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Original Research

Research on Energy Saving and Rebound Effects of Technological Progress from the Perspective of Regime Switch

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Abstract

Technological progress has been considered as the essential backbone of reducing energy consumption and achieving low-carbon transmission. It is universally accepted that the technological level and energy structure change with time, indicating a significant characteristic of regime switching. From the perspective of regime switching, this paper considers the saving and rebound effect of technological progress and uses MSIH-VAR model to empirically analyze energy consumption changes in Zhejiang Province from 1990 to 2019. The results show that technological progress restricts the growth of energy consumption. Specifically, in the whole period, the variables show significant characteristics of double regimes, whose attributes are different. Moreover, the boundary between regimes is clear, and the state is stable. Technological progress in regime 1 positively promotes the increase of energy consumption, while in regime 2 decreases energy consumption. The saving effect is stage or lag under different regimes.

Keywords: energy consumption, technological progress, rebound effect, saving effect, regime switch

Introduction

Technological progress has always been regarded as an important means to effectively reduce energy consumption and achieve efficient and green development [1-4]. From the dynamic relationship between technology and energy consumption, the current studies show that there is a dynamic nonlinear relationship between technology and energy consumption. Through the Complete Decomposition Model and decomposition of the driving effect of the decoupling of energy consumption in the three industries in the Beijing-Tianjin-Hebei region, Wu and Ji constructed an evaluation model for the decoupling of economic development and energy consumption under dual control action. The results showed that during the "13th Five-Year Plan", the structural adjustment effect of the energy consumption of the primary industry and the structural adjustment effect of the energy consumption of the secondary industry in the Beijing-Tianjin-Hebei region has played a significant role [5]. Hussain Jamal et al. applied the systematic generalized moment method to examine the impact of globalization, industrialization, urbanization and financial development on energy demand and

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environmental quality, respectively. The results reveal that globalization, financial development, industrialization, urbanization, and economic growth significantly increase the energy demand over the sample period [6]. Meng et al. adopted a hybrid structural decomposition analysis to explore drivers of energy consumption and regional disparities. The results show that there are differences in energy consumption among regions and different sectors. The positive effect of energy consumption caused by income growth is more significant in cities [7]. Han et al. applied the quantile regression technique to explore the impact of trade openness and urbanization effect on renewable and non-renewable energy consumption in China. The results show that trade significantly increases the non-renewable energy consumption. Meanwhile, urbanization does not affect renewable energy consumption as in almost all quantiles the coefficients are statistically insignificant [8]. Zhang et al. employed the super-efficiency Slack-Based Measure model (super-efficiency SBM model) to measure the energy efficiency of 30 provinces in China and used the Geographically and Temporally Weighted Regression (GTWR) to analyze the spatial-temporal heterogeneity of its driving factors. They found that the technical level, energy consumption structure and economic development level have significant spatial heterogeneity [9].

To sum up, most existing studies focus on the correlation between industrial structure, energy consumption and economic growth, urbanization development level, regional development, trade liberalization, industrialization process and other factors [34,10-13], while ignoring the impact of technological progress on energy consumption. Compared with previous studies, the marginal contributions of this study can be summarized as the following three aspects. First, from the perspective of technological progress, this paper explores the impact of technological progress on energy consumption. Second, considering the impact of energy policies and economic development on energy consumption in different periods, this paper introduces the concept of regime system to further explore the impact of technological progress within non-regime system [14-15]. Lastly, due to the saving effect and rebound effect caused by technological progress, this paper further investigates the mechanism of the impact of technological progress on energy consumption.

The remainder of this article is organized as follows. Section 2 briefly reviews the relevant literature, presents the model theory and hypothesis, and introduces the structure of Markov autoregressive model, while the empirical results and validity analysis are introduced in Section 3. Finally, this paper summarizes the empirical results.

Materials and Methods

Theoretical Background and Hypothesis

From the perspective of regime switch characteristics of technology and energy consumption, it can be divided into two cases: obvious regime switch characteristics and no regime switch characteristics. When variables have significant regime switch characteristics, the conversion probability, volatility, and impact relationship of samples in different regions are different [16-19]. Most of the existing studies investigate the relationship between technological progress and energy consumption growth under the single regime. Liu et al. defined the energy efficiency rebound effect of the coal industry and compared the rebound effect coefficient at the coal industry level and the enterprise level. This study found that energy intensity at the macro and micro levels has been downward, but with a rebound effect [20]. Zhang et al. conducted an empirical analysis using spatial econometric methods and geographically and temporally weighted regression, indicating that energy “growth drag” effect has positive direct effect and spillover effect [21]. Chandio et al. used the autoregressive distributed lag (ARDL) bounds testing approach to cointegration to investigate the long-run and short-run determinants of agricultural economic growth in Pakistan. The results of the ARDL bounds testing approach to cointegration revealed that long-run linkage exists among the study variables [22].

