The Spillovers Between Education and Technology Markets: Evidence from the Time-Frequency Domain

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Abstract. Under the time and frequency domain framework, this paper use DY-BK method to study the spillovers between education and technology markets. The results show that: (1) there are significant static and dynamic spillover effects between education market and technology market, and the dynamic spillover effects between education market and technology market are time-varying. (2) In terms of static spillover effect, the spillover effect of elementary education, higher education and online education on digital economy income is very significant. The strongest spillover effect is in online education, followed by elementary education. (3) In terms of dynamic spillovers, the post-pandemic education market, especially the higher education and elementary education markets, has shown strong technological leadership.

Keywords: technology · education · DY-BK · spillovers

1 Introduction

Since the 20th century, technology industry has become an essential engine for each country in the current world patterns [1]. Under this background, tech industry has become a new investment focus [2]. But, in a challenging era, the development of the technology industry faces many uncertainties. Therefore, there is an urgent need to find factors highly relevant to the technology industry to control risks and promote its benign development. In this paper, we propose a new relationship between three education and technology markets from the time-frequency domain perspective, including "elementary education (EE), higher education (HE), and online education (OE)". The mutual relationship between education and technology have been studied for decades [3]. However, there are few quantitative studies of such relationships, which is not conducive to the development of the technology industry.

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We use the DY spillover index method put forward by Diebold and Yılmaz. This method cannot only get the direction of spillovers, but also calculate the size of directional spillover between any two markets. But, The DY method is only suitable for time domain research and cannot reflect the information spillover strength between variables in different time frequency ranges. Baruník and Křehlík (2018) constructed a frequency model (BK) to study the spillover effects of variables in different frequency domain systems [4]. Therefore, based on the methods of DY-BK model, we studied the dynamic characteristics of information spillover effects of education and technology markets.

2 Methodology and Data

2.1 Methodology

To explore the spillovers between education and technology markets in the time domain, we employ the DY framework proposed by Diebold and Yilmaz [5], which is built according to a VAR (p) model as follows:

$$X_t = \Phi(L)X_t + \varepsilon_t = \sum_{h=1}^{p} \Phi_h L^h X_t + \varepsilon_t \tag{1}$$

where $X_t = (X_{1t}, X_{2t}, \ldots, X_{nt})$ is a variable vector at time t, $\Phi(L)$ is a pth lag order matrix measuring the autoregressive coefficients, L presents the lag operator, Φ_h is the moving average coefficient matrix with the hth lag order, ε_t is a white noise vector with zero mean, and its covariance matrix is Σ.

Let us suppose that the covariance in this VAR model is stable; hence, the moving average form can be shown as

$$X_t = \Psi(L)\varepsilon_t = \sum_{i=1}^{\infty} \Psi_i \varepsilon_{t-i} + \varepsilon_t \tag{2}$$

where $\Psi(L)$ is the moving average coefficients with an infinite lag order.

In the DY framework, the generalized forecast error variance decomposition (GFEVD) at forecast horizon H is presented as

$$\theta_{jk}(H) = \frac{\sigma_{kk}^{-1} \sum_{h=0}^{H} \left((\Psi_h \Sigma)_{jk} \right)^2}{\sum_{h=0}^{H} \left(\Psi_h \Sigma \Psi_h^{'} \right)_{jj}} \tag{3}$$

where σ_{kk} is the diagonal element at the kth row/column of matrix Σ. Furthermore, we can normalize $\theta_{jk}(H)$ as

$$\widetilde{\theta}_{jk}(H) = \frac{\theta_{jk}(H)}{\sum_{k=1}^{n} \theta_{jk}(H)} \tag{4}$$

where $\sum_{k=1}^{n} \widetilde{\theta}_{jk}(H) = 1$. In this way, $\widetilde{\theta}_{jk}(H)$ can be used as a representative of the standard directional spillover effect from variable k to variable j at forecast horizon H.

Using the direction connectedness, other essential measures of the spillover effect are proposed, including the overall spillover, the TO spillover and the FROM spillover.

The total spillover measures the forecasting variance caused by the other variables in the system and is defined as follows:

$$(C_H) = 100 \times \frac{\sum_{j,k=1,j\neq k}^{n} \tilde{\theta}_{jk}(H)}{\sum_{j,k=1}^{n} \tilde{\theta}_{jk}(H)} \tag{5}$$

The TO spillover is used to measure the directional connectedness from variable j to all other elements in the system:

$$(C_H)_{.\leftarrow j} = 100 \times \frac{\sum_{k=1,k\neq j}^{n} \widetilde{\theta}_{kj}(H)}{\sum_{j,k=1}^{n} \widetilde{\theta}_{kj}(H)} \tag{6}$$

The FROM spillover, i.e., the directional spillover received by variable j from other variables is defined as:

$$(C_H)_{j\leftarrow .} = 100 \times \frac{\sum_{k=1,k\neq j}^{n} \widetilde{\theta}_{jk}(H)}{\sum_{j,k=1}^{n} \widetilde{\theta}_{jk}(H)} \tag{7}$$

The net directional spillover of variable j is measured as the difference between TO and FROM connectedness:

$$(C_H)_j = (C_H)_{.\leftarrow j} - (C_H)_{j\leftarrow .} \tag{8}$$

Finally, the net pairwise spillover between element j and k is calculated as the difference between the spillover effect transmitted from element j to k and that transmitted from element k to j, which can be calculated as follows:

$$(C_H)_{jk} = 100 \times \frac{\widetilde{\theta}_{kj}(H) - \widetilde{\theta}_{jk}(H)}{\mathrm{n}} \tag{9}$$

A positive $(C_H)_{jk}$ suggests that the spillover transmits from element k to j, and a negative $(C_H)_{jk}$ suggests that the spillover transmission has the opposite direction.

