



Multi-scale decomposition of energy-related industrial carbon emission by an extended logarithmic mean Divisia index: a case study of Jiangxi, China

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Abstract Our objective has been to decompose the energy-related industrial carbon emissions (ERICE) from both the macroeconomic and the microeconomic scales using an extended logarithmic mean Divisia index (LMDI), which few scientists have applied, for

Jiangxi, China, over the period of 1998–2015. The macroeconomic factors were output, industrial structure, energy intensity, and energy structure. The microeconomic factors were investment intensity, R&D intensity, and R&D efficiency. It was found that output, R&D intensity, and investment intensity were mainly responsible for the increase of the ERICE, and their average annual contribution rates were 33.212%, 9.537%, and 4.200%, respectively. However, considering the infeasibility of decelerating industrial activities related to these three drivers, the development pattern of a circular economy was promoted. Then, the driving effect of the energy structure was the weakest (0.017%). Nevertheless, the potential of energy structure optimization to improve energy efficiency in Jiangxi should be given sufficient attention, e.g., greatly reducing the use of coal. Inversely, the R&D efficiency, energy intensity, and industrial structure presented obvious mitigating effects on the ERICE (−13.737%, −11.652%, and −7.804%, respectively). Therefore, some regulatory policy instruments have been recommended. For example, carbon reduction liability and carbon labels related to R&D investment should be implemented to encourage industrial firms to improve their energy efficiency. Then, reducing the energy intensity unceasingly while inhibiting the possible rebound effect should serve as a long-term strategy for the local government. Last, the potential mitigation effect of industrial structure optimization should be given sufficient attention when designing related reduction policies. Particularly, the top five energy-intensive subsectors S33 (Production and

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Supply of Electric Power and Heat Power), S23 (Smelting and Pressing of Ferrous Metals), S17 (Processing of Petroleum, Coking, and Processing of Nuclear Fuel), S22 (Manufacture of Non-metallic Mineral Products), and S1 (Mining and Washing of Coal) should be given priority.

Keywords Energy-related industrial carbon emissions (ERICE) · Energy efficiency · Logarithmic mean Divisia index (LMDI) · Multi-scales · Drivers · Macroeconomic · Microeconomic · Jiangxi Province

Introduction

According to the Intergovernmental Panel on Climate Change (IPCC), most of the global average surface temperature rise since the 1950s may be caused by human activities (IPCC 2013; Qu et al. 2016). The reason is that human activities can create a large amount of greenhouse gases (GHGs) through the burning of fossil fuels such as coal, oil, and natural gas (IPCC 2006; Specht et al. 2016). Therefore, reducing the emissions of GHGs has become a common challenge in the world. As the world's largest emitter of GHGs, China has to positively confront this problem. For example, it was forecast that China's GHG emissions would reach a startling value of 11.4 billion metric tons in 2030 without any emission reduction constraints (Xiao et al. 2014). Moreover, it was reported that approximately 83% of the total GHGs had arisen from the industrial department of China (Zhang and Liu 2014). In addition, since 2000, approximately 70% of China's energy consumption also came from the industrial sector (Liu et al. 2016). Thus, it could be concluded that the contribution of the industrial sector to the entire quantity of GHGs was extremely high in China and that we should pay sufficient attention to it. Similarly, as a central province of China, Jiangxi's industrial department has almost the same importance. In other words, as is the case for all of China, controlling and reducing energy use and the related GHG emissions of Jiangxi's industrial sector have also become a serious and urgent challenge. However, what should we do to confront this challenge? The first and most important thing could be to identify the main influencing factors (drivers) of the energy-related industrial carbon emissions (ERICE) in Jiangxi. So, Jiangxi's ERICE value was first calculated, and the factor decomposition method was adopted to analyze

the ERICE drivers. Then, based on these driver-related results, some specific countermeasures or strategies could be proposed to reduce the ERICE and improve the utilization efficiency of local energy consumption. Some scholars have even explored Jiangxi's CO₂ emissions from the perspectives of the power grid (Cao et al. 2016), tourism transportation (Jia et al. 2014), and developmental strategies (Zhang et al. 2012), etc., but specific investigations of the ERICE and its drivers in this region have been few. Therefore, to a certain extent, it has been innovative for us to complete this work.

