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RESEARCH ARTICLE

Spillover effect of environmental investment: evidence from panel data at provincial level in China

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Abstract This paper considers pollution density as a function of environmental investment. The higher environmental investment, the lower pollution density. The lower the pollution density is the higher production technology becomes. This is called the spillover effect. We collected China's panel data at the provincial level from 2005 to 2009, and tested the spillover effect of environmental investment. This paper finds that the environmental investment influenced production technology positively. There is a significant positive relation between government expenditure and spillover effect.

Keywords environmental investment, spillover effect, endogenous growth

1 Introduction

In the 1970s, economists began to pay more attention to the energy problem, natural resources and environmental pollution, analyzing environmental pollution under the endogenous growth model. Dasgupta and Heal [1], and Stiglitz [2] analyzed the optimal way to make use of the exhaustible resources under the Ramsey-Cass-Koopmans Model. They believe that per capital consumption may increase continuously, although resources are limited under certain technology. However, in these models, they assume that the technology is exogenous. In the late 1980s, the Endogenous Growth Theory [3–5] was created. Environmental economists began to analyze environmental pollution and sustainable development based on Endogenous Growth Theory. Bovenberg and Smulders [6], Hung et al. [7], and Scholz and Ziemes [8] considered environmental pollution as one factor which determined the output on the basis of Romer's model. Stokey [9] modified the AK model, defined pollution density to represent environmental pollution and analyzed the sustainable economic growth, which is considered the basic research framework for environmental problems. Aghion and Howitt [10] defined the minimum level of environmental resource as a restriction for sustainable economic development and analyzed the influence of environmental resource restriction on sustainable economic development based on the R&D model. Barbier [11] considered resource scarcity and the increasing population growth in Romer-Stiglitz model and found the optimal path for sustainable economic development. Grimaud and Rouge [12] edited the Neo-Schumpeterian model and analyzed the relationship between resource restriction and sustainable development. Grimaud and Giuseppe [13] divided labor resource into two groups, and some of the labor force was allocated into the environmental protection department. These labor forces that are engaged in the environmental protection do not produce any output. In China, Sun [14] considered environmental investment in the Stokey-Aghion model and found that environmental investment played an important role in sustainable economic development. Peng and Bao [15] analyzed the environmental problem in China on the basis of the R&D model. Li and Zhao [16] considered the resource restriction in endogenous growth model.

Generally speaking, most research considers environmental problems under the framework of the endogenous growth theory and believes that good environmental protection will be associated with a low economic growth rate. According to this idea, the government officials prefer a high economic growth rate rather than a good environment, because the performance evaluation standard for officials is a good economic growth rate. The officials believe that more environmental investment is at the expensive of economic growth. Especially in the underdeveloped areas, the officials are eager to promote

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economic development as soon as possible. They are not willing to invest more into environmental protection. For example, the proportion of environmental investment to government expenditure in Shandong Province, China is 14.06%. On the contrary, this proportion in Guizhou Province, China is only 1.54%. Thus, the officials in underdeveloped provinces will not pay enough attention to environmental protection unless the economy advances.

However, we do not believe the environmental investment is certainly associated with a low economic growth rate. Three scenarios are as follows: first of all, same as in ordinary investment, when environmental investment is put into environmental industry and other industries, it generates capital by "multiplier effect", which is good for economic growth in the next period. Secondly, as a result of environmental investment in the current period, environmental investment improves environmental quality, but does not generate capital. Last but not the least, as a procession of environmental investment, environmental investment can promote the upgrade of environmental technology in factories. According to environmental regulation, the pollution discharge by one factory is limited. So when using certain technology, the output is limited. To produce more, the factories must promote technology to decrease pollution density per unit. We define the above three effects: the first effect is "ordinary investment effect"; the second effect is "environmental improvement effect"; and the last one is "spillover effect". Previous research focused on the first and second effect of environmental investment and ignored the "spillover effect" of environmental investment, which is the main topic of this paper.

Environmental investment promotes the upgrade of environmental technology, decreases the pollution emission per unit output, and then raises the output under a certain environmental standard. This is the spillover effect of environmental investment. The ways of using environmental investment to influence economic growth is shown in Fig. 1.

