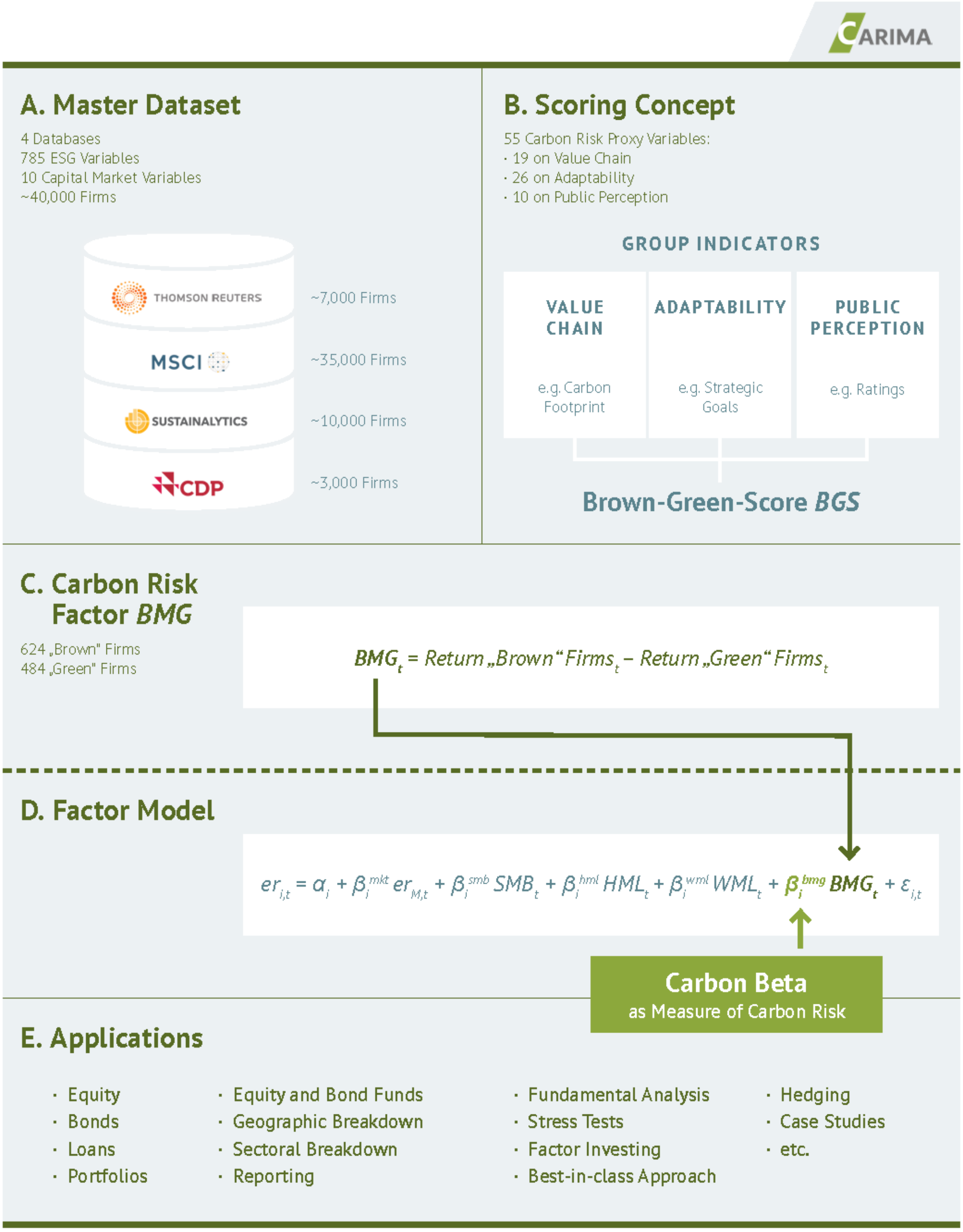
The core idea of CARIMA is to use fluctuations in stock prices to determine the risks and opportunities for single stocks and portfolios. The CARIMA concept thus derives the carbon risks directly from historical stock prices on the capital market, where new information about the expectations of market participants concerning the transition towards a green economy is constantly processed and priced.

Thus, the CARIMA concept presents a capital market-based approach where carbon risks and opportunities of the economy's transition process can be quantified comparatively easy, since they are simply “extracted” from the historical returns of global stock prices using a Carbon Risk Factor *BMG* (Brown-Minus-Green) in a factor model.

3 Methodology introduction of the CARIMA concept

This section briefly outlines the different modules of the development and application of the CARIMA concept. Figure 34-1 shows an overview of the CARIMA concept with its five modules A to E.

Figure 34-1 The five modules of the CARIMA concept



<u>Module A:</u> Master dataset

The construction and calculation of a Carbon Risk Factor *BMG* with a high degree of discriminatory power requires a huge amount of fundamental information from firms. It is crucial that the data allow a sufficiently accurate assessment of a firm's change in value in the event of unexpected changes in the transition process of the economy. The better firms can be divided into highly selective portfolios in this respect, the more efficient the carbon risk factor calculated will be. Therefore, data from different databases, namely Thomson Reuters ESG, MSCI ESG-Stats and IVA-Ratings, Sustainalytics ESG Ratings, and CDP is used. This data is carefully prepared, processed, and combined with capital market data (e.g., return data) from Thomson Reuters Datastream.

The individual ESG databases used have different strengths and weaknesses. By combining the databases, some weaknesses in the individual databases are compensated for. For example, the dataset contains information on firms that was collected using various approaches, such as audited annual reports, external scorings, and ratings, (ESG) analyst assessments and self-disclosures. By combining the databases, database-specific distortions can be reduced and various estimation methods from analysts can be integrated. This gives us an extensive selection of firms from which to calculate a meaningful Carbon Risk Factor *BMG*.

***Module B:* Scoring concept**

Module B describes the 55 Carbon Risk Proxy Variables, which are selected to support a fundamental assessment of whether firm values (and thus their stock prices) are influenced positively or negatively by unexpected changes in the ongoing transition process. These 55 variables are assigned to one of the three group indicators “Value Chain”, “Adaptability”, and “Public Perception”, which represent three impact channels of carbon risk.

The first group indicator “Value Chain” contains Carbon Risk Proxy Variables that reflect the impact of carbon risk across a firm‘s value chain. This group indicator therefore contains variables that deal with all components of a firm’s value chain – such as its production, processes, products, technologies, and supply chain.

The second group indicator “Public Perception” consists of Carbon Risk Proxy Variables that map the influence of carbon risks through another impact channel, so-called public perception. For example, a firm with low-emission production may still be affected by carbon risks if the public believes that the firm is particularly affected by unexpected changes in the transition process to a green economy.

The third group indicator “Adaptability” mainly comprises Carbon Risk Proxy variables that deal with the strategies, guidelines, and management of a firm. A firm can be prepared for unexpected changes in the transition process so that it can respond to these changes efficiently. The effect of the carbon risk on a firm is therefore reduced by a high degree of adaptability.