In short, this paper formulates hypothesis 1 as follows:

H1: There exist significant regime switch characteristics in the sample space.

From the perspective of the saving and rebound effect of technology on energy consumption, it is generally believed that technological progress contributes to the improvement of energy use efficiency, thus reducing the total amount of energy consumption [23-24]. Jevons, an economist, put forward the contrary argument that in the long run, technological progress would lead to the improvement of energy use efficiency, and the increase in energy consumption caused by the increase in demand would be greater than the decrease in energy consumption caused by the improvement in energy efficiency, leading to the increase in total energy consumption [25]. Most of the existing studies only investigate the inhibition or promotion effect of technology on energy consumption from a single direction, ignoring the positive and negative effects of technological progress on energy consumption. Kulmer and Seebauer analyzed the rebound effect of energy from the perspective of consumer preference and sensitivity to elasticity and found that economy-wide rebound effect is less sensitive to model specification than direct rebound [26]. Nässén and Holmberg built an input-output model based on the Swedish Household Budget Survey to analyze how different parameter assumptions affect the quantification of rebound effect and the possible reasonable range. The results demonstrated that the total rebound effects of energy efficiency improvements appear to be in the range 5-15% in most cases [27]. Binswanger started with the traditional neoclassical analysis of the rebound effect in a partial equilibrium framework that concentrates on the demand of one energy service such as mobility or room temperature. The results indicated that the overall effect of an increase in energy efficiency on total energy use depends on the on the assumptions about the substitutability between the services considered and the direction of the income effect [28]. Wei et al. applied the LMDI decomposition analysis to investigate the factors affecting coal consumption in these industries and confirmed that there exists a coal rebound effect in energy intensive industries [29].

To sum up, existing studies focus on the nonlinear relationship between technological progress and energy consumption under a single regime. From the perspective of regime switch, there are few comprehensive analyses that combine the saving effect and rebound effect, and few studies adopt different lag orders for different variables. In summary, this paper formulates hypothesis 2, 3, and 4 as follows:

H2: There exist positive saving effect and negative rebound effect of technological progress on energy consumption.

H3: The effect of saving effect and rebound effect caused by technological progress varies in different regimes.

H4: The effect of saving effect caused by technological progress is greater than its rebound effect in the sample space.

To bridge the gap in the existing literature, this paper calculates the technological progress rate of Zhejiang Province from 1990 to 2019 and selects the appropriate MS(M)-VAR(P) model according to AIC and SC criteria. Furthermore, we identify the nonlinear relationship between variables and the attributes of regime based on the estimation results. Finally, the impulse response is applied to simulate the change trend of technological progress and energy consumption when an economy is hit, as well as the change of saving effect and rebound effect caused by technological progress when the sample system is transferred.

Materials and Methods

Reduced form vector autoregressive (VAR) models, established by Sims, have been widely applied in empirical macroeconomics. Markov-switching vector autoregressions can be considered as generalizations of the basic finite order VAR model of order p. [30-31] Consider the p-th order autoregression for the K-dimensional time series vector $y_t = (y_{1t}, \ldots y_{kt})'$ t = 1, …., T.

$$y_t = v + A_1 y_{t-1} + \ldots + A_p y_{t-p} + \mu_t \quad (1)$$

where $u_t \sim IID\ (0,\Sigma)$ and $y_0, \ldots y_{1-p}$ are fixed. Denoting $A(L) = I_k - A_1 L_1 - \ldots - A_p L_p$ as the (K*K) dimensional lag polynomial. We assume that there are no roots on or inside the unit circle $|A(z)| \neq 0$ for $|z| \leq$. where L is the lag operator, so that $y_{t-j} = L^j y_t$. If a normal distribution of the error is assumed, $u_t \sim NID\ (0, \sum)$, Equation (1) is known as the intercept form of a stable Gaussian VAR(p) model. This can be reparametrized as the mean adjusted form of a VAR model:

$$y_t - \mu = A_1 (y_{t-1} - \mu) + \ldots + A_p (y_{t-p} - \mu) + \mu_t \quad (2)$$

where $\mu = (I_k - \sum_{j=1}^{p} A_j)^{-1} v$ is the (K*1) dimensional mean of y_t.

