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Access to Digital Financial Services and Green Technology Advances: Regional Evidence from China

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Abstract: Using data of 265 Chinese cities from 2010 to 2017, we studied the impact of access to digital financial services on green technology advances in the context of regional competition. We found that access to digital financial services significantly promotes green technology advances within the region but inhibits those in other regions. We also found that modest regional competition can promote green technology advances, whereas excessive competition impairs the positive relationship between access to digital financial services and green technology advances. We identified a significantly positive spatial spillover effect for green technology advances.

Keywords: access to financial services; use of green technology; regional competition

1. Introduction

Over the past decade, China has realized that its extensive economic growth mode with high inputs, pollution, and energy consumption is unsustainable, and now seeks green economic growth. In this context, advancing green technology has become a new development goal. Two types of policy instruments are conducive to promoting green technologies: environmental regulation, which forces corporations to innovate [1]; and financial instruments, which can induce green innovations. In this paper, access to digital financial services refers to digital access to and use of formal financial services by excluded and underserved populations. We use green total factor productivity to measure green technology advances.

Chinese regional governments are continually in competition for resources, especially capital, to stimulate local economic development and improve political performance. Although such inter-regional competition is considered an effective method to promote technological change and optimize economic structure, it also increases the resource imbalance between regions. Access to digital financial services has been introduced to reduce financial constraints on small businesses and promote regional economic growth. Since a complete credit system is not yet formed in China, it is challenging for middle- and low-income groups to obtain loans from financial institutions. Using modern technologies such as big data and cloud computing to collect personal credit information, access to digital financial services significantly reduces transaction costs and expands the coverage of financing services. In this study, we aimed to answer the following research questions: (1) Does access to digital financial services affect green technology advances and, if so, how? (2) Does regional competition impact the effect of access to digital financial services, since the latter increases capital flows across regional borders?

Using the data of 265 Chinese cities from 2011 to 2017, we studied the impact of access to digital financial services on green technology advances in the context of regional

competition. First, we measured the green technology advances with a GML index-based super SBM model. Then, we explored the impact of access to digital financial services on green technology advances. Finally, we used the spatial Durbin model to analyze the spatial effect of access to digital financial services on green technology advances under regional competition, the direct and indirect effect of which was separated using the partial differential method.

This study differs from other studies in three ways: Firstly, we not only analyzed the effects of access to digital financial services on green technology advances, but also considered regional competition since access to digital financial services increases the liquidity of the capital for which regional governments compete. Most related studies have focused on innovation induced by environmental regulations [1,2], whereas few have highlighted the shocks incurred by new financial instruments such as those induced by access to digital financial services. Among the studies considering access to digital financial services, most examined its effects on the economy [3], consumption [4], and financing constraints [5]; however, the relationship between access to digital financial services and green technology advances has rarely been included in the scope of these studies. We aimed to address these gaps.

Secondly, we did not merely identify the impact of access to digital financial service but further isolate the spillover of access to digital financial services on neighboring regions because technologies spread quickly and adjacent areas respond quickly to local technological changes. Among the studies considering access to digital financial services [3–5], most examined its benefit in a region but did not consider the spatial spillover. We also examined the direct and indirect effect of access to digital financial services to explore what is actually promoting green technology.

Finally, we employed a GML index-based super SBM model to measure green technology advances. The GML index is typically employed to estimate the efficiency between inputs and outputs, such as the total factor productivity [6]. The conventional model for induced-effect analysis is an ML index based on the SBM model [7], which cannot offer feasible solutions to linear programming and circularity. To compensate for such shortcomings, we adopted the GML index-based super SBM model, which treats pollution as an unexpected output, to obtain prefectural green technology advances. Since technologies spill over to neighboring areas, we employed a spatial Durbin model to confirm its spillover effect. We further used a partial differential equation to separate both the effect of access to digital financial services and its interaction with regional competition into direct effects and indirect effects. In addition, we used a series of indexes regarding access to digital financial services collected by Guo et al. [8], including coverage, use, and digital indexes. This dataset enabled us to analyze access to digital financial services, an area that has seldom been analyzed in the existing literature, and frees us from data limitations.

The remainder of this paper is organized as follows: Section 2 reviews the related literature and hypotheses. Section 3 provides the data and method, including the measurement model for green technology advances, the basic model, the spatial model, and the data source and definition. Section 4 presents the results of the basic model, spatial spillovers, and direct and indirect effects. The discussion is provided in Section 5, and the conclusions are outlined in Section 6.