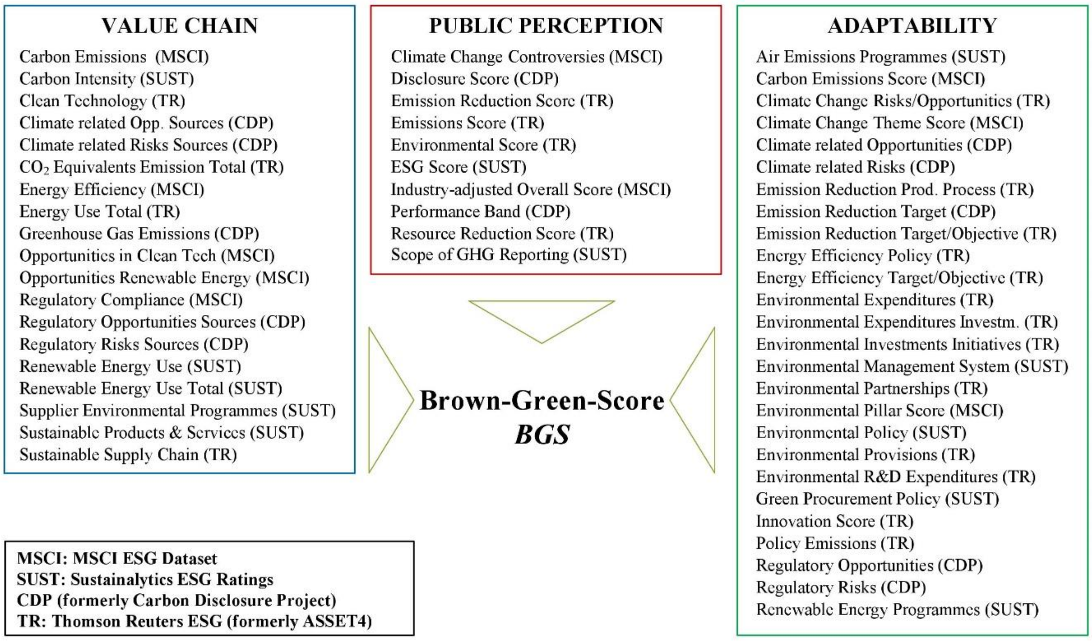
As part of the development of the CARIMA concept, the selection and allocation of variables were discussed and finalized in two specially organized workshop with climate and financial experts from NGOs, universities, and consulting firms to ensures the variables’ ability to accurately assess a firm’s change in value in the event of unexpected changes in the transition process of the economy as this is a prerequisite for the construction of highly selective portfolios and thus the efficiency of the Carbon Risk Factor *BMG* formed based on this information.

In a next step, the information from these 55 variables is condensed into the three group indicators via a simple scoring concept in order to calculate the so-called Brown-Green-Score *BGS* for each firm. A detailed documentation of this scoring concept and the aggregation of the three subscores to the final BGS can be found in the CARIMA manual.

This measure ultimately provides a fundamental assessment of the direction and strength of the changes in – or in other words risks to − firm values. *BGS* is determined annually for each firm. It is important to note that this scoring concept is only the prerequisite for deriving the

Carbon Risk Factor, which is described in the next paragraph. It is not an assessment measure on its own.

Figure 34-2 Assignment of the 55 Carbon Risk Proxy Variables to group indicators



<u>Module C:</u> Carbon risk factor BMG

Next, appropriate firms for the factor construction are selected. First, all non-listed firms are excluded. In addition, firms in the financial sector are not included, as their carbon risk differs significantly from firms in other sectors. For example, banks have almost no direct emissions of their own, but they finance firms with high emissions that can be particularly affected by carbon risks. Banks may therefore be indirectly affected by carbon risks through their loan portfolio, but this may not be reflected in the fundamental data. An in-depth analysis of the financial sector's carbon risk can be found in the CARIMA manual.

In addition, only firms that are represented in all four databases and for which data is available for at least five Carbon Risk Proxy Variables are used for factor construction. These conditions are necessary to minimize distortions in the database-specific data collection methodology.

In total, these criteria lead to a sample of 1,637 listed global firms from 50 countries. Table 34-1 shows the geographical and sectoral distribution of the 1,637 firms selected. Most of these firms are based in the USA, followed by Japan and the United Kingdom.

Table 34-1 Geographical and sectoral distribution of the 1,637 firms selected for the construction of the Carbon Risk Factor BMG

Country	**N**	**%**	**Sector**	**N**	**%**
USA	418	25.53	Industry	368	22.48
Japan	227	13.87	Consumer Cyclical	277	16.92
UK	193	11.79	Basic Materials	239	14.60
Canada	97	5.93	Technology	191	11.67
Australia	75	4.58	Consumer Defensive	167	10.20
France	66	4.03	Energy	118	7.21
South Africa	59	3.60	Utilities	104	6.35
Germany	53	3.24	Healthcare	109	6.66
Taiwan	48	2.93	Communication Services	64	3.91
South Korea	36	2.20			
Other Europe	237	14.48			
Other Asia	78	4.76			
Other Americas	37	2.26			
Other Oceania	13	0.79			
Total	1,637	100.00	Total	1,637	100.00

Looking at the sectoral breakdown of the dataset, most firms are active in the sectors "Industry", "Consumer Cyclical" and "Basic Materials". The Carbon Risk Factor *BMG* is constructed using firms from numerous countries and various sectors. This ensures that the factor contains global information from all sectors of the economy.

Based on their average Brown-Green-Score *BGS*, those 1,108 firms (624 "brown" and 484 "green" firms) are then assigned to one of two mimicking stock portfolios: the first portfolio consists of stocks of "brown" firms and the other of stocks of "green" firms. Breakpoints for this classification are the terciles of the average Brown-Green-Score *BGS*.

However, the Carbon Risk Factor *BMG* should also be as independent as possible from the size of a firm. Each firm is therefore assigned the characteristic "small" or "large" based on its market capitalization, independently of its BGS. This classification is based on the median.

Subsequently, the Carbon Risk Factor "Brown-Minus-Green" (*BMG*) can be formed from the historical returns of the four value-weighted portfolios described (brown/small (BS), brown/big (BB), green/small (GS) and green/big (GB) following formula 1:

$$BMG_t \;=\; 0.5\,(BS_t \;+\; BB_t) - 0.5\,(GS_t \;+\; GB_t) \qquad (5)$$

The Carbon Risk Factor *BMG* reflects a hypothetical portfolio that is invested long in "brown" and short in "green" stocks, thus reflecting the return difference between fundamentally "brown" and "green" firms.

Of course, it is also possible to consider other ways of constructing the Carbon Risk Factor *BMG*. For example, the threshold value of a characteristic that serves as the basis for the sorting into the different portfolios can be varied. Country-specific or sector-specific factors are also conceivable, depending on requirements. More information on such modifications can be found in the CARIMA manual.

