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The Impact of Green Total Factor Productivity on Stock Returns: An Empirical Analysis Based on Data from Chinese Listed Companies

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Abstract: The aim of this paper is to explore the impact of the Green Total Factor Productivity (GTFP) factor on the excess returns of quantitative investment strategies in the secondary market of China's capital market. The study integrates the GTFP factor into the Fama-French five-factor model and employs the Newey-West regression method for empirical analysis. The results indicate that the GTFP factor has a significant positive impact on stock excess returns across various industries, with the second-order lag model showing improved statistical significance compared to the first-order model. This finding highlights the importance of considering environmental sustainability factors in investment decision-making and provides investors with investment strategies based on green factors. Furthermore, the results offer insights for policymakers in promoting the development of green finance. This paper enriches the literature in the field of asset pricing and offers a new perspective for both the theory and practice of green finance.

Keywords: Green Total Factor Productivity (GTFP), quantitative investment, Fama-French five-factor model, asset pricing model.

1. Introduction

With the growing global emphasis on sustainable development and environmental protection, Green Total Factor Productivity (GTFP) is gradually becoming a crucial indicator for assessing corporate efficiency and investment value. As one of the largest carbon emitters in the world, China has been vigorously promoting corporate green innovation and sustainable development policies in recent years, providing a unique context and opportunity for studying the role of green factors in the capital market.

This paper aims to construct a Green Total Factor Productivity factor and incorporate it into the classic Fama-French five-factor model to analyze whether this factor can bring excess returns to quantitative investment in the secondary market. The objective of the study is to explore the relationship between green investment factors and industry excess returns, providing investors with investment strategies based on green factors.

In the field of finance, Green Total Factor Productivity (GTFP), as a key indicator of corporate efficiency and investment value, is shifting from theoretical discussions to diversified practices and analyses. Fama and French extended the classic asset pricing model to develop the Fama-French five-factor model[1], which provides a foundation for incorporating green factors into asset pricing models and validates their applicability on a global scale, offering a comprehensive analytical framework for subsequent research. Edmans provided theoretical support for ESG investment from an economic perspective, emphasizing the application of economic principles in ESG investment decisions, laying the theoretical foundation for the empirical study of green factors[2].

Furthermore, empirical research has begun to focus on how green factors influence market responses and corporate performance. Leite and Uysal found that high ESG scores significantly enhance the positive market reaction to credit rating upgrades, providing direct evidence of the role of ESG factors in asset pricing[3]. Tong et al. analyzed the impact of environmental regulation, green finance, and green technology investment on GTFP in the Asian region, highlighting the importance of policies and financial tools in promoting green productivity[4]. At the Chinese level, Sun et al. analyzed the relationship between regional social capital, corporate green innovation, and GTFP based on data from Chinese A-share listed companies, revealing the role of social capital in promoting green innovation and enhancing GTFP, thereby enriching the theory of the relationship between green factors and corporate performance[5]. At the regional economic level, Yu et al. studied the impact of the spatial concentration of foreign direct investment on urban GTFP in China, offering a new perspective on how regional economic factors influence corporate green productivity[6].

Building on these research foundations, this paper employs the SBM-GML model to measure the Green Total Factor Productivity of listed companies and constructs a Green Total Factor Productivity factor based on corporate GTFP. The green factor is then incorporated into the five-factor model, and empirical analysis is conducted on key industries within China's capital market using the factor indicators. Finally, the study evaluates the impact of Green Total Factor Productivity on quantitative investment in the secondary market.

This paper has two main innovations. First, the application of Chinese data: As the most populous country in the world, China plays a pivotal role in the global capital market in terms of its scale and dynamism. In recent years, China has made significant progress in the field of green innovation, thanks to national-level policy support and the accumulation of tangible results. Based on data from China's capital market, this paper explores the application of the Green Total Factor Productivity (GTFP) factor in quantitative investment. Second, the construction of the green factor: Building on the five-factor model, this paper innovatively constructs the Green Total Factor Productivity factor and empirically analyzes its impact on the excess returns of industry portfolios, offering a new investment perspective for secondary market quantitative investors.

2. Model

2.1. Construction of the Green Total Factor Productivity (GTFP) Factor

To comprehensively assess the green efficiency of enterprises in the production process, the SBM-GML model is used to measure Green Total Factor Productivity (GTFP). The construction of GTFP covers two key aspects: input and output, with the goal of achieving a dual consideration of corporate production efficiency and environmental impact.

