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Analysis of the non-linear impact of digital economy development on energy intensity: Empirical research based on the PSTR model

Haoran Zhao [a,] , Sen o [b]

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b

A R T E

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igital economy
Energy intensity
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provincial regions in hina

A S T R A T

ith the rapid development of digital technologies, digital economy E grad ally plays a cr cial role in changing the pattern of economic and social development Ho ever, the relationship bet een the E and energy intensity is still nclear To ll this gap, this investigation rstly eval ates the development level of the E of provincial regions in hina from to Then the non-linear relationship bet een the E development and energy intensity is investigated based on the panel smooth transition PSTR model ta ing real P, r-bani ation rate, the proportion of the secondary ind stry in P, R& f nds for ind strial enterprises above designated si e, and foreign direct investment as transformation variables The empirical analysis testi es that the E development can promote the energy intensity and the relationship bet een the E development and energy intensity tends to be an invert shape nder the in ence of ve transformation variables al es of conversion variables in most provincial regions have not cross thresholds Especially, the in ence coef cients of the E development on energy intensity have great space to decline nder the impact of rbani ation rate and the proportion of the secondary ind stry in P Therefore, the ind strial str ct re sho ld be contin o sly optimi ing and the process of green rbani ation sho ld be accelerating oreover, it is necessary to stim late the integration of digitali ation technologies and energy system so as to improve energy allocation ef ciency and reali e energy conservation and emissions red ction

1. Introduction

The emergence of digital economy E opens a ne era theme in the later stage of ind striali ation and rbani ation process t is a ne economic form ta ing digital reso rces as the main prod ction factors and information net or as a cr cial s pporter to s f ciently tili e m ltiple prod ction reso rces in the society thro gh modern information comm nication and internet technologies , Thro gh the development of E, the latest information technologies, s ch as clo d comp ting, arti cial intelligence A , and big data, have provided technical assistance for the scale e panding of ne -type economies and ind stries Hence, the transformation of prod ction mode, social governance, and lifestyle can be promoted and greater economic bene- ts can be obtained , Th s, E ill grad ally become the cr cial drivers of economic gro th and the booster to enhance the national strength in the f t re n Th

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for ard that the E can decrease energy cons ming, optimi e energy allocation, and reverse the traditional energy cons ming concept , o ssan et al ,

Thro gh s mmari ing the e isting literat re, three primary limitations can be discovered irstly, the e isting researches primarily foc sed on investigating the in ence of the E on economic gro th, carbon emissions, and other iss es t is dif c lt to nd an investigation on the relationship bet een the E and energy cons mption rom the perspective of historical development, the economic gro th greatly relied on energy cons mption Since the E becomes the ne engine of economic development, the gro th of E depends on information technology infrastr ct re hich re ires a h ge amo nt of energy, hence, the relationship bet een the E and energy cons mption sho ld be investigated Secondly, the previo s literat re mainly cond cted linear relationship analysis based on panel data model Ho ever, the relationship bet een the E and energy cons mption e ists disp tes The nclear part is hether the E ill lead to a net increase in energy demand as the rebo nd effect might e ist Hence, researching on the nonlinear relationship bet een energy cons mption and the E is of cr cial signi cance to achieve the goal of carbon ne trality and mitigate global arming, especially for hina hich is still in the process of ind striali ation and rbani ation Thirdly, the in ence mechanism of the E on energy cons mption is poorly disc ssed Th s, it ill be of signi cant bene t for policy ma ers to deeply nderstand the in -encing mechanism decrease energy demand thro gh increasing energy ef ciency ange et al implied that the digitali ation enhanced energy ef ciency hich made energy cons ming become lo er evertheless, the development of T and economic gro th bro ght by the digitali ation o ld ca se more incremental energy sing Salah ddin disc ssed that the digital technology can decrease energy cons ming in the short term, hile the rebo nd effect ca sed by the digitali ation ill boost energy demand in the long term ,

onsidering abo t the complicated relationship bet een the E and energy cons ming, this paper deeply researched on the nonlinear correlation bet een the E and energy intensity of provincial regions in hina And the in encing mechanism is investigated from economic scale and str ct re, society str ct re, technological innovation, and opening degree