If the time series are subject to shifts in regime, the stable VAR model with its time invariant parameters may be inappropriate. Then, the MS–VAR model may be considered as a general regime-switching framework [32-33]. The general idea behind this class of models is that the parameters of the underlying data generating process of the observed time series vector y_t depend upon the unobservable regime variable s_t, which represents the probability of being in a different state of the sample space. The special characteristic of the Markov-switching model is the assumption that the unobservable realization of the regime $s_t \in \{1, \ldots, M\}$ is governed by a discrete time, discrete state Markov stochastic process, which is defined by the transition probabilities. Here is the formula:

$$p_{ij} = Pr(s_{t+1} = j | s_t = i), \sum_{j=1}^{M} p_{ij} = 1 \quad \forall i, j \in \{1, \ldots, M\} \quad (3)$$

More precisely, it is assumed that s_t follows an irreducible ergodic M state Markov process with the transition matrix. The matrix can be expressed as follows:

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1M} \\ p_{21} & p_{22} & \cdots & p_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ p_{i1} & p_{i2} & \ldots & p_{iM} \end{bmatrix}$$

where $p_{iM} = 1 - p_{i1} - \ldots - p_{iM-1}$, i = 1, ..., M.

In generalization of the mean-adjusted VAR(p) model, we consider Markov-switching vector autoregressions of order p and M regimes:

$$\begin{aligned} y_t - \mu(s_t) = A_1(s_t)(y_{t-1} - \mu(s_{t-1})) + \ldots \\ + A_p(s_t)(y_{t-p} - \mu(s_{t-p})) + \mu_t \end{aligned} \quad (4)$$

where $u_t \sim NID\ (0, \sum(s_t))$ and $\mu(s_t)$, $A_1(s_t)$, ..., $A_p(s_t)$, $\sum(s_t)$ are parameter shift functions describing the dependence of the parameters μ, A_1, ..., A_p, $\sum$ on the realized regime s_t, e.g.

$$\mu(s_t) = \begin{cases} \mu_1 & if\ s_t = 1, \\ \vdots \\ \mu_M & if\ s_t = M, \end{cases}$$

In Model 4, there is after a change in the regime an immediate one–time jump in the process mean. Occasionally, it may be more plausible to assume that the mean smoothly approaches a new level after the transition from one state to another. In such a situation the following model with a regime-dependent intercept term $v(s_t)$ may be used:

$$y_t = v(s_t) + A_1(s_t)y_{t-1} + \ldots + A_p(s_t)y_{t-p} + \mu_t \tag{5}$$

In the most general specification of an MS-VAR model, all parameters of the autoregression are conditioned on the state s_t of the Markov chain such that each regime m VAR (p)parameterization v(m) (or μ_m), $\sum_m$, A_{1m}, ..., A_{jm}, m = 1, …, M, such that

$$y_t = \begin{cases} v_1 + A_{11}y_{t-1} + \ldots + A_{p1}y_{t-p} + \Sigma_1^{1/2}\mu_t, & if\ s_t = 1 \\ v_M + A_{1M}y_{t-1} + \ldots + A_{pM}y_{t-p} + \Sigma_M^{1/2}\mu_t, & if\ s_t = M \end{cases}$$

where μ_t~NID (0, I_K).

However, for empirical applications, it may be more helpful to employ a model where only some parameters are conditioned on the state of the Markov chain, while the other parameters are regime invariant. Particular MS-VAR models can be introduced where the autoregressive parameters, the mean, or the intercepts, are regime-dependent and where the error term is hetero- or homoscedastic [31].

The MS-VAR model allows for a great variety of specifications. To establish a unique notation for each model, we specify with the general MS(M) term the regime-dependent parameters:

M Markov-switching mean,
I Markov-switching intercept term,
A Markov-switching autoregressive parameters,
H Markov-switching heteroskedasticity.

To sum up, MSIH(M)-VAR(P) is selected as the proper model in this paper. The autoregressive parameters don't transform with the switch of regime, but the intercept transform with the switch of regime. Meanwhile the error term has significant heteroscedastic property.

Results and Discussion

Model Parameter Extraction

Oxmetric software was applied to perform MSIH(M)-VAR(P) model, and the AIC and SC statistics of the model were calculated when the number of blocks M was 2 and the variable lag order P was 3-4.