2. Literature Review and Hypothesis

2.1. Green Technology Advances and Spatial Spillovers

Jaffe et al. [9] proposed three stages of technological changes: invention, innovation, and diffusion. Diffusion of technology implies technologies spreading across space. Most of the early studies on technology diffusion considered the time dimension. For example, Mansfield [10] analyzed the diffusion of industrial innovations and found an S curve. With more extensive research, however, greater attention has been paid to spatial diffusion. Hagestrand [11] simulated the diffusion of agricultural technological innovations over

spatial distance, which provided the theoretical foundation for the spatial diffusion of green technology.

Technology diffusion plays an important role in boosting innovation. Some scholars discovered that technological diffusion attenuates with distance, whereas others focused on the path of spatial technological spillovers and realized that differences in innovative capabilities, intellectual property protection, and absorption capabilities are important for technological diffusion [12,13].

Keller [14] found a significant correlation between technological spillovers and geographical distance in OECD countries. Green technology can be seen as biased technological change. Based on the data from 266 cities in China, Pan [15] discovered that green technologies spread from developed to less-developed economies. In China, research foundations, R&D investment, and talent pools vary from city to city, making spatial technological spillovers possible. Therefore, we propose our first hypothesis:

Hypothesis 1 (H1). *With all else unchanged, green technology advances have a spatial spillover effect.*

2.2. Access to Digital Financial Services and Green Technology Advances

Scholars have not yet agreed on the relationship between financial development and technological advances. Aghion et al. [16] found that credit constraints increase the possibility of liquidity difficulties for commercial enterprises, which are then forced to invest more in short-term production instead of innovation. Maskus et al. [17] and Meierrieks [18] confirmed a positive relationship between financial development and innovation from both micro- and macroperspectives. Another view is that a nonlinear relationship exists between financial market development and technological advances, such as that proposed by Zhu et al. [19], who empirically tested the nonlinear effect of financial development on regional innovation.

For historical reasons, prices are distorted in China's financial markets, and technological innovation has been significantly inhibited. In recent years, the Chinese government introduced a strategy to develop access to digital financial services, aiming at optimizing the allocation of financial resources and thus promoting technological change [20]. Access to digital financial services can stimulate innovative activities by reducing the financing cost of corporate debt [21], improving the allocation of credit resources in the region, and increasing household consumption [22].

Technological advances simultaneously address polluters and solutions to pollution [23]. Green technology is important for increasing sustainability [24]. However, studies on green technology advances and financial development are relatively rare. The literature shows that an active financial market can boost green total factor productivity [25]. Therefore, we present our second hypothesis:

Hypothesis 2 (H2). *With all else unchanged, access to digital financial services promotes green technology advances.*

2.3. Regional Competition, Access to Digital Financial Services, and Green Technology Advances

The efforts and achievements of local governments in promoting local economic and social development resulted in China's rapid development for more than 40 years. The incentives of local governments can be explained mainly from two perspectives: competition for promotion [26] and competition for investment or fiscal revenue [27,28]. To obtain more economic benefits and improve political performance with limited funds, local governments directly or indirectly use their administrative power to intervene in and even manipulate their local financial system and financial institutions [29,30]. Regional competition has thus become a financial contest.

Access to digital financial services has played a positive role in relaxing corporate credit constraints [5], increasing household consumption [4], inducing technological innovation [31], and promoting economic growth [3]. It is therefore reasonable for local

governments to take advantage of this new financial instrument. However, local governments may lose control of their local financial systems and financial institutions in this financial contest, which can lead to a competitive disadvantage in less-developed regions and negatively impact green technology advances for the whole of society. We therefore present our third hypothesis:

Hypothesis 3 (H3). *Access to digital financial services induces green technologies under moderate regional competition, but excessive competition inhibits green technology advances.*

3. Method and Data

3.1. Data

3.1.1. Measurement of Green Technology Advances

Green total factor productivity is the productivity that considers factor inputs, resource consumption, and environmental costs, and input–output variables are shown in Table 1. In this paper, labor and capital are selected as input factors. Labor inputs are expressed in terms of the total population, and capital inputs are calculated using the method of sustainable inventory [32]. Outputs include desired output and undesired outputs. Desired output is real GDP based on 2002 and reduced by regional consumer price indices. The undesired outputs are industrial effluents, industrial sulfur dioxide, and industrial fumes [33].