3. Methods

The model of this research as established according to the PSTR model proposed by on alea et al The s periority of this model is that it can better handle the problem of mping change before and after the door limit in Hansen's panel threshold model A contin o s transformation f nction has been introd ced into the model hich can ma e model parameters grad ally change ith the vary of transformation variables, hence, it is more consistent ith act al economy esides smooth transformation, the PSTR model can ef ciently capt re the heterogeneity bet een different parts and is s itable for m lti-section data research The PSTR model is established as

$$Energy_{i,t} = \beta_0 + \beta_1 Dige_{i,t} + \sum_{j=1}^{r} \beta_{2j} Dige_{i,t} \times G_j(q_{i,t}, \gamma, c) + \beta_z Z_{i,t} + \varepsilon_{i,t}$$

here , is the e plained variable representing the energy cons mption intensity of provincial region in period β is the constant term of the f nction , is the E development level of provincial region in period , hich is deemed as the core e planatory variable in o r research β is the correlation coef cient of the E development level on energy intensity, hich is deemed as the core parameter β , is the coef cient of the non-linear part , indicates a series of control variables β is the coef cient of control variables ε , is the random dist rbance term , is the conversion variable (, , γ,) is the transformation f nction, hich is a contin o s, bo nded f nction of a transformation variable , And the val e of the conversion f nction is normali ed in the interval of , $\gamma >$ represents the slope coef cient, hich determines the speed at hich model conversion occ rs The larger the val e of γ, the greater the slope of the transformation f nction, demonstrating the larger the conversion speed = (, , …) is an -dimensional positional parameter vector, also no n as a threshold val e, hich represents the location here model transformation occ rs The transformation f nction is generally e pressed in the form of a ogistic f nction as

$$G_j(q_{i,t}, \gamma, c) = \left\{ 1 + \exp\left[-\gamma \prod_{z=1}^{m} (q_{i,t} - c_z) \right] \right\}^{-1}, \gamma > 0, c_1 \leq \ldots \leq c_m$$

eca se is a contin o s f nction, hen contin o sly changes ithin the , interval, the regression coef cient ill complete a contin o s and stable transformation ithin the interval [β , β + $\sum$ = β] oreover, in the PSTR model, val es of t o critical parameters and sho ld be determined represents the n mber of positional parameters, and on alea believes that a val e of or for is s f cient to be representative represents the amo nt of conversion f nctions

efore establishing the PSTR model, a linearity test needs to be cond cted The PSTR model can only be established nder the conte t that the data se ences are non-linear The linearity test can determine the val e of in the transformation f nction The n ll ass mption of linearity test is s pposed as : = or : β = evertheless, nder s ch ass mption, nrecogni able parameters ill be generated in the PSTR model Hence, on alea et al solve this problem by proposing the n ll ass mption as : = Sim ltaneo sly, to avoid the identi cation iss e, Taylor series e pansion as employed for (, , γ,) hen = , hich is e pressed as:

$$y_{i,t} = \mu_i + \beta_0' x_{i,t} + \beta_1' x_{i,t} q_{i,t} + \square + \beta_m' x_{i,t} q_{i,t}^m + \mu_{i,t}'$$

n E ation , β' , β' $\square\beta'$ are generated by and they are constant μ' , = μ , + β' , is the remainder of Taylor e pansion Th s, the n ll ass mption of the linearity e amination is the same as : β' = $\square$ = β' = f the n ll ass mption is accepted, the PSTR model is inappropriate to be established ther ise, if the n ll ass mption is re ected, the data se ences are nonlinear and the PSTR model is reasonable to be b ilt

The cond ction of no remaining non-linearity test of the PSTR model aims at e amining hether the resid al term μ still incl des obvio s nonlinear components The concept of this e amination is the same as the linearity e amination The n ll ass mption is ritten as: : β'^* = $\square$ = β'^* = f this ass mption is accepted, the PSTR model has f lly capt red the non-linear correlation among data se ences ther ise, the model is nreasonable

The speci c operation process of the PSTR model is ill strated as follo s

Step 1 Stability test

To prevent the occ rrence of false regression, this paper rst ses the panel nit root test methods to test the data stationarity of each variable