We check the correlation between *BMG* and other risk factors and test an orthogonalized variant of the factor to ensure that *BMG* is not already covered by other common risk factors.

We also test the scoring concept for robustness by varying the weights for the subscores and breakpoints. More details can be found in the CARIMA manual.

Module D: ***Factor model***

Module D describes how the carbon risk of practically all stocks and other financial assets, as well as the portfolios containing them, can be estimated relatively easily based on the Carbon Risk Factor *BMG*.

Since stock market prices at any time reflect the speed of the transition process that market participants currently assume is occurring and thus which transition path is expected by society, the return time series of the Carbon Risk Factor *BMG*, constructed as a mimicking portfolio for carbon risk, contains such information in a condensed form. This information can be extracted by breaking down the firm's (or generally speaking a financial asset's) return time series into its individual components using a simple regression analysis. One of these components, besides other known risk components, such as a firm's exposure to common risk factors like SMB or HML, is a firm's carbon risk exposure, which is assessed by the Carbon Beta through the Carbon Risk Factor BMG. Thus, the Carbon Beta reflects the capital market's assessment of the carbon risk of the respective financial asset or portfolio.

So, who determines the Carbon Beta in the end? The answer is simple: all market participants, i.e., all buyers and sellers of the stocks and portfolios under consideration, i.e., all equity analysts and other capital market participants worldwide, because they determine the changes in stock prices worldwide, from which the Carbon Risk Factor *BMG* is calculated. It can also be said that the Carbon Beta is in principle the aggregated assessment of the carbon risk (of all participants) on the capital market.

Only the historical returns of the financial assets or portfolios are required as the dependent variable in the regression. The return time series of the explaining variables, such as the Carbon Risk Factor *BMG* and the other factors, are available on the project website and further publicly accessible websites, respectively.

Economic intuition and interpretation of the Carbon Beta

The Carbon Beta estimates the impacts or effects on firms, and their values or stock prices, of possible changes in expectations that may occur as the present economy moves towards a green economy. Sudden changes in expectations regarding the transition process of the economy are reflected in the Carbon Beta. The higher the absolute Carbon Beta value, the greater the impact (either upward or downward) on the stock price.

Estimation of the market's carbon risk

However, there may also be unexpected changes in the transition process that affect all firms ("brown", "neutral", and "green") to the same or at least a very similar extent. This "general market carbon risk" is not captured with the individual Carbon Betas of the stocks, as it is part of the total market risk. In general, the Carbon Beta is used to estimate the individual risk of a stock in relation to the overall market. It thus determines how the value of a stock is likely to change in relation to the market as a whole if expectations about the transition process of the economy change. The "general market carbon risk" can be estimated through the correlation between the market factor and the Carbon Risk Factor *BMG*. Our empirical research shows a (slightly) positive and constant correlation between the (global) market index and the Carbon Risk Factor *BMG.* This suggests that an acceleration of the transition process of the economy towards a green economy will tend to reduce the value of all stocks in the overall market.

In this context, as already described above, the CARIMA manual offers details on the use of an orthogonalized variant of risk factors in the regression model. Here, the correlation between *BMG* and the other factors in the factor model is set to zero without changing its variance structure. This ensures that the factor continues to explain only those risks that are specific to it and does not capture any other systematic effects.

Carbon Betas quantify risks and opportunities

The CARIMA concept does not only quantify the risk of losses, but also the chance of profits. When talking about risks in the following, not only negative events (i.e., risks in conventional language), but also positive events (i.e., opportunities in conventional language) are considered. In this respect, the Carbon Beta is comparable to the volatility (standard deviation) of equity returns, which is widely used in financial practice. This indicator also subsumes opportunities and risks.

<u>Module E:</u> Applications

A variety of potential applications for the Carbon Beta is included in Module E. The Carbon Beta can be determined for different asset classes such as stocks, corporate bonds, loans, portfolios, and funds. Furthermore, various country and sector aggregations and corresponding analyses are possible. Scenarios for stress testing the values of financial assets and portfolios can be generated based on the Carbon Beta. In portfolio management, the Carbon Beta can be integrated into investment strategies, such as Factor Investing and Best-in-class approaches and can be used for hedging carbon risks. The potential applications mentioned here are explained in more detail in the CARIMA manual and supported by exemplary Excel applications.

The CARIMA concept for different user groups

The CARIMA concept is applicable for both, users who “only” want to estimate carbon risk exposure, and for advanced users, who want to construct and validate the Carbon Risk Factor *BMG* by themselves. By making the Carbon Risk Factor *BMG* publicly available, any user can start directly with determining the carbon risk of financial assets and portfolios easily and quickly by themselves, since only the historical return time series of the respective financial assets or portfolios are needed.

More detailed explanations of modules A to D are given in the CARIMA manual, which is available on the project website. These explanations address advanced users in particular, who would like to adapt and further develop the CARIMA concept to their individual needs and have the appropriate resources to do so.

4 Determination of Carbon Beta with the Carbon Risk Factor *BMG*

As already described, the CARIMA concept offers a market-based approach to quantify carbon risks by using factor models. The relevance of factor models is reflected not only in their acceptance as study content at practically all universities, but also in their broad recognition in academia and in a wide range of applications in financial practice.

Factor models as the starting point for the calculation of Carbon Betas

A typical factor model that is widely used in both financial practice and science is the Carhart (1997) four-factor model, which is a further development of the very well-known Fama and French (1993) three-factor model, which is again a further development of the Nobel Prize-winning Capital Asset Pricing Model (CAPM) of Sharpe (1964), Lintner (1965), and Mossin

(1966). However, the Carbon Risk Factor *BMG* can in principle be added to any factor model as long as no other factor is too highly correlated with the Carbon Risk Factor *BMG*.

In the following applications, the Carbon Risk Factor "Brown-Minus-Green" (BMG) extends the Carhart model so that it has the following form:

$$er_{i,t} = \alpha_i + \beta_i^{mkt} er_{M,t} + \beta_i^{smb}\, SMB_t + \beta_i^{hml}\, HML_t + \beta_i^{wml}\, WML_t + \beta_i^{bmg}\, BMG_t + \varepsilon_{i,t} \qquad (6)$$

With:

- $er_{i,t}$ = return on an asset *i* minus return on a risk-free investment in period *t* (excess return)
- $er_{M,t}$ = excess return of the market in period *t*
- SMB_t = return of the global size factor in period *t*
- HML_t = return of the global value factor in period *t*
- WML_t = return of the global momentum factor in period *t*
- BMG_t = return on the global Carbon Risk Factor *BMG* in period *t*
- α_i, β_i^{mkt}, β_i^{smb}, β_i^{hml} und β_i^{wml} = parameters α_i and β_i^x of the Carhart Model
- β_i^{bmg} = Carbon Beta of the asset *i*. This key figure serves as the central carbon risk measure. It is estimated via a simple multiple linear regression according to this factor model

The central idea of factor models is that the returns on assets and thus the overall risks of those assets can be broken down into various components ("factors"). One of these components is the sensitivity of an asset's value towards unexpected changes in the transition process of the economy. Assets can be equities, funds or portfolios. In addition, the CARIMA concept is also suitable in principle for determining the carbon risk of corporate bonds and loans. For this, however, some additional considerations and modifications are necessary.

