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The impact of commercial bank branch expansion on energy efficiency: Micro evidence from China

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ABSTRACT

The debate has long prevailed as to whether the financial sectors can enhance energy efficiency. We attempt to provide new insight into this debate from the perspective of commercial bank branch expansion. This paper manually collects the longitude and latitude of commercial bank branches and manufacturing firms in China, and constructs multiple bank branch expansion variables at the firm level. Then, by utilizing Environmental Survey and Reporting database, Annual Survey of Industrial Firms, and firm-level patent application dataset from 1998 to 2009, this paper empirically examines the impact of commercial bank branch expansion on firms' energy efficiency for the first time and discusses the potential impact channels. We find that the expansion of commercial bank branches within a radius of 10 km of firms has improved the manufacturing firms' energy efficiency. Furthermore, we also confirm that there exist multiple heterogeneous nexuses between the bank branch expansion and energy efficiency. Finally, the financial availability caused by the bank branch expansion is not able to affect the energy efficiency, whereas the bank competition will increase the energy efficiency. Also, the bank branch expansion increases energy efficiency by promoting capital renewal instead of technological innovation.

1. Introduction

Since 1978, China's financial system has experienced successive fundamental reformations for the purpose of getting rid of the dilemma characterized by inefficient financial resource allocation and non-market distortions, and one of the most considerable dimensions of the former is the reconstruction of the banking sector. After diverse rounds of reform, China is gradually embarking on a specialized, commercialized and market-oriented banking sector. In particular, there is a remarkable rise in the number of commercial bank branches during this process (as shown in Fig. 1). Actually, the geographic expansion of commercial banks also tends to occur in the deregulation and liberalization of banking industries in other countries (Chen, Poncet, & Xiong, 2020). Hence, investigating the effect of the expansion of commercial bank branches is of great significance.

The existing literature on the geographic expansion of commercial banks is extensive and focused particularly on financial consequences, such as bank risk (Faia, Laffitte, & Ottaviano, 2019; Goetz, Laeven, & Levine, 2016), bank value (Goetz, Laeven, & Levine,

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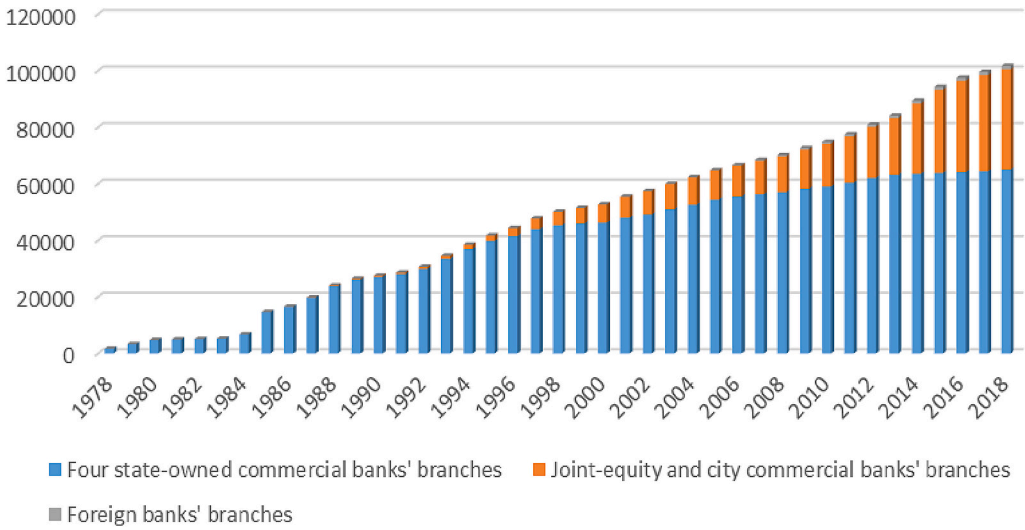

Fig. 1. The number of commercial bank branches.

2013; Yildirim & Efthyvoulou, 2018), funding costs (Levine, Lin, & Xie, 2021), credit risks (Zamore, Beisland, & Mersland, 2019), loan (Doerr & Schaz, 2021; Keil & Müller, 2020; Wan & Lee, 2023) and so on. Up to now, however, an investigation of the consequences of commercial bank branch expansion on manufacturing firms' energy efficiency is still lacking to our knowledge. This is a significant issue, especially in the circumstance of climate warming and environmental deterioration induced by the excessive use of fossil energy (Lee, Wang and Thinh, 2023; Lee, Chang, & Wang, 2022; Lee, Wang, & Chang, 2023b; Li, Liu, & Du, 2019; Wang & Lee, 2022; Wei, Löschel, & Managi, 2020). This study seeks to fill the gap.

The geographic expansion of commercial banks will directly affect the financing channels and credit supply, and this impact is in fact ambiguous. Theoretically, some studies have shown that the beneficial effect of the expansion of commercial bank branches on the cost and scale of debt financing (Beck, Demirgüç-Kunt, & Maksimovic, 2004; Lee & Wang, 2022; Rice & Strahan, 2010), but others have shown a deterioration in the cost and scale of loan (Di Patti & Dell'Ariccia, 2004; Petersen & Rajan, 2002). Furthermore, the actions, such as developing innovative technologies and purchasing advanced equipment with higher energy efficiency, taken by firms to decrease energy efficiency tend to need external finance support. This means that what remains unclear is whether the commercial bank branch expansion is able to improve energy efficiency, owing to theoretically vague anticipation. And we attempt to provide one of the first empirical examinations on this issue.

By exploiting the hand-collected data of commercial bank branches and the three most detailed firm-level datasets from 1998 to 2009 in China, we analyze the impact of the expansion of commercial bank branches on manufacturing firms' energy efficiency. To this end, we first hand collected data of commercial bank branches from the official website of China Banking and Insurance Regulatory Commission, and then we utilized python technology to obtain the latitude and longitude of each commercial bank branches. Second, we merged three firm-level datasets, these are the Environmental Survey and Reporting (ESR) database from the Ministry of Environment Protection of China, the Annual Survey of Industrial Firms (ASIF) from the National Bureau of Statistics of China and the firm-level patent application dataset from China National Intellectual Property Administration to construct our sample. Similarly, we employed python technology to gain the precise latitude and longitude information of manufacturing firms in our sample. Third, we relate the commercial bank branches data to these firm-level datasets, and on the basis of the latitude and longitude information of commercial bank branches and manufacturing firms, this paper calculates the number of commercial bank branches within a specific kilometer radius (5, 10, 15, 20, 25 and 30 km, respectively) of the firm to construct the independent variables. Fourth, we can estimate the impact of commercial bank branch expansion on manufacturing firms' energy efficiency. Note that the expansion of commercial bank branches is usually associated with intensifying bank competition and improvement in financial availability. To precisely isolate the impact of bank competition and improvement of financial availability (caused by the expansion of commercial bank branches) on energy efficiency, we also generate a battery of variables that can reflect the degree of bank competition and financial availability and then construct some interactions between the commercial bank branch expansion and the formers. By regressing energy efficiency on these interactions, respectively, we can estimate and identify their effect on energy efficiency. Finally, we discuss potential mechanisms from the perspective of capital renewal and technological innovation.