Step 2 inearity test

efore sing the PSTR model for estimation, it is necessary to rst cond ct a linear test to test hether the development of the E has a non-linear impact on energy cons mption intensity nder the in ences of different transformation variables Three statistics, , , and RT, are sed to cond ct the e amination nly if the test res lts re ect the original hypothesis : = , a PSTR model can be constr cted

Step 3 Remaining non-linearity test

The p rpose of the remaining non-linearity test is to determine the optimal n mber of r in the transformation f nction of the PSTR model f the original ass mption : = is accepted, it is considered appropriate to set only one transformation f nction for the model f the original ass mption is re ected, it means that the model needs to set m ltiple conversion f nctions

Step 4 The n mber of positional parameters determination

After determining the n mber of transformation f nctions, it is necessary to f rther determine the n mber of positional parameter m for each PSTR model's transformation f nction t is essential to perform PSTR estimation nder m = and m = , respectively, and determine the optimal n mber of location parameter based on A and information criteria

4. Data

The e plained variable is energy cons mption intensity, hich is represented by the ratio of energy cons mption to real P The core e planatory variable is the development level of the E Thro gh revie ing e isting literat re and related reports, e fo nd that there is no niform standard for the meas rement of the E Thro gh referring to some literat re , – researching on the comprehensive eval- ation of the E development level, the indicators sed to represent the development level of the E in o r research are listed in Table The indicators are selected from fo r perspectives incl ding digital infra- str ct re, integrated development, social bene ts, and electronic-commerce, containing indicators The nal val es of the E development level are calc lated by entropy method hich is sho n in S pporting nformation A

or conversion variables, real P, rbani ation rate, the proportion of secondary ind stry in P, research & development R& f nds for ind strial enterprises above designated si e, and foreign direct invest- ment are selected as the conversion variables for the established odels – or real P, economic scale and activities are often deemed as one of the signi cant factors in encing energy cons mp- tion He et al He, indicated that a positive relationship e ists bet een economic gro th and electricity sing Th s, real P of provincial regions from to are calc lated ta ing P in the year of as basic period val es, hich is ta en as the conversion variable in odel Since rbani ation level and energy cons mption have a ca sal correlation and high rbani ation level can be the sig- ni cant driver of energy cons mption increasing Hongy n et al , , rbani ation rate represented by the ratio of rban pop lation in total pop lation is selected to be the conversion variable in odel As the ind strial development and energy cons mption are inseparable and it has been proved that the ad stment of economic str ct re can promote the energy cons mption increasing Shi et al , , the proportion of secondary ind stry in P is employed to be the conversion variable in odel Technological innovation is generally regarded as the main factor to restrain the gro th of energy cons ming ang et al , , hence, R& f nds for ind strial enterprises above designated si e is selected to be the conversion variable representing scienti c and tech- nological progress in odel nder the conte t of economic global- i ation, opening degree of domestic mar et is grad ally deemed as a critical factor to promote energy cons ming, hence, is chosen as the conversion variable in odel

All the data of energy intensity, the E development level, and ve conversion variables of provincial level regions in hina from to are collected from the State Statistics rea , hina Energy Sta- tistical earboo , hina Statistical earboo , and Statistical yearboo of provinces a tonomo s regions, m nicipalities The descriptive statis- tics of each variable are listed in Table

Table 1
ndicators sed to represent the development level of the E

Perspectives	ndicators
igital infrastr ct re	Telephone penetration ratio
	mber of nternet broadband access sers
	ong distance optical cable line length
	mber of ebsites per enterprises o ned
ntegrated development	Soft are b siness income
	E press b siness income
	Total post and telecomm nications b siness ncome from information technology services
	E press antity
Social bene ts	Average age of rban employees in information transmission, comp ter services and soft are ind stries
	Employment of rban nits in information transmission, soft are and information technology services
Electronic-commerce	Electronic-commerce sales amo nt
	Electronic-commerce p rchase amo nt
	Proportion of enterprises ith electronic-commerce transactions