Table 1. Markov-Switching Vector Autoregressive Models.

Model	AIC	SC
MSIH(2)-VAR (3)	-7.6358	-6.6759
MSIH(2)-VAR (4)	-7.1588	-6.0645
MSIH(2)-VAR (3)	-7.6128	-6.5569
MSIH(2)-VAR (4)	-6.7646	-5.5709

According to AIC and SC criteria, when M = 2 and p = 3, the AIC and SC of the model are the smallest, so the MSIH (2)-VAR (3) model is the most appropriate. The regime of the model is dual regime, the lag order of energy consumption growth rate is 1 period, and the lag order of technology progress rate is 3 periods.

Dynamic Result Analysis of Technological Progress and Energy Consumption Growth

According to Table 2, the LR statistic is 18.334, indicating that the model has significant nonlinear characteristics at the significance level of 5%. The results show that the MSIH (2)-VAR (3) model is superior to the traditional VAR model in exploring the impact of technological progress on energy consumption, thus, H1 is confirmed.

The intercepts of EC and TFP in regime 1 are 0.4166 and 1.0405, respectively, and those of EC and TFP in regime 2 are 0.4659 and 1.0455, respectively. The intercepts of EC and TFP in regime 2, notably, are larger than those in regime 1. Therefore, regime 1 is regarded as a slow growth regime and regime 2 as a fast growth regime.

The standard deviation of EC in regime 1 is 0.0197, which is larger than the standard deviation (Se) of EC in regime 2. The uncertainty and volatility of energy consumption in the fast-growing regimes are relatively small, while those of energy consumption in the slow-growing regimes are relatively large, which is different from the development status of most provinces. In fact, Zhejiang province is a big energy consumption province but a small energy province. For a long time, energy shortage has been restricting the optimization development of energy structure in Zhejiang. Therefore, in the slow-growth regime, energy is restricted by supply, and the uncertainty and volatility of energy consumption are greater. As the Zhejiang government vigorously has developed new clean and renewable energy and optimized the energy supply structure, the shortage of energy supply is alleviated, and more stable energy supply is available. The energy demand expands at this stage. Therefore, in the rapid development regime, the uncertainty and volatility of energy consumption growth are relatively small. By comparing the standard deviation of TFP in different regimes, the fluctuation of technological progress in the slow growth regime is smaller than that in the fast growth regime, that is, the

Table 2. MSIH(2)-VAR (3) estimation results.

	EC	TFP
Const (Reg.1)	0.4166 (0.1411)	1.0405 (0.2379)
Const (Reg.2)	0.4659 (0.1444)	1.0455 (0.2470)
EC-1	0.4418 (0.0990)	0.1458 (0.1680)
TFP-1	-0.1558 (0.0756)	0.1977 (0.1438)
TFP-2	-0.1527 (0.1018)	-0.3121 (0.1758)
TFP-3	-0.0753 (0.0218)	0.0955 (0.0366)
Se (Reg.1)	0.0197	0.0340
Se (Reg.2)	0.0143	0.0415
log-likelihood	123.0826	
LR linearity test:	18.3340	Chi (5) = [0.0026]** Chi(7) = [0.0106] *

Note:**, * are at the significance level of 5% and 10% respectively, and the standard deviation is indicated in parentheses

reaction of technological progress is “inactive” in the slow growth stage, while the volatility and uncertainty are greater in the fast growth stage, and technological progress is more “active”.

From the perspective of the influence factors of EC dynamic equation, the correlation coefficient of EC lag order 1 (EC-1) is 0.4418, greater than 0, indicating that the growth of energy consumption in the previous period has a positive promoting effect on the growth of energy consumption in the later period. In other words, the increase of energy consumption in the earlier period will aggravate the growth of energy consumption in the later period. However, the correlation coefficients between the third-order lag of technological progress rate and EC are all negative, indicating that technological progress has a negative inhibitory effect on the growth of energy consumption in the whole sample space, that is, technological progress will inhibit the growth of energy consumption.

In summary, there is a significant nonlinear relationship between energy consumption and technological progress. In the whole sample period, there are apparent features of regime switching. Regime 1 is a slow development regime, in which the growth of energy consumption is “active”, and the reaction of technological progress is “inactive”. Additionally, regime 2 is a rapid development regime, in which the technological progress is “active”, and the energy consumption growth reaction is “inactive”. The EC dynamic equation shows that the growth of energy consumption in the former stage promotes the growth of energy consumption in the later stage, while the technological progress inhibits the growth of energy consumption.