Regarding inputs, three dimensions are considered: capital input, labor input, and energy input. The estimation of capital input uses the perpetual inventory method, and the specific calculation formula is as follows:

$$K_t = \frac{I_t}{P_t} + (1 - \delta_t)K_{t-1} \tag{1}$$

In this context, K_t represents the capital stock in period t, δ is the depreciation rate (set at 5%), I_t is the net value of fixed assets in period t, and P_t is the investment price index for the province where

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the enterprise is located in period t. The labor input is represented by the number of employees in the enterprise. For energy input, the electricity consumption of industrial enterprises in the city where the listed company is located is used as a proxy indicator.

Regarding output, the study primarily focuses on expected output, which is the enterprise's main business income, while also considering undesirable outputs, which mainly refer to pollutant emissions. The calculation of undesirable outputs is based on the "China Statistical Yearbook," by determining the pollutant emissions of prefecture-level cities and calculating the adjustment coefficient W_i, with the formula as follows:

$$W_i = \frac{P_{ij}/O_i}{(\sum P_{ij})/(\sum O_i)} \tag{2}$$

where P_{ij} and O_i represent the emissions of pollutant j in prefecture-level city i and the total industrial output of city i respectively. The national emission totals for pollutant j and the national industrial output are also considered in this calculation. The corporate emission level is defined as:

$$cm_{i,j,k} = cm_{i,j} \times \left(\frac{Q_{i,k}}{\sum Q_i}\right) \tag{3}$$

Since the SBM-GML model directly measures the green total factor growth rate, we use a multiplicative method to calculate the Green Total Factor Productivity (GTFP) for each year. Taking 2010 as the base year with GTFP set to 1, the formula for calculating the GTFP for subsequent years is as follows:

$$Green_t = GML_t \times Green_{t-1} \tag{4}$$

where GML_t is the green total factor growth rate for year t and $Green_{t-1}$ is the GTFP for the previous year.

Using this method, we calculate the annual GTFP indicators for China's A-share listed companies from 2002 to 2022 based on their financial data. The GTFP values for each company in each year are then ranked from highest to lowest. The companies are grouped into three categories based on their GTFP scores: the top 30%, the middle 40%, and the bottom 30%. The GTFP factor is obtained by subtracting the average GTFP of the bottom 30% group from that of the top 30% group.

2.2. Calculation of Industry Stock Excess Returns

To calculate industry stock excess returns, the first step is to analyze the industry stock returns, which reflect the price changes of industry stocks over a certain period. The specific formula for calculating industry stock returns is as follows:

$$R_{i,t} = \frac{P_{i,t} - P_{i,t-1}}{P_{i,t-1}} \tag{5}$$

where $R_{i,t}$ represents the industry stock return, $P_{i,t}$ represents the closing stock price of industry i at time t (the last trading day of the month), and $P_{i,t-1}$ represents the closing stock price of industry i at time t−1 (the last trading day of the previous month).

Next, to isolate the portion of industry stock returns that exceeds the risk-free rate, the calculation of the excess return of industry stocks is conducted. This process is achieved by subtracting the risk-free rate from the industry stock returns, with the one-year government bond yield typically used as a proxy for the risk-free rate. The specific formula is as follows:

$$ER_{i,t} = R_{i,t} - R_{f,t} \tag{6}$$

where $R_{i,t}$ represents the industry stock excess return, and $P_{i,t}$ represents the one-year government bond yield at time t.

2.3. Construction of the Factor Model

To provide a more comprehensive explanation of industry stock excess returns, this paper innovatively incorporates the Green Total Factor Productivity (GTFP) factor into the classic Fama-French five-factor model, resulting in a more comprehensive six-factor model. This model not only considers traditional financial factors such as market risk, company size, book-to-market ratio, profitability, and investment style, but also emphasizes the potential impact of corporate environmental responsibility and green production efficiency on stock returns.

The mathematical expression of the model is as follows:

$$Y_{i,t} = \beta_{i0} + \beta_{i1}GTFP_{i,t} + \beta_{i2}risk\_pre_{i,t} + \beta_{i3}smb_{i,t} + \beta_{i4}hml_{i,t} + \beta_{i5}rmw_{i,t} + \beta_{i6}cma_{i,t} + u_{it} \tag{7}$$

In this model, Yit represents the excess return of industry i at time t, while α is the intercept term of the model. The coefficients β_{i1} to β_{i6} represent the sensitivity coefficients for each factor in the model, indicating the degree to which each factor influences the industry's excess returns. The factors $risk\_pre_{i,t}$, $smb_{i,t}$, $hml_{i,t}$, $rmw_{i,t}$, cma_i, correspond to the five traditional factors in the Fama-French model: market risk premium, company size, book-to-market ratio, profitability, and investment style, respectively. $GTFP_{i,t}$ is the newly introduced Green Total Factor Productivity factor, which reflects the efficiency of a company's green production.