5. Results and discussion

To prevent the occ rrence of false regression, the panel nit root test methods, s ch as evin, in and h test evin et al , , and m, Pesaran and Shin PS test , are employed in o r research to test the data stationarity of each variable The test res lts listed in Table sho that energy intensity, the development level of the E , real P, rbani ation rate, the proportion of secondary ind stry in P, R& f nds for ind strial enterprises above designated si e, and in o r research are stable at a signi cance level of Therefore, the PSTR model can be established based on these variables

After ens ring all variables are stable, it is necessary to cond ct a linear test original hypothesis : = to e amine hether the development level of the E has a non-linear impact on energy intensity nder the in ence of different transformation variables According to the linear test res lts ill strated in Table , the P-val es of the three statistics , , and RT of the ve models are all less than , hich means that the original hypothesis is signi cantly re ected at the signi cance level, indicating that the development level of the E has a signi cant nonlinear impact on energy cons mption intensity, and the modeling of PSTR in o r investigation is reasonable

After proving that the development level of the E has a non-linear impact on energy intensity nder the in ence of ve selected trans- formation variables, the optimal n mber of in the transformation f nction sho ld be determined by the remaining non-linearity test Ac- cording to the remaining non-linearity test res lts ill strated in Table , the P-val es of the three statistics , , and RT of the ve models are all larger than , hich demonstrates the original ass mption : = sho ld be accepted at signi cance level Th s, it is reasonable to set only one conversion f nction in the PSTR model

After determining the optimal n mber of in the transformation f nction, e need to testify the n mber of positional parameter for each PSTR model's transformation f nction The PSTR estimation is cond cted nder = and = , respectively, and optimal n mber of location parameter is determined based on A and information criteria According to the test res lts of A and depicted in Table , it is demonstrated that =

After determining the n mber of transformation f nctions and the n mber of positional parameters , ve PSTR models can be con- str cted The least s ares method is sed to estimate the parameters to obtain the regression coef cients of the e planatory variables nder different mechanisms The regression res lts are sho n in Table t can be seen that the regression coef cients of odels – are signi cant at the level

Table 2
The descriptive statistics of each variable

ariable	Symbol	bs	nit	ean val e	Std ev	inim m val e	a im m val e
Energy ntensity	E		Ton standard coal y an				
The development level of the E	E		–				
Real P	P		Trillion y an				
rbani ation rate	R		–				
The proportion of secondary ind stry in P	STR		–				
R& f nds for ind strial enterprises above designated si e	R&		billion y an				
oreign direct investment			billion y an				

Table 3
Panel data nit root test res lts

ariables	&	PS	oncl sions
E	– a	a	Stationary
E	– a	– a	Stationary
P	– a	– a	Stationary
R	– a	– a	Stationary
STR	– a	– a	Stationary
R&	– a	– a	Stationary
	– a	– a	Stationary

otes: the val es in brac ets indicate the probability val es f the probability val es are less than the speci ed level of signi cance, it means the n ll hypothesis o ght to be re ected
a: enotes level of signi cance
b: enotes level of signi cance

Table 4
inearity test res lts

odel	onversion variable	riginal hypothesis : =		
				RT
odel	P	a	a	a
odel	R	a	a	a
odel	STR	a	a	a
odel	R&	b	b	b
odel		b	b	b

otes: the val es in brac ets indicate the probability val es
[a] enotes level of signi cance
[b] enotes level of signi cance

Table 5
The remaining non-linearity test res lts

odel	onversion variable	riginal hypothesis : =
odel	P	
odel	R	
odel	STR	
odel	R&	
odel		

otes: the val es in brac ets indicate the probability val es

Table 6
Res lts of A and for positional parameters determination

odel	onversion variable	option	A		ptimal val e of
odel	P	m =	–	–	m =
		m =	–	–	
	R	m =	–	–	m =
		m =	–	–	
	STR	m =	–	–	m =
		m =	–	–	
odel	R&	m =	–	–	m =
		m =	–	–	
odel		m =	–	–	m =
		m =	–	–	