Analysis of Attribute Characteristics of Regime Switching

According to the above estimation results, the technological progress has different effects on energy consumption growth in different regimes. Technological progress improves energy efficiency and reduces the demand for energy. This reduction in energy consumption caused by technological progress is called the saving effect of technology. According to Jevons Paradox, technological progress leads to the improvement of energy use efficiency, and people’s demand for energy will increase. The growth of total energy consumption due to technological progress is called the rebound effect of technology on energy. In human production and life, whether technological progress can promote or inhibit the growth of energy consumption should be compared with the absolute value of the saving effect and rebound effect. If the saving effect is greater than the rebound effect, technological progress will inhibit the growth of energy consumption; on the contrary, if the saving effect is less than the rebound effect, technological progress will promote the growth of energy consumption.

Table 3 shows the correlation coefficient between energy consumption and technological progress in different regimes. In regime 1, the correlation coefficient between energy consumption growth and technological progress is 0.6717, which is positively correlated. Consequently, the rebound effect is greater than the saving effect, that is, technological progress will lead to the growth of energy consumption, and technological progress will promote the growth of energy consumption. In regime 2, however, the

Table 3. Correlation coefficient between energy consumption growth and technological progress in regime 1 and 2.

Regime	Variable	Energy consumption	Technological progress
Regime 1	Energy consumption	1.0000	0.6717
	Technological progress	0.6717	1.0000
Regime 2	Energy consumption	1.0000	-0.5733
	Technological progress	-0.5733	1.0000

correlation coefficient is -0.5733, which is negatively correlated. In other words, the rebound effect is smaller than the saving effect, and technological progress will inhibit the growth of energy consumption. In summary, during the slow growth period, technological progress promotes the growth of energy consumption. But, during periods of rapid growth, technological progress restrains energy consumption growth. The findings confirm our H2.

The effect of technological progress on energy consumption growth is different in two regimes. In consequence, it is essential to figure out the division between the two regimes and stability of the regimes' state. To cope with these problems, this paper further studies the attribute of interval.

Fig. 1 shows the probability of falling within regime 1 and regime 2 in different years, and the boundary between the two regimes is clear. From 1993 to 2000 and from 2009 to 2019, the energy consumption was obviously in the regime 1, and the energy consumption was in the slow growth stage. Since China's accession to the WTO in 2000, Zhejiang Province, as a coastal open province, has actively responded to the national policies and vigorously developed economic and foreign trade, increasing the growth rate of energy consumption. And the energy consumption growth was shifted from regime 1 to regime 2. From 2001 to 2008, the growth of energy consumption was in the regime 2, and the growth of energy consumption was in the stage of rapid development. In 2007, Zhejiang Province took energy saving and consumption reduction as an important breakthrough to transform the development model, adjusted the economic structure, and paid close attention to the implementation of various measures. In 2009, the growth of energy consumption switched from regime 2 to regime 1.

As shown in Table 4, the probability of sample not being switched in regime 1 is 94.47%, and the probability of sample being switched from regime 1 to regime 2 is 5.53%. The probability of no switch is 85.32%, and the probability of transfer from regime 2 to regime 1 was 14.68%. In conclusion, the conversion probability of the regime is not high, and it is very likely to keep the original regime, and the state of the regime is relatively stable.

The number of samples in regime 1 and regime 2 are 19.0 and 8.0, and the frequency is 72.63% and 27.37%, respectively. The duration in regime 1 is 18.08 and that in regime 2 is 6.81. The sample size, probability, and mean duration in regime 1 are all greater than those in regime 2. It indicates that the technological progress and energy consumption of Zhejiang province are more likely to be within regime 1, that is, it is easier to form a balance of high technology and low energy consumption or low technology and high energy consumption, and the sustained period is about 18 years.

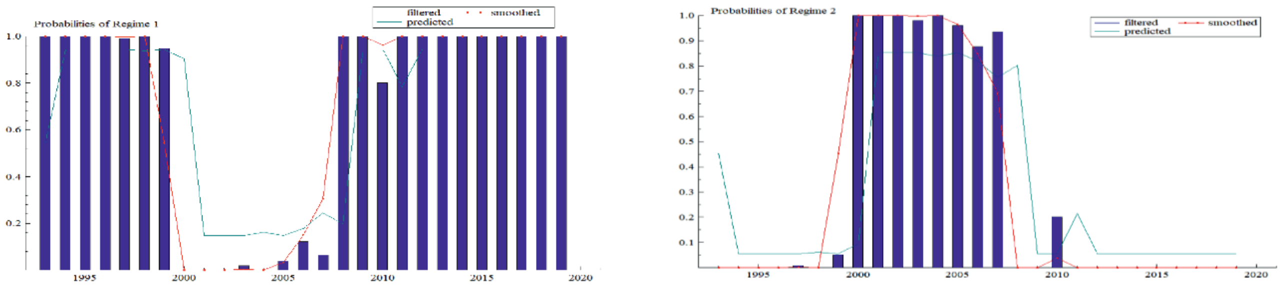

Fig. 1. Partition smooth probability.