By incorporating the GTFP factor into the model, the study not only considers traditional financial factors such as market risk, company size, book-to-market ratio, profitability, and investment style, but also emphasizes the potential impact of corporate environmental responsibility and green production efficiency on stock returns. This model structure allows for different sensitivities to the GTFP factor across industries, reflecting how industry characteristics influence the impact of green production efficiency.

3. Empirical Results

3.1. Data

In this study, to analyze industry stock excess returns in depth, we select monthly data from the Fama-French five-factor model for A-shares and ChiNext stocks listed on the Shanghai and Shenzhen stock exchanges from 2002 to 2022. The data is sourced from the CSMAR database. The research employs Portfolio Type 1 from the Fama-French model, which is based on the 2*3 portfolio classification method. To calculate the monthly risk-free rate, the average one-year government bond yield for all trading days within the month is used as the risk-free rate for that month, with relevant data also sourced from the CSMAR database.

Industry classification follows the classification of the Shenwan Securities secondary industry index, and the corresponding industry return data comes from the Wind database's Shenwan Securities secondary industry index, covering the period from 2002 to 2022. To ensure the completeness and accuracy of the data, strict data cleaning was performed on the industry return data, removing records with missing values. This ensures the continuity and reliability of the data for the period from 2002 to 2022.

To incorporate the Green Total Factor Productivity (GTFP) factor into the analysis framework, GTFP values for the period from 2001 to 2021 are calculated. Since some of the data is annual, the GTFP factor is treated as an annual indicator. Given that listed companies typically release the previous year's financial data in the first half of the following year, and that quantitative investment practices in the secondary market require the use of past GTFP data to forecast future market trends, this paper adopts a practical approach: the GTFP factor for the period from July of the current year to June of the following year is taken as the GTFP value for the previous year.

The descriptive statistics for the independent variables are shown in Table 1.

Table 1: Descriptive Statistics od Independent Variables

Vaeiable	Variable Meaning	Mean	Standard Devistion	Sample Size
GTFP	Green Total Factor Productivity (GTFP) factor	11.493	6.766	246
risk_pre	Market risk premium factor	0. 611	7.552	252
smb	Size factor	0.637	4.730	252
hml	Book-to-market ratio factor	0.091	3.352	252
rmw	Profitability factor	0.068	3.077	252
cma	Investment style factor	-0.011	2.287	252

When the Green Total Factor Productivity (GTFP) factor is tested individually, its p-value is found to be 0.00, which is much lower than the commonly used significance level of 0.05. This indicates that the GTFP factor is statistically significantly different from zero. According to statistical principles, when the p-value is smaller than the significance level, the null hypothesis is rejected, meaning the factor is capable of generating excess returns. In this study, the significance of the GTFP factor confirms its effectiveness in predicting stock excess returns, establishing it as a valid factor.

3.2. Results

Since heteroscedasticity and autocorrelation in financial time series data can affect the standard error estimates of regression coefficients, this study uses the Newey-West adjustment to ensure the accuracy of statistical inferences. This allows for an effective test of whether the expected returns of the new factors are significantly different from zero.

The study selects core and representative industries from China's capital market and applies the Newey-West regression to these industries with a one-period lag. The specific regression analysis results are shown in Table 2.

Table 2: Newey-West First-Order Lag Significance Analysis of the Green Total Factor Productivity Factor in Asset Pricing.