Table 1. Green technology advances.

Indicator	Factor	Symbol	Index	Unit
Input	Labor	L	Employment	10,000
	Capital	K	Capital stock	100 million
Output	Desired output — Economic output	O	GDP	100 million
	Undesired output — Pollution	UO	Industrial effluents	10,000 tons
			Industrial sulfur dioxide	10,000 tons
			Industrial fumes	10,000 tons

3.1.2. Variables

With regard to regional competition (*rc*), researchers have constructed different indicators based on different perspectives. Fu and Ma [34] established an evaluation system using human capital, fixed assets, and economic intervention capabilities. Luo and Peng [35] built a comprehensive indicator with administrative participation, land competition, infrastructure competition, and promotion competition. The above methods well-reflect regional competitions, but possibly lead to collinearity problems. Regional competition is actually capital contest, which can be represented by foreign capital. Thus, we followed Li and He [36] and employed the actual use of foreign capital amount (USD billion).

Control variables included regional financial development, population density, economic structure, innovative ability, and environmental regulation, and their definitions are shown in Table 2. Regional financial development measures savings of financial institutions, which is an important alternative to access to digital financial service to finance innovations. Population density, economic structure and technologically innovative ability are factors impacting innovations. Environmental regulation will naturally trigger green technology.

We used the prefectural data of 265 Chinses cities from 2011 to 2017. The data were retrieved from the China City Statistical Yearbook, the China Statistical Yearbook, and China City and Industrial Innovation Report. The statistical summary is in Table S1.

3.2. Empirical Strategy

3.2.1. Measurement Method of Green Technology Advances

Technology advances are usually measured using three method. The first is the input method, which is indicated by the input, such as R&D expenditure and the number of

researchers involved in R&D activities [37]. This method may overestimate the productivity of R&D, however, ignores the possible Solow Paradox. The second is the output method, which uses the number of patents and the turnover of technology contracts as indicators of technological change. This method not only ignores the quality of patents, but also fails to explain the considerable contribution of pending technologies. The third method is total factor productivity [7]. Färe et al. [38] stated that technology advances are the main driver of total factor productivity, and the latter is a reasonable indicator of its coverage of factors other than capital and labor. In this paper, we use green total factor productivity to indicate green technology advances, which incorporates resource and environmental factors into the model and treats pollution as an undesired output.

Table 2. Variable name and definition.

Variable Name	Symbol	Definition	Source/Reference
Access to digital financial services	f	Digital financial inclusive index/100	Guo et al., 2020 [8]
Regional competition	rc	Foreign investment actually used in that year	China City Statistical Yearbook
Regional financial development	fin	Savings deposit in all financial institutions at the end of year/GDP	China City Statistical Yearbook
Population density	pd	Population per square kilometers	China Statistical Yearbook
Economic structure	ec	Ratio of secondary industry to service sector	China Statistical Yearbook
Technologically innovative ability	$tech$	City innovative index/100	2017 China City and Industrial Innovation Report
Environmental regulation	er	Reduction of Industrial SO2 emissions/ real GDP	China Statistical Yearbook

Total factor productivity is mainly measured by the Solow residual value, data envelopment analysis, and stochastic frontier analysis methods. Among them, the data envelopment method is widely used because it requires few subjective assumptions and is not affected by the number of inputs and outputs or the dimensions of the data. It also incorporates resource and environmental factors into the calculation model and treats them as undesired outputs. The slacks-based measure (SBM) model can avoid the deviation and influence caused by differences in radial and angular selection and has good discrimination ability when dealing with undesired outputs [39]. However, the SBM fails to compare effective units with the same efficiency value. The super SBM model proposed by Tone [7] compensated for this defect. However, the ML index-based super SBM does not have circularity and offers no feasible solution in linear programming. The global Malmquist–Luenberger (GML) proposed by Oh [6] offers feasible solutions in linear programming and avoids the deviation and influence caused by differences in radial and angular selection [39]. Thus, in this paper, we measure green total factor productivity using the GML index-based super SBM model.