This study is complementary to previous research in two aspects. First, this paper contributes to an emerging argument on the finance-energy nexus. On the one hand, previously published studies on the finance-energy nexus usually focus on one of the dimensions of the financial sector, that is the aggregated general financial development or financial depth (proxied by a simple indicator), on energy consumption (Chiu & Lee, 2020; Kahouli, 2017; Sadorsky, 2010; Yue, Lu, Shen, & Chen, 2019), and they pay too little attention to the impact of other characteristic on energy efficiency, especially the role of geographic expansion of commercial banks. To this end, this paper expands the literature on the significance of geographic diversification of banks by providing detailed discussion and empirical evidence for the impact of the expansion of commercial bank branches on energy efficiency (Chen et al., 2020;

Fafchamps & Schündeln, 2013; Goetz et al., 2016; Keil & Müller, 2020; Levine et al., 2021). On the other hand, the debate has long prevailed as to whether bank competition and financial availability can positively promote economic growth and other economic variables through more efficient financial resource allocation (Bellucci, Borisov, & Zazzaro, 2013; Di Patti & Dell'Ariccia, 2004; Guzman, 2000; Lee & Luca, 2019; Love & Martínez Pería, 2015). Given that external financing plays a vital role in improving energy efficiency, it is also ambiguous in the nexus between bank competition (financial availability) and energy efficiency. Actually, to date, no previous study has empirically examined the impact of bank competition as well as financial availability on firms' energy efficiency. To this end, by constructing the interactions between bank branch expansion and bank competition variable (financial availability variable) and adding them into our empirical specification, we discuss the impact of enhancement of bank competition (financial availability) caused by the expansion of bank branches on energy efficiency to fill the gap.

Second, the existing literature usually utilizes the macro and aggregate data to investigate the economic consequences of commercial bank branch expansion. Employing aggregate regional commercial bank branch number data will lead to endogeneity issues induced by measurement error. It is argued that there is a "threshold radius" in the geographic scope of the external financing that firms can obtain (Amore, Schneider, & Žaldokas, 2013; Skrastins & Vig, 2019; Nie & Lee, 2023; Zhu & Lee, 2022), which means that if the distance between firms and bank branch is too long, the firms may not be affected by this branch. Against this background, we can construct a more precious firm-level financial variable by collecting and exploiting detailed information on the longitude and latitude of manufacturing firms and bank branches. Then, by combing firm-level financial variables with the three most detailed firm-level datasets in China, we can obtain a more consistent estimation of the finance-energy nexus and test some potential micro-impact channels through which bank branch expansion affects energy efficiency. It is also noteworthy here that almost all studies on the finance-energy nexus use aggregate macro-level data such as cross-country datasets, implying that they are not able to give an exhaustive examination of the finance-energy nexus as well as corresponding impact channels (Canh, Thanh, & Nasir, 2020; Chen, Huang, & Zheng, 2019; Uddin, Pan, Saima, & Zhang, 2022).

The remainder of this paper is organized as follows. Section 2 illustrates how commercial bank branch expansion affects energy efficiency and proposes some hypotheses. Section 3 describes econometric specifications and data. Section 4 presents empirical findings, and section 5 reviews our main conclusions.

2. How does commercial bank branch expansion affect energy efficiency?

It is widely argued that a well-functioning financial system plays a significant role in improving energy efficiency by supplying external financing (Chiu & Lee, 2020; Fleiter, Schleich, & Ravivanpong, 2012; Guo, Zeng, & Lee, 2023; Rohdin, Thollander, & Solding, 2007). And one of the main sources of external financing is still loans from commercial banks in countries where the bank sector plays a pivotal role in the financial system such as China.[2] This implies that the commercial bank branch expansion may act a vital role in the improvement of energy efficiency. After obtaining bank loans, firms can take heterogeneous measures, such as technological innovation and capital renewal, to improve energy efficiency. Hence, we propose the following hypothesis.

Hypothesis 1. The commercial bank branch expansion can positively affect energy efficiency.

One of the most vital facets of commercial bank branch expansion is the advancement of financial availability. On one side, improving financial availability may mitigate the information asymmetry between banks and firms, which will reduce the cost of the loan and increase the scale of the loan (Arnold, Fishe, & North, 2010; Flögel, 2018; Hollander & Verriest, 2016). The enhancement of financial availability will strengthen the communications between the commercial bank and firm ex-ante, which will enable a deeper understanding of banks on firms' production and innovation activities and assist banks with capturing more soft information concerning firms (Chen, Cheng, & Lee, 2022; Gilje, Loutskina, & Strahan, 2016). This will benefit banks to pick firms up with better prospects and expected profit to reduce the loan risk, resulting in more access to loans by firms with lower interest rates. Also, in accordance with resource dependence theory, firms will obtain the resources based on their own living environment (Pfeffer & Salancik, 1979). More precisely, to obtain persistent external financing applied for innovation activities, firms have stronger incentives to keep in touch with proximate banks when the financial availability improves, which will also alleviate the information asymmetry. On the other side, financial availability can cut the transaction cost generated by the long geographic distance between firms and banks down (Lee & Luca, 2019; Wen, Chen, & Lee, 2023), causing lower loan costs faced by firms. For example, the increase in financial availability will reduce the supervision cost of banks *ex-post*, implying that banks are willing to loan to firms close to itself at a lower interest rate (Bernini and Brighi,2018; Agarwal & Hauswald, 2010; Petersen & Rajan, 2002). Therefore, firms can benefit from the advancement of financial availability and obtain more banking loans at lower costs. Subsequently, they may minimize their energy intensity via a variety of methods, such as developing new technology and utilizing new equipment. On the basis of the discussions above-mentioned, we deduce that the commercial bank branch expansion will increase energy efficiency by improving financial availability and propose the following hypothesis.

Hypothesis 2. The commercial bank branch expansion will improve financial availability, thus increasing energy efficiency.

The commercial bank branch expansion will bring about a more competitive local banking market structure, which is able to exert a negative effect on the cost and scale of loans (Pagano, 1993), therefore enhancing energy efficiency. In the context of China, despite the

[2] More detailed information concerning the China banking industry is available in Chen et al. (2020) and Chen et al. (2013).

four stated-owned commercial banks still dominate the banking industry, the rapid expansion of foreign, joint-equity and city commercial banks has shocked the notorious concentrated banking market structure (Chen et al., 2020). Noteworthy here is that apart from the competition among various commercial banks, there also exists competition in loan scale among different commercial bank branches from one commercial bank since the scale of deposit and loan are directly related to the performance appraisal of bank branches and employee compensation. Hence, the expansion of the commercial bank branch will also intensify the competition in the local banking market.

Traditionally, it has been argued that stronger bank competition may lead to a higher credit supply at a lower cost (Love & Martínez Pería, 2015; Rice & Strahan, 2010; Shankarnarayan & Ramakrishna, 2021). Also, a competitive banking market will alleviate the information asymmetry, reducing the cost of loans and increasing the scale of the loan. Since there is higher pressure from customer competition and performance in a competitive banking market, banks have stronger incentives to dig for information concerning firms (Barth, 2004; Gilbert, 1984). This mitigates the information asymmetry between banks and firms, and leads to more access by firms to loans at a lower interest rate. Finally, firms that have access to loans may reduce their energy intensity. In view of the discussion above, we propose the following hypothesis.

Hypothesis 3. The commercial bank branch expansion will intensify the banking market competition, thus increasing energy efficiency.

Firms can increase energy efficiency through technological innovation and capital renewal (Huang, Lai, & Hu, 2020; Lee, Chang, & Wang, 2022; Lee, Yuan, Lee, & Chang, 2022). However, both of them require a lot of financial support (Amore et al., 2013; Lee, Wang, & Chang, 2023a). The commercial bank branch expansion can help firms obtain more loans at a lower cost by intensifying banking competition and improving financial availability, which will promote the improvement of energy efficiency by motivating innovation and capital renewal (Benfratello, Schiantarelli, & Sembenelli, 2008; Fleiter, Worrell, & Eichhammer, 2011; Lee, Wang, & Chang, 2023a; Zhang, Li, & Ji, 2020). By gaining more external financing with lower cost, firms can increase research and development expenditure to invest in innovation activities, such as innovation in process or product, to directly reduce the energy consumption in industrial processes (Lee, Wang, & Chang, 2023a). Previous works have confirmed the negative impact of innovation on energy intensity by utilizing country-level, sector-level and firm-level data (Herrerias, Cuadros, & Luo, 2016; Hille & Lambernd, 2020; Liu, Zhang, Adebayo, & Awosusi, 2022; Pan, Uddin, Han, & Pan, 2019; Sun, Edziah, Kporsu, Sarkodie, & Taghizadeh-Hesary, 2021). For instance, Chakraborty and Mazzanti (2020) have confirmed the reduction effect of innovation on energy intensity by using cross-country panel data, and they also found there exists heterogeneousness in the nexus between innovation and energy efficiency in various countries. Unlike these study, Wurlod and Noailly (2018) investigated the relationship between innovation and energy intensity at sector level, and they found that a 1% increase in green patenting will lead to a 0.03% reduction in intensity. Also, firms can purchase advanced equipment with higher productivity and energy efficiency to implement capital renewal (Lai et al., 2022; Saadaoui & Chtourou, 2023). This is also able to increase firms' energy efficiency. Specifically, utilizing advanced equipment with higher energy efficiency in industrial processes is able to ameliorate production processes by complementing and increasing the abilities of human laborers physically, thus increasing productivity and reducing energy intensity. For instance, Lee, Chang, and Wang (2022) have confirmed that firm obtaining loans will carry out the capital renewal to improve their energy and environmental performances. Along this line, Lee and Wang (2022) also highlights the significant role of industrial robots in reducing energy intensity. Actually, industrial robots can be regarded as advanced equipment, and utilizing industrial robots in industrial processes is implementing capital renewal in other words. Therefore, we propose the following hypothesis:

