A Study on the Impact of Digital Finance on Innovation of Photovoltaic Enterprises-Based on Panel Data of Listed Photovoltaic Companies

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Abstract. This study explores the impact of digital finance on the innovation of listed PV companies based on panel data of listed PV companies from 2018-2022. The article summarizes the data through descriptive statistics, elaborates the relationship between variables using correlation analysis, and further explores the path of financing constraints through panel regression models. It is found that the development of digital finance has a significant positive impact on the innovation of PV listed companies, and the impact is heterogeneous, with larger companies being promoted more significantly by digital finance. Digital finance provides PV listed enterprises with more convenient financing channels, reduces financing costs, improves information transparency, improves risk control and other paths, so that they can obtain more innovation opportunities and resources, thus promoting their technological innovation and business model innovation.

Keywords: digital finance; financing constraints; photovoltaic companies.

1 Introduction

As a technology-intensive enterprise, photovoltaic enterprises have large capital investment at the early stage of development, and financing is difficult and costly, making it difficult to produce immediate results. Digital finance through the Internet, big data, artificial intelligence and other technical means of traditional financial business innovation, financial innovation to strengthen not only to open the institutional risk appetite and science and technology enterprises in the early stage of the investment does not match the difficulty, but also for the photovoltaic listed enterprises to provide a more convenient and efficient financial services.

During 2018-2022, the supply chain, market demand and investment environment of the PV industry fluctuated due to the epidemic, but the Chinese government's supportive policies for the PV industry continued to strengthen. During the same period, digital finance developed rapidly, and digital financial innovation products and services such as blockchain and internet finance brought new financing channels and business models for PV enterprises. Studying the data of PV listed companies in this period can observe the coping strategies and innovation behaviors of the enterprises under

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different economic environmental systems and ensure the relevance of the research results. Therefore, this paper selects 66 photovoltaic enterprises listed on Shanghai and Shenzhen A-shares as research objects, constructs a panel data model, and takes 2018-2022 as the time span to empirically study the role of China's digital finance in influencing the innovation of photovoltaic enterprises

2 Research Design

2.1 Research Hypothesis

This paper explores the impact of digital finance on the innovation of PV-listed firms by analyzing the indicator data of PV firms. In addition to this, the size of listed PV enterprises is usually related to their resource capacity and market share, and larger PV enterprises may be more likely to receive support from digital finance. Therefore, this paper proposes the following preliminary hypotheses.

H1: Digital finance has a significant impact on innovation in PV firms.

H2: There is a positive correlation between the development of digital finance and the innovation input as well as the innovation output of listed PV firms.

H3: The development of digital finance has different impacts on the innovation of PV firms of different sizes.

2.2 Sample Selection and Data Description

Data preprocessing can ensure the overall quality of data and reduce errors. This study takes China's Shanghai and Shenzhen A-share PV listed companies from 2018-2022 as the research object, excludes ST, *ST and other special sample data, and finally obtains the panel data of 66 PV listed companies. The level of digital financial development is based on the data of the degree of digital inclusive financial development in each province in 2018-2022. The research data comes from CSMAR database, China Photovoltaic Industry Association, and data research report of Digital Inclusive Finance Research Center of Peking University.

Data processing and analysis were performed using SPSS, python, SPSSPRO [1] and Excel. In this paper, the median was first utilized to fill in the missing values during data processing, including missing values and outliers in the Digital Financial Measurement Index (DFMI). Due to the different units of variables and indicators in the data, these data need to be normalized to eliminate data quantification. However, the specific maximum and minimum values in the data series are unknown and there are outliers that are outside the range of values, so Z-Score normalization[2], which is mean-variance normalization, is chosen to refer to the new data obtained by subtracting the standard deviation from the mean of the variable or indicator data. The new data has a mean of 0 and a variance of 1. The formula is as follows

$$x^* = \frac{x - \mathrm{mean}(x)}{\mathrm{std}(x)} \tag{1}$$

2.3 Variable Selection

Core Explanatory Variables.

The Digital Financial Inclusion Index (DFI) is a core explanatory variable for measuring the level of digital financial development. The group of Peking University's Digital Finance Research Center cooperated with Ant Financial Services to compile the "Peking University Digital Financial Inclusion Index" and compiled three first-level indices based on the total index[3].

Explained Variables.

The innovation ability of PV enterprises is measured by the number of patent applications (Pat) [4]. Patent is an effective indicator to measure the innovation activities of enterprises, and the number of patent applications can reflect the efforts and achievements of enterprises in technological innovation.

Control Variables.