Industry Name	Coal Mining	Power Grid Equipment	Chemical Production	Textile Manufacturing	Environmental Management	Railway&Highway	Trade
GTFP	0.096**	0.103***	0.053*	0.084***	0.070**	0. 071***	0.128***
	(0.031)	(0.002)	(0.057)	(0.005)	(0.028)	(0.004)	(0.001)
risk_pre	1.099***	0.930***	0.921***	0.995***	0.991***	0.829***	1.111***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
smb	-0.197	0.783***	0.373***	0.797***	0.796***	0.125	0.472***
	(0.273)	(0.000)	(0.003)	(0.000)	(0.000)	(0.129)	(0.000)
hml	0.352	-0.314***	-0.433***	0.053	0.159	0. 274***	0.134
	(0.115)	(0.002)	(0.000)	(0.509)	(0.174)	(0.003)	(0.299)
rmw	-0.222	0.336*	0.072	-0.228	0.056	-0. 069	-0.438*
	(0.530)	(0.100)	(0.737)	(0.212)	(0.771)	(0. 636)	(0.072)
cma	0.546*	0.371**	0.474**	0.344**	0.219	0. 375**	0.318
	(0.081)	(0.020)	(0.018)	(0.028)	(0.220)	(0.016)	(0.119)
_cons	-3.246***	-3.766***	-2.858***	-4.078***	-3.916***	-3.635***	-3.930***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Sample Size	246	246	246	246	246	246	246
$adj.R^2$	0.6466	0.8003	0.8136	0.8792	0.8181	0.7960	0.8315

Note: *** , **, and * represent significance at the 1%, 5%, and 10% levels, respectively; the values in parentheses indicate the p-values. This notation applies to all subsequent tables.

The first-order lag significance analysis conducted using the Newey-West regression method shows that the Green Total Factor Productivity (GTFP) factor has a significant positive impact on stock returns across multiple industries. Specifically, the p-values for the GTFP factor in all industries in Table 2 are less than 0.10, indicating that the GTFP factor is statistically significant and has a notable effect on stock returns. The GTFP coefficients for the trade, power grid equipment, and textile manufacturing industries are relatively high, at 0.128, 0.103, and 0.084, respectively, with p-values all less than 0.005. This reflects that improvements in green total factor productivity in these industries have a significant positive impact on excess returns of industry portfolios. The GTFP coefficients for the environmental management and railway and highway industries also show significant positive impacts, at 0.070 and 0.071, with p-values of 0.028 and 0.004, respectively.

Although the GTFP coefficient for the chemical products industry is relatively small, at 0.053, and the p-value is 0.057, which is close to the 0.05 significance level, this indicates that the impact of green total factor productivity on stock excess returns in this industry is relatively small, but still shows some positive effect. The GTFP coefficient for the coal mining industry is 0.096, with a p-value of 0.031, indicating a positive impact of green productivity improvements on excess returns, with the effect being of medium strength compared to other industries listed. Overall, the model results demonstrate that the GTFP factor is generally significant across different industries, with varying degrees of impact on stock returns. The adjusted R^2 values differ across industries but are generally high, suggesting that the model explains stock returns in these industries well.

Considering that the first-order lag model may not fully capture the complex dynamics and long-term effects in the data, and that the second-order lag model can take into account the correlations between the current value, the previous value, and the value two periods ago, a second-order lag model is used for further analysis to achieve more accurate predictive results and more reliable parameter estimates. The regression results are shown in Table 3.

Table 3: Newey-West Second-Order Lag Significance Analysis of the Green Total Factor Productivity Factor in Asset Pricing.

Industry Name	Coal Mining	Power Grid Equipment	Chemical Production	Textile Manufacturing	Environmental Management	Railway&Highway	Trade
GTFP	0.096** (0.036)	0.103*** (0.002)	0.053** (0.049)	0.084*** (0.004)	0.070** (0.029)	0. 071*** (0.003)	0.128*** (0.000)
risk_pre	1.099*** (0.000)	0.930*** (0.000)	0.921*** (0.000)	0.995*** (0.000)	0.991*** (0.000)	0.829*** (0.000)	1.111*** (0.000)
smb	-0.197 (0.266)	0.783*** (0.000)	0.373*** (0.005)	0.797*** (0.000)	0.796*** (0.000)	0.125 (0.110)	0.472*** (0.000)
hml	0.352 (0.121)	-0.314*** (0.001)	-0.433*** (0.000)	0.053 (0.510)	0.159 (0.195)	0.274*** (0.001)	0.134 (0.259)
rmw	-0.222 (0.530)	0.336 (0.105)	0.072 (0.744)	-0.228 (0.214)	0.056 (0.767)	-0.069 (0. 611)	-0.438* (0.069)
cma	0.546* (0.077)	0.371** (0.015)	0.474** (0.017)	0.344** (0.025)	0.219 (0.232)	0.375** (0.017)	0.318 (0.120)
_cons	-3.246*** (0.000)	-3.77*** (0.000)	-2.858*** (0.000)	-4.078*** (0.000)	-3.916*** (0.000)	-3.635*** (0.000)	-3.930*** (0.000)
Sample Size	246	246	246	246	246	246	246
adj.R²	0.6466	0.8003	0.8136	0.8792	0.8181	0.7960	0.8315