Hypothesis 4. The commercial bank branch expansion can enhance energy efficiency through technological innovation.

Hypothesis 5. The commercial bank branch expansion can enhance energy efficiency through capital renewal.

3. Model and data

To explore the effect of commercial bank branch expansion on energy efficiency, the empirical model can be set as following:

$$LnEi_{cjit} = \alpha_0 + \alpha_1 LnBranchK_{ijit} + \beta_1 X_{it} + \beta_2 Y_{jt} + \mu_i + \mu_t + \mu_j + \mu_c + \varepsilon \tag{1}$$

where *i*, *j*, *c* and *t* denote the firm, two-digit industry, city and year, separately; *Ei* is the energy intensity; $BranchK_{it}$ is the number of commercial bank branches with a radius of *K* kilometers near the firm *i* at year *t*. ($K = 5, 10, 15, \dots, 30$). X_{it} consists of a series of firm characteristics variables, including *Age*, *Size*, *Ci*, while Y_{jt} consists of and industry characteristics variables, including *Hhi*, *Eg*. μ_i, μ_t, μ_j and μ_c is the firm, year, two-digit industry and city fixed effect. This paper mainly concentrates on α_1, if the α_1 is significantly positive (negative), implying that the commercial bank branch expansion will reduce (increase) the firms' energy efficiency.

The research data are mainly compiled from four sources. First, this paper hand collects commercial bank branches data from the official website of China Banking and Insurance Regulatory Commission. Based on the name of commercial bank branches, we utilize the python technology to collect the longitude and latitude of each commercial bank branches.

Second, this paper utilizes Environmental Survey and Reporting (ESR) database from the Ministry of Environment Protection of China. This dataset offers the most detailed firm-level energy consumption data, and it is a unique source of firm-level energy consumption, including the energy consumption of coal, oil and natural gas in China. Nevertheless, some concerns concerning this dataset should be pointed out. On the one hand, it only supplies the amount of coal, oil and natural gas consumption, implying that we cannot gain information concerning firm-level power consumption. Considering the significance of power consumption, this may lead to an underestimated effect of branch expansion on firms' energy efficiency. For instance, the technological innovation caused by branch expansion may directly decrease the power consumption without impacting output negatively by improving the industrial process, which cannot be reflected in the estimated coefficient of *lnBranch*. On the other hand, the energy consumption data is only available in the period of 1998 to 2010, which forces this paper to restrict the sample period.

Third, the firm-level characteristics, including the establishment year, the number of employees and capital intensity, are obtained from the Annual Survey of Industrial Firms (ASIF) issued by the National Bureau of Statistics of China. It covers all stated-owned and non-stated-owned industrial firms with annual sales exceeding 5 million yuan and firms in this dataset produce almost 85% of China's industrial output. Though this dataset is widely utilized to study Chinese economic issues, it needs to point out that there are flaws in this database. In line with Fan, Hu, and Tang (2021) and Brandt, Van Biesebroeck, and Zhang (2014), we exclude the 2010 data from the empirical analysis since there is a remarking decrease in the number of firms, and it does not provide firm characteristics information needed by our paper. Furthermore, this study follows Yu (2015) to clean the dataset to alleviate the effect of outliers on our estimated coefficients.

Fourth, this study also collects the firm-level patent application dataset from 1998 to 2010, which is obtained from China National Intellectual Property Administration. This dataset supplies firm-level application numbers of invention patents, utility models and design patents.

We merge these three firm-level datasets according to the firms' names and unique Chinese organizing institution bar codes to construct our research sample. In the meanwhile, we also use python technology to collect the detailed latitude and longitude information of manufacturing firms in our sample. And the sample period is from 1998 to 2009.

The explained variable is energy intensity (*Ei*), which is defined by the ratio of total energy consumption to real output. Note that this study has converted the physical amount of coal, oil and natural gas consumption into standard coal amount according to the electrothermal equivalent method. Also, we deflate the nominal output to gain real output on the basis of the producer price index.

The key explanatory variable is the commercial bank branch expansion variable (*lnBranchK*).[3] Note that we mainly concentrate on the four stated-owned commercial banks, joint-equity and city commercial banks and foreign banks. According to the latitude and longitude of bank branches and firms, we compute the numbers of commercial bank branches around the manufacturing firms within a specific radius at the city level. More precisely, we calculate the numbers of bank branches around the manufacturing firms within the radius of 5, 10, 15, 20, 25, and 30 km, respectively. Given the fact that there is a "threshold radius" in the geographic scope of the external financing that firms can obtain (Amore et al., 2013; Skrastins & Vig, 2019), if the distance between firms and bank branch is too long, the firms may not be affected by this branch. Therefore, we only calculate the number of bank branches from 5 to 30 km. Compared with previous country-level literature, a significant advantage of using geographic information to construct firm-level finance variables is to alleviate the endogeneity issues to a great extent. Since there is a strong correlation between financial variables and economic development, it will be difficult to isolate the real effect of financial variables due to the omitted variables, such as institution status, while utilizing the aggregate data to investigate the economic consequences of financial variables. Another vital advantage of using a micro financial variable is that we can carry on a host of empirical tests on the potential mechanisms, which cannot be achieved if utilizing macro aggregate data.

We control some firm-level characteristics, including age (*Age*, defined as the difference between the current year and establishment year plus one) and size (*Size*, defined as the number of employees), capital intensity (*Ci*, defined as the ratio of real fixed asset on the number of employees) (Becker, Pasurka, & Shadbegian, 2013; Chen et al., 2020; Cole, Elliott, & Strobl, 2008; Haider, Danish, & Sharma, 2019; Liu & Lee, 2022; Wang & Lee, 2022). In addition, inspired by the previous researches (Tanaka & Managi, 2021; Zhao & Lin, 2019), this paper also computes the Herfindahl–Hirschman index (*Hhi*) reflecting the market concentration of manufacturing and Ellison-Glaeser index (*Eg*) reflecting the industrial agglomeration at city-industry level, and then adds them into our model. The descriptive statistics of all variables are presented in Appendix Table A1.