First, take each prefecture-level city as a decision making unit (DMU) and assume that each DMU has as inputs $x = (x_1, \ldots, x_a) \in R_+^a$ and produces b expected $y = (y_1, \ldots, y_b) \in R_+^b$ and c undesired outputs $u = (u_1, \ldots, u_c) \in R_+^c$. The input and output of the jth city at time t can be expressed as $u = (u_1, \ldots, u_c) \in R_+^c$, then a production possibility set for green technology advances is constructed:

$$P^t(x^t) = \left\{ (y^t, u^t) | \bar{x}_{ja}^t \geq \sum_{j=1}^{J} \lambda_j^t x_{ja}^t, \bar{y}_{jb}^t \leq \sum_{j=1}^{J} \lambda_j^t y_{jb}^t, \bar{u}_{jc}^t \geq \sum_{j=1}^{J} \lambda_j^t u_{jc}^t, \lambda_j^t \geq 0, \forall a, b, c \right\} \quad (1)$$

Following Tone (2002), we built a super SBM model:

$$\rho^* = min \frac{\frac{1}{a}\sum_{i=1}^{a}\frac{\overline{x}_i}{x_{i0}}}{\frac{1}{b+c}\left(\sum_{m=1}^{b}\frac{\overline{y}_m}{y_{m0}}+\sum_{n=1}^{c}\frac{\overline{u}_n}{u_{n0}}\right)}$$

$$s.t. = \begin{cases} \overline{x} \geq \sum_{j=1,\neq 0}^{J}\lambda_j x_j, \\ \overline{y} \geq \sum_{j=1,\neq 0}^{J}\lambda_j y_j, \\ \overline{u} \geq \sum_{j=1,\neq 0}^{J}\lambda_j u_j, \\ \overline{x} \geq x_0, \overline{y} \geq y_0, \overline{u} \geq u_0, \overline{y} \geq 0, \lambda_j \geq 0 \end{cases} \quad (2)$$

where $\overline{x}$, $\overline{y}$, and $\overline{u}$ are the slack variables of input, output, and unexpected output, respectively; λ_j is the weight vector; and ρ^* is the target function, a larger value of which means greater efficiency.

Following Oh [33], we constructed the global production possible sets $P^g(x^t) = P^1(x^1) \cup P^2(x^2)\cdots\cup P^T(x^T)$; that is, during the whole time T, $P^g(x^t)$ is:

$$P^g(x^t) = \left\{(y^t, u^t) | x_{ja}^t \geq \sum_{t=1}^{T}\sum_{j=1}^{J}\lambda_j^t x_{ja}^t, y_{jb}^t \leq \sum_{t=1}^{T}\sum_{j=1}^{J}\lambda_j^t y_{jb}^t, u_{jc}^t \geq \sum_{t=1}^{T}\sum_{j=1}^{J}\lambda_j^t u_{jc}^t, \lambda_j^t \geq 0\right\} \quad (3)$$

Assuming the directional vector is $g = (g_y, g_u)$, $g \in R_+^b \times R_+^c$, then the global directional distance function is $\overline{D}^G(x, y, u; g_y, g_u) = max\{\beta | (y + \beta g_y, u - \beta g_u) \in P^G(x)\}$. The GML index based on the super SBM model is:

$$GML_t^{t+1}\left(x^t, y^t, u^t, x^{t+1}, y^{t+1}, u^{t+1}\right) = \frac{1 + \overrightarrow{D}^G\left(x^t, y^t, u^t; g_y^t, g_u^t\right)}{1 + \overrightarrow{D}^G\left(x^{t+1}, y^{t+1}, u^{t+1}; g_y^{t+1}, g_u^{t+1}\right)} \quad (4)$$

3.2.2. Spatial Weight Matrix

Geographical distance and economy are important factors in the spatial diffusion of technology [40–43]. Thus, we use a nested spatial weight matrix [44,45] as follows:

$$w_{ij} = w_d w_e \, where \, w_d = \begin{cases} \frac{1}{d_{ij}} & i \neq j \\ 0 & i = j \end{cases} \qquad w_e = \begin{cases} \frac{1}{Y_i - Y_j} & i \neq j \\ 0 & i = j \end{cases} \quad (5)$$

where w_d is the geographic weight matrix, d_{ij} is the distance between two prefecture-level cities calculated by latitude and longitude, and w_e is the economic distance weight matrix. The local economy is presented as GDP per capita, which is assigned a greater weight for a smaller economic gap between two regions.