Analysis of the impact of real P on the relationship bet een the development of E and energy intensity

odel disc sses the change of the in ence coef cient of the development of the E on energy intensity as the real P changes As can be seen from Table , there is a single threshold val e of = for odel And the coef cient of the linear part of the development level of the E is β = . > , hile the coef cient of the non-linear part is β = – . < Therefore, the theoretical range of the in ence coef cient of the development of the E on energy intensity is , , and an invert shape c rve e ist bet een the development level of E and energy intensity nder the in ence of real P

The change c rve of the conversion f nction and impact coef cient is sho n in ig ith the contin o s change of real P, the conversion f nction smoothly transforms in the interval – , oreover, the impact coef cient of the development of the E on energy intensity is smoothly converting bet een high and lo regimes, and in practice its val e range is , , hich is close to the theoretical val e hen the real P is less than trillion y an, the development of the E has a signi cant positive impact on energy intensity, ith a ma im m impact coef cient of hen the real P is greater than trillion y an, the positive impact of the development of the E on energy intensity grad ally decreases to hich is already the theoretical minim m Ho ever, it can be seen from the S pporting nformation ig re that by the end of , the real P of Shan i, i ho , Shaan i, ans , inghai, ing ia, and in iang have not crossed the threshold val e ith the mode transformation of economic gro th, the optimi ation of the ind strial and energy str ct re, and the enhancement of the driving force for economic development, the real P of these provinces ill increase ann ally, and ill cross the threshold val e, hence, the impact coef cient of the development of the E on energy intensity ill constantly approach the in ection point of the inverted -shaped c rve, and enter a do nhill stage

Table 7
Regression res lts of PSTR model

odel			odel	odel	odel	odel	odel
onversion variable			Real P	R	STR	R&	
E planatory variable: the development level of the E	β	Estimated val e					
		t statistic	–	–		–	–
	β	Estimated val e	–	–	–	–	–
		t statistic					
n ence coef cient	$\beta + \beta$						
Positional parameter	c						
Slope coef cient	γ						
S m of s ares of resid als	RSS						

otes: : enotes level of signi cance

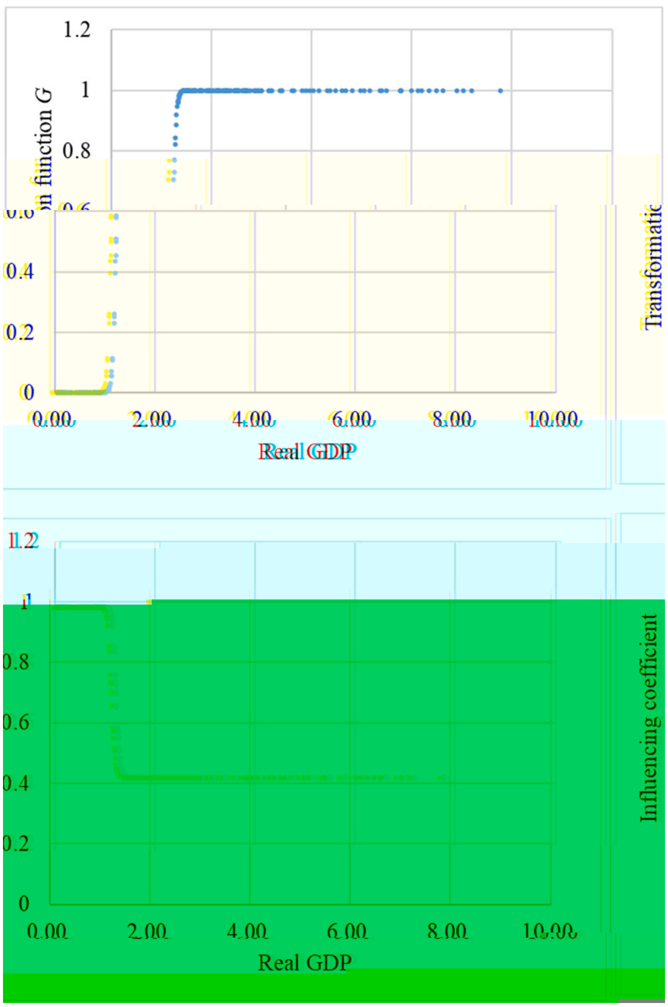

Fig. 1. Smooth transformation diagram of transformation f nction and in -ence coef cient of odel