For example, the carbon risk of corporate bonds can be determined using different factor models that are specifically designed to explain the returns of corporate bonds, such as the models by Fama and French (1993) or Elton et al. (1995). However, determining Carbon Betas for loans is somewhat more demanding, because unlike, e.g., stocks or bonds, there are typically no market prices and thus no historical time series of returns for loans. Without these time series returns, no direct estimation of the Carbon Beta using a factor model is possible. Under certain circumstances, the Carbon Betas of firms' stocks and corporate bonds can be used to estimate the Carbon Betas of loans more or less accurately (see Table 34-2). More information can be found in the CARIMA manual.

Table 34-2 Using Carbon Betas from stocks and corporate bonds to determine Carbon Betas of loans

	Carbon Beta of the stock of the same firm is known	**Carbon Beta of the stock of the same firm is unknown**
Carbon Beta of a corporate bond of the firm is known	Using the Carbon Beta of the stock or a corporate bond to determine the Carbon Beta of the loan	Using the Carbon Beta of a corporate bond to determine the Carbon Beta of the loan
Carbon Beta of a corporate bond of the firm is unknown	Using the Carbon Beta of the stock to determine the Carbon Beta of the loan	Using the Carbon Beta of comparable firms to determine the Carbon Beta of the loan

General interpretation of the Carbon Beta

The Carbon Beta β_i^{bmg} of an asset can be interpreted as follows: if the Carbon Beta is greater than zero, it can be expected that the value of this asset will fall compared to the market, if the transition process of the economy towards a green economy accelerates unexpectedly. If, on the other hand, the Carbon Beta is less than zero, the value of this asset will rise compared to an average asset in expectation, if the transition process of the economy towards a green economy decelerates unexpectedly. The value of an asset with a Carbon Beta close to zero is influenced to a market-average extent by the transition process.

Input for calculating Carbon Betas: Historical returns of the Carbon Risk Factor BMG and other risk factors

One of the explanatory variables on the right side of Equation (6) is the Carbon Risk Factor *BMG*. *BMG* is simply a time series of historical returns on a specific hypothetical stock portfolio; more precisely, it is the difference between the historical returns from "brown" firms and those from "green" firms. This time series is illustrated in Figure 34-3 on a monthly basis from January 2010 to December 2018.

Figure 34-3 Monthly returns of the Carbon Risk Factor BMG (2010-2018)

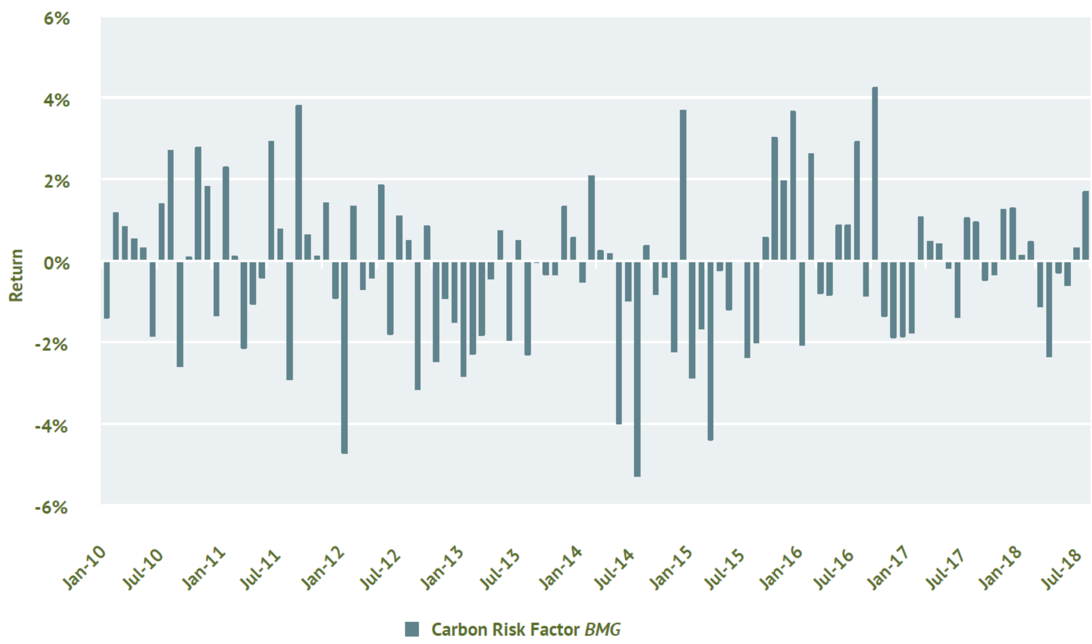


Figure 34-4 shows the historical cumulative returns of the "brown" portfolio and the "green" portfolio as well as the historical returns of the Carbon Risk Factor *BMG*. The cumulative return on the Carbon Risk Factor *BMG* is slightly positive in the first years of the reviewed period but falls back to zero by the end of 2012. From 2013 to the end of 2015, the cumulative return on the factor fell almost steadily to almost –30% overall. During this period, "brown" firms thus had a much lower return than "green" firms. In the last years of the reviewed period, however, there was a slight increase again, so that the Carbon Risk Factor *BMG* shows a cumulative return of –20% overall.

Figure 34-4 Cumulative returns of the Carbon Risk Factor BMG and the two portfolios "green" and "brown"