3.2.3. Baseline Model

To examine the impact of the access to digital financial services on green technology advances under local competition, the following baseline model was constructed:

$$gtp_{it} = \alpha + \alpha_1 f_{it} + \alpha_2 rc_{it} + \alpha_3 X_{it} + \sigma_i + u_t + \varepsilon_{it} \quad (6)$$

where i represents the ith city; t is the tth year; the explained variable gtp_{it} is green technology advances; the explanatory variable f is access to digital financial services; rc is the proxy variable for regional competition; X_{it} is a set of control variables, including regional financial development (fin), population density (pd), economic structure (es), technological innovation ability ($tech$), and environmental regulation (er); σ_i is the regional fixed effect; u_t is the time fixed effect; and ε_{it} is the error term.

To further study the role of local competition and the access to digital financial services on green technology advances, the interaction term between local competition and the access to digital financial services ($rc \times f$) was added to Equation (6) as follows:

$$gtp_{it} = \alpha + \alpha_1 f_{it} + \alpha_2 rc_{it} + \alpha_3 X_{it} + \alpha_4 rc_{it} \times f_{it} + \sigma_i + u_t + \varepsilon_{it} \tag{7}$$

3.2.4. Spatial Durbin Model

Both local promotion and the regional interaction of access to digital financial services impact green technology advances. Thus, spatial correlation was introduced. We use the spatial Durbin model, which not only captures the spatial correlation of the explanatory variables but also the spatial correlation of explanatory variables and error terms. We set the model as follows:

$$gtp_{it} = pw \times gtp_{it} + \beta_1 f_{it} + \beta_2 rc_{it} + \beta_3 X_{it} + \theta_1 w \times f_{it} + \theta_2 w \times rc_{it} + \theta_3 w \times X_{it} + \sigma_i + u_t + \varepsilon_{it} \tag{8}$$

where ρ is the parameter of the interactions of green technology advances between neighboring regions, β and θ are the $k \times 1$ dimension vector of the estimated parameter, w is an $N \times N$ dimension non-negative spatial weight matrix, σ_i is the spatial effect, u_t is the time effect, and ε_{it} is the error term.

To further study the role of local competition and the access to digital financial services on green technology advances, we built a new spatial Durbin model as follows:

$$gtp_{it} = pw \times gtp_{it} + \beta_1 f_{it} + \beta_2 rc_{it} + \beta_3 X_{it} + \beta_4 rc_{it} + f_{it} + \theta_1 w \times f_{it} + \theta_2 w \times rc_{it} + \theta_3 w \times X_{it} + \theta_4 w \times rc_{it} \times f_{it} + \sigma_i + u_t + \varepsilon_{it} \tag{9}$$

3.2.5. Indirect and Direct Effects

The spatial Durbin model contains both the explanatory variables and spatial lag terms of the explanatory variables; however, changes in the explanatory variables in one city affect not only the local green technology advances but also the explanatory variables in other regions. Therefore, the effect of an explanatory variable on green technology advances cannot simply be reflected by the estimation coefficient. In this paper, we follow LeSage and Pace [46] and divide the total effect into direct and indirect effects using the partial differential method.

4. Results

4.1. Baseline Model

The results of the baseline model are shown in Table 3. The results of the Hausman test showed that a fixed-effect model should be used. Column (1) of Table 1 indicates that access to digital financial services had a significantly positive effect on green technology advances. As the index used was the digital financial inclusive index [8] divided by 100, the effect of access to digital financial services is important even though the coefficient is not large. Regional competition also significantly contributed to the access to digital financial services, which supports Hypothesis 2.

The interaction term of regional competition and access to digital financial services ($rc \times f$) is added in columns (3) and (4) in Table 4. The interaction between local competition and the promotion of access to digital financial services is significantly negative. The influence function of access to digital financial services on green technology advances is 0.0262–0.0038rc, indicating that interactions occurred between access to digital financial services and regional competition, i.e., the impact of access to digital financial services on green technology advances was subject to regional competition, as follows: as regional government competition intensifies, the positive effect of access to digital financial services on green technology advances will diminish, and when regional competition exceeds the turning point of 2.125, the impact of access to digital financial services becomes negative. The above empirical results support Hypothesis 3.

Table 3. Baseline model.