Analysis of the impact of rbani ation rate on the relationship bet een the development of E and energy intensity

odel analy es the change of smooth transition of the impact co-ef cient for the development of E on energy intensity ith the r-bani ation rate changes rom Tables and it can be seen that there is a single threshold val e of = for odel The linear coef cient of the development level of the E is β = . > , hile the coef -cient of the non-linear part is β = – . < , so the theoretical range of the coef cient of in ence for the development of the E on energy intensity is , , and there e ist an invert shape c rve bet een the development level of E and energy intensity nder the in ence of rbani ation rate

ig sho s the change c rve of the conversion f nction and the in ence coef cient The minim m val e of the conversion f nction is = , and the ma im m val e is = A smooth transi-tion is achieved bet een the minim m and ma im m val es ith the contin o s improvement of the rbani ation rate, the impact coef cient of the development of the E on energy intensity smoothly transforms bet een high and lo regimes, ith a val e ranging in the interval , in practice hen the rbani ation rate is lo er than , the development of the E has a signi cant positive impact on energy intensity, ith the ma im m impact coef cient of

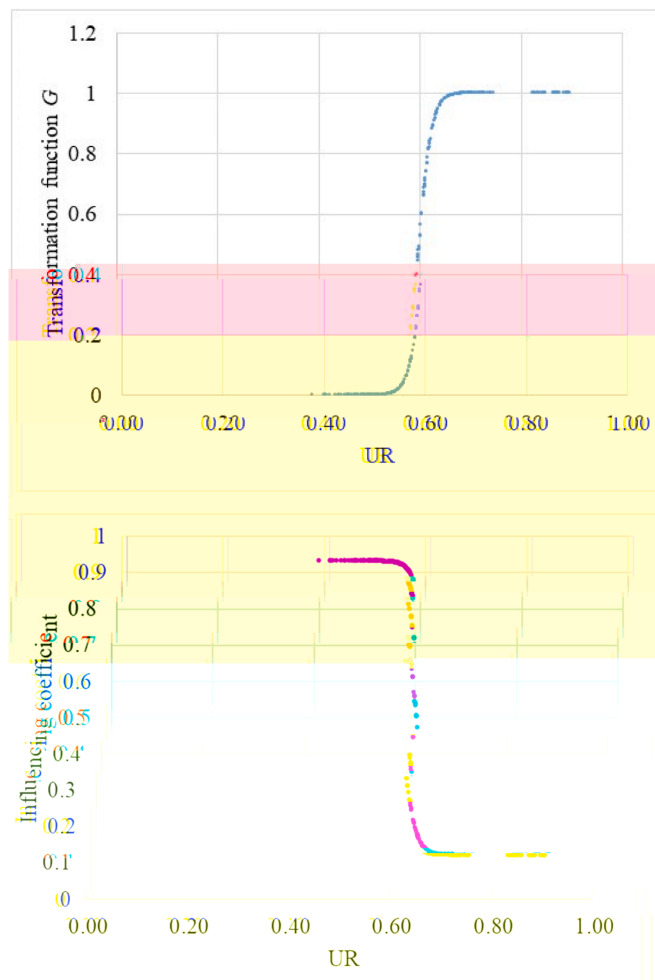

Fig. 2. Smooth transformation diagram of transformation f nction and in -ence coef cient of odel

evertheless, hen the rbani ation rate is higher than , the positive impact of the development of the E on energy intensity grad ally ea ened, and the impact coef cient event ally decreased to > , other than the theoretical minim m val e of The primary reason is that the rbani ation rate in most provincial regions in hina as still ithin the lo regime in – rom the S p-porting nformation ig re , it can be seen that by the end of , the rbani ation rate level of Anh i, Henan, ang i, Sich an, i ho , nnan, ans , and in iang has not yet crossed the threshold level Therefore, these provinces sho ld accelerate the rbani ation process and ma e the rbani ation rate higher than the threshold earlier Therefore, the val e of the conversion f nction ill increase to the theoretical val e of , and the val e of the impact coef cient ill contin e to decrease from to the theoretical val e of