In fact, as the government generally realizes the importance of environmental protection, the first action is to treat the present pollution problem by environmental investment immediately. However, the pollution treatment is not helpful for promoting economic growth, since this kind of environmental investment impacts economic growth by the "environmental improvement effect". Next, the government starts to promote the environmental industry in order to promote the application of environmental facility. Following the emerging of the environmental industry, environmental investment behaves as an ordinary investment and generates capital for economic growth in the next period. However, the above are measures taken after pollution not before pollution. To realize sustainable economic development, we must prevent more pollution from destroying the environment. The key point is to decrease pollution density, which is determined by environmental technology. Environmental investment can reduce pollution emission per unit output, which is good for environmental technology upgrade. This is the spillover effect of environmental investment.

This paper views pollution density as a function of environmental investment. The more environmental investment there is the lower pollution density becomes. The economic growth may realize sustainable development because of the environmental investment. Environmental investment becomes at least a social capital, like subways or bridges, which improves the lives of its citizens who become more efficient and effective due to better health. Furthermore, we collected the provincial environmental investment data in China from 2005 to 2009. Then we tested the spillover effect of environmental investment and the factors influencing spillover effect. We concluded that the environmental investment promotes technology, and the spillover effect in eastern China is significantly more obvious than that in western China.

The contribution of this paper is the definition of spillover effect, which is ignored by researchers and officials. Though previous research analyzes environmental investment based on endogenous growth model, there is still some difference between previous studies and this paper. We present pollution density as a function of environmental investment. The other researchers view pollution density as an exogenous variable. So the previous research does not realize the spillover effect.

The structure of this paper is as follows: Section 2 describes the model, and characterizes the spillover effect of environmental investment, Section 3 sets out the empirical test design and describes the data, Section 4

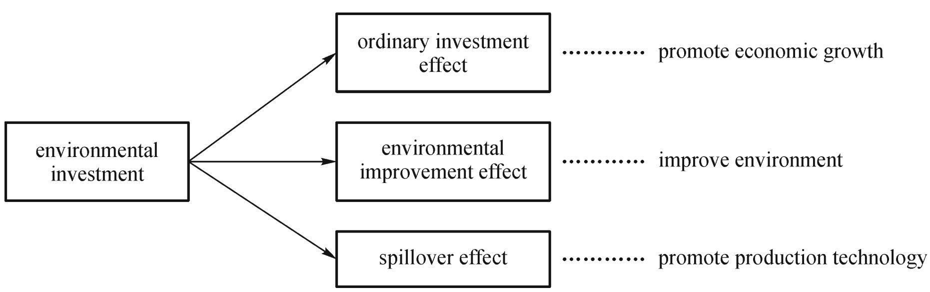

Fig. 1 Three effects of environmental investment

performs the empirical analysis, and Section 5 presents the conclusion.

2 Basic model

Suppose a closed economic system which is made up of homogeneous consumers; the population is unchanged; the utility of consumer comes from the consumption and environmental quality. The consumer's utility function is $U(c,E)$, where, c refers to per capital consumption. Suppose population is 1, thus c refers to total consumption, E refers to environmental quality, where $u_c > 0$, $u_E > 0$, $u_{cc} < 0$.

The consumer welfare in his lifetime is

$$W = \int_0^{\infty} \mathrm{e}^{-\rho t} U(c,E)\mathrm{d}t, \tag{1}$$

where, $\rho > 0$ refers to temporal discounting, which means more attention we pay for offspring, a bigger ρ implies less attention for offspring, and if $\rho \rightarrow 0$, it means equal attention for ourselves and for offspring.

Formally, let $Y = AKz$ denote production function, where, A is technology, K is capital, z is pollution density. The factory's aim is to maximize profit, so the optimal choice for factory is to emit pollution just equal to the discharge standard given by the government. If the emission standard and production technology are limited, the output is also limited according to the environmental standard. To produce more, the producer must promote technology to decrease pollution density. The environmental technology is determined by environmental investment. So the output is a function of technology, capital, and pollution density. The environmental investment (I) influences environmental technology positively, and then reduces the pollution density. Suppose the relationship between environmental investment (I) and pollution density (z) is as follows:

$$z = z(I) = \alpha + \beta I, \tag{2}$$

where $\dfrac{\partial z(I)}{\partial I} < 0$, and thus $\beta < 0$.