	(1)	(2)	(3)	(4)
f	0.0244 *** (0.004)	0.0183 *** (0.004)	0.0262 *** (0.004)	0.0222 *** (0.004)
rc	0.0075 *** (0.003)	0.0127 *** (0.003)	0.0135 *** (0.005)	0.0240 *** (0.005)
fin	−0.0346 *** (0.010)	−0.0212 ** (0.009)	−0.0363 *** (0.010)	−0.0249 *** (0.009)
pd	−0.0115 * (0.006)	0.0013 (0.003)	−0.0137 ** (0.006)	−0.0002 (0.003)
es	0.2081 *** (0.055)	0.1800 *** (0.051)	0.2052 *** (0.055)	0.1752 *** (0.051)
tech	−0.0053 (0.010)	0.0072 (0.009)	0.0099 (0.014)	0.0330 *** (0.013)
er	0.0823 *** (0.013)	0.0756 *** (0.013)	0.0815 *** (0.013)	0.0740 *** (0.013)
rc × *f*			−0.0038 * (0.003)	−0.0073 *** (0.002)
cons	0.0929 ** (0.043)	0.0358 (0.035)	0.1023 ** (0.043)	0.0420 (0.035)
N	1855	1855	1855	1855
Hausman test	78.42 ***		72.08 ***	
Model	FE	RE	FE	RE

Note: ***, **, and * denote significance at the 0.01, 0.05, and 0.1 levels, respectively. T-values are in parentheses.

Table 4. Spatial correlation test.

Test	(1)		(2)	
	Coefficient	*p*-Value	Coefficient	*p*-Value
LM test no spatial lag	2.770	0.096	2.958	0.085
Robust LM test no spatial lag	8.908	0.003	9.857	0.002
LM test no spatial error	5.543	0.019	5.997	0.014
Robust LM test no spatial error	11.681	0.001	12.896	0.000

4.2. Spatial Spillover

We performed an LM test as well as a robust LM test to verify the spatial correlation. Columns (1) and (2) in Table 4 present results of models (6) and (7), showing that a spatial correlation existed. We further conducted a Wald test and an LR test to explore which of the following models should be used: the spatial Durbin model, spatial autoregression model, or the spatial errors model. Combined with the results of the Hausman test, Table 5 indicates that the spatial Durbin fixed-effects model was best for our purposes.

Table 5. Model selection and Hausman test.

Test	(1)		(2)	
	Coefficient	*p*-Value	Coefficient	*p*-Value
Wald spatial lag test	83.315	0.000	99.892	0.000
LR spatial lag test	94.729	0.000	112.870	0.000
Wald spatial error test	77.103	0.000	93.216	0.000
LR spatial error test	90.833	0.000	108.588	0.000
Hausman test	106.172	0.000	144.190	0.000

Table 6 reports the results of the spatial Durbin model (SDM). According to Table 6 (a), the coefficient of the spatial lag item ρ for green technology advances is significant at the 1% level, indicating a significantly positive spatial correlation between green technology advances in neighboring regions, i.e., green technology advances in adjacent regions contribute to those locally, which supports Hypothesis 1.

Table 6. Spatial Durbin model.

Variable	(1)				(2)			
	(a)	**(b)**	**(c)**	**(d)**	**(a)**	**(b)**	**(c)**	**(d)**
	Coefficient	Direct Effect	Indirect Effect	Total Effect	Coefficient	Direct Effect	Indirect Effect	Total Effect
f	0.0501 ** (2.1644)	0.0501 ** (2.1094)	−0.0256 (−1.0274)	0.0245 *** (3.2)	0.0512 ** (2.2155)	0.0521 ** (2.253)	−0.0380 * (−1.5722)	0.0141 * (1.6599)
rc	0.0072 ** (2.563)	0.0075 *** (2.6804)	0.0116 (0.7376)	0.0191 (1.1849)	0.0142 *** (2.848)	0.0133 *** (2.7089)	−0.0706 *** (−2.6653)	−0.0573 ** (−2.1415)
fin	−0.0348 *** (−3.457)	−0.0355 *** (−3.5068)	−0.0387 (−1.2438)	−0.0742 ** (−2.4704)	−0.0368 *** (−3.6629)	−0.0372 *** (−3.8592)	−0.0191 (−0.5838)	−0.0562 * (−1.7985)
pd	−0.0126 ** (−2.1921)	−0.0132 ** (−2.3131)	−0.0401 *** (−2.6743)	−0.0533 *** (−3.2808)	−0.0123 ** (−2.0738)	−0.0126 ** (−2.1601)	−0.0356 ** (−2.2761)	−0.0483 *** (−2.8305)
es	0.2251 *** (4.0044)	0.2203 *** (4.0207)	−0.4305 *** (−3.2637)	−0.2102 (−1.5737)	0.2387 *** (4.2626)	0.2330 *** (4.2609)	−0.4025 *** (−2.7963)	−0.1695 (−1.1986)
$tech$	0.0255 ** (2.4111)	0.0225 ** (2.1796)	−0.2141 *** (−6.8873)	−0.1916 *** (−6.475)	0.0365 ** (2.5612)	0.0312 ** (2.1568)	−0.3939 *** (−6.9306)	−0.3627 *** (−6.2507)
er	0.1244 *** (7.0482)	0.1240 *** (7.0615)	−0.0881 *** (−3.5677)	0.0359 * (1.7885)	0.1265 *** (7.2056)	0.1264 *** (7.0982)	−0.0741 *** (−2.8293)	0.0523 ** (2.418)
$rc \times f$					−0.0043 * (−1.6724)	−0.0038 (−1.4543)	0.0394 *** (3.9685)	0.0356 *** (3.564)
$W \times f$	−0.0284 (−1.187)				−0.0386 (−1.612)			
$W \times fin$	−0.0301 (−1.0589)				−0.0142 (−0.4972)			
$W \times pd$	−0.0340 ** (−2.4711)				−0.0301 ** (−2.1853)			
$W \times es$	−0.4085 *** (−3.1792)				−0.3915 *** (−3.0596)			
$W \times rc$	0.0099 (0.6838)				−0.0649 *** (−2.8003)			
$W \times tech$	−0.1943 *** (−6.8679)				−0.3527 *** (−7.305)			
$W \times er$	−0.0929 *** (−3.8817)				−0.0799 *** (−3.3212)			
$W \times rc \times f$					0.0353 *** (4.1514)			
ρ	0.1190 *** (2.5905)				0.1280 *** (2.7983)			
R^2	0.9082				0.9093			
Log-L	2731.4987				2741.9474			
σ^2	0.0035				0.0035			