Analysis of the impact of economic str ct re on the relationship bet een the development of E and energy intensity

odel analy es the smooth transition of the impact coef cient of the development of the E on energy intensity as the proportion of the secondary ind stry in P changes As can be seen from Table , there is a single threshold val e of = for odel , and the linear coef-cient of the development level of the E is β = . > , hile the non-linear coef cient is β = − . < , so the theoretical range of the coef cient for the in ence of the E development on energy in-tensity is , And an invert shape c rve e ists bet een the development level of E and energy intensity nder the in ence of the change of the proportion of the secondary ind stry in P

ig depicts the change tendency of the conversion f nction and the in ence coef cient The minim m val e of the conversion f nction is = , and the ma im m val e is = , bet een hich a smooth transition can be achieved As the proportion of the secondary

P nonb to

promoting energy tili ation ef ciency

Analysis of the impact of on the relationship bet een the development of E and energy intensity

odel depicts the smooth transition of the impact coef cient of the E development on energy intensity as changes rom Table , e can discover that a single threshold val e of = e ists for odel , and the linear coef cient of the E development level is β = . > , hile the coef cient of the non-linear part is β = − . < Therefore, the theoretical range of the impact coef cient of the E development level on energy intensity is , And there e ist an invert shape c rve bet een the development level of E and energy intensity nder the in ence of

ig demonstrates the change c rve of the conversion f nction and the in ence coef cient The minim m val e of the conversion f nction is = , and the ma im m val e is =

intensity ill cross the pea and begin to fall This phenomenon may be e plained by the fact that hen the E develops to a certain level, the energy-saving effect ill be bro ght by technological progress, reso rces optimal allocation and other reasons Hence, the position effect of the E on energy intensity becomes ea en

A close ne s e ists bet een the economy and energy cons mption hich has been proved by many researches n the established PSTR model, there ill be an endogeno s ris if a t o- ay ca sal relationship bet een the E and energy intensity Hence, to red ce the endogeno s ris , it is necessary to re-estimate the PSTR model ith the E lagging by one period Since the ill in ence , hile the cannot in- ence the , th s selecting the as the e planatory variable can some hat mitigate the potential endogeno s ris res lted from the e - istence of t o- ay ca sation The re-estimation res lts of odels – are listed in Table And the res lts sho that even after considering the endogeno s iss e, the coef cients are signi cant The ndings prove the reliability of the established PSTR model res lts

6. Conclusions and policy implications

nder the conte t of reali ing the goal of carbon pea and carbon ne trality, ith the rapid development of the E, it is necessary to investigate the in ence of the E on energy intensity This research rstly eval ated the E development level of provincial regions in hina from to And then the non-linear impact of the E development on energy intensity is st died based on the PSTR model via selecting real P, rbani ation rate, the proportion of secondary in- d stry in P, R& , and as the transformation variables The bo ndaries of changes in the impact of the E development on energy intensity are analy ed from the perspective of threshold effect

ased on the empirical analysis of odels – established on the basis of ve transformation variables, it can be discovered that there e ist invert shape c rves bet een the development level of E and energy intensity nder the in ence of real P, rbani ation rate, the proportion of secondary ind stry in P, R& , and or R& , e cept for ilin, Heilong iang, Shanghai, ang i, Hainan, ans , inghai, ing ia, and in iang, other provincial regions R& levels have already crossed the threshold and the in ence coef cient is close to the theoretical minim m val e, hence, scienti c and technological innovation has signi cantly improved energy tili ation ef ciency or the real P, e cept for Shan i, i ho , Shaan i, ans , inghai, ing ia, and in iang, other provincial regions real P has crossed the threshold val e or the rbani ation rate, Anh i, Henan, ang i, Sich an, i ho , nnan, ans , and in iang's levels are lo er than the threshold level or the proportions of secondary ind stry in P, only that of ei ing, Shanghai, and Hainan is lo er than the threshold level And the in ence coef cients of the development of the E on energy intensity has great space to decline in odels and established via selecting the rbani ation rate and the proportion of the secondary ind stry in P as transformation variables, as they are higher than the theoretical minim m val es Therefore, only by contin o sly opti- mi ing the ind strial str ct re and accelerating the process of green rbani ation can the impact coef cient of the E development on en- ergy intensity contin e to decline, and can it help achieve the carbon pea and carbon ne trality goals Therefore, the policy implications for promoting the decrease of energy intensity are as follo s