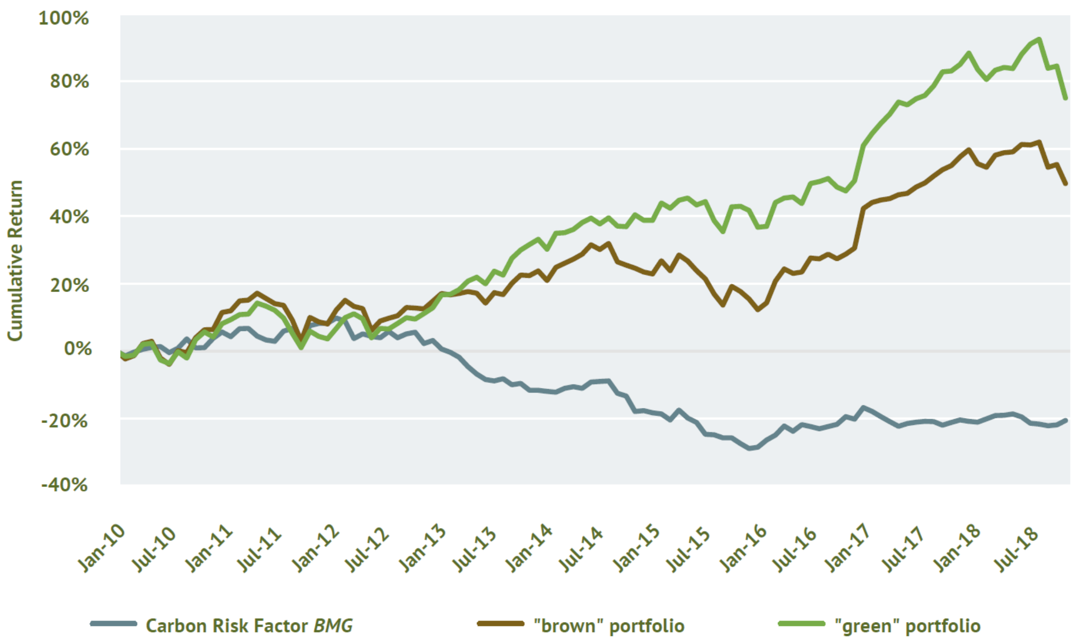


Table 34-3 shows descriptive statistics of the monthly Carbon Risk Factor BMG and its correlations with other global risk factors of the reference model. The average monthly return on the Carbon Risk Factor BMG is negative at −0.25%, the standard deviation is 1.95%. The correlations between the Carbon Risk Factor BMG and the market, size, value, and momentum factors are all relatively low. As mentioned above, a low correlation with other risk factors of the Carhart model is a good first indication for the factor model.

Table 34-3 Descriptive statistics and correlations of the Carbon Risk Factor BMG

Factor	Ø Return (%)	Standard-deviation (%)	t-stat.	Correlations				
				BMG	er_M	*SMB*	*HML*	*WML*
BMG	−0.25	1.95	−1.17	1.00				
er_M	0.76	4.02	1.74	0.09	1.00			
SMB	0.06	1.39	0.37	0.20	−0.02	1.00		
HML	−0.00	1.68	−0.02	0.27	0.19	−0.06	1.00	
WML	0.57	2.53	2.06	−0.24	−0.20	0.00	−0.41	1.00

Input for calculating Carbon Betas: Historical returns of other risk factors

Other key explanatory variables include the excess returns of the entire stock market $er_{M,t}$, SMB_t, a global size factor, HML_t, a global value factor, and WML_t, a global momentum factor at the time of t. These factors are available free of charge on the Internet. They can for example be downloaded from the Kenneth R. French Data Library[4] or the AQR Data Library[5]. All common factors based on the published literature can also be reproduced individually.

Output: Carbon Betas for stocks

Figure 34-5 Carbon Betas of some example stocks

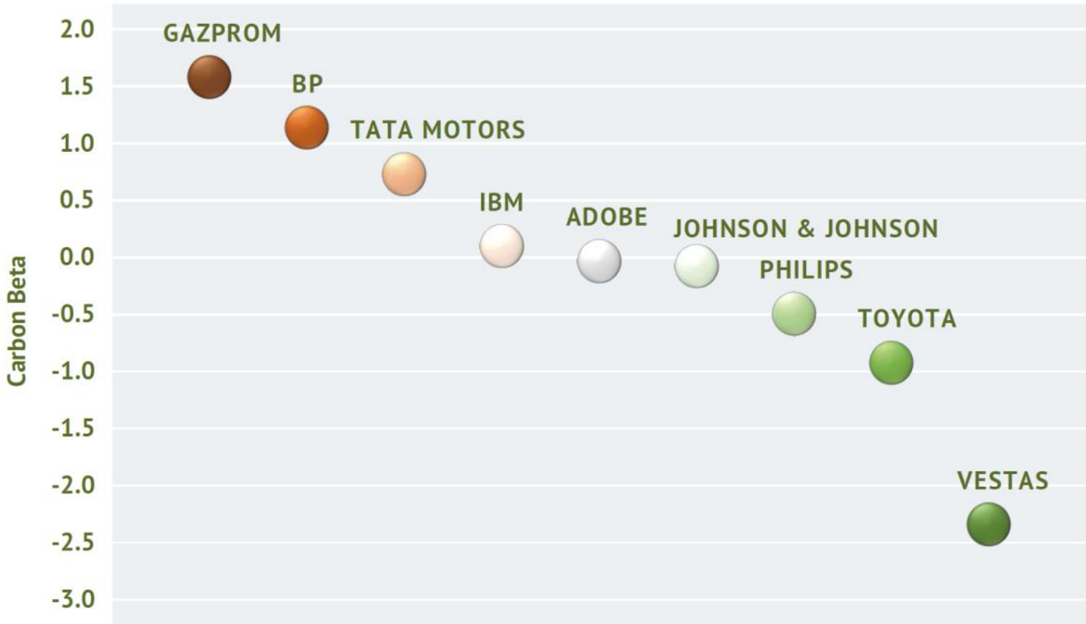


Figure 34-5 shows the calculated Carbon Betas for some well-known example firms. It is clear that in particular those firms have a high Carbon Beta, which are usually classified as “brown”. On the other hand, especially "green" firms show low Carbon Betas. Similarly, some firms have Carbon Betas close to zero, i.e., apart from the general market carbon risk mentioned above, they are not exposed to carbon risk.

It is not surprising that the Carbon Betas of “brown” stocks are usually more or less positive, and the Carbon Betas of “green” stocks are more or less negative. However, at this point it is worth mentioning that it may also be the case that a firm that, e.g., does not burn fossil fuels itself and is therefore commonly seen as “clean”, also has a positive Carbon Beta and belongs by CARIMA-definition to the “brown” firms.

This could be the case if the firm relies heavily on “brown” inputs or is a supplier to “brown” firms. In this case, an unexpected acceleration in the transition process of the economy could be expected to lead to a decline in profits for this “clean” firm as well, since this firm depends

[4] See http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html

[5] See https://www.aqr.com/Insights/Datasets/

in turn on firms whose value and business models are negatively affected by the unexpected acceleration. The same, of course, applies vice versa.

The level of the estimated Carbon Betas can be used very easily to compare the carbon risk exposures of different firms.

Output: Carbon Beta for portfolios

In a similar way as for stocks, carbon risk can also be determined for portfolios. When assessing the current carbon risk in portfolios for today or future periods, respectively, two approaches, in particular the top-down and bottom-up approach, are conceivable. In both cases, historical return time series serve to estimate a portfolio's current carbon risk. The composition of the portfolio, or more precisely its change over time, is a key factor in choosing the appropriate approach.

For the top-down approach, only the portfolio's historical time series of returns must be known, while the bottom-up approach requires the current portfolio weights of the individual assets and their return time series.

To determine a portfolio's Carbon Beta using the top-down approach, the user only needs to have the portfolio's historical time series of the excess returns. This corresponds to the weighted excess returns of the individual stocks in the portfolio. These excess returns are used as a dependent variable in the regression, as previously described for stocks. Thus, the Carbon Beta can be determined directly from the regression Equation (6). This once again illustrates the great advantage of the CARIMA concept. For portfolios with any number of different types of financial securities, the carbon risk can be estimated with just one regression.