For the ERICE driver analysis, there are two commonly used methods (Xiao et al. 2016; Nie et al. 2016): structural decomposition analysis (SDA) and index decomposition analysis (IDA). SDA often requires the economic data of the input–output table, while IDA only needs the aggregate data of each industrial category (Cellura et al. 2012; Cansino et al. 2016; Yang et al. 2016). In addition, SDA can only analyze the change between the limited years, while IDA usually can analyze the change between any years (Hoekstra and van der Bergh 2003; Moutinho et al. 2016). Therefore, considering the available data of the industrial sector in Jiangxi, the IDA method was adopted for this investigation. In the IDA methods, there are still many optional indices for quantifying the impacts of factorial changes on the aggregating industrial sector. These indices are, for instance, the Laspeyres index (Lu et al. 2014), the Paasche index (Liu et al. 2016), the Arithmetic Mean Divisia index (Hatzigeorgiou et al. 2008), and the Logarithmic Mean Divisia Index (LMDI) (Ang 2005; Wang et al. 2005; Lee and Oh 2006; Wood and Lenzen 2006). Among them, the LMDI has become the most popular one because of its incomparable advantages (Chen 2011; Tan et al. 2011; Ren et al. 2012; Zhang et al. 2013; Tian et al. 2013; Shao et al. 2016). For example, it was concluded that the LMDI had some outstanding properties in its theoretical foundation (i.e., no unexplained residuals), adaptability, ease of use, and result interpretation (Ang and Liu 2001; Ang et al. 2003; Ang 2004, 2005; Ang and Liu 2007). Therefore, the LMDI model was chosen to study the ERICE drivers of Jiangxi. This model already was adopted to analyze the carbon emissions or energy consumptions or other environmental changes of some special places. For example, it has been used to analyze the change of industrial CO₂ emissions (Liu et al. 2007; Marcucci and Fragkos 2015; Guo et al. 2016), energy intensity (Ma and Stern 2008; Kerimray et al. 2018), and the food consumption

CE values of all of China (Lin and Xie 2016). Similarly, it has also been used to research the same issues at other different scales (global, national or urban), i.e., the European Union (Moutinho et al. 2015; Kopidou et al. 2016), South Korea (Jung et al. 2012), Shanghai (Zhao et al. 2010), Jiangsu (Wang et al. 2013), Taiwan (Lin et al. 2006), Yunnan (Deng et al. 2016), Guangdong (Wang et al. 2011), and the Hotan Prefecture in Xinjiang of China (Xiong et al. 2016).

Generally, in these existing studies, the total effect on carbon emission change could be decomposed into the effects of several conventional factors such as the economic amount (output), industrial structure, energy intensity, energy mix, population, and emission coefficient. However, these effects can only address the macroeconomic influences on CO₂ emissions, but cannot reveal the microeconomic roots of CO₂ emission changes. For example, an enterprises' investment and R&D decision-making have some crucial microeconomic impacts on the energy saving and emission reduction performance (Collard et al. 2005; Ang 2009; Shao et al. 2011). However, studies of these impacts have been few (or even none) in the existing literature. In fact, the ERICE changes are often determined by various drivers and it is difficult to determine real reasons from one single scale. Therefore, it is necessary to combine these microeconomic factors with conventionally macroeconomic factors to more fully and accurately study the drivers of the ERICE in Jiangxi. In other words, these drivers should be investigated simultaneously at both the macroeconomic and the microeconomic levels. Thus, in this investigation, we decomposed the ERICE changes of Jiangxi not only into the conventional factors but also into some novel factors at the microeconomic level. This resulting approach could be considered to be an extension of the existing LMDI.