Firm size, gearing ratio, operating income growth rate, R&D investment, and government subsidies are selected as control variables, which are measured as in Table 1

Table 1. Description of variables

Type of variable	Variable Name	Variable Symbol	Variable Definition	Variable Description
Implicit variable	Photovoltaic Enterprise Innovation Capacity	Pat	Number of Patent Applications	Patents of Industrial Enterprises Above Scale
Independent variable	Digital Finance Development Level	DFI	Digital Inclusive Finance Index	Peking University Digital Inclusive Finance Index
Control variable	Enterprise Scale	Size	Total Assets	Total of Assets by Item
	Asset-Liability Ratio	Lev	Solvency	Total liabilities/total assets
	Operating Income Growth Rate	Growth	Development Capacity	(Amount of total operating income for the current period of the year - Amount of total operating income for the same period of the previous year)/Amount of total operating income for the same period of the previous year)
	R&D Investment	R&D	Research Capacity	Total amount of funds invested in R&D
	Government Subsidy	Subsidy	Other Income	Government grants related to the daily activities of the enterprise but not suitable for revenue recognition or cost reduction

3 Empirical Analysis

3.1 Descriptive Statistics

As shown in Table 2, the maximum value of the number of patent applications is 150.73, the minimum value is 95.73, the average value is 123.439, and the standard deviation is 22.938, which indicates that there is a large difference in the innovation ability of each PV listed enterprise, and the difference in the number of patent applications is obvious.

The maximum value of the level of digital financial development of DFI enterprises is 379.44, the minimum value is 300.21, and the average value is 343.464, and the data gap between the minimum value and the maximum value is more obvious, indicating that different PV enterprises are affected by the development of digital finance to different degrees. The difference between the indicators in the control variables is large, indicating that there are great differences in the operating conditions of the listed PV enterprises.

Table 2. Descriptive statistics

Variables	Sample size	Maximum value	Minimum value	Mean	Standard deviation	Median	Median	Kurtosis	Skewness	Coefficient of Variation (CV)
Pat	325	150.73	95.73	123.439	22.938	124.393	526.158	-2.044	-0.049	0.186
Size	325	16347.028	6516.044	10503.36	4014.713	9659.961	16117923.592	-0.653	0.742	0.382
Lev	325	0.54	0.434	0.491	0.038	0.5	0.001	1.508	-0.529	0.078
Growth	325	1.611	0.299	0.632	0.55	0.407	0.303	4.798	2.177	0.871
R&D	325	50075.386	14709.255	27898.497	14422.289	21793.254	208002411.715	0.173	1.089	0.517
Subsidy	325	8474.24	4427.095	6028.131	1499.676	5844.065	2249029.532	2.514	1.267	0.249
DFI	5	379.44	300.21	343.464	33.225	341.22	1103.89	-1.784	-0.193	0.097
GDP-F	5	11972.25	9657.636	10885.128	906.186	11020.008	821173.364	-0.892	-0.312	0.083

3.2 Correlation Analysis

Table 3 shows the results of the normality test of GDP index-financial sector, total index, total assets, gearing ratio, growth rate of gross operating income, amount of R&D investment, other earnings, and the number of patent applications, including the median and the mean, which are used to test the normality of the data. As can be seen from Table 3, the GDP index-financial sector sample significance P = 0.955, the level does not show significance, cannot reject the original hypothesis, so the data to meet the normal distribution.

Table 3. Normality test results

Variable name	Median	Mean	Standard deviation	Skewness	Kurtosis	S-W test	K-S test
GDP-F	11020.008	10885.128	906.186	-0.312	-0.892	0.984(0.955)	0.159(0.997)
DFI	341.22	343.464	33.225	-0.193	-1.784	0.942(0.678)	0.211(0.943)

Size	9659.961	10503.36	4014.713	0.742	-0.653	0.937(0.648)	0.183(0.985)
Lev	0.5	0.491	0.038	-0.529	1.508	0.947(0.718)	0.211(0.942)
Growth	0.407	0.632	0.55	2.177	4.798	0.651(0.003***)	0.426(0.245)
R&D	21793.254	27898.497	14422.289	1.089	0.173	0.897(0.394)	0.264(0.799)
Subsidy	5844.065	6028.131	1499.676	1.267	2.514	0.897(0.396)	0.304(0.647)
Pat	124.393	123.439	22.938	-0.049	-2.044	0.956(0.779)	0.177(0.990)

Pearson's correlation coefficient, generally denoted by the letter r, is used to measure the linear relationship between two random variables. A significance (P<0.05) test needs to be performed between the variables XY to determine if there is a statistically significant relationship, and then the correlation coefficients are analyzed for positivity and negativity as well as the degree of correlation between the coefficients.3.3 Panel regression model