4. Empirical findings

4.1. The effect of commercial bank branch expansion on energy efficiency

4.1.1. The overall effect of commercial bank branch expansion on energy efficiency

Table 1 displays the estimated results obtained from eq. (1) for the effect of branch expansion on firms' energy efficiency. We separately estimate eq. (1) without control variables and eq. (1) with control variables. The results are shown in Panel A and B of Table 1. Interestingly, as shown in columns (2), the coefficients of *Lnbranch10* are −0.0083 and − 0.0080, and they are significant at a 5% level, whereas the rest of the branch expansion variables are not significant. These results suggest that the expansion of bank branches within a radius of 10 km near the firm can increase the firm's energy efficiency, and more specifically, a 10% increase in the number of bank branches leads to an 8% decrease in energy efficiency. To this end, we can confirm ***hypothesis 1***. Note that the bank branches within a radius of 5 km cannot affect energy efficiency, and a possible interpretation for this is that the number of branches is too few to affect the bank competition and financial accessibility. Moreover, the expansion of bank branches, which are ten kilometers away from firms, will not affect firms' energy intensity. Thus, we mainly focus on the bank branch expansion within the radius of 10

[3] The organizational structure of a commercial bank in China usually consists of five levels, named the head office, first-level branch, second-level branch, first-level sub-branch, and second-level sub-branch. The "bank branch" in this paper refers to the "sub-branch of the bank" (i.e., the lowest level in the organizational structure of a commercial bank).

Table 1
The impact of commercial bank branch expansion on energy efficiency.

Panel A Eq. (1) without control variables

	(1)	(2)	(3)	(4)	(5)	(6)
	LnEi	*LnEi*	*LnEi*	*LnEi*	*LnEi*	*LnEi*
Lnbranch5	0.0011 (0.0032)					
Lnbranch10		−0.0083** (0.0041)				
Lnbranch15			−0.0043 (0.0048)			
Lnbranch20				−0.0062 (0.0054)		
Lnbranch25					−0.0086 (0.0061)	
Lnbranch30						−0.0098 (0.0068)
Control variables	No	No	No	No	No	No
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	238,846	238,846	238,846	238,846	238,846	238,846
adj. R^2	0.8469	0.8469	0.8469	0.8469	0.8469	0.8469

Panel B Eq. (1) with control variables

	(1)	(2)	(3)	(4)	(5)	(6)
	LnEi	*LnEi*	*LnEi*	*LnEi*	*LnEi*	*LnEi*
Lnbranch5	0.0012 (0.0032)					
Lnbranch10		−0.0080** (0.0041)				
Lnbranch15			−0.0039 (0.0048)			
Lnbranch20				−0.0056 (0.0054)		
Lnbranch25					−0.0080 (0.0061)	
Lnbranch30						−0.0091 (0.0068)
Control variables		Yes	Yes	Yes	Yes	Yes
Fixed effect		Yes	Yes	Yes	Yes	Yes
N	238,846	238,846	238,846	238,846	238,846	238,846
Adj. R^2	0.8470	0.8470	0.8470	0.8470	0.8470	0.8470

Notes: Robust standard errors in parentheses. *, ** and *** represents significant at 10%, 5% and 1% level, respectively. Fixed effect includes firm-fixed effect, year fixed effect, two-digit industry fixed effect and city fixed effect. branch5, branch10, …, branch30 are the number of commercial bank branches within the radius of 5, 10, …, 30 km near the firm, respectively. Control variables consist of firm age (*Age*), size (*Size*), capital intensity (*Ci*), Herfindahl–Hirschman index (*Hhi*) and Ellison-Glaeser index (*Eg*).

km around firms (i.e., *Lnbranch10*) in the following analysis.

Our results are partly consistent with Aller, Jesus Herrerias, and Ordóñez (2018), who investigated the impact of financial development on energy intensity by employing province-level data in the context of China and claimed that financial development would improve energy efficiency. This finding also accords with Chen et al. (2019), who found that financial development is able to improve energy efficiency by applying the two-way fixed-effects model to a cross-country sample consisting of 98 countries. It is noteworthy that our results indicate that if firms are far away from bank branches, it is difficult for their energy efficiency to be affected by local financial development. This means that the negative nexus on finance-energy nexus from the previous literature may be caused by the improvement in the energy efficiency of firms where bank branches are located nearby.

4.1.2. The effect of financial availability and bank competition on energy efficiency

It is widely argued that expanding bank branches will increase competition in the banking industry and enhance financial accessibility. In order to accurately separate the impact of banking competition and financial accessibility caused by the bank branch expansion on energy efficiency, this paper will construct the following variables based on the latitude and longitude information of the firm and the bank and then construct a variety of interaction terms between branch expansion variables and the formers to replace $lnBranchK_{it}$ in eq. (1), separately.

$$LnEi_{it} = \alpha LnBranchK_{it} + \gamma LnBranchK_{it} \times Fa_{it} + \delta Fa_{it} + \beta X_{it} + \mu_i + \mu_t + \mu_j + \mu_c + \varepsilon \tag{2}$$

$$LnEi_{it} = \alpha LnBranchK_{it} + \gamma LnBranchK_{it} \times Bc_{it} + \delta Bc_{it} + \beta X_{it} + \mu_i + \mu_t + \mu_j + \mu_c + \varepsilon \quad (3)$$

With regard to financial availability, in line with the previous literature (Bellucci et al., 2013), we employ two measurements to proxy for it, naming $Fa1_{it}$ (defined as the distance between the firm and the bank branch closest to the firm) and $Fa2_{it}$ (it equals 1, if the distance between the firm *i* and bank branch closest to firm decreases, otherwise 0). With respect to banking competition, we employ three dummy variables, these are $Bc1_{it}$ (it equals 1, if the number of banks within a radius of 10 km near the firm *i* increases at year *t*, otherwise 0), $Bc2_{it}$ (the number of banks within a radius of 10 km near the firm) and $Bc3_{it}$ (it equals 1 if the bank market Herfindahl-Hirschman index is less than one-third quantile, otherwise 0). The bank market Herfindahl-Hirschman index (*Bank HHI*) can be obtained by the following equation:

$$Bank\ HHI_{it} = \sum_{b=1}^{N_{ibt}} \left(\frac{Branch_{ibt}}{\sum_{b=1}^{N_{ibt}} Branch_{ibt}} \right)^2 \quad (4)$$

where *b* denotes the bank; *N* is the total number of banks at city *c*, $Branch_{ibt}$ is the number of commercial bank branches belonging to bank *b* within the radius of 10 km.

We report our estimated results in Table 2. What stands out in this table is that the coefficients of *Lnbranch10* × *Fa1* and *Lnbranch10* × *Fa2* are both not significant, indicating that the improvement of financial availability caused by the bank branch expansion will not affect the energy efficiency. However, the coefficients of *Lnbranch10* × *Bc1*, *Lnbranch10* × *Bc2* and *Lnbranch10* × *Bc3* are all significantly negative, demonstrating that a competitive bank market will indeed cause the enhancement of energy efficiency. Thus, we are able to accept ***Hypothesis 3***, but reject ***Hypothesis 2***.

Though some literature concerning developed countries has claimed that the increase in financial availability may reduce the information cost and interest premium (Bellucci et al., 2013; Hollander & Verriest, 2016; Yahya, Abbas, & Lee, 2023), our results suggest that there may not exist reducing the effect of the former on financing cost in the context of China and hence, the financial availability is not able to increase the energy efficiency. A possible explanation for this is that the improvement of financial availability is associated with the shortening of geographical distance between banks and firms. Banks can capture more private information about the borrower and raise the interest rate on the basis of information to obtain additional information rents, which is also called the hold-up problem (Hoff & Stiglitz, 1998; Rajan, 1992; Sharpe, 1990).

4.2. Robustness tests

To ensure the robustness of our results, this paper conducts a battery of robustness checks. To start with, since there may exist significant differences in information share and competition of the branches in the same commercial bank and different ones, we drop the duplicated samples of the same commercial bank in the range of 5, 10, …, 30 km and generate six new branch expansion variables (e.g., *branch5new*, *branch10new*, …, *branch30new*).[4] By replacing these new branches variables with $LnBranchK_{it}$ in eq. (1), we re-estimate the impact of commercial bank branch expansion on firms' energy efficiency and report the corresponding findings in Table 3. We can still observe a significantly negative impact of the expansion of bank branches within a radius of 10 km near the firm on firms' energy efficiency.