In addition, based on the rebound effect theory, some parts of the anticipated energy savings and emission reductions from the improvement of energy efficiency may be offset by the additional energy consumption and corresponding carbon emissions resulting from the new round of economic growth induced by technological progress (Sorrell and Binswanger 2001; Sorrell and Dimitropoulos 2008; Sorrell et al. 2009; Shao et al. 2011, 2014, 2016). So, if the equipment updates and R&D efforts of industrial enterprises are targeting energy savings and emission reductions, the related investment and R&D activities will facilitate the reduction of the ERICE. However, if they are targeting the expansion

of the production and productivity improvements, the investment and R&D activities may induce an additional increase in the energy consumption and carbon emissions. In other words, the complexity of the problem clearly increases with the introduction of the relative investment and R&D factors into the LMDI model. The corresponding results and conclusions, however, may be of more significance. Thus, this idea was also adopted in this investigation.

It should be noted that, starting in 1953, with a gap during 1963–1965, the government of China has proposed plans for national economic and social development every 5 years, namely, the “Five-Year Plan”. For example, in the 12th “Five-Year Plan” (2011–2015), China announced that it would try hard to reduce carbon emissions through a variety of measures and that the carbon emission intensity in 2015 should be reduced by 17% compared with the 2010 level (SCPRC 2011). As a result of the 5-year planning cycle, China's development also presented an obvious 5-year periodic property. Correspondingly, as a province of China, similar plans have also been implemented every 5 years, such as the 9th, 10th, 11th, and 12th “Five-Year Plan” periods in Jiangxi, which were consistent with the periods of 1996–2000, 2001–2005, 2006–2010, and 2011–2015, respectively. In these plans, the items of energy conservation and improving energy use efficiency were all mentioned, required, and planned at varying degrees. Particularly, during the 12th “Five-Year Plan” of Jiangxi, the comprehensive energy consumption per GDP was planned to decrease by 16%, which was based on the result that it had decreased by 20% during the 11th “Five-Year Plan”. Therefore, overall, the energy consumption intensity of Jiangxi had a decreasing trend over the studied period of 1998–2015. However, the severe acute respiratory syndrome (SARS) crisis and global financial crisis began in 2003 and 2008, respectively, which might cause some interference in the implementation of the government's energy conservation policies and measures. Thus, the factors of plans and emergencies were also researched in this investigation. The remaining parts of this paper are organized as follows. The method of ERICE calculation, the extended LMDI decomposition model, and the corresponding data sources are presented in section “[Methodology and data](#)”. The results of the ERICE, the decomposition result analysis, and

related discussions are presented in section “**Results and discussion**”. Some conclusions are summarized and some particular countermeasures for the sustainable future or low carbon development of Jiangxi, especially in the industrial sector, are proposed in section “**Conclusions**”.

Methodology and data

ERICE calculation

The total ERICE (abbreviated as C in the following equations) was calculated based on the energy consumption data, carbon emission coefficient, and the fuel’s oxidation percentage, as recommended by the IPCC (2006):

$$C = \sum_{i=1}^{35} C_i = \sum_{i=1}^{35} \sum_{j=1}^9 C_{ij} = \sum_{i=1}^{35} \sum_{j=1}^9 E_{ij} \cdot f_j \quad (1)$$

where the meanings of the corresponding variables are

$$\frac{d\ln C}{dt} = \sum_{i=1}^{35} \sum_{j=1}^9 \left[\varphi_{ij}(t) \cdot \left(\frac{d\ln f_j}{dt} + \frac{d\ln ES_i}{dt} + \frac{d\ln EI_i}{dt} + \frac{d\ln RE_i}{dt} + \frac{d\ln RI_i}{dt} + \frac{d\ln II_i}{dt} + \frac{d\ln IS_i}{dt} + \frac{d\ln O}{dt} \right) \right] \quad (3)$$

$$\text{where } \varphi_{ij}(t) = \frac{f_j \cdot ES_i \cdot EI_i \cdot RE_i \cdot RI_i \cdot II_i \cdot IS_i \cdot O}{C} = \frac{C_{ij}}{C}$$

listed in Table 1. For example, E_{ij} denotes the consumption amount of fuel j in industry i , its units are metric tons of standard coal equivalent (tce).