However, to ensure that this approach does not lead to wrong results in the estimation of current Carbon Betas, the composition of the portfolio must, strictly speaking, have remained the same over the entire historical period under consideration. Note that the weights of the stocks in the portfolio can change automatically over time depending on the performance of stocks in the portfolio.

If the assumption of a constant portfolio composition over time is (severely) violated, it is more reasonable to determine the portfolio's Carbon Beta using the bottom-up approach. However, for this approach, the historical time series of (excess) returns of the individual stocks and their weighting in the portfolio are required. Subsequently, the Carbon Betas of each stock in the portfolio can be determined using Formula (6). The Carbon Beta of the portfolio is then calculated as the weighted sum of the Carbon Betas of the stocks held in the portfolio.

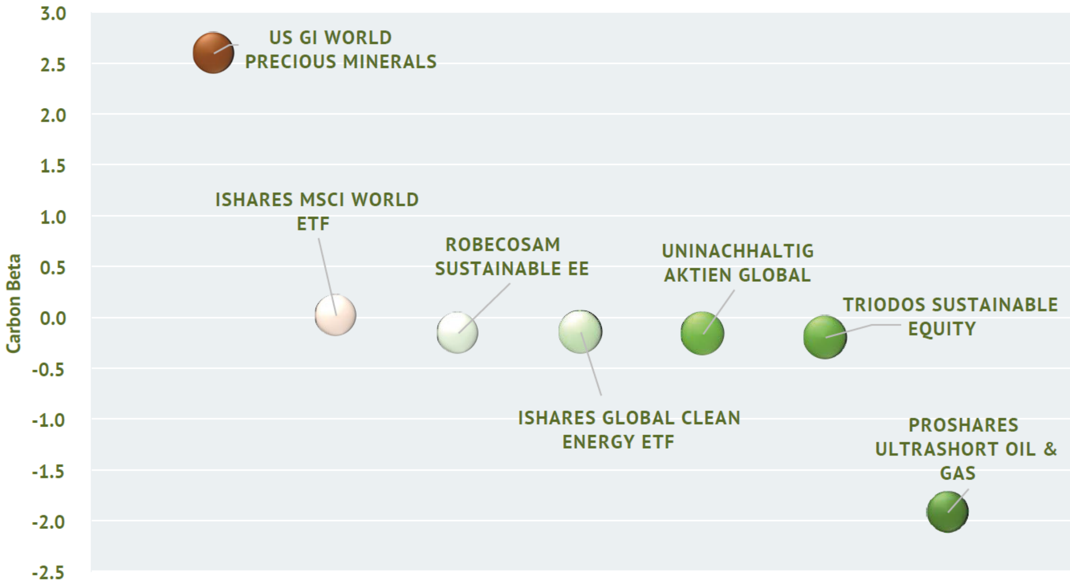
Output: Carbon Beta of funds

The following section describes how to determine the Carbon Beta of funds, in particular, equity funds. Equity funds are investment funds that invest their assets primarily or exclusively in (individual) stocks.

Determining the Carbon Beta at fund level is basically analogous to the procedure for portfolios, since funds are basically special forms of portfolios that also consist of various individual securities. The carbon risk of a fund can thus also be determined bottom-up or top-down. Nevertheless, some differences between funds and portfolios must be considered.

Certainly, the main difference is the fact that, unlike a private portfolio, funds are managed externally. This typically leads to different degrees of knowledge about the composition and the historical time series of returns of the portfolio and fund. In many cases, the historical time series of returns is unknown for a private portfolio, while the composition of the portfolio is known. In contrast, the historical time series of returns is often available for funds, but the (historical) composition of a fund is often unknown. Therefore, the top-down approach is particularly relevant for funds.

Figure 34-6 Carbon Betas of various example funds



As an example, the Carbon Betas for some funds were determined above. Based on a Carhart four-factor model extended by the Carbon Risk Factor *BMG*, a (constant) Carbon Beta for the period from January 2010 to December 2018 is estimated using monthly return data. The results are visualized in Figure 34-6. The US GI World Precious Minerals fund has a high carbon risk with a Carbon Beta of 2.59. This suggests that in the event of an unexpected change in the transition towards a green economy, the fund would be severely adversely affected. However, it is also possible to find funds with a negative Carbon Beta that would develop positively in the event of an unexpected change in the transition process towards a green economy. This applies to ProShares UltraShort Oil & Gas (Carbon Beta –1.92) and to a lesser extent to Triodos Sustainable Equity (Carbon Beta –0.20) and UniNachhaltig Aktien Global (Carbon Beta –0.17). This is offset by funds such as RobecoSam Sustainable EE and iShares Global Clean Energy ETF, for which no Carbon Beta significantly different from zero can be measured. A possible explanation for the relatively low (negative) Carbon Betas of these funds is the fact that the Carbon Beta estimates the individual carbon risk of a stock (or an asset in general) in relation to the market. It thus determines how the value of a stock is likely to change in relation to the market as a whole if expectations about the transition process of the economy change. However, since funds are mostly very broadly invested, i.e., their returns depend more on the movements of the market, the funds' return time series primarily load on the market factor. In other words, these funds are only affected by the average carbon risk of the market.

5 Further applications of the CARIMA concept

This chapter presents some more practical applications of the CARIMA concept from a perspective of a portfolio manager. In the CARIMA manual, the applications shown in the following as well as further applications are described in detail. Many of these applications can also be reproduced with the corresponding Excel tool.