Note: ***, **, and * denote significance at the 0.01, 0.05, and 0.1 levels, respectively. T-values are in parentheses.

Column (1) of Table 6 (1) indicates that access to digital financial services contributed to green technology advances, which further validates Hypothesis 2. In addition, we found that green technological progress was not only affected by factors including promotion of access to digital financial services, regional financial development, population density, economic structure, regional competition, technological innovation, and environmental

regulation in the region, but also by similar factors in neighboring areas. Under other conditions, economic structure, regional competition, technological innovation, and environmental regulation in the region could significantly improve the progress of green technology, whereas local financial development and population density significantly inhibited its progress. Population density, economic structure, technological innovation, and environmental regulation in adjacent regions all had a significant negative impact on local green technology advances.

To examine the impact of regional competition, we added an interaction term between regional competition and access to digital financial services, and the results are shown in column (2) of Table 6. The interaction term is significantly negative, implying that moderate regional competition was beneficial to green technology advances, whereas fierce regional competition weakened the positive effect of access to digital financial services on green technology. Apart from the interaction term, the results in column (2) share similar characteristics to those in column (1), further validating Hypothesis 3.

4.3. Direct and Indirect Effects

Due to local competition, strategic interactions between governments are common. For example, an action taken by one local government can trigger adjustments by another neighboring government. We therefore divided the effects of access to digital financial services on green technology into direct and indirect effects.

First, regarding the direct effects of access to digital financial services, Table 6 shows that the latter significantly contributed to green technology advances. The coefficients of access to digital financial services in the spatial model are higher than those in the panel fixed-effects model in Table 3, suggesting that the impact of access to digital financial services on green technology will be underestimated if the spatial effect is ignored. The coefficients of access to digital financial services in column (1) are higher than those in column (2), indicating that the impact of access to digital financial services on green technology can be partially attributed to the combined effect of regional competition and access to digital financial services.

Second, regarding the indirect effects of access to digital financial services, the coefficient in Table 6 (1) is insignificant and that in Table 6 (2) is significant at the 10% level, indicating that, with the combined effect of access to digital financial services and regional competition removed, the promotion of access to digital financial services will harm green technology nearby.

Third, regarding the direct and indirect effects of regional competition, with or without the interaction term, regional competition was significantly positively related to green technology. However, the indirect effects of these conditions were different. In other words, whereas regional competition boosted green technology advances in a given region, in the context of regional competition, the promotion of access to digital financial services inhibited green technology in neighboring regions.

Fourth, concerning the direct and indirect effects of the interaction term between regional competition and access to digital financial services, Table 6 (2) shows that the direct effect is negative but not significant, the indirect effect is significantly positive, and the total effect is significantly negative. The results showed that the combination of regional competition and access to digital financial services indirectly inhibited local green technology while promoting green technology in neighboring regions. Overall, however, a significant inhibition effect still existed.