Table 4. Technology progress and energy consumption zone transition probability matrix and attribute matrix.

	Regime1	Regime 2	The number of samples	Frequency	Duration
Regime 1	0.9447	0.0553	19.0	0.7263	18.08
Regime 2	0.1468	0.8532	8.0	0.2737	6.81

The above studies further prove H2 and explore the probability and duration of regime transition of variables.

In summary, the period 1990-2019 can be divided into two regimes, which have obvious time domain division and significant characteristics of regime attributes. In regime 1, energy and technology grow slowly, and technology progress is positively correlated with energy consumption. However, in regime 2, energy and technology increase rapidly, and technological progress is negatively correlated with energy consumption. In addition, the probability of energy consumption and technological progress maintaining in regime 1 is greater, and variables will not be easily transferred between the two regimes.

Impulse Response Analysis of Regime Switch and Model Validity Analysis

To further investigate the relative size of the saving effect and rebound effect brought by technological progress, this paper employed the impulse response of regime switch to analyze the relative changes of these two effects. As shown in Figure 2, the abscissa represents the lag period of technological progress and the growth rate of energy consumption aftershocks to the economic system, and the ordinate represents the response degree of technological progress and the growth rate of energy consumption to shocks when shocks are given to the economic system.

When technological progress and energy consumption growth are in the process of regime 1 or switch from regime 2 to regime 1, the economic system will be impacted, and the rate of technological progress and the rate of energy consumption growth will decrease first, but the impact of the latter impact is greater. Moreover, when technological progress and energy consumption are within the regime 2 system or from the regime 1 to regime 2, the economic system will be impacted, and the rate of technological progress and the growth rate of energy consumption will rise first, but the impact of the latter impact is greater.

In regime 1, when the economic system is impacted, energy consumption will first have a downward trend, and when the lag period is 1, it will fall to the lowest point, and then rebound, and eventually it will be higher than the original growth level. Furthermore, in the long run, the rebound effect is greater than the saving effect. Given the impact on the economic system, the saving effect will lead to a decrease in energy consumption in a short period of time, but after a period, the rebound effect will dominate energy consumption, that is, the saving effect has a certain stage.

In regime 2, energy consumption tends to increase first when the economic system is impacted. When the lag is 1 period, it will rise to the highest point, and then it will decline, and eventually it will be lower than the original growth level. Moreover, in the long run, the rebound effect is smaller than the saving effect, which has an impact on the economic system. In a short period, the rebound effect will lead to the rise of energy consumption first, but after a period, the saving effect will dominate the energy consumption, that is, the saving effect has a certain lag. The above results confirm H3 and explore the influencing mechanism