The extended LMDI model

The total ERICE changes were decomposed not only into the conventional factors at the macroeconomic level but also into some novel factors at the microeconomic level. Therefore, the extended LMDI model contained the following eight factors:

$$C = \sum_{i=1}^{35} \sum_{j=1}^9 C_{ij} = \sum_{i=1}^{35} \sum_{j=1}^9 \frac{C_{ij}}{E_{ij}} \cdot \frac{E_{ij}}{E_i} \cdot \frac{E_i}{O_i} \cdot \frac{O_i}{R_i} \cdot \frac{R_i}{I_i} \cdot \frac{I_i}{O_i} \cdot O \quad (2)$$

$$= \sum_{i=1}^{35} \sum_{j=1}^9 f_j \cdot ES_i \cdot EI_i \cdot RE_i \cdot RI_i \cdot II_i \cdot IS_i \cdot O$$

where the meanings of these variables are also listed in Table 1.

Taking the logarithmic differentiation of equation (2) based on time, we obtain

Integrating equation (3) over the time interval $[0, T]$, we obtain

$$\ln \frac{C_T}{C_0} = \sum_{i=1}^{35} \sum_{j=1}^9 \int_0^T \varphi_{ij}(t) \cdot \left(\frac{d\ln f_j}{dt} + \frac{d\ln ES_i}{dt} + \frac{d\ln EI_i}{dt} + \frac{d\ln RE_i}{dt} + \frac{d\ln RI_i}{dt} + \frac{d\ln II_i}{dt} + \frac{d\ln IS_i}{dt} + \frac{d\ln O}{dt} \right) \cdot dt \quad (4)$$

Then, we obtain the exponentiation of equation (4):

$$\begin{aligned} \frac{C_T}{C_0} &= \exp \left(\sum_{i=1}^{35} \sum_{j=1}^9 \int_0^T \varphi_{ij}(t) \frac{d\ln f_j}{dt} dt \right) \cdot \exp \left(\sum_{i=1}^{35} \sum_{j=1}^9 \int_0^T \varphi_{ij}(t) \frac{d\ln ES_i}{dt} dt \right) \cdot \exp \left(\sum_{i=1}^{35} \sum_{j=1}^9 \int_0^T \varphi_{ij}(t) \frac{d\ln EI_i}{dt} dt \right) \\ &\cdot \exp \left(\sum_{i=1}^{35} \sum_{j=1}^9 \int_0^T \varphi_{ij}(t) \frac{d\ln RE_i}{dt} dt \right) \cdot \exp \left(\sum_{i=1}^{35} \sum_{j=1}^9 \int_0^T \varphi_{ij}(t) \frac{d\ln RI_i}{dt} dt \right) \cdot \exp \left(\sum_{i=1}^{35} \sum_{j=1}^9 \int_0^T \varphi_{ij}(t) \frac{d\ln II_i}{dt} dt \right) \\ &\cdot \exp \left(\sum_{i=1}^{35} \sum_{j=1}^9 \int_0^T \varphi_{ij}(t) \frac{d\ln IS_i}{dt} dt \right) \cdot \exp \left(\sum_{i=1}^{35} \sum_{j=1}^9 \int_0^T \varphi_{ij}(t) \frac{d\ln O}{dt} dt \right) \end{aligned} \quad (5)$$

Table 1 Meanings of the major variables

Variables	Meaning	Unit
i	Industrial subsectors, $i = 1, 2, \dots, 35$	
j	Fuel’s categories, $j = 1, 2, \dots, 9$	
C_i	CO ₂ emission of industry i	Mt
C_{ij}	CO ₂ emission of industry i by using fuel j	Mt
E_{ij}	Consumption amount of fuel j in industry i	tce
f_j	CO ₂ emission’s coefficient of fuel j	t/tce
E_i	Total energy consumption amount of subsector i	tce
O_i	Industrial output of subsector i	RMB
R_i	R&D expenditure of subsector i	RMB
I_i	Fixed asset investment of subsector i	RMB
O	Total industrial output	RMB
ES_i	Energy structure: shares of different fuels in gross energy consumption of subsector i	%
EI_i	Energy intensity: energy consumption per unit output in subsector i	tce/RMB
RE_i	R&D efficiency: output per unit of R&D expenditure in subsector i	
RI_i	R&D intensity: share of R&D expenditure in fixed asset investment of subsector i	%
II_i	Investment intensity: share of fixed asset investment in output of subsector i	%
IS_i	Industrial structure: output share of subsector i in total industrial output	%