Moreover, Baruník and Křehlík (2018) put forward a new measure of connectedness in the frequency domain, which could help us analysis the spillovers on various time scales. Through the wavelet transform, we have $\Psi\left(e^{-i\omega}\right) = \sum_h e^{-i\omega h}\Psi_h$, where $i = \sqrt{-1}$. Thus, the portion of variable j' s fluctuation attributed to variable k at frequency ω can be described as:

$$\theta_{jk}(\omega) = \frac{\sigma_{kk}^{-1}\left|\left(\Psi\left(e^{-i\omega}\right)\Sigma\right)_{jk}\right|^2}{\sum_{h=1}^{H}\left(\Psi\left(e^{-i\omega}\right)\Sigma\Psi^{-1}\left(e^{i\omega}\right)\right)_{jj}} \tag{10}$$

Therefore, we can conclude that forecast period H is unrelated to the BK framework. The normalized $\theta_{jk}(\omega)$ is denoted as:

$$\widetilde{\theta}_{jk}(\omega) = \frac{\theta_{jk}(\omega)}{\sum_{k=1}^{n}\theta_{jk}(\omega)} \tag{11}$$

Additionally, we can extend frequency ω to a frequency band as $d = (a, b)$. Thus, the directional spillover at frequency band d is

$$\tilde{\theta}_{jk}(d) = \int_a^b \tilde{\theta}_{jk}(\omega) d\omega \quad (12)$$

2.2 Data

The data of education market and technology index is daily and both derived from CITIC Securities Co., Ltd, including three sub-domain of education "elementary education (EE), higher education (HE), and online education (OE)", The sample period covers from Dec 2, 2019 to Jan 11, 2023, including 758 observations.

3 Empirical Findings

First, this paper analyses the static spillover effect in the time domain and frequency domain. Second, this paper further analyzes the dynamic spillover effect in the system. There are four variables in both the return systems. In each panel, FROM represents the spillovers from all other factors and TO represents the spillover impact of the factor on all other factors. NPDC denotes the number of positive net pairwise directional connectedness.

3.1 Static Spillovers Between Education and Technology Markets

The results in Table 1 show that the static spillovers between education and technology markets is very high, and total effects reach 156.9. The spillovers from three submarkets of education to digital economy returns are very remarkable, which suggest that education market have a significant effect to impact the trend of technology market returns, i.e. 12.85, 8.91, 16.33, respectively. The cause might be that the education system has greatly promoted the development of science and technology industry. On the other hand, we investigate how spillovers information transmits from the technology market to three submarkets of education and find that technology returns also has a strong impact on education. That is, both sides have witnessed steadily deepened cooperation. From the results of frequency analysis shown in Fig. 1. we can find that the short-term returns total connectedness (142.61) between education and technology markets is much larger than the long-term (14.30). It means that investors tends to emphasize short-run profit rather than long-run profitability. From the from the NPDC standpoint, obviously, the elementary education (EE) and online education (OE) are main total spillover transmitter, and TECH is the spillover receiver. The same spillover direction is also found in short-term. However, in the long-run, TECH and higher education (HE) become the spillover transmitters.

Table 1. Static spillovers in time domain and frequency domain (in %).

Total	TECH	EE	HE	OE	FROM
TECH	61.91	12.85	8.91	16.33	38.09
EE	12.12	58.1	18.34	11.44	41.9
HE	8.85	19.45	61.58	10.12	38.42
OE	16.26	12.13	10.11	61.50	38.5
TO	37.22	44.42	37.37	37.89	**156.9**
NPDC	0	3	1	2	
Short-term frequency: 1 to 5 days	TECH	EE	HE	OE	FROM
TECH	56.16	11.84	8.04	14.83	34.71
EE	10.80	53.04	16.81	10.41	38.02
HE	8.07	17.85	56.27	9.33	35.25
OE	14.64	10.93	9.06	55.66	34.62
TO	33.51	40.62	33.91	34.57	**142.61**
NPDC	1	3	0	2	
Long-term frequency: longer than 5 days	TECH	EE	HE	OE	FROM
TECH	5.75	1.01	0.87	1.50	3.38
EE	1.31	5.06	1.54	1.03	3.88
HE	0.78	1.59	5.31	0.79	3.16
OE	1.62	1.20	1.05	5.84	3.87
TO	3.71	3.80	3.46	3.32	**14.30**
NPDC	2	2	2	0	