Except the spillover effect, the environmental investment (I) has the multiplier effect as ordinary investment, which generate capital for economic growth in the next period. This effect is written into the capital accumulation equation:

$$\dot{K} = AKz - c. \tag{3}$$

We define the best environment quality is 0, and the worst environment quality is $E_{\min}$, so $E \in [E_{\min},0]$. E is determined by the following three factors. First, E is a negative function of pollution (p), and p is associated with output, thus $P(Y,z) = Yz^{\gamma} = AKz^{\gamma+1}$, where Y refers to the output, $z \in [0,1]$ refers to pollution density, $\gamma > 1$ refers to marginal cost of pollution. Secondly, environment has self-renewal ability, so E is a positive function of self-renewal rate (θ). Finally, the environmental investment has "environmental improvement effect" on E. Let $R(I)$ denote the contribution of environmental investment for environment renew, and $R'(I) > 0$. Thus the motion equation of E is as below:

$$\dot{E} = -Yz^{\gamma} + \theta E + R(I). \tag{4}$$

The dynamic optimization of a social planer is:

$$\max_{c,E} \int_0^{\infty} \mathrm{e}^{-\rho t} U(c,E)\mathrm{d}t$$

$$\begin{aligned} s.t.\ \dot{K} &= AKz - c \\ \dot{E} &= -AKz^{\gamma+1} + \theta E + R(I) \end{aligned}, \tag{5}$$

In addition, $K(0) = K_0$, $E(0) = E_0$, $z = \alpha + \beta I$.

Define the Hamilton function as below:

$$H = U(c,E) + \lambda(AKz - c) + \mu[-AKz^{\gamma+1} + \theta E + R(I)], \tag{6}$$

Two controlling variables are c and I, two state variables are K and E. TVC is as follows:

$$\lim_{t\rightarrow\infty} \lambda K \mathrm{e}^{-\rho t} = 0, \lim_{t\rightarrow\infty} \mu E \mathrm{e}^{-\rho t} = 0, \tag{7}$$

The first order condition of controlling variables is as below:

$$\frac{\partial H}{\partial c} = u_c - \lambda = 0, \tag{8}$$

$$\frac{\partial H}{\partial I} = \lambda Az - \mu Az^{\gamma}[z + I(\gamma+1)z\beta] + \mu R'(I) = 0. \tag{9}$$

From Eqs. (8) and (9), we get

$$\lambda = u_c, \tag{10}$$

$$\mu = \frac{\lambda Az}{Az^{\gamma}[z + I(\gamma+1)z\beta] - R'(I)}. \tag{11}$$

The Euler equation is as below:

$$\frac{\partial H}{\partial K} = -\rho\lambda + \lambda Az - \mu Az^{\gamma+1} = -\dot{\lambda}, \tag{12}$$

$$\frac{\partial H}{\partial E} = -\rho\mu + u_E - \mu\theta = -\dot{\mu}, \tag{13}$$

According to Eq. (10), we get

$$\dot{\lambda} = u_{cc}\dot{c}. \tag{14}$$

Rewrite Eq. (14), we conclude that the consumption path considering spillover effect of environmental investment as follows:

$$\frac{\dot{c}}{c} = \frac{1}{\varepsilon}\left[Az\left(1 - \frac{Az^{\gamma+1}}{Az^{\gamma}(z + I(\gamma+1)z\beta) - R'(I)}\right) - \rho\right], \quad (15)$$

where $\frac{1}{\varepsilon} = -\frac{u_c}{u_{cc}c}$ refers to cross-elasticity of substitution.

From the consumption path, we find $\dot{c}/c > 0$, if the sustainable economic growth can be realized, thus

$$Az\left(1 - \frac{Az^{\gamma+1}}{Az^{\gamma}(z + I(\gamma+1)z\beta) - R'(I)}\right) - \rho > 0. \quad (16)$$

Equation (16) equals to:

$$R'(I) < \frac{Az^{\gamma+1}(\rho - I(\gamma+1)\beta(Az-\rho))}{\rho - Az}. \quad (17)$$

According to Stokey-Aghion model, $Az-\rho > 0$ is the necessary condition of economic growth, otherwise $\dot{c}/c > 0$ can not be realized. Similar to Stokey-Aghion model, we suppose $Az-\rho > 0$.