The quotient of covariance and standard deviation between two variables is calculated as follows:

$$\rho_{X,Y} = \frac{cov(X,Y)}{\sigma_X \sigma_Y} = \frac{E[(X-\mu_X)(Y-\mu_Y)]}{\sigma_X \sigma_Y} \tag{2}$$

Estimation of covariance and standard deviation for the sample gives the Pearson correlation coefficient r as follows:

$$= \frac{\sum_{i=1}^{n}(X_i-\overline{X})(Y_i-\overline{Y})}{\sqrt{\sum_{i=1}^{n}(X_i-\overline{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i-\overline{Y})^2}} \tag{3}$$

The above principle of solving leads to the correlation analysis as follows Table 4, which demonstrates the table of parameter results of the model test, including the correlation coefficient, significance p-value

Table 4. Correlation analysis and testing

	GDP-F(P-value)	DFI(P-value)	Size(P-value)	Lev(P-value)	Growth(P-value)	R&D(P-value)	Pat (P-value)	Subsidy(P-value)
GDP-F	1(0.000***)	0.982(0.003***)	0.955(0.012**)	0.962(0.009***)	-0.291(0.634)	0.917(0.028**)	0.99(0.001***)	0.908(0.033**)
DFI	0.982(0.003***)	1(0.000***)	0.948(0.014**)	0.909(0.032**)	-0.286(0.641)	0.916(0.029**)	0.99(0.001***)	0.852(0.067*)
Size	0.955(0.012**)	0.948(0.014**)	1(0.000***)	0.894(0.041**)	-0.368(0.542)	0.99(0.001***)	0.971(0.006***)	0.946(0.015**)
Lev	0.962(0.009***)	0.909(0.032**)	0.894(0.041**)	1(0.000***)	-0.092(0.883)	0.868(0.056*)	0.916(0.029**)	0.934(0.020**)
Growth	-0.291(0.634)	-0.286(0.641)	-0.368(0.542)	-0.092(0.883)	1(0.000***)	-0.292(0.634)	-0.381(0.527)	-0.184(0.767)
R&D	0.917(0.028**)	0.916(0.029**)	0.99(0.001***)	0.868(0.056*)	-0.292(0.634)	1(0.000***)	0.935(0.020**)	0.952(0.012**)
Pat	0.99(0.001***)	0.99(0.001***)	0.971(0.006***)	0.916(0.029**)	-0.381(0.527)	0.935(0.020**)	1(0.000***)	0.886(0.045**)
Subsidy	0.908(0.033**)	0.852(0.067*)	0.946(0.015**)	0.934(0.020**)	-0.184(0.767)	0.952(0.012**)	0.886(0.045**)	1(0.000***)

Table 4 demonstrates that there is a positive and statistically significant (p<0.05) correlation between the GDP index of the financial sector and the growth of the total index, asset size, gearing ratio, gross operating income, R&D investment, number of patent applications and other benefits. There is a negative correlation between gearing ratio and the growth of GDP index of financial sector and the growth of total index, but the correlation with other variables is not significant. There is a significant negative correlation between the growth rate of gross operating income and the number of patent applications and other earnings. There is a significant positive correlation between the growth rate of R&D investment and the number of patent applications and other gains. There is a correlation between the growth rate of the number of patent applications and other earnings, but the correlation is not significant.

There is a positive and statistically significant ($p<0.05$) relationship between the total digital finance index and the number of R&D investment and patent applications. This indicates that digital finance has a significant impact on innovation in PV companies.

Total assets have a positive but statistically insignificant ($P>0.05$) correlation with GDP Index-Finance, gearing ratio, growth rate of total operating income, amount of R&D investment, number of patent applications and other earnings. This indicates that listed PV firms of different sizes are significantly differently affected by the growth of GDP index-financial sector and between gearing ratio and other variables.

The results of the above analysis also further verify that digital finance, as an emerging financial service model, utilizes advanced information technology means to provide more convenient and efficient financing channels for various industries, and has a significant impact on the innovative development of listed PV enterprises. There is a positive correlation between the development of digital finance and the innovation input and output of PV enterprises. Hypotheses H1 and H2 are established.

3.3 Panel Regression Model

Panel regression model[5] is based on panel data to study the effect of the independent variable on the dependent variable, generally there are three forms of mixed estimation model, fixed effect model, random effect model can be chosen. Tests need to be conducted to determine the type of model chosen, including the F test is used to compare the choice of FE model and POOL model, when $P < 0.05$ indicates that the FE model is better, and vice versa, you should choose to use the POOL model; comparison of the RE model and the POOL model with the Breusch-Pagan test, if the $P < 0.05$ then the RE model is better, and vice versa, then the use of POOL model ; the choice of FE model and RE model was tested by Hausman test, if $P<0.05$ then FE model is better, and vice versa the same. In this study, the F test, Breusch-Pagan test and Hausman test are conducted on the panel data of PV listed companies for the research hypothesis H3, and the test comparison Table 5 is obtained.