Next, we control a vital policy that may affect the manufacturing firms' energy intensity, that is the eleventh five-year plan. The Chinese central government put forward a target to reduce energy intensity in the eleventh five-year plan for the first time. They requested that the overall energy intensity will reduce by 20% during the period from 2006 to 2010. And then, these targets are assigned to province governments by the central government. Meanwhile, provincial governments are responsible for allocating these targets to cities. And this target will affect the energy efficiency of manufacturing firms in different cities to a great extent (Chen et al., 2020). Hence, this paper manually collects the city-level reduction targets of energy intensity from the official website of the city government. And this paper adds these targets into the right side of eq. (1) to control for the effect of the five-year plan. As shown in column (1) of Table 4, commercial bank branch expansion can still significantly reduce energy intensity.

Moreover, we add a series of city-level and firm-level control variables to mitigate endogeneity problems caused by omitted variables. On the one hand, we add the GDP per capita (*Gdppc*, defined as the ratio of GDP to population), foreign direct investment (*Fdi*, defined as the ratio of foreign direct investment to GDP), government financial spending (*Gfs*, defined as the ratio of government financial spending to GDP), infrastructure (*Inf*, defined as the ratio of road surface area to population) and population density (*Pd*, defined as the ratio of population to city land area) to the right side of eq. (1).[5] On the other hand, we also include a set of control variables that may affect the operating efficiency of the firm, including total factor productivity (*Tfp*, we use the ACF-OP method to calculate the total factor productivity), government subsidy (*Gs*) and export ratio (*Er*, defined as the ratio of export value to total output value) as extra control variables at the firm level.[6] The empirical results are reported in columns (2) and (3) of Table 4, and it is obvious that bank branch expansion can negatively affect firms' energy intensity.

[4] Specifically, if there are different branches of the same commercial bank around the enterprise, we keep only the nearest branch and eliminate the remaining branches.

[5] The city-level control variables are collected from China City Statistical Yearbook. Due to many missing values in the 1999 China City Statistical Yearbook, the interval of city-level control variables is from 1999 to 2009.

[6] The government subsidy data is only available between 1998 and 2007, causing a reduced sample size.

Table 2
The effect of financial availability and bank competition on energy efficiency.

	(1)	(2)	(3)	(4)	(5)
	LnEi	*LnEi*	*LnEi*	*LnEi*	*LnEi*
Lnbranch10 × *lnFa1*	−0.0007 (0.0008)				
Lnbranch10 × *Fa2*		−0.0015 (0.0035)			
Lnbranch10 × *Bc1*			−0.0101*** (0.0035)		
Lnbranch10 × *Bc2*				−0.0103* (0.0056)	
Lnbranch10 × *Bc3*					−0.0186** (0.0085)
Control variables	Yes	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes	Yes
N	238,846	238,846	238,846	238,433	238,846
adj. R^2	0.8470	0.8470	0.8470	0.8470	0.8470

Notes: Robust standard errors in parentheses. *, ** and *** represents significant at 10%, 5% and 1% level, respectively. Fixed effect includes firm-fixed effect, year fixed effect, two-digit industry fixed effect and city fixed effect. Control variables consist of firm age (*Age*), size (*Size*), capital intensity (*Ci*), Herfindahl–Hirschman index (*Hhi*) and Ellison-Glaeser index (*Eg*). Note that we also add the corresponding sub-components of the interaction term in these regressions, respectively (not report).

Table 3
Utilizing new commercial bank branch expansion variables.

	(1)	(2)	(3)	(4)	(5)	(6)
	LnEi	*LnEi*	*LnEi*	*LnEi*	*LnEi*	*LnEi*
Lnbranch5new	0.0009 (0.0067)					
Lnbranch10new		−0.0222** (0.0106)				
Lnbranch15new			−0.0064 (0.0131)			
Lnbranch20new				−0.0117 (0.0148)		
Lnbranch25new					−0.0215 (0.0161)	
Lnbranch30new						−0.0158 (0.0170)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	238,846	238,846	238,846	238,846	238,846	238,846
Adj. R^2	0.8470	0.8470	0.8470	0.8470	0.8470	0.8470

Notes: Robust standard errors in parentheses. *, ** and *** represents significant at 10%, 5% and 1% level, respectively. Fixed effect includes firm-fixed effect, year fixed effect, two-digit industry fixed effect and city fixed effect. If there are different branches of the same commercial bank around the enterprise, we keep only the nearest branch and eliminate the remaining branches. Based on this criterion, we generate *branch5new*, *branch10new*, …, *branch30new*, respectively. Control variables consist of firm age (*Age*), size (*Size*), capital intensity (*Ci*), Herfindahl–Hirschman index (*Hhi*) and Ellison-Glaeser index (*Eg*).

Although this paper has added firm fixed effects, which can mitigate the interference of confounding factors involved in firm relocation, in eq. (1), to a greater extent, we still rule out these relocating firms and only keep firms with the consistent address to generate a new sample. Based on the new sample, we re-estimate eq. (1) and show the estimated result in column (4) of Table 4. And it shows similar results.

Furthermore, it takes a certain period for firms to carry out technology innovation and capital renewal after obtaining bank loans, indicating that the contemporaneous terms (i.e., *lnbranch10*) might not fully capture the impact of commercial bank expansion on energy efficiency. To this end, we test the impact of the lag term of *branch10* (*L.lnbranch10*) on energy efficiency to investigate the lag effect of commercial bank branch expansion. This paper displays the estimation results in column (5) of Table 4, and we find that the expansion of commercial bank branches in the last year can significantly reduce the intensity of business in the current year.

Finally, we utilize the instrumental variable method to handle this issue to alleviate further the possible endogeneity issue induced by unobservable variables omitted. Specifically, this paper calculates the average number of branches per commercial bank (*abranch10*) at the city level and uses it as the instrumental variable. A higher average number of branches per commercial bank in a city means more bank branches may exist near the firm in this city. And the average number is not related to the residuals in our DID equation. Columns (6) and (7) of Table 4 show the estimation results. The F statistic in the first stage reveals that our instruments are

Table 4
The results of robustness tests.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Energy reduction target	Extra city control variables	Extra firm control variables	Ruling out relocating firms	Testing the lag-effect	First stage	Second stage
	LnEi	*LnEi*	*LnEi*	*LnEi*	*LnEi*	*Lnbranch10*	*LnEi*
Lnbranch10	−0.0085**	−0.0090**	−0.0111***	−0.0185***			−0.0578***
	(0.0041)	(0.0044)	(0.0042)	(0.0069)			(0.0187)
L.lnbranch10					−0.0578***		
					(0.0187)		
Lnabranch10						0.7296***	
						(0.0105)	
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	234,100	191,484	154,079	187,255	149,068	238,846	238,846
Adj. R^2	0.8475	0.8479	0.8607	0.8449	0.8602	–	–
Kleibergen-Paap rk Wald F statistic	–	–	–	–	–	4787.927	–

Notes: Robust standard errors in parentheses. *, ** and *** represents significant at 10%, 5% and 1% level, respectively. Fixed effect includes firm-fixed effect, year fixed effect, two-digit industry fixed effect and city fixed effect. Control variables consist of firm age (*Age*), size (*Size*), capital intensity (*Ci*), Herfindahl–Hirschman index (*Hhi*) and Ellison-Glaeser index (*Eg*). Note that we also add the energy intensity reduction target as a control variable in column 1. Moreover, we utilize GDP per capita (*Gdppc*), foreign direct investment (*Fdi*), government financial spending (*Gfs*), infrastructure (*Inf*) and population density (*Pd*) as control variables in column 2. Furthermore, we include total factor productivity (*Tfp*), government subsidy (*Gs*) and export ratio (*Er*) as extra control variables in column (3).

valid. And the expansion of branches can still significantly reduce the energy intensity, strengthening the robustness of our results again.

4.3. Heterogeneous effects

Having confirmed the positive effect of commercial bank branch expansion on energy efficiency, it is now to turn to explore the possible heterogeneous relationship between the two. In particular, we investigate the probable heterogeneity from the perspectives of banks, firms, and the macro environment.