Now, we analyze the left hand and right hand of Eq. (17). For the left side of Eq. (17) , if $R''(I) < 0$, the equation will establish forever, as long as the maximization of $R'(I)$ is bigger than the right of Eq. (17). If $R''(I) = 0$, the equation will establish all the time as far as $R'(I)$ equals to the right of equation. If $R''(I) > 0$, unless $R'(I)$ has a maximization and the maximization is smaller than the right of Eq. (17), the sustainable economic growth will not come true.

For the right side of Eq. (17), let $f(z,\gamma,A,\rho,I,\beta) = \frac{Az^{\gamma+1}(\rho - I(\gamma+1)\beta(Az-\rho))}{\rho - Az}$, we get $\partial f/\partial z < 0$, $\partial f/\partial I > 0$, $\partial f/\partial \gamma < 0$, $\partial f/\partial A > 0$, $\partial f/\partial \rho < 0$, and $\partial f/\partial \beta > 0$.

In conclusion, environmental investment affects the sustainable economic growth in several ways. The environmental investment can not only change the left of Eq. (17), but also the right of Eq. (17). Environmental investment plays a negative role on pollution density. The more environmental investment is, the lower pollution density (z) is, and the bigger spillover effect is. Moreover, the bigger spillover effect, the more likely sustainable economic growth happens.

3 Empirical specification and data

The result of spillover effect is technology promotion. We test the spillover effect by the below empirical model:

$$\begin{aligned}\text{Technology}_{i,t} &= \varphi_0 + \varphi_1 E\text{Investment}_{i,t} + \varphi_2 \text{Contolling}_{i,t} \\ &\quad + \varphi_3 \text{Contolling}_{i,t} \times E\text{Investment}_{i,t} + \varepsilon, \quad (18)\end{aligned}$$

where i and t denote the province and year. Here, Technology is dependent variable, and refers to the production technology. *E*Investment is independent variable, and refers to the environmental investment. Controlling is a controlling variable, and refers to other factors which may influence the technology, such as the initial technology, GDP, industry structure, fixed assets, and government expenditure. Influence is a moderator which refers to the factors which influence spillover effect. We let the cross multiplication of *E*Investment and Controlling to denote the moderators.

We collect environmental investment data for 30 provinces (Special administrative regions like Hongkong and Macao, Tibet as well as Taiwan Province were not included in the current study due to data missing) in China from *China Environment Statistical Yearbook* (2005–2009), and other data from *China Statistical Yearbook for Regional Economy* (2005–2009). According to the *China Environment Statistical Yearbook* (2005–2009), environmental investment covers three parts: Investment in Urban Environmental Infrastructure Facilities, Investment in Treatment of Industrial Pollution Sources, and Investment in Environment Components for New Construction Projects. The three parts of environmental investment affect economic growth in different ways. Investment in Urban Environmental Infrastructure Facilities influences economic growth by the “ordinary investment effect”. Investment in Treatment of Industrial Pollution Sources influences economic growth by the “environmental improvement effect”. Investment in Environment Components for New Construction Projects influences economic growth by the “ordinary investment effect”, “environmental improvement effect”, and “spillover effect”. So we made use of the data of Investment in Environment Components for New Construction Projects to represent environmental investment for further research. The data summery of Investment in Environment Components for New Construction Projects from 2005 to 2009 is shown in Table 1.

Table 1 displays environmental investment in 30 provinces. The environmental investment in the 30 provinces is definitely different. In some province, such as Jiangsu, Zhejiang, and Shandong, the average environmental investment exceeded 400 billion RMB, but the environmental investment in some provinces, such as Hainan, Qinghai, Guizhou, Gansu, and Ningxia, is lower than 80 billion RMB. Many factors contribute to this gap, including GDP, government expenditure, industry structure, fixed assets, and initial technology. The difference of environmental investment in the 30 provinces causes the difference of the spillover effect.

We define the following variables as shown in Table 2.

The descriptive statistics for dependent and independent variables are shown in Table 3.