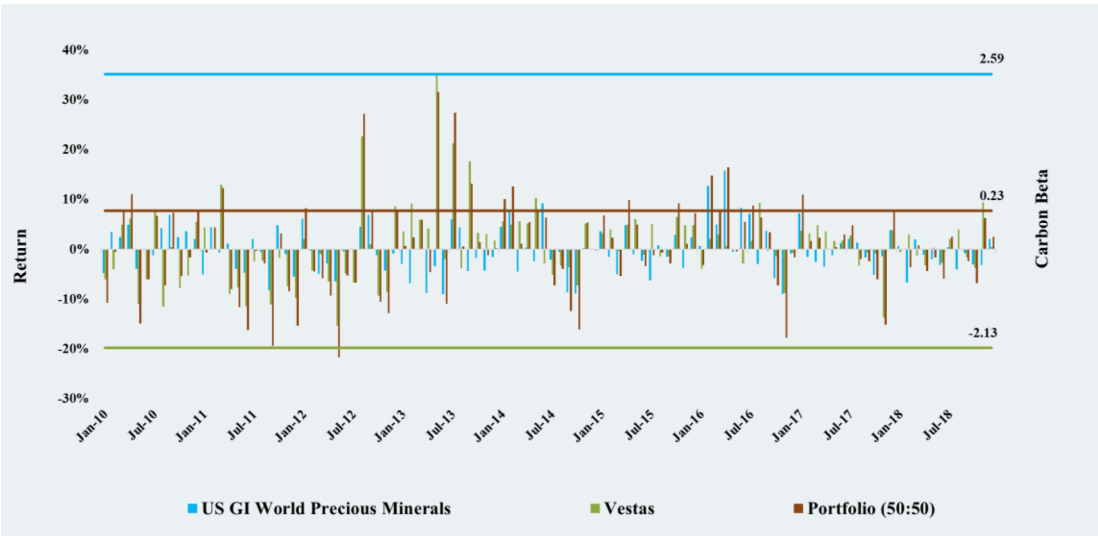
Management and hedging of carbon risks

The Carbon Beta enables portfolio managers and investors to manage the carbon risk of their portfolios. For example, they can steer the exposure to carbon risks of a certain portfolio to the desired level. Portfolio managers can construct "green" and "brown" portfolios in a targeted manner and speculate on developments that may occur in the economy's transition process (unexpected by the market). Furthermore, portfolio managers can use the Carbon Beta to *create* portfolios that are neutral to carbon risks, in other words, portfolios hedged against this risk. In this way, not only hedging strategies can be implemented into *existing* portfolio strategies, but also *new* portfolios and products with a certain carbon risk exposure can be generated.

Example application: hedging carbon risk

It is assumed that a portfolio manager has various investment opportunities, in this example the US Global Investors Precious Minerals Fund, the iShares MSCI World Exchange Traded Fund (ETF), and the stock of Vestas. Initially, the portfolio manager is invested solely in the US Global Investors Precious Minerals Fund. This fund shows a relatively high Carbon Beta of 2.59 and can thus be classified as "brown". The portfolio manager is now urged by his investors to actively reduce the carbon risk of this portfolio. If he includes the stock of Vestas in his portfolio with a Carbon Beta of –2.13, the carbon risk can be reduced. For example, if the portfolio manager opts for an equal weighting of the fund and the stock in the portfolio, the Carbon Beta is 0.23. Thus, this portfolio formation enables the manager to reduce the carbon risk of his portfolio. The returns and values of the Carbon Beta of the hedged portfolio and its respective underlyings are shown in Figure 34-7.

Figure 34-7 Returns and Carbon Betas of the hedged portfolio and its respective underlyings



Of course, due to the additivity of the betas, it is also possible to achieve other degrees of exposure to carbon risks. This example makes clear that portfolio managers and investors can use the Carbon Beta to hedge their portfolios easily. In addition, Carbon Betas can be realized at almost any magnitude, i.e., any investment strategy can be pursued through the composition of "green", "neutral", and "brown" portfolios.

Portfolio allocation strategies: "Best-in-class" approach based on the Carbon Beta
The idea of a best-in-class approach is to select the stocks with the lowest Carbon Beta in a particular group of firms, in this example from each sector. This group of stocks is referred to as the "Best-in-class" portfolio. The other way around, stocks with the highest Carbon Beta within their sector are grouped into the "Worst-in-class" portfolio, i.e., the "brown" portfolio. For these two portfolios, different thresholds for the classification into "green" or "brown" are conceivable. Such best-in-class approaches are often used for the construction of (sustainability) indices. For example, the Dow Jones Sustainability World Index is constructed in such a way that the selected firms are among the top ten percent of sustainable firms in terms of the defined sustainability characteristics. Such indices serve as benchmarks and thus as a basis for other financial products.

Example application: "Best-in-class" approach
Figure 34-8 Best-in-class approach across eleven sectors

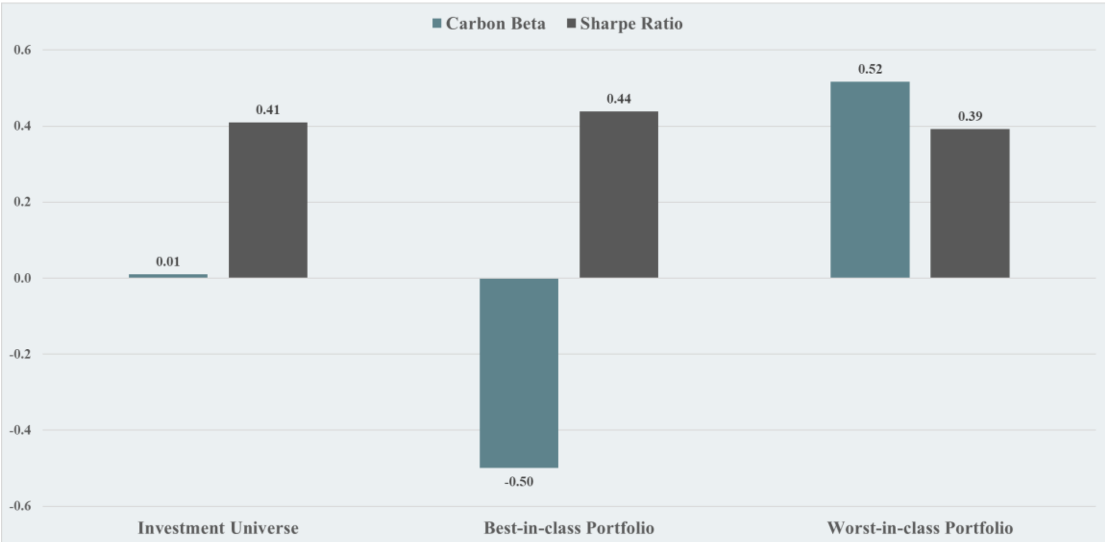


Figure 34-8 shows an example for this approach and the respective results. The threshold value in this example is defined as the median of the Carbon Beta within each sector. Stocks below the median of a particular sector are included in the Best-in-class portfolio, while stocks with a Carbon Beta above the median enter into the Worst-in-class portfolio for that sector. The average values across eleven sectors per portfolio are shown. In this example, a global investment universe is assumed. The global investment universe shows a Carbon Beta of 0.01 and a Sharpe Ratio of 0.41, whereas the Best(Worst)-in-class Portfolio shows a Carbon Beta of –0.50 (0.52) and a Sharpe Ratio of 0.44 (0.39).

Thus, the difference between the Carbon Betas of the Best-in-class and Worst-in-class portfolios amounts to –1.02, whereas the Sharpe Ratios do not show any major differences. In this scenario, portfolio managers and investors can maintain the sector allocation of their portfolios with a corresponding Sharpe Ratio while simultaneously managing carbon risk via the Best-in-class approach.

Factor Investing taking carbon risks into account
In Factor Investing, stocks are selected based on certain factors, such as firm size or book-to-market ratio. The ultimate objective is to generate a stock portfolio that shows certain characteristics (exposures) with respect to these factors across all stocks.

According to Invesco's Global Factor Investing Study (Invesco, 2018), risk reduction and better control over the risk exposure of a portfolio are key reasons to implement Factor Investing strategies. In addition, factor strategies can be used to easily map thematic focuses, e.g., regarding ESG risks in the portfolio.