4.3.1. Discussion of bank type

The object of this section is to inspect whether the impact of branch expansion on energy efficiency will differ over the bank types. Namely, we attempt to explore the impact of the branch expansion of four stated-owned commercial banks, joint-equity and city commercial bank and foreign bank on energy efficiency. In the context of China, the credit decision of four stated-owned commercial banks tends to be driven by the political interferences of Chinese authorities, and they tend to loan to stated-owned firms. Though the reform of four stated-owned commercial banks aims to get rid of this situation, the credit supply from them appears to be still dominated by political pressure instead of business behavior (Chen et al., 2020; Chen, Liu, & Su, 2013; Zhang, Cai, Dickinson, & Kutan, 2016). Contrary to the four stated-owned commercial banks with inefficient credit supply, the joint-equity bank, city commercial bank and the foreign bank are less subject to restriction from authorities, thus responding to the credit demand from various sectors and serving the local economic development effectively (Ferri, 2009).[7] Therefore, it is interesting to investigate whether the improvement impact of bank branches on energy efficiency varies by bank types, and we expect that the improvement impacts of the branch expansions of joint-equity, city and foreign commercial banks on energy efficiency are stronger than that of four stated-owned banks.

We generate three new branch expansion variables, naming *Sobranch10* (defined as the number of four stated-owned bank branches within a radius of 10 km), *Jecbranch10* (defined as the sum of the number of joint-equity bank branches and the number of city commercial bank branches within the radius of 10 km) and *Fbranch10* (defined as the number of foreign bank branches within the radius of 10 km). Hereafter, we utilize these variables to substitute for $BranchK_{it}$ in eq. (1). Regression results are presented in columns (1)–(3) of Table 5. The negative impact of branch expansion of joint-equity bank and city commercial bank on energy efficiency is stronger, followed by the foreign bank branch expansion and four stated-owned bank expansions, which accords with our anticipation.

4.3.2. Discussion of the functional distance between branch and firm

Several studies have emphasized the importance of functional distance between headquarters and branches to access bank finance (Bernini & Brighi, 2018; Zhao & Jones-Evans, 2017). To put it simply, less functional distance can alleviate the credit constraints faced by the firms since the bank headquarters can effectively process loan applications submitted by the bank branches from firms.

[7] A significant difference between the four stated-owned banks and city commercial bank is that city commercial bank possesses many shareholders. The plurality of shareholders tends to associate with effective management and better performance, implying that it is likely to be less affected by the obstruction of authorities in the process of loan decisions (Ferri, 2009).

Table 5
Heterogeneity analysis of bank type, functional distance and firm's ownership.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Stated-owned bank	Je and cc bank	Foreign bank	Less functional distance	Greater functional distance	Stated-owned firms	Foreign firms	Other firms
	LnEi	*LnEi*	*LnEi*	*LnEi*	*LnEi*	*LnEi*	*LnEi*	*LnEi*
LnSobranch10	−0.0056							
	(0.0039)							
LnJecbranch10		−0.0138***						
		(0.0040)						
LnFbranch10			−0.0058*					
			(0.0035)					
Lnbranch10				−0.0308***	−0.0150	−0.0109	−0.0326	−0.0106**
				(0.0105)	(0.0092)	(0.0102)	(0.0539)	(0.0045)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	238,846	238,846	238,846	114,866	117,402	45,336	5975	183,327
adj. R^2	0.8470	0.8470	0.8470	0.8382	0.8482	0.8593	0.8322	0.8479

Notes: Robust standard errors in parentheses. *, ** and *** represents significant at 10%, 5% and 1% level, respectively. Fixed effect includes firm-fixed effect, year fixed effect, two-digit industry fixed effect and city fixed effect. Control variables consist of firm age (*Age*), size (*Size*), capital intensity (*Ci*), Herfindahl–Hirschman index (*Hhi*) and Ellison-Glaeser index (*Eg*). Je and cc mean the joint-equity bank and city commercial bank, respectively.

Accordingly, we calculate the number of the bank branch at higher levels (i.e., head office, first-level branch, second-level branch, and first-level sub-branch) within the radius of 10 km and split the whole sample into two sub-samples based on the median of the bank branch number at higher levels. We infer that the increase in the number of bank branches at higher levels will improve bank efficiency and help firms access bank finance more easily. This can reinforce the improvement effect of bank branch expansion on firms' energy efficiency.

To provide direct empirical evidence for our conjecture, we re-estimate eq. (1) by utilizing two sub-samples, respectively. As can be seen from columns (4) and (5) of Table 5, the coefficient of *Lnbranch10* is significantly negative at the 1% level, meaning that the expansion of bank branches can exert a more pronounced effect on energy efficiency when the functional distance is less.

4.3.3. Discussion of firm's ownership

A large number of evidence suggests that compared with non-stated-owned firms, stated-owned firms can easily obtain bank finance in the context of China (Cull & Xu, 2003; Huang, Du, & Tao, 2017). Given this, the commercial bank branch expansion may not result in a greater improvement effect on the stated-owned firms' energy efficiency. In other words, even if the number of bank branches does not increase, stated-owned firms can still easily obtain bank loans, causing the marginal effect of bank expansion on the energy efficiency of stated-owned firms is low. It is also noteworthy that stated-owned firms usually have a weaker motivation to enhance energy efficiency since they can bargain with local governments, and they usually face weaker regulation (Chen et al., 2020). This means that the expansion will result in a greater improvement effect on the non-stated-owned firms' energy efficiency. Moreover, foreign firms may be less affected by the bank branch expansion in China since they are able to obtain financing support abroad, such as financial transfers from affiliated firms from home countries (Poncet, Steingress, & Vandenbussche, 2010). This means that the bank branch expansion mainly affects the energy efficiency of non-foreign firms instead of foreign firms.

To test these statements, we separate our sample into various sub-samples based on the ownership of firms. If the firm is a stated-owned firm (foreign firm), we classify it into the stated-owned sub-sample (foreign sub-sample), otherwise non-stated-owned, and non-foreign sub-sample. Subsequently, we applied eq. (1) to different sub-samples, and the estimated results are set out in columns (5)–(8) of Table 5. It is apparent from this table that the commercial bank branch expansion mainly negatively affects the energy intensity of non-stated-owned and non-foreign firms.

4.3.4. Discussion of energy type

Since our firm-level energy consumption dataset provides detailed information concerning the energy consumption of various energy types (i.e., coal, oil and natural gas), we can examine the diverse effect of commercial bank branch expansion on energy efficiency of different energy types. To this end, we produce three new energy intensity variables to measure the energy efficiency of specific energy types, named *Eicoal* (defined as the ratio of coal consumption to real output), *Eioil* (defined as the ratio of oil consumption to real output) and *Eigas* (defined as the ratio of natural gas consumption on real output).

Afterward, we can examine the diverse impact of bank branches on the energy efficiency of specific energy types by applying eq. (1). Column (1)–(3) of Table 6 shows our empirical results. We can find that there are negative correlations between branch expansion and coal intensity as well as oil intensity, whereas the branch expansion is not able to reduce the natural gas intensity significantly. Also, it is noteworthy that there exists a stronger negative effect of bank branches on coal intensity. Actually, these results may be caused by the energy structure where coal dominates in China.

4.3.5. Discussion of financial dependence

Previous research has established differences in financial dependence across manufacturing sectors (Rajan & Zingales, 1996). This suggests that firms in sectors with high financial dependence may benefit more from commercial bank branch expansion. On the contrary, firms in sectors with low financial dependence are less dependent on external financing and insensitive to bank branch expansion. Thus, we suppose that the energy efficiency of firms in manufacturing sectors characterized by high financial dependence will be improved more than firms in manufacturing sectors characterized by low financial dependence. We utilized the data of investment in fixed assets in different manufacturing sectors to identify the degree of financial dependence at the level of the two-digit industry, and more specifically, we use the ratio of funding sources other than self-raised funds on the total funding in the period of 2004 to 2009 to measure the industry's dependence on external financing.[8] Then, we can divide our sample into two sub-sample based on the median of the ratio of funding sources other than self-raised funds on the total funding. Finally, we use eq. (1) to investigate the impact of branch expansion on energy efficiency in two sub-samples.