3.2 Dynamic Spillovers Between Education and Technology Markets

In Fig. 1 and Fig. 2, we show the dynamic total spillover effect between education and technology markets in time domain and frequency domain. During the whole sample period, the trend of the dynamic spillover is time-varying and presenting backward V type in time domain and short-term frequency domain, whereas line of the dynamic spillover in long-term frequency domain is low with small variation. The effects show a local extreme point of the spillovers at the initial stage in year 2020, but it began to decline with the spread of the global epidemic. In addition, we further demonstrate the dynamic overall spillovers in time domain and frequency domain. Compared with time domain, the volatility of dynamic net spillovers is more significant. Before 2021, the dynamic net spillovers of TECH indicate volatility clustering and large fluctuating, acting as net transmitter. But after that, the amplitude of TECH net spillovers turns to negative, but it is still fluctuating violently. This means that the TECH has become receiver. This requires us to constantly adjust the parameters in investment process of technology industry. With the re-evaluation of the relationship between education and technology, the education market in the post-epidemic era has shown a strong leading

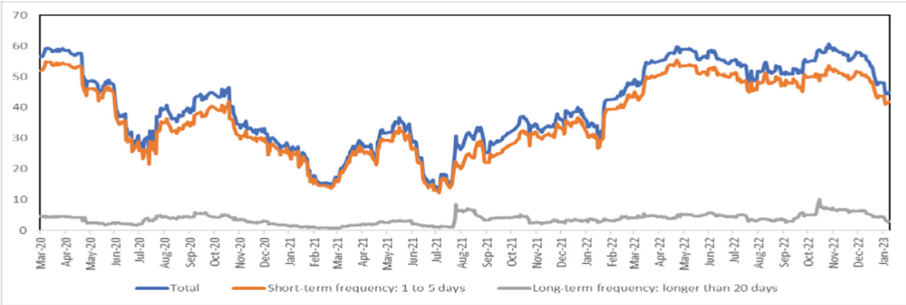


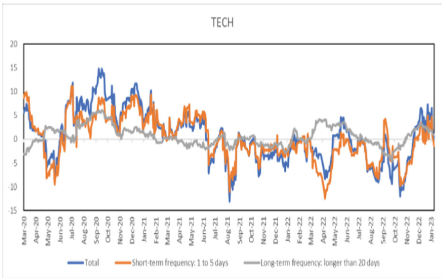
Fig. 1. Dynamic overall spillovers in time domain and frequency domain

role in technology, especially the higher education and basic education markets. The remarkable and persistent spillovers effect of education on TECH suggest that education can be an important determinant of how to predict the trend of the technology market.

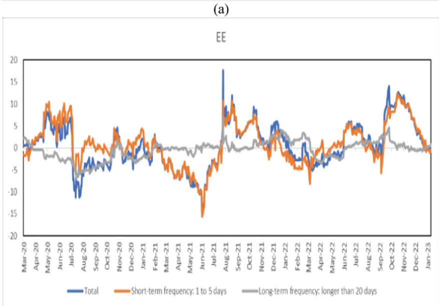
4 Conclusions and Implications

Under the DY-BK time and frequency domain analysis framework, this paper makes an empirical study on spillovers between education and technology markets. First, there is strong connectivity between education and technology markets. Second, according to subdivision of education system, the strongest transmitter is online education, followed by elementary education. Third, the dynamic spillover effect between education and technology markets has significantly dynamic and time-varying effects. Fourth, the results of dynamic net spillovers show that TECH is the main net transmitter and shows volatility clustering and large fluctuating in the early stage of the epidemic, and the later the net transmitter has become education markets.

These findings imply that some important policy recommendations could be derived as follows: First of all, stakeholders can better establish a market-based linkage mechanism, and to predict market fluctuations. Second, the inclusion of education variables in the portfolio and hedge management of the technology markets can help reduce the systemic risk. Third, the technology industry should consider the development trend and potential risks from the educational level, especially in different periods. Fourth, policy managers should attach great importance to the training of high-quality basic innovative talents to encourage cutting-edge scientific and technological innovation.



(a)



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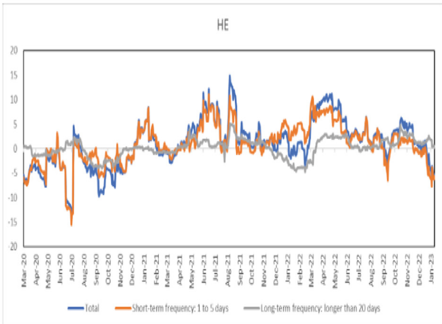

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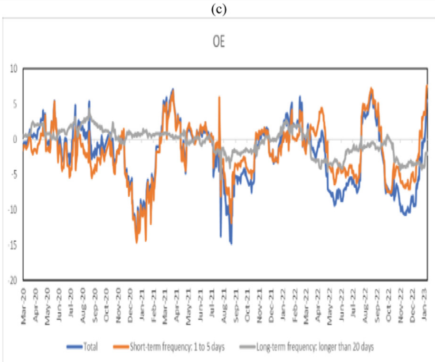

(d)

Fig. 2. Dynamic net spillovers in time domain and frequency domain

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