Table 1 Environmental investment from 2005 to 2009 in China/(billion CNY)

province	2009	2008	2007	2006	2005	average
Beijing	250	261	412	287	80	258
Tianjin	296	160	247	79	243	205
Hebei	764	720	615	285	210	518.8
Shanxi	554	454	187	127	112	286.8
Inner Mongolia	244	313	225	296	176	250.8
Liaoning	323	280	223	165	171	232.4
Jilin	157	240	110	71	34	122.4
Heilongjiang	138	255	92	82	42	121.8
Shanghai	893	719	383	378	289	532.4
Jiangsu	1100	1706	1035	933	734	1102
Zhejiang	796	3995	904	574	561	1366
Anhui	351	567	256	99	65	267.6
Fujian	429	337	240	153	203	272.4
Jiangxi	180	102	190	66	91	125.8
Shandong	1119	1240	795	379	217	750
Henan	480	354	393	230	174	326.2
Hubei	519	256	73	143	112	220.6
Hunan	427	245	167	80	80	199.8
Guangdong	341	373	403	664	528	261.8
Guangxi	355	317	56	69	69	173.2
Hainan	41	47	55	27	21	38.2
Chongqing	406	241	254	237	116	250.8
Sichuan	424	403	289	193	144	290.6
Guizhou	71	51	97	43	41	60.6
Yunnan	366	251	159	95	109	196
Shaanxi	374	216	246	124	52	202.4
Gansu	135	49	87	30	39	68
Qinghai	56	109	51	14	33	52.6
Ningxia	144	88	64	38	32	73.2
Xinjiang	191	118	88	63	74	106.8

Source: Ministry of Environmental Protection of China, *China Environment Statistical Yearbook* (2005–2009), China Environmental Press [17–21]

4 Empirical tests

4.1 Unit root test

Table 4 exhibits the unit root test about Technology, *E*Investment, GDP, industry structure, fixed assets and government expenditure. ADF test results show that all the variables are stationary.

4.2 Regression test in national scale

Table 5 shows the result of regression of spillover effect in China. The coefficient of *E*Investment is significantly positive, which means that a higher level of local environmental investment leads to a higher technology level, since the spillover effect of environment investment. The coefficient of initial Technology is significantly positive. The coefficient of GDP is negative, but this relation is not significant. The coefficient of industry structure is significantly positive. This result demonstrates that the high proportion of tertiary industry in GDP is good for technology upgrade, since the high-tech companies belong to the tertiary industry, which is the origin of advanced environmental technology and the place where the advanced environmental technology is practiced. The coefficient of fixed assets is significantly positive. The coefficient of government expenditure is significantly positive, which proves the important role of government in technology improvement.

To check the influencing factors of spillover effect, we

Table 2 Variable and definition

variable	definition
technology	the number of patents accepted
*E*Investment	investment in Environment Components for New Construction Projects
initial technology	the technology last year
GDP	the natural logarithm of gross domestic product
industry structure	the proportion of tertiary industry in GDP
fixed assets	the natural logarithm of local fixed assets
government expenditure	the proportion of government expenditure in GDP

examine several cross multiple of the *E*Investment and other variables. Table 6 shows the result. The coefficient of *E*Investment is significantly positive, which demonstrates the spillover effect again. The coefficient of initial technology × *E*Investment is significantly positive. This result tells us that the higher initial technology creates a higher spillover effect. The coefficient of GDP × *E*Investment is significantly negative. So in the underdeveloped areas, the spillover effect is more obvious. In the underdeveloped areas, we should pay more attention to the spillover effect of environmental investment, which causes technology promotion and economic development. The coefficient of industry structure × *E*Investment is significantly negative. The smaller the proportion of tertiary industry in GDP is, the stronger the spillover

Table 3 Descriptive statistics

variable	mean	median	maximize	minimize	Std. Dev.
technology/unit	19157.84	7913.50	174329	97	28888.48
*E*Investment/(billion CNY)	300.4	206.5	3995	0	407.3
GDP/(billion CNY)	90521.6	70210	394825.6	2512.1	79458.9
industry structure/%	40	39	76	28	0.08
fixed assets/(billion CNY)	47175.1	36536.7	190345.3	2703.4	37653
government expenditure/%	20.08	16.99	96.41	7.92	13.95

Source: *China Environment Statistical Yearbook* (2005–2009) [17–21], and *China Statistical Yearbook for Regional Economy* (2005–2009) [22–26]