As shown in columns (4) and (5) in Table 6, we can observe a significantly negative impact of branch expansion on energy efficiency in the high financial dependence sub-sample, whereas this negative impact cannot be observed in the low financial dependence sub-sample. This suggests that the effect of commercial bank branch expansion on the energy efficiency of firms characterized by high financial dependence is indeed more substantial.

4.3.6. Discussion of the legal environment

Prior studies have established that it is more likely for firms to have a stronger ability to loan in the context of a better law environment (Thapa, Rao, Farag, & Koirala, 2020). A better law environment is associated with stronger legal enforcement and investment conservation, this means that the loan contract can be executed on time, and banks are willing to make a loan decision. Hence, we test whether there exists a stronger improvement effect of bank branch expansion on energy efficiency in a better law environment. To gauge the law environment, we utilize the sub-components of the marketization index constructed by Fan, Wang, and Zhu (2011), that is the development of market intermediaries and legal environment.[9] A higher score means that the province performs better in the corresponding dimension. Based on the median score of the development of market intermediaries and the legal environment from 1998 to 2009, we partition our sample into two sub-samples. Subsequently, we estimate eq. (1) based on two sub-samples, respectively.

As columns (6) and (7) of Table 6 show, there is a significantly negative impact of bank branch expansion on energy intensity in a better legal environment, whereas this impact does not exist if the legal environment is bad. These findings align with our anticipation, and the law environment plays a significant role in the impact of bank branch expansion on energy efficiency.

4.4. Mechanisms tests

Having discussed the effect of commercial bank branch expansion on energy efficiency, turning now to explore through which channels bank branch expansion affects energy efficiency. This section has been divided into two parts. In the first part, this paper examines the impact channel from the perspective of technological innovation, while the second part mainly deals with whether the bank branch expansion affects energy efficiency through capital renewal.[10] This paper uses four variables to proxy for the technological innovation, including the number of total patent applications (*Ntp*, defined as the sum of the application number of invention patents and utility model), the application number of invention patents (*Nip*), the application number of utility model (*Num*) and the expenditure of research and development (*Erd*). To test whether the commercial bank branch expansion affects energy efficiency through capital renewal, this study exploits the following variables, these are total fixed asset (*Tfa*), productive fixed asset (*Pfa*), non-productive fixed asset (*Npfa*, defined as the total fixed asset minus productive fixed asset), depreciation of fixed asset (*Dfe*), the growth rate of depreciation of fixed asset (*Grdfe*) and the capital productivity (*Cp*, defined as the ratio of real output on fixed asset).

By replacing these variables with *LnEi* in eq. (1), we can investigate whether ***Hypothesis 4***, respectively. We present our estimation results on the innovation channel in Table 7. All coefficients of *Lnbranch10* are not significant, and no evidence was found for the significant impact of bank branch expansion on technological innovation. Our finding is partly in line with Atanassov, Nanda, and Seru (2007), Chava, Oettl, Subramanian, and Subramanian (2013), Cornaggia, Mao, Tian, and Wolfe (2015) and Hombert and Matray

[8] Since there is no data on investment in fixed assets classified by fund sources before 2004, we only utilize the data from 2004 to 2009 to calculate the ratio.

[9] The marketization index intends to measure the degree of regional market development at the province level. And it consists of five sub-components, named the government-market relation, development of the non-stated-owned sector, development of product markets, development of factor markets, and development of market intermediaries and legal environment. This indicator has been widely utilized in existing literature, such as Li et al. (2019), Firth et al. (2009), and Li et al. (2009).

[10] We also utilize equation (1) to examine the impact of commercial bank branch expansion on interest rates and loans of firms, and we report the estimated results in Appendix B. Since there is no loan data and the interest of different loans in our dataset, we utilize the debt to proxy for loans indirectly and only calculate the total interest rate (defined by the ratio of interest on total debt). According to the results, we can find an insignificantly negative impact of bank branch expansion on interest rates. We can also find an insignificantly positive impact of bank branch expansion on long debt and a significantly positive impact of bank branch expansion on the level of debt and short debt, respectively. These results reveal that the bank branch expansion can significantly the level of total debt and short debt. And the insignificant impact of commercial bank branch expansion on interest rates may be due to the fact that the expansion may only affect the interest rate of short debt. Overall, our results provide evidence for the reduction effect of expansion on energy efficiency.

Table 6
Heterogeneity analysis of energy type, financial dependence and legal environment.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Coal intensity	Oil intensity	Natural gas intensity	High financial dependence	Low financial dependence	High score	Low score
	LnEicoal	*LnEioil*	*LnEigas*	*LnEi*	*LnEi*	*LnEi*	*LnEi*
Lnbranch10	−0.0045***	0.0011**	−0.0001	−0.0108**	−0.0024	−0.0151**	0.0049
	(0.0018)	(0.0005)	(0.0005)	(0.0052)	(0.0065)	(0.0060)	(0.0060)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	238,846	238,846	238,846	111,109	126,727	115,168	110,335
adj. R^2	0.8429	0.6925	0.5738	0.8528	0.7930	0.8531	0.8556

Notes: Robust standard errors in parentheses. *, ** and *** represents significant at 10%, 5% and 1% level, respectively. Fixed effect includes firm-fixed effect, year fixed effect, two-digit industry fixed effect and city fixed effect. Control variables consist of firm age (*Age*), size (*Size*), capital intensity (*Ci*), Herfindahl–Hirschman index (*Hhi*) and Ellison-Glaeser index (*Eg*).

(2017). They regard banking deregulation as a quasi-natural experiment and investigate the impact of banking expansion on innovation. Their empirical results reveal that the banking expansion will not cause innovation activities. Hence, we can reject ***Hypothesis 4***. The commercial bank branch expansion will not affect energy efficiency by affecting technological innovation.

Turning now to the capital renewal channel, we show the estimation results in Table 8. Strong evidence of a positive relationship between commercial bank branch expansion and capital renewal is found in columns (1)–(6). The commercial bank branch expansion can increase the productive fixed asset, depreciation, the growth rate of depreciation and capital productivity, while the former will not significantly non-productive fixed asset. These results demonstrate that the commercial bank branch expansion can significantly improve the energy efficiency through promoting capital renewal. And ***Hypothesis 5*** holds.

5. Conclusions and implications

It is widely accepted that reducing energy consumption without restraining economic development is an urgent global problem in the background of global warming and environmental degradation. To alleviate the collision between energy consumption and growth, there has been a growing body of literature investigating the determinants of energy efficiency. Different from previous literature, this study primarily discusses the impact of commercial bank branch expansion on manufacturing firms' energy efficiency. This work will supply a fresh insight into the side effect of geographic diversification of banks from the perspective of energy economics, especially in developing countries.

One of the significant advantages of our study is that we merge and exploit three firm-level datasets, which are the Environmental Survey and Reporting database, the Annual Survey of Industrial Firms and firm-level patent application dataset to construct our sample. This means that we can give a comprehensive discussion and empirical examination concerning the micro-impact channels through which commercial bank branch expansion affects energy efficiency. Note that we also utilize python technology to obtain the latitude and longitude of the firm in our sample. Another advantage is that we construct a firm-level commercial bank branch expansion variable, which can alleviate the endogeneity issues caused by the utilization of aggregate financial variables to a great extent. To this end, we first manually collect all commercial bank branches information from the official website of China Banking and Insurance Regulatory Commission, and then we utilize the python technology to obtain the latitude and longitude of each commercial bank branches. Finally, by combing the latitude and longitude of bank branches and firms, we can construct a series of firm-level commercial bank branch expansion variables.