It can be assumed that the integration of ESG issues into Factor Investing will gain in importance in upcoming years. It is therefore obvious that carbon risks will also find their way into new factor strategies. By taking the Carbon Beta into account, portfolio managers and investors can incorporate carbon risk into the composition of their portfolios. The Carbon Beta, for example, can be used to develop a multi-factor strategy aimed at specifying a specific carbon risk without deviating from the original investment strategy. This allows portfolio managers to consider investors' preferences for carbon risks in conventional factor strategies.

Example application: "Factor Investing" approach

In the following scenario, a portfolio manager wants to achieve a certain level of carbon risk for his portfolio while maintaining the sensitivity (betas) to the risk factors market, SMB, and HML. The portfolio manager's investment universe consists of global stocks. He determines all factor sensitivities for each of these stocks, in other words he uses a multi-factor strategy. The sensitivities with regard to the factors market, SMB, and HML are crucial, whereby two portfolios with similar sensitivities should exist while being "brown" or "green" depending on investors' preferences. In a three-step procedure, the portfolio manager sorts all stocks into portfolios according to their sensitivities with regard to the factors market, SMB, and HML. For portfolio formation, a quintile classification is carried out. First, all firms are divided into quintile portfolios based on their market beta. The companies in each of these five portfolios are then sequentially divided into further portfolios based on their SMB-beta and finally their HML-beta. This results in a total of 125 (5x5x5) portfolios which each show a certain sensitivity, i.e., beta, to the factors market, SMB, and HML. Each of these portfolios is then categorized as either a "green" or "brown" Carbon Beta portfolio based on the median of the Carbon Betas of the stocks in that specific portfolio. Investments can now be made into these portfolios according to the multi-factor strategy selected.

Figure 34-9 Carbon Betas in Factor Investing

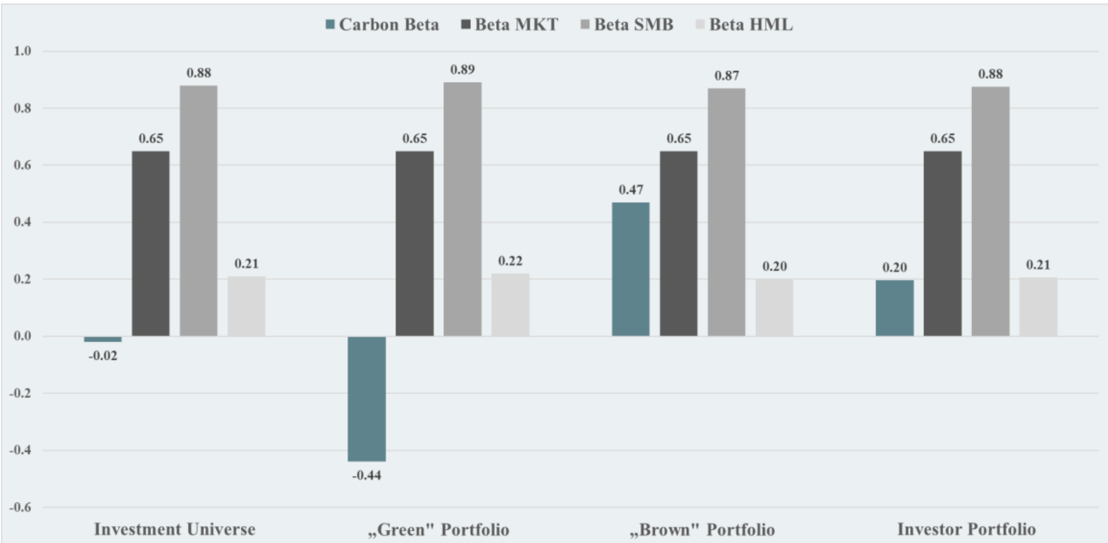


Figure 34-9 shows four potential portfolios. If the portfolio manager adopts a multi-factor strategy based on the entire investment universe without taking the Carbon Beta into account, he obtains a portfolio with a Carbon Beta of –0.02, which is almost neutral to carbon risks.

From this investment universe, portfolios are constructed with a Carbon Beta below the median ("Green" Portfolio) and above the median ("Brown" Portfolio). These two portfolios represent the extreme cases, with a Carbon Beta of –0.44 for the "Green Portfolio" and 0.47 for the "Brown Portfolio", respectively. The other factor loadings, i.e., Beta MKT, Beta SMB, and Beta HML, on the other hand, hardly differ at all.

Generally, a portfolio manager will set a bandwidth for the carbon risk of his portfolio. In this case, one could imagine that the portfolio manager prefers a slightly positive Carbon Beta between 0.15 and 0.25. He can easily implement this by composing his portfolio accordingly, for example by combining the "Brown" and "Green" Portfolios with different weightings. This is demonstrated by the Investor Portfolio with a Carbon Beta of 0.20. The portfolio manager can thus realize any level of the Carbon Beta. Again, the betas of the factors market, SMB, and HML differ only marginally, while the Carbon Beta can be steered towards any desired level.

6 Conclusion

CARIMA provides a new measure for financial market actors to assess risks and opportunities in stocks and portfolios arising from climate change and the transition process of the economy towards a green and in particular low-carbon economy, based on capital market information. In other words, CARIMA supports the financial sector in the transition process of the economy towards a green economy and can thus contribute to the overall societal goal of preventing welfare losses.

Nevertheless, a number of related topics in research and practice are relevant for the future. Examples include the integrative consideration of carbon risks in asset management, the evaluation of carbon risks in derivative financial instruments, and the question how carbon risks influence expected returns of stocks and other financial assets. Subsequent work will not only fill gaps in scientific and applied research, but will also support the financing of the transition process of the economy towards the 2°C target and, where appropriate, the fulfillment of further sustainable development goals.

Bibliography

Carhart, M. M. (1997). On Persistence in Mutual Fund Performance. *Journal of Finance*.

Elton, E. J., Gruber, M. J., & Blake, C. R. (1995). Fundamental Economic Variables, Expected Returns, and Bond Fund Performance. *The Journal of Finance, 50*(4), 1229-1256.

Fama, E. F., & French, K. R. (1993). Common risk factors in the returns on stocks and bonds. *Journal of financial economics, 33*(1), 3-56.

Görgen, M., Jacob, A., Nerlinger, M., Riordan, R., Rohleder, M., & Wilkens, M. (2019). *Carbon Risk*. SSRN 2930897.

Invesco. (2018). *Invesco Global Factor Investing Study 2018*.

Lintner, J. (1965). Security Prices, Risk, and Maximal Gains From Diversification. *The Journal of Finance, 20*(4), 587-615.

Mossin, J. (1966). Equilibrium in a Capital Asset Market. *Econometrica, 34*(4), 768-783.

Sharpe, W. F. (1964). Capital Asset Prices: A Theory of Market Equilibrium under Conditions of Risk. *The Journal of Finance, 19*(3), 425-442.