Table 4 Unit root test

variable	ADF	variable	ADF
Technology	$-8.9528^{a)}$	industry structure	$-13.7872^{a)}$
*E*Investment	$-7.8821^{a)}$	fixed assets	$-7.7864^{a)}$
initial technology	$-7.5560^{a)}$	government expenditure	$-6.4495^{a)}$
GDP	$-7.7824^{a)}$		

Notes: a) significant at the 1% level, two-tailed

Table 5 Spillover effect in China

variable	model(1)	model(2)	model(3)	model(4)	model(5)	model(6)
*E*Investment	$0.1183^{a)}$ (10.8118)	0.0003 (0.7105)	$0.0006^{c)}$ (1.7463)	$0.0009^{b)}$ (2.3787)	$0.0008^{b)}$ (2.2849)	$0.0008^{b)}$ (2.2355)
initial technology		$1.0206^{a)}$ (467.4646)	$0.9524^{a)}$ (43.7598)	$0.9435^{a)}$ (43.6656)	$0.9581^{a)}$ (42.3160)	$1.0216^{a)}$ (39.4188)
GDP			$0.0673^{a)}$ (3.1502)	$0.0581^{a)}$ (2.7357)	−0.0759 (−1.0520)	−0.0443 (−0.6525)
industry structure				$0.3795^{b)}$ (2.4121)	$0.4592^{a)}$ (2.9204)	$0.4566^{a)}$ (2.9145)
fixed assets					$0.1245^{c)}$ (1.9415)	$0.1699^{b)}$ (2.3643)
government expenditure						$0.0070^{a)}$ (4.2413)
adjusted R^2	0.2012	0.9887	0.9896	0.9901	0.9904	0.9917
sample	124	124	124	124	124	124

Notes: a) significant at the 1% level, two-tailed; b) significant at the 5% level, two-tailed; c) significant at the 10% level, two-tailed

Table 6 Influencing factors of spillover effect in China

variable	model(1)	model(2)	model(3)	model(4)	model(5)	model(6)
*E*Investment	0.1183[a)] (10.8118)	1.0617[a)] (10.6525)	1.0256[a)] (12.2728)	0.9160[a)] (10.6687)	1.9464[a)] (8.1909)	2.3894[a)] (13.2190)
initial technology × *E*Investment		–0.0889[a)] (–9.5739)	–0.0722[a)] (–8.9065)	–0.0772[a)] (–9.7965)	–0.0242[b)] (–1.7733)	0.0483[a)] (3.8899)
GDP × *E*Investment			–0.0822[a)] (–7.2029)	–0.0844[a)] (–7.7252)	–0.1036[a)] (–9.4872)	–0.0802[a)] (–9.5604)
industry structure × *E*Investment				0.4160[a)] (3.4847)	–0.1936 (–1.1123)	–0.9332[a)] (–6.3350)
fixed assets × *E*Investment					–0.1443[a)] (–4.5999)	–0.25573[a)] (–9.9477)
government expenditure × *E*Investment						0.0041[a)] (9.9245)
adjusted R^2	0.6812	0.9566	0.7305	0.6717	0.5583	0.5767
sample	124	124	124	124	124	124

Notes: a) significant at the 1% level, two-tailed; b) significant at the 10% level, two-tailed

effect works. The spillover effect is good for the industrial structure optimization. The coefficient of fixed assets × *E*Investment is significantly negative. This result means that the environmental investment may promote technology when the fixed assets are not helpful for economic growth. The coefficient of government expenditure × *E*Investment is significantly positive. In China, the behavior of government impacts technology promotion significantly.

4.3 Regression test in regional scale

For further examination about the difference of spillover effect between different provinces, we divide all the provinces into three regions: eastern region, middle region, and western region. The eastern region includes Beijing, Fujian, Guangdong, Hainan, Hebei, Jiangsu, Shandong, Shanghai, Tianjin, Zhejiang, Heilongjiang, Jilin, and Liaoning. The middle regional includes Anhui, Henan, Hubei, Hunan, Jiangxi, and Shanxi. The western region includes Chongqing, Gansu, Guangxi, Guizhou, Inner Mongolia, Ningxia, Qinghai, Shaanxi, Sichuan, Xinjiang, and Yunnan. We test the spillover effect in three regions.