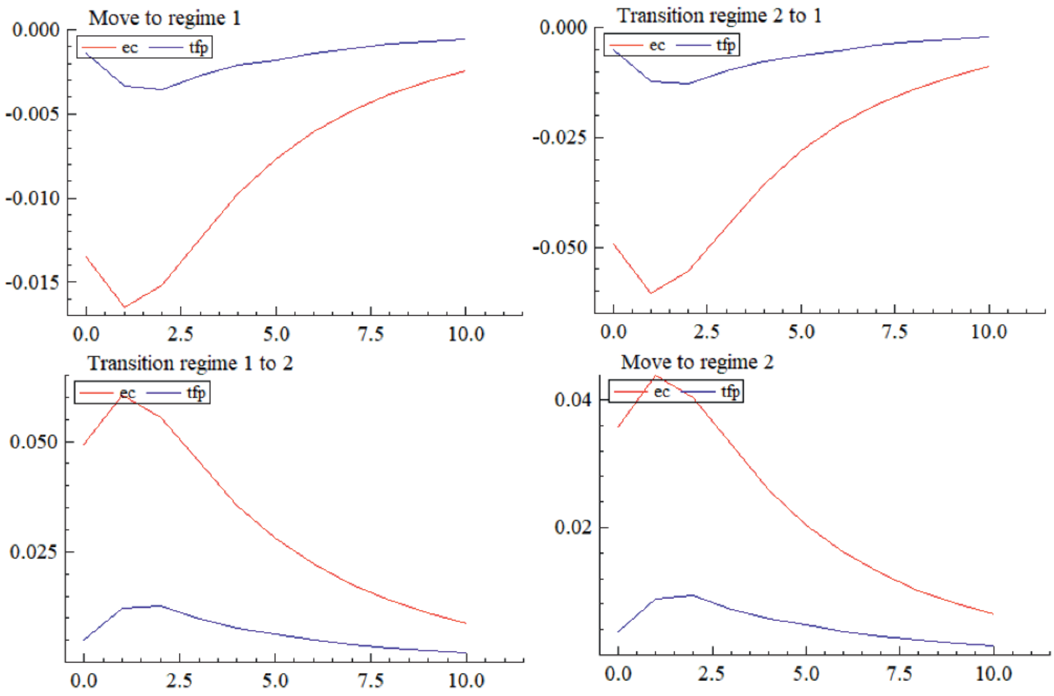

Fig. 2. Impulse response in different regimes.

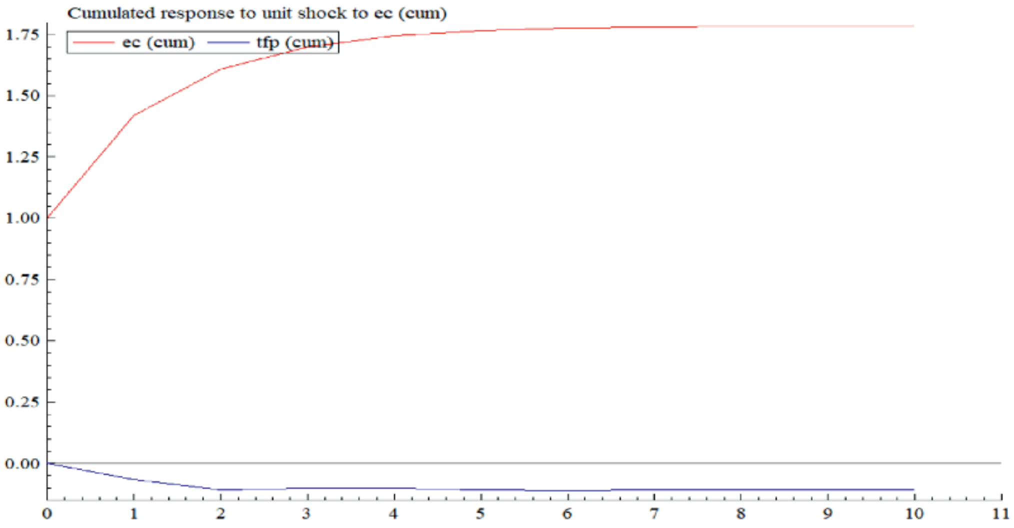

Fig. 3. Energy consumption growth rate accumulates pulse.