Table 5. Model selection test

Type of test	Statistic	P	Conclusion
F-test	0.139	1.000	POOL
Breusch-Pagan- test	38.477	0.000***	RE
Hausman- test	7.274	0.064*	RE

According to the above table, F test with significance $P=1.000>0.05$, does not present significance and cannot reject the original hypothesis, so it is better to choose POOL model. Breusch-Pagan test with significance $P=0.000<0.05$, presents significance at the 1% level and rejects the original hypothesis, it is better to choose RE model as opposed to hybrid POOL model. Hausman test, significance P=0.064>0.05, does not present significance and cannot reject the original hypothesis, so the RE model should be chosen. According to the test results, this paper finally selects the random effect model to carry out the following regression analysis of the impact of digital finance on the innovation ability of PV listed enterprises.

Table 6. RE stochastic model

Variable	Coefficient	Standard error	t	P	R^2	F
const	-1491254.804	29391.304	-50.738	0.000***		
SA index	-1381.261	6840.185	-0.202	0.840		
Growth	-612.739	196.957	-3.111	0.002***	within=0.98 between=0	F=3040.134
Size	0	0	1.516	0.130	overall=0.98	P=0.000***
Subsidy	0	0	-1.228	0.220		
GDP-F	249.895	1.893	131.999	0.000***		

Dependent variable: number of patent applications(Pat)

The table 6 demonstrates the parameter results and test results of this model, including the model's unstandardized coefficients, standard errors, statistics, P, R^2, F-value, etc. The F-test results of the RE stochastic model show the significance p=0.000<0.01, which is horizontally significant, and the original hypothesis is rejected, therefore the RE stochastic model is valid. The relationship between the SA index and the firms' innovative capacity presents a non-significant negative effect (β_2=-1381.261, p=0.840>0.05). PV listed PV listed enterprises can obtain more financial support, optimize capital structure, improve risk management ability, promote industry chain integration, attract and retain talents, enhance corporate image and market influence, as well as better respond to changes in the policy and economic environment by expanding financing channels, which helps to improve the innovation ability of enterprises.

The natural logarithm of the total assets of PV listed enterprises has a non-significant positive effect on the innovation ability of enterprises (β_4=0, p=0.130>0.05), relative to the total assets of smaller PV listed enterprises, the total amount of assets of larger enterprises in the acquisition of financial science and technology innovation is more likely to form a scale effect, they are more willing to take the initiative to carry out financial scientific research and innovation activities in order to enhance their own competitive advantage, and to occupy market share. Occupy the market share, so the digital financial development of the innovation of enterprises with a larger amount of assets has a more obvious effect than enterprises with a smaller amount of assets. So, the hypothesis H3 is valid.

4 Conclusions

4.1 The Impact of Digital Finance on the Size Heterogeneity of Listed Photovoltaic Firms

Larger PV firms usually have a more complete technological base and a mature online market, and are more likely to receive digital finance support for strong technological innovation and effective marketing activities. For small and medium-sized PV enterprises, the impact of digital finance is more reflected in providing them with equal opportunities to compete. These PV enterprises are difficult to obtain the necessary financial support through traditional financial channels due to their own small scale and insufficient financial strength, and the emergence of digital financial platforms has effectively lowered the threshold of financial services.

4.2 The Practice of Digital Finance in Listed Photovoltaic Companies

Digital finance is deeply integrated into the digital transformation of photovoltaic enterprises through the Internet platform and mobile payment and other tools, while providing more diversified financing channels for photovoltaic listed enterprises, such as financial supply chain, network loans, etc., which can effectively shorten the cycle of enterprise's capital recovery, enabling photovoltaic enterprises to invest funds in R&D and innovation more quickly; and it also fully utilizes credit, bonds, leasing, investment banking, It also fully utilizes credit, bonds, leasing, investment banking, equity and other methods to serve the green and low-carbon transformation of the economy and society and create digital inclusive credit.

4.3 The Promotion of Digital Finance for the Management of Photovoltaic Companies

PV-listed enterprises can realize automation and intelligence of financial management, optimize supply chain financing by using digital financial technology, and improve the accuracy of credit assessment of suppliers and customers. Digital financial technology can help PV enterprises explore new business models, and utilize the convergence model of PV+energy storage internet, as well as blockchain-based energy trading platforms, to expand PV-listed enterprise's market and increase revenue sources. PV-listed enterprises can also commonly adopt online customer service, personalized recommendations, and mobile applications to enhance the convenience and personalization of customer service, thereby increasing customer satisfaction and loyalty.

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