Table 7 shows the regression result of spillover effect in three regions. From the figures in Table 7, we find that the spillover effect in eastern China is more obvious than that in middle China and western China. The spillover effect in western China is not significant. This result means that there are some preconditions for spillover effect to work, such as the innovation mechanism, flexible financing standard, and strict patent protection. Compared to systems in other regions, the system in the eastern region is perfect, which provides a suitable condition for spillover effect of environmental investment. Moreover, the proportion of third industry in the eastern region is bigger than those in the western and middle regions. Most factories in third

Table 7 Spillover effect in three regions

variable	eastern	middle	western
*E*Investment	0.0006[b)] (2.4181)	0.0035[c)] (1.8044)	–0.0002 (–0.0442)
initial technology	0.9890[a)] (34.9261)	0.8972[a)] (9.6071)	1.0592[a)] (18.7899)
GDP	0.0170 (0.2660)	0.0425 (0.2570)	–0.1706 (–0.7171)
industry structure	0.1538 (0.7719)	0.8648 (0.8983)	–1.1724 (–1.3554)
fixed assets	0.0064 (0.1072)	0.0377 (0.1993)	0.1657 (0.6352)
government expenditure	–0.0019 (–0.4988)	0.0017 (0.0947)	0.0121[a)] (3.3700)
adjusted R^2	0.9958	0.9769	0.9811
sample	52	24	48

Notes: a) significant at the 1% level, two-tailed; b) significant at the 5% level, two-tailed; c) significant at the 10% level, two-tailed

industry are high-tech factories. So the spillover effect in the eastern region is more significant. The coefficient of government expenditure is different among three regions. In the western region, the coefficient is significantly positive. In the middle region, the coefficient is positive, but not significant. In the eastern region, the coefficient is negative. Therefore, the technology improvement in the underdeveloped areas relies on the backup of the government. However, in the developed areas, the importance of government is not obvious.

Furthermore, we analyze the factors influencing spillover effect in three regions.

As shown in Table 8, the coefficients of GDP × *E*Investment, fixed assets × *E*Investment, and government expenditure × *E*Investment are similar. There is some difference of the coefficients of initial technology ×

Table 8 Influencing factors of spillover effect in three regions

variable	eastern	middle	western
*E*Investment	2.1953[a)] (9.9826)	3.5960[a)] (7.8108)	3.0130[a)] (5.4405)
initial technology × *E*Investment	0.0525[a)] (3.6573)	0.0552 (1.0578)	0.0080 (0.2239)
GDP × *E*Investment	−0.0628[a)] (−7.4218)	−0.1922[a)] (−4.1590)	−0.2149[a)] (−3.8922)
industry structure × *E*Investment	−0.9462[a)] (−5.7571)	−1.1418[b)] (−1.8609)	0.0840 (0.0904)
fixed assets × *E*Investment	−0.2436[a)] (−8.2728)	−0.3827[a)] (−5.1073)	−0.3052[a)] (−5.5197)
government expenditure × *E*Investment	0.0051[a)] (9.9390)	0.0070[a)] (4.8542)	0.0023[a)] (3.4722)
adjusted R^2	0.9436	0.6150	0.5088
sample	52	24	48

Notes: a) significant at the 1% level, two-tailed; b) significant at the 10% level, two-tailed

*E*Investment and industry structure × *E*Investment in three regions. The influence of fixed assets and industry structure on spillover effect is more significant in the eastern region, which means that the spillover effect in the middle and western regions are not enough.

5 Conclusions

Environmental investment promotes economic growth in the following three ways: “ordinary investment effect”, “environmental improvement effect”, and “spillover effect”. According to the endogenous theory, this paper presents the pollution density as a function of environmental investment. When there is more environmental investment, pollution density becomes lower, and technology becomes higher. This is the spillover effect of environmental investment. The spillover effect means that the environmental investment can not only promote economic growth by “ordinary investment effect”, but also improve environmental technology by “spillover effect”. Under certain environmental standards, output is limited. The only way to enlarge output under a certain standard is to promote production technology. Thus, the spillover effect works.