Note: “null” denotes that the corresponding indicator has only an absolute number and no units. Mt and RMB are the acronyms for “million metric tons” and “Chinese Yuan”, respectively. In f_j , the fuel’s oxidation percentages were selected according to the literature (Shao et al. 2016) and are listed in Appendix Table 5

In accordance with the definite integral middle value theorem, equation (5) can be transformed as

$$\begin{aligned}
 \frac{C_T}{C_0} \cong & \exp\left(\sum_{i=1}^{35} \sum_{j=1}^9 \varphi_{ij}(t^*) \ln \frac{f_{j,T}}{f_{j,0}}\right) \cdot \exp\left(\sum_{i=1}^{35} \sum_{j=1}^9 \varphi_{ij}(t^*) \ln \frac{ES_{i,T}}{ES_{i,0}}\right) \cdot \exp\left(\sum_{i=1}^{35} \sum_{j=1}^9 \varphi_{ij}(t^*) \ln \frac{EI_{i,T}}{EI_{i,0}}\right) \\
 & \cdot \exp\left(\sum_{i=1}^{35} \sum_{j=1}^9 \varphi_{ij}(t^*) \ln \frac{RE_{i,T}}{RE_{i,0}}\right) \cdot \exp\left(\sum_{i=1}^{35} \sum_{j=1}^9 \varphi_{ij}(t^*) \ln \frac{RI_{i,T}}{RI_{i,0}}\right) \cdot \exp\left(\sum_{i=1}^{35} \sum_{j=1}^9 \varphi_{ij}(t^*) \ln \frac{II_{i,T}}{II_{i,0}}\right) \\
 & \cdot \exp\left(\sum_{i=1}^{35} \sum_{j=1}^9 \varphi_{ij}(t^*) \ln \frac{IS_{i,T}}{IS_{i,0}}\right) \cdot \exp\left(\sum_{i=1}^{35} \sum_{j=1}^9 \varphi_{ij}(t^*) \ln \frac{O_T}{O_0}\right)
 \end{aligned} \tag{6}$$

where $\varphi_{ij}(t^*)$ is the weight function given by $\varphi_{ij}(t) = \frac{C_{ij}}{C}$ above at point $t^* \in [0, T]$.

According to the logarithmic mean weight function recommended by Ang and Liu (2001), the weight function of $\varphi_{ij}(t^*)$ can be expressed as

$$\varphi_{ij}(t^*) = \frac{L(C_{ij,T}, C_{ij,0})}{L(C_T, C_0)} \tag{7}$$

where the logarithmic mean of two positive numbers is

$$L(x, y) = \begin{cases} (x-y)/(\ln x - \ln y), & x \neq y > 0 \\ x & x = y > 0 \end{cases} \tag{8}$$

Then, the equation (6) can be simplified as

$$\Psi C_{TOT} = C_T / C_0 = \Psi C_f \cdot \Psi C_{ES} \cdot \Psi C_{EI} \cdot \Psi C_{RE} \cdot \Psi C_{RI} \cdot \Psi C_{II} \cdot \Psi C_{IS} \cdot \Psi C_O \tag{9}$$

where

$$\Psi C_{\zeta} = \exp \left(\sum_{i=1}^{35} \sum_{j=1}^9 \frac{(C_{ij,T} - C_{ij,0}) / (\ln C_{ij,T} - \ln C_{ij,0})}{(C_T - C_0) / (\ln C_T - \ln C_0)} \cdot \ln \frac{\zeta_{ij,T}}{\zeta_{ij,0}} \right),$$

and ζ denoted f, ES, EI, RE, RI, II, IS, and O. $\Psi C_f, \Psi C_{ES}, \Psi C_{EI}, \Psi C_{RE}, \Psi C_{RI}, \Psi C_{II}, \Psi C_{IS},$ and ΨC_O are, respectively, the emission's coefficient effect, the energy structure effect, the energy intensity effect, the R&D efficiency effect, the R&D intensity effect, the investment intensity effect, the industrial structure effect, and the output effect.