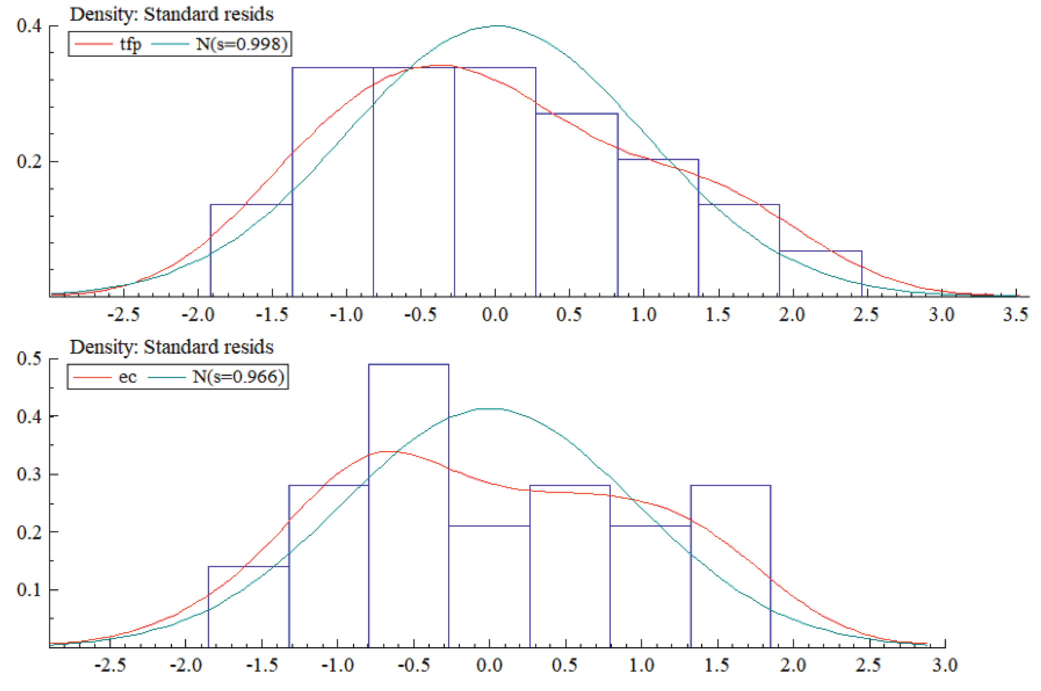

Fig. 4. Dynamic and standardized residual distribution.

of the saving effect and rebound effect caused by technological progress in different regimes.

In view of the unique characteristics of the conservation effect under different regimes, relevant government departments should consider the characteristics of the regime in the current year and pay attention to the phase or lag of the conservation effect when making energy policies.

The third-order correlation coefficients of TFP in EC dynamic equation are all negative, illustrating that the growth rate of energy consumption is negatively correlated with technological progress. Hence, the saving effect brought by technological progress will reduce the growth rate of energy consumption. To further observe the dynamic relationship between technological progress and energy consumption in the whole period, the cumulative impulse function is drawn. As pictured in Figure 3, there is a significant negative correlation between energy consumption growth and technological progress. In other words, in the whole period, the saving effect caused by technological progress is greater than the rebound effect, and technological progress will inhibit the rapid growth of energy consumption, thus, H4 is verified.

Furthermore, we apply residual distribution diagram to conduct model validity analysis. As shown in Figure

4, the residual conforms to the normal assumption, so the MSIH (2)-VAR (3) model is effective in estimating the nexus between the technological progress and energy consumption in Zhejiang province.

Conclusions

From the perspective of regime switch, this paper studies the saving effect and rebound effect of technological progress on energy consumption. The MSIH (2)-VAR (3) model is applied to empirically investigate the relationship between technological progress and energy consumption in Zhejiang province from 1990 to 2019. The conclusions are as follows.

Firstly, technological progress restrains energy consumption growth throughout the whole sample period. The growth of energy consumption is constrained by inertia. The growth of energy consumption in the former stage has a significant promoting effect on the growth of energy consumption in the latter stage. The influence of technological progress on energy consumption is reflected in the relative size of saving effect and rebound effect. In general, the saving effect of technology is greater than the rebound effect, and technological progress effectively restricts the growth of energy consumption.

Secondly, there are notable characteristics of regime switch between technological progress and energy consumption growth. The specific performance is that the whole period is divided into two regimes, and the boundary is obvious. The slow growth regimes are from 1990 to 2000, and from 2009 to 2019, respectively. And the fast growth regime is from 2001 to 2008. Different from existing studies, energy consumption in Zhejiang Province has a large fluctuation in the slow-growth regime, and a relatively small fluctuation in the fast-growth regime.

Thirdly, the influence of technological progress on energy consumption growth in different regimes is not consistent. In the slow growth stage, the growth of energy consumption first decreases and then increases. The rebound effect caused by technological progress is dominant, and the saving effect of technological progress has a certain stage. In this regime, technological progress is positively correlated with energy consumption, and technological progress promotes the growth of energy consumption. While, in the rapid growth regime, the growth of energy consumption increases first and then decreases. In the long run, the saving effect takes the dominant position, and the saving effect has a certain lag. In this regime, technological progress is negatively correlated with energy consumption, and technological progress restricts the growth of energy consumption.

There are some limitations in this paper, so we provide some directions for future research. Firstly, this study empirically investigated the relationship between technological progress and energy consumption in Zhejiang Province. However, if the differences among different cities can be further studied, richer results will be obtained. Secondly, if data is available, researchers can further study the impact of technological progress on energy consumption in different industries and compare their differences. Lastly, the direct impact of policy orientation on technological progress and energy consumption can be further explored in future research.

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Conflicts of interest

The authors have no relevant financial or nonfinancial interests to disclose.

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