This paper collects China’s provincial panel data from 2005 to 2009, and tests the spillover effect of environmental investment. We find the spillover effect of environmental investment is significant. However, the spillover effect in eastern region is more obvious than those in other regions. The spillover effect is determined by GDP, industry structure, fixed assets, and government expenditure. For example, when the government expenditure is higher, spillover effect becomes more significant. We suggest the local government should pay more attention to the spillover effect of environmental investment and supply more convenient condition for spillover effect.

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References

1. Dasgupta P, Heal G. The optimal depletion of exhaustible resources. The Review of Economic Studies, 1974, 41(2): 3–28
2. Stiglitz J. Growth with exhaustible natural resources: efficient and optimal growth paths. Review of Economic Studies, 1974, 41(5): 123–137
3. Romer P M. Increasing returns and long-run growth. Journal of Political Economy, 1986, 94(5): 1002–1037
4. Romer P M. Endogenous technological change. Journal of Political Economy, 1990, 98(5): 71–102
5. Lucas R E. On the mechanics of economic development. Journal of Monetary Economics, 1988, 22(1): 3–42
6. Bovenberg A L, Smulders S A. Environmental quality and pollution-augmenting technological change in a two-sector endogenous growth model. Journal of Public Economics, 1995, 57(3): 369–391
7. Hung V T Y, Chang P, Blackburn K. Endogenous growth, environment and R&D. In: Carraro C, ed. Trade Innovation and Environment. Dordrecht: Kluwer Academic Press, 1994
8. Scholz C M, Ziemes G. Exhaustible resources, monopolistic competition, and endogenous growth. Environmental & Resource Economics, European Association of Environmental and Resource Economists, 1999, 13(2): 169–185
9. Stokey N. Are there limits to growth? International Economic Review, 1998, 39(1): 1–31
10. Aghion P, Howitt P. Endogenous Growth Theory. Cambridge: MIT Press, 1998
11. Barbier E. Endogenous growth and natural resource scarcity. Environmental and Resource Economics, 1999, 14(1): 51–74
12. Grimaud A, Rouge L. Non-renewable resources and growth with vertical innovations: optimum, equilibrium and economic policies. Journal of Environmental Economics and Management, 2003, 45 (2): 433–453
13. Grimaud A, Giuseppe D V. Captal accumulation, interest, and the income-pollution pattern: a simple model. Economic Modelling, 2008, 25(2): 225–235
14. Sun G. Pollution, environmental protection and sustained growth. World Economic Forum, 2004, 47(5): 47–58 (in Chinese)
15. Peng S J, Bao Q. Environmental pollution, endogenous growth and sustainable development. The Journal of Quantitative & Technical Economics, 2006, 23(9): 114–126 (in Chinese)
16. Li S B, Zhao D T. Economy sustainable development endogenous growth model under the restrains of environment pollution. Forecasting, 2008, 27(1): 72–76 (in Chinese)
17. Ministry of Environmental Protection of China. China Environment Statistical Yearbook (2005). Beijing: China Environmental Press,

2006 (in Chinese)
18. Ministry of Environmental Protection of China. China Environment Statistical Yearbook (2006). Beijing: China Environmental Press, 2007 (in Chinese)
19. Ministry of Environmental Protection of China. China Environment Statistical Yearbook (2007). Beijing: China Environmental Press, 2008 (in Chinese)
20. Ministry of Environmental Protection of China. China Environment Statistical Yearbook (2008). Beijing: China Environmental Press, 2009 (in Chinese)
21. Ministry of Environmental Protection of China. China Environment Statistical Yearbook (2009). Beijing: China Environmental Press, 2010 (in Chinese)
22. National Bureau of Statistics of China. China Statistical Yearbook for Regional Economy (2005). Beijing: China Statistics Press, 2006 (in Chinese)
23. National Bureau of Statistics of China. China Statistical Yearbook for Regional Economy (2006). Beijing: China Statistics Press, 2007 (in Chinese)
24. National Bureau of Statistics of China. China Statistical Yearbook for Regional Economy (2007). Beijing: China Statistics Press, 2008 (in Chinese)
25. National Bureau of Statistics of China. China Statistical Yearbook for Regional Economy (2008). Beijing: China Statistics Press, 2009 (in Chinese)
26. National Bureau of Statistics of China. China Statistical Yearbook for Regional Economy (2009). Beijing: China Statistics Press, 2010 (in Chinese)