Equation (9) is the multiplicative formation of the LMDI model for the ERICE changes. The corresponding additive formation of LMDI decomposition can be written as follows based on the work of Ang (2005) and Xu et al. (2017):

$$\begin{aligned} \Delta C_{TOT} = C_T - C_0 = & \Delta C_f + \Delta C_{ES} + \Delta C_{EI} \\ & + \Delta C_{RE} + \Delta C_{RI} + \Delta C_{II} \\ & + \Delta C_{IS} + \Delta C_O. \end{aligned} \quad (10)$$

where $\Delta C_{\zeta} = \sum_{i=1}^{35} \sum_{j=1}^9 \frac{C_{ij,T} - C_{ij,0}}{\ln C_{ij,T} - \ln C_{ij,0}} \cdot \ln \frac{\zeta_{ij,T}}{\zeta_{ij,0}}$. Correspondingly, $\Delta C_f, \Delta C_{ES}, \Delta C_{EI}, \Delta C_{RE}, \Delta C_{RI}, \Delta C_{II}, \Delta C_{IS},$ and ΔC_O are, respectively, the additive formations of the emission's coefficient effect, the energy structure effect, the energy intensity effect, the R&D efficiency effect, the R&D intensity effect, the investment intensity effect, the industrial structure effect, and the output effect.

It should be explained that, according to the article of Ang et al. (2003), the LMDI decomposition mentioned above is actually the pattern of LMDI I and there is another pattern of decomposition, which is regarded as the LMDI II. Considering that the decomposition results for LMDI I and LMDI II are consistent, the decomposition by LMDI II was omitted for saving space. Moreover, the CO₂ emission coefficients of the various fuels were all assumed to be fixed when calculating Jiangxi's ERICE. Therefore, they, in reality, had no contributions to the ERICE changes. In other words, here, the ΨC_f and ΔC_f in equations (9) and (10) should be 1 and 0, respectively. Hence, the final drivers of Jiangxi's ERICE changes were decomposed into seven corresponding indicators. In addition, among the seven indicators, ES, EI, IS, and O are four conventional macroeconomic factors, and RE, RI, and II are three potential microeconomic drivers of which few have

been previously studied by scholars, especially in Jiangxi. Therefore, they have been given much more attention in the following text. Particularly, RE means the R&D efficiency, reflecting the transformation capacity of R&D expenditure on output. In the condition of all other factors being unchanged, the greater the value of RE, the more the output transformed from R&D expenditure is. Similarly, the RI means the R&D intensity, reflecting the innovation impetus and technological content of the industrial subsector. The greater the value of RI, the stronger the innovation enthusiasm is. The II means the investment intensity, reflecting the intensity of expanded production in the industrial subsector. The greater the value of II, the stronger the capacity of expanded production is. Therefore, we could easily find the three novel microeconomic level factors that embodied the industrial investment and R&D activities from the enterprise's perspective. The extended LMDI model might give us much more useful information and deserved being considered thoroughly.

Data description

The studied province (Jiangxi of China) is located at 24° 29' 14"–30° 04' 41" N and 113° 34' 36"–118° 28' 58" E, with an administrative area of 166,900 km². So, all the related economic and energy data were derived from the Jiangxi Statistical Yearbook (1999–2016). As the leading principle in the IPCC method (2006), the use of the special parameters of each country is encouraged to assure the accuracy of the results. So, as used in the article of Shao et al. (2016), some related parameters announced officially in China were also adopted in this investigation. To eliminate the influence of price changes, we deflated the raw data at the current prices to constant 2010 prices using the corresponding price indices. To obtain more accurate results, we considered all nine fossil fuels reported in the statistical yearbooks. They were raw coal, cleaned coal, other cleaned coal, coke, crude oil, gasoline, kerosene, diesel, and fuel oil.