5. Discussion

Compared with existing studies, this study is unique in terms of its objectives, methods, and results. In terms of objectives, green technology advances have gained considerable attention from many scholars. Most related studies have focused on innovation induced by environmental regulations [1,2], but few have highlighted the shocks incurred by new financial instruments such as those induced by access to digital financial services.

Among the studies considering access to digital financial services, most examined its effects on the economy [3], consumption [4] and financing constraints [5]; however, the relationship between access to digital financial services and green technology advances has rarely been included within the scope of these studies. To fill this gap, the objective of this study was to analyze the effects of access to digital financial services on green technology advances. We also considered regional competition, since access to digital financial services increases the liquidity of the capital for which regional governments compete. Moreover, the spillover effect of access to digital financial services on neighboring regions was isolated because technologies spread fast and adjacent areas respond quickly to local technological changes.

In terms of methodology, we employed a GML index-based super SBM model to measure green technology advances. The GML index is typically employed to estimate efficiency between inputs and outputs, such as total factor productivity [6]. The conventional model for induced-effect analysis is an ML index based on the SBM model [7], which cannot offer feasible solutions to linear programming and circularity. To compensate for such shortcomings, we adopted the GML index-based super SBM model, which treats pollution as an unexpected output, to determine prefectural green technology advances. Since technologies spill over to neighboring areas, we used a spatial Durbin model to confirm its spillover effect. We further used a partial differential equation to separate both the effect of access to digital financial services and its interaction with regional competition into direct effects (effects on local green technology advances) and indirect effects (effects on neighbors' green technology advances). In terms of data, development of access to digital financial services has rarely been empirically discussed in the literature because of data limitations. Guo at al. [8] constructed a series of indexes regarding access to digital financial services, including coverage, use, and digital indexes. We selected the digital financial inclusive index, since it is a composite that provides a full picture of prefectural development of access to digital financial services. Therefore, the results we obtained with this combination of methods have higher practical value.

Our results showed that green technology advances had significant spatial diffusion. Some scholars have reported similar findings [8,13]; for example, Keller [14] found that the impact of technology spillover in OECD countries is greater locally, but over time, technological knowledge becomes considerably more global. International diffusion of technological knowledge is enhanced by physical and technological proximity or by sharing a common language [11,47]. Our results also indicated that access to digital financial services significantly promotes local green technologies while inhibiting those in neighboring regions. This result is in line with other studies related to the effects of financial instruments on technology advances: access to digital financial services is beneficial for R&D activities by offering a new route to finance [19] and by decreasing financing costs [20]. We conclude that while regional competition is conditionally favorable for green technologies, excessive competition harms the positive effect of access to digital financial services on green technology. Related studies provide partial evidence that regional competition is in actuality a contest for capital [48], and that governments of less-developed regions will lose intervention or control of financial institutions in the presence of access to digital financial services [29,46], which will negatively impact local R&D activities.

6. Conclusions and Implications

In this study, we investigated the effect of access to digital financial services on green technology advances in the context of Chinese regional competition. We used the GML index-based super SBM model to measure green technology advances with prefectural data from 2010 to 2017. We then constructed a spatial Durbin model to explore the spatial effect of access to digital financial services, the direct and indirect effects of which were analyzed separately.

We found that: (1) the influence of access to digital financial services on green technology advances shows significant spatial correlations that play an important role in

promoting green technology advances in a given region, but can inhibit those in other regions; (2) regional competition can promote local green technology advances, whereas excessive competition will impair the positive effect of access to digital financial services; (3) interactions between regional competition and access to digital financial services have negative impacts on green technology advances; and (4) green technology advances have a significantly positive spillover effect.

Our results imply that it is necessary to (1) improve competition mechanisms and maintain moderate local competition and (2) optimize financial markets and reduce the distortion of capital prices to promote green technologies.

Digital financial services are accessed using Grameen Bank's method in Bangladesh, which was the first bank providing financial service for the poor. The method has been successfully replicated in over 41 countries. With booming innovations, China has many small businesses. The access to digital financial services has promoted green technology advances in China, as it likely has in the other 40 counties. However, due to space limitations, the generalization of the findings of China to other developing countries was not empirically investigated in this study. Future works should investigate the effect of the access to digital financial service on poverty alleviation.

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