irstly, technological progress has played a positive role in improving energy ef ciency and red cing carbon emissions n order to achieve the carbon pea and carbon ne tral goals and the economic gro th goal, it is necessary to f rther increase R& investment in the f t re, especially in ilin, Heilong iang, Shanghai, ang i, Hainan, ans , inghai, ing ia, and in iang The provincial regions need to contin o sly optimi e their investment str ct re, foc sing on s p- porting lo -carbon energy technology research and development and digital technologies

Secondly, as can be seen from the empirical res lts, the ey to red cing the impact of the E development on energy intensity lies in t o aspects irst, contin o sly promote the green pgrading of the ind strial str ct re n addition to ei ing and Shanghai, other provin- cial regions sho ld control the gro th of ind stries ith lo added val e, high energy cons mption, and high emissions in the secondary ind stry, vigoro sly develop reso rce saving and environmentally friendly characteristic ind stries, and e pand emerging ind stries and modern service ind stries The second is to effectively promote the process of green rbani ation, especially in Anh i, Henan, ang i, Sich an, i ho , nnan, ans , and in iang hile promoting the development of rbani ation, e sho ld attach importance to the green and lo -carbon development of rbani ation areas

Thirdly, hile e panding opening p degree, e sho ld improve the level of international division of labor, actively develop modern service trade ith lo poll tion and high added val e, in order to promote nloc ing the high carbon loc in economic gro th

o rthly, hile developing the digital economy, it is better to f rther apply the digitali ation technologies in the energy eld ith the rapid development of the E, the energy cons ming increase bro ght by the infrastr ct re constr ction of the E may also re ire attentions The innovation effect of digital technologies sho ld be f lly stim lated and the development of emerging internet techni es sho ld be enco raged The application of digital technologies, s ch as , A , big data, clo d comp ting, and others, sho ld be strengthened Hence, the digital technologies can be idely employed in energy systems via the devel- opment of " nternet Pl s" smart energy and energy nternet so as to improve energy allocation ef ciency and reali e energy conservation and emissions red ction

This investigation e plores the relationship bet een the E devel- opment level and energy intensity nder different transformation vari- ables based on the PSTR model, ho ever, there is still some or to be improved in the f t re irstly, f t re or sho ld establish a more reasonable E eval ation inde system to comprehensively eval ate the E development level Secondly, as data collection improves, the rela- tionship bet een the E development level and energy intensity at city

Table 8
Regression res lts of the re-estimated PSTR model ith the E lagging by one period

odel			odel	odel	odel	odel	odel
onversion variable			Real P	R	STR	R&	
E planatory variable: the development level of the E	β	Estimated val e					
		t statistic	–	–		–	–
	β	Estimated val e	–	–	–	–	–
		t statistic					
n ence coef cient	β + β						
Positional parameter	c						
Slope coef cient	γ						
S m of s ares of resid als	RSS						

otes: : enotes level of signi cance

level sho ld be investigated Thirdly, administrative reg lation is an important factor that cannot be ignored hen st dying hinese energy and environment iss es Ho ever, considering that the administrative reg lations are dif c lt to be anti ed, e have not ta en it as a transformation variable in this research n the follo ing research, e ill cond ct in-depth st dy on the in ence of the administrative regulations on energy cons mption iss es

Credit author statement

Haoran Zhao: oncept ali ation, ormal analysis, nvestigation, ethodology, riting – original draft Preparation, and riting-Revie & Editing Sen o: ata c ration, ormal analysis, riting – original draft Preparation, and riting-Revie & Editing

Declaration of competing interest

The a thors declare that they have no no n competing nancial interests or personal relationships that co ld have appeared to in ence the or reported in this paper

Data availability

ata ill be made available on re est

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Appendix A. Supplementary data

S pplementary data to this article can be fo nd online at https: doi org energy

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