The results show that the GTFP factor has a significant positive impact across all the industries examined. Notably, the GTFP coefficients for the trade, textile manufacturing, and power grid equipment industries are especially prominent, with values of 0.128, 0.084, and 0.103, respectively, and p-values of 0.002 or lower. This indicates that improvements in green productivity in these industries have a significant positive impact on excess returns. Although the GTFP coefficients for the chemical products and coal mining industries are relatively smaller, they are still statistically significant, with values of 0.053 (p-value = 0.049) and 0.096 (p-value = 0.036), further confirming the widespread importance of the GTFP factor in asset pricing.

Compared to the first-order lag analysis, the results from the second-order lag analysis maintain the same level of significance, indicating that the impact of the GTFP factor on asset pricing is stable over time. The adjusted R^2 values for all industries are generally high, suggesting that the models including the GTFP factor can effectively explain variations in industry stock returns. This provides investors with a powerful tool to better understand and predict market dynamics. Combining the results from both the first- and second-order lag analyses, it can be concluded that the GTFP factor plays a crucial role in asset pricing, with its significance and positive impact on stock returns being generally present across different industries.

4. Conclusion

This study aims to explore the impact of Green Total Factor Productivity (GTFP) on excess stock returns in China's capital market. In recent years, with the rise of environmental awareness, China's capital market has increasingly focused on green innovation and sustainable development initiatives. The purpose of this paper is to integrate the GTFP factor into the established Fama-French five-factor model, in order to assess its potential contribution to excess returns in secondary market quantitative investment strategies. The research results indicate that by using the Newey-West autoregressive model to analyze major sectors in China's capital market, the GTFP factor is statistically significant in most industries, regardless of the current level of green development or whether the industry is traditional or emerging with strong innovation capabilities. Empirical analysis shows that the GTFP factor is not only statistically significant, but its impact varies across industries. The trade industry exhibits the highest GTFP coefficient, indicating a robust positive correlation between green total factor productivity and excess stock returns. Similarly, the power equipment and textile manufacturing industries also show a significant effect from the GTFP factor, suggesting that implementing green investment strategies in these fields may lead to a higher probability of generating excess returns. The application of the second-order lag model further reinforces the importance of the GTFP factor. Compared to the first-order lag model, the p-values for most industries slightly decrease, suggesting that when higher-order dependencies are considered, the impact of green productivity on stock returns becomes more pronounced.

The conclusions of this paper offer new perspectives for participants in the capital market and policymakers.

First, the research results highlight the importance of the Green Total Factor Productivity (GTFP) factor in asset pricing. This finding suggests that considering environmental sustainability factors in the investment decision-making process may lead to excess returns for investors. This is in line with the growing global focus on Environmental, Social, and Governance (ESG) factors, providing empirical support for integrating green investment principles into traditional financial analysis.

Second, the differentiated impact of the GTFP factor across industries implies that investors should adopt industry-specific strategies when constructing their portfolios. This means that investors need to conduct in-depth analysis of the green productivity characteristics of different industries and how these characteristics influence the long-term performance of their stocks. Such industry-level analysis helps investors more accurately identify green investment opportunities and optimize their investment strategies to maximize risk-adjusted returns.

Finally, the results of this paper also offer valuable insights for policymakers. The rapid development of China's capital market and the deepening of green innovation policies have provided fertile ground for the development of green financial products. Policymakers can use the findings of this study to further advance the formulation and implementation of green finance policies,

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encouraging both enterprises and investors to place greater emphasis on the role of environmental factors in investment decisions, thereby promoting sustainable economic development.

Given the vast scale of China's capital market and its significant position in the global economy, this in-depth analysis of the Chinese market not only has local significance but also possesses broad external validity. In the current global context of a shared focus on carbon peak, carbon neutrality, and green development, China's capital market, as a pioneer in green transformation, offers valuable experiences that can be emulated and promoted by other developing countries. By studying China's capital market, we can gain insights into the role of the GTFP factor in asset pricing. These findings not only apply to China but can also provide strategic guidance and policy insights for other countries committed to green development, thus advancing the deepening and development of sustainable finance practices worldwide[7].

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