This paper finds that the commercial bank branch expansion indeed improves the manufacturing firms' energy efficiency and this improvement effect passes a variety of robustness checks. We also confirm that the increase in financial availability will not significantly affect energy efficiency, whereas the competitive banking market will cause the enhancement of energy efficiency. Moreover, there are various heterogeneous nexuses between the two. First, the negative impact of branch expansion of joint-equity and city commercial bank on energy efficiency is stronger, followed by the foreign bank branch expansion and four stated-owned bank expansion. Second, the less functional distance can strengthen the improvement effect of commercial bank branch expansion on energy efficiency. Third, the positive effect of bank branch expansion is more pronounced on the energy efficiency of non-stated-owned and non-foreign firms. Fourth, the bank branch expansion has caused a greater improvement in coal intensity. Fifth, we find that the expansion of bank branches mainly enhances the energy efficiency of firms with high financial dependence and in a better legal environment. Finally, the bank branch expansion improves energy efficiency by promoting capital renewal instead of technological innovation.

Overall, our results reveal that the banking sector is vital in improving energy efficiency. To further leverage the banking sector's role in reducing the energy intensity of businesses, the government needs to put in place measures to stimulate the positive role of improved financial accessibility. On the one hand, the government can issue guidance criteria to guide banks in choosing suitable addresses to set up branches, thus preventing excessive competition among branches and ensuring the positive role of financial accessibility in the reduction of energy efficiency. On the other hand, as a major component of China's banking sector, the government must direct stated-owned commercial banks to contribute more to energy efficiency. From the perspective of the commercial bank, in

Table 7
The impact of commercial bank branch expansion on technological innovation.

	(1)	(2)	(3)	(4)
	LnNtp	*LnNip*	*LnNum*	*LnErd*
Lnbranch10	0.0006	0.0005	0.0002	−0.0422
	(0.0009)	(0.0006)	(0.0006)	(0.0283)
Control variables	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes
N	238,846	238,846	238,846	61,216
adj. R^2	0.3301	0.2551	0.3154	0.6898

Notes: Robust standard errors in parentheses. *, ** and *** represents significant at 10%, 5% and 1% level, respectively. Fixed effect includes firm-fixed effect, year fixed effect, two-digit industry fixed effect and city fixed effect. Note that the data concerning the expenditure of research and development is only available in the period from 2005 to 2007. Control variables consist of firm age (*Age*), size (*Size*), capital intensity (*Ci*), Herfindahl–Hirschman index (*Hhi*) and Ellison-Glaeser index (*Eg*).

Table 8
The impact of commercial bank branch expansion on capital renewal.

	(1)	(2)	(3)	(4)	(5)	(6)
	LnTfa	*LnPfa*	*LnNpfa*	*LnDfe*	*Grdfe*	*LnCp*
Lnbranch10	−0.0030	0.0080**	−0.0087	0.0098**	−0.0101**	0.0081***
	(0.0033)	(0.0037)	(0.0185)	(0.0047)	(0.0045)	(0.0030)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	238,846	155,361	155,361	177,864	118,069	238,846
adj. R^2	0.8861	0.8716	0.4370	0.8252	−0.0513	0.6358

Note: Robust standard errors in parentheses. *, ** and *** represents significant at 10%, 5% and 1% level, respectively. Fixed effect includes firm-fixed effect, year fixed effect, two-digit industry fixed effect and city fixed effect. Note that the data concerning the productive fixed asset and non-productive fixed asset are only available from 1998 to 2006. Control variables consist of firm age (*Age*), size (*Size*), capital intensity (*Ci*), Herfindahl–Hirschman index (*Hhi*) and Ellison-Glaeser index (*Eg*). And the data concerning depreciation are only available from 1998 to 2007.

response to China's green financial strategy, commercial banks can develop more green financial products to assist firms in lowering their energy intensity. Meanwhile, commercial banks must reduce the functional distance between branches and their parent departments by utilizing information and communication technology. Finally, our results indicate that firms increase energy efficiency through capital renewal instead of innovation. To turn the situation around, the government must provide financial incentives to encourage banks to grant more special loans aimed at promoting innovation.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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Declaration of Competing Interest

Both authors declare that they have no conflict of interest. The authors declare that we have no relevant or material financial interests that relate to the research described in this paper. Both authors contributed equally to this study and share first authorship.

Data availability

Data will be made available on request.

Appendix A

Appendix Table A1
Descriptive statistics of all variables.

Variable	Obs.	Mean	Std. Dev.	Min	Min
LnEi	238,846	−0.7391	1.7724	−8.3767	6.9888
LnBranch5	238,846	2.4893	1.3425	0	6.0210
LnBranch10	238,846	3.3367	1.2917	0.6931	6.2596
LnBranch15	238,846	3.8464	1.2777	0.6931	7.2964
LnBranch20	238,846	4.2069	1.2616	0.6931	7.6866
LnBranch25	238,846	4.4934	1.2437	0.6931	7.8372
LnBranch30	238,846	4.7320	1.2200	0.6931	7.9051
LnAge	238,846	2.4810	0.9146	0	4.1109
LnSize	238,846	5.5058	1.0632	2.0794	10.8548
LnCi	238,846	3.3550	1.3776	−10.1092	9.9969
Hhi	238,846	0.0013	0.0021	0.0002	0.0604
Eg	238,846	1.7385	2.0673	0	60.6895
LnSobranch10	238,846	2.7911	1.3588	0	6.0283
LnJecbranch10	238,846	1.1678	1.4396	0	5.5215
LnFbranch10	238,846	0.9069	1.3024	0	5.0562
LnEicoal	238,846	0.6379	0.7177	0	6.9897
LnEioil	238,846	0.0270	0.1516	0	4.8265
LnEigas	238,846	0.0137	0.1369	0	5.5311
lnFa1	238,846	−0.9032	2.6581	−12.3391	2.3025
Fa2	238,846	0.1368	0.3437	0	1
Bc1	238,846	0.1995	0.3996	0	1
Bc2	238,846	3.3367	1.2917	0.6931	6.2596
Bc3	238,846	0.2943	0.4557	0	1
LnNtp	238,846	0.0377	0.2042	0	1.7918
LnNip	238,846	0.0193	0.1321	0	1.0986
LnNum	238,846	0.0221	0.1533	0	1.3863
lnrdmoney	71,102	0.8928	2.2677	0	13.3567
LnTfa	238,846	9.5799	1.5492	0.6931	15.9494
LnPfa	161,128	9.7595	1.5353	0.6931	16.1983
LnNpfa	161,128	5.3153	4.0103	0	14.4586
LnDfe	184,277	8.6830	1.7734	0.6931	15.8510
Grdfe	118,341	0.0094	0.9031	−3.4546	3.4860
LnCp	238,846	1.2665	0.8395	0.0005	11.2642

Appendix B. The impact of bank branches on interest rate and size of debt

Appendix Table B1
The impact of bank branches on interest rate and debt.

	(1)	(2)	(3)	(4)
	lnfin	*lndebt*	*lnlongdebt*	*lnshortdebt*
LnBranch10	−0.0002	0.0109***	−0.0052	0.0110**
	(0.0004)	(0.0037)	(0.0151)	(0.0053)
Control variables	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes
N	225,425	238,846	238,846	238,846
adj. R^2	0.2665	0.8545	0.6652	0.6953

Notes: Robust standard errors in parentheses. *, ** and *** represents significant at 10%, 5% and 1% level, respectively. Fixed effect includes firm-fixed effect, year fixed effect, two-digit industry fixed effect and city fixed effect. Note that the data concerning the expenditure of research and development is only available in the period from 2005 to 2007. Control variables consist of firm age (*Age*), size (*Size*), capital intensity (*Ci*), Herfindahl–Hirschman index (*Hhi*) and Ellison-Glaeser index (*Eg*). *Lnfin* is the share of interest expense on debt, *lnloan*, *lnlongloan* and *lnshortloan* is the level of *debt*, long debt and short debt of firm, respectively. Note that since there are not loan data in our dataset, we utilize the debt to proxy for the loan.

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