The amount and share of weapons and ammunition manufacturing (WAM) in Jiangxi were marginal, and its fossil fuel consumption was close to zero in most years; so, the WAM industry was excluded. Similarly, some other industries were

also excluded. All in all, 35 industrial subsectors were evaluated in this investigation (Table 2). The calculated ERICE values of all the subsectors during 1998–2015 are shown in Appendix Table 6.

The data of all types of energy consumption in different industrial subsectors was obtained directly from the statistical yearbook according to the government's official website (<http://www.jxstj.gov.cn/Column.shtml?p5=423>). Moreover, for the industrial enterprises above a designated size, the R&D expenditure reached approximately 0.7% of the total revenue of the principal businesses in 2015, according to the R&D expenditure-related report published by the local government (http://www.jiangxi.gov.cn/zcc/ajg/sbgt/201705/t20170510_1334887.htm). Therefore, the R&D expenditures of different industrial subsectors in 2015 were obtained by multiplying this coefficient (0.7%) with the corresponding total revenue of principal businesses, which was also obtained directly from the statistical data. In addition, the R&D expenditures of different industrial subsectors in other years were also calculated based on these coefficients and corresponding statistical data. Considering that the

government had paid increasing emphasis on innovation and R&D activities during 1998–2015, these coefficients were supposed to increase by 0.02% yearly from 1998 to 2015.

Results and discussion

Overall trends of the ERICE and the contributions of various drivers

As shown in Fig. 1a, in 1998, the industrial output of Jiangxi was 69.12×10^9 RMB based on the constant 2010 prices, and the corresponding ERICE was 52.78 Mt (Appendix Table 6). With rapid economic growth and the improvement of people's living standards, Jiangxi's industrial output had steadily increased to 771.31×10^9 RMB in 2015. The growth amount was 702.19×10^9 RMB with an average annual increase of 15.25%. The corresponding ERICE also had an obvious growth to 176.37 Mt in 2015, a growth amount of 123.59 Mt, and an average annual increase of 7.35% (Fig. 1a).

Table 2 Classification of industrial subsectors

No.	Sector	No.	Sector
S1	Mining and Washing of Coal	S19	Manufacture of Medicines
S2	Mining and Processing of Ferrous Metal Ores	S20	Manufacture of Chemical Fibers
S3	Mining and Processing of Non-Ferrous Metal Ores	S21	Manufacture of Rubber & Plastics
S4	Mining and Processing of Nonmetal Ores	S22	Manufacture of Non-metallic Mineral Products
S5	Processing of Food from Agricultural Products	S23	Smelting and Pressing of Ferrous Metals
S6	Manufacture of Foods	S24	Smelting and Pressing of Non-ferrous Metals
S7	Manufacture of Beverages	S25	Manufacture of Metal Products
S8	Manufacture of Tobacco	S26	Manufacture of General Purpose Machinery
S9	Manufacture of Textile	S27	Manufacture of Special Purpose Machinery
S10	Manufacture of Textile Wearing Apparel, Footware and Caps	S28	Manufacture of Transport Equipment
S11	Manufacture of Leather, Fur, Feather and Related Products	S29	Manufacture of Electrical Machinery and Equipment
S12	Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm, and Straw Products	S30	Manufacture of Communication Equipment, Computers and Other Electronic Equipment
S13	Manufacture of Furniture	S31	Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work
S14	Manufacture of Paper and Paper Products	S32	Manufacture of Artwork and Other Manufacturing
S15	Printing, Reproduction of Recording Media	S33	Production and Supply of Electric Power and Heat Power
S16	Manufacture of Articles for Culture, Education and Sport	S34	Production and Supply of Gas
S17	Processing of Petroleum, Coking, Processing of Nuclear Fuel	S35	Production and Supply of Water
S18	Manufacture of Raw Chemical Materials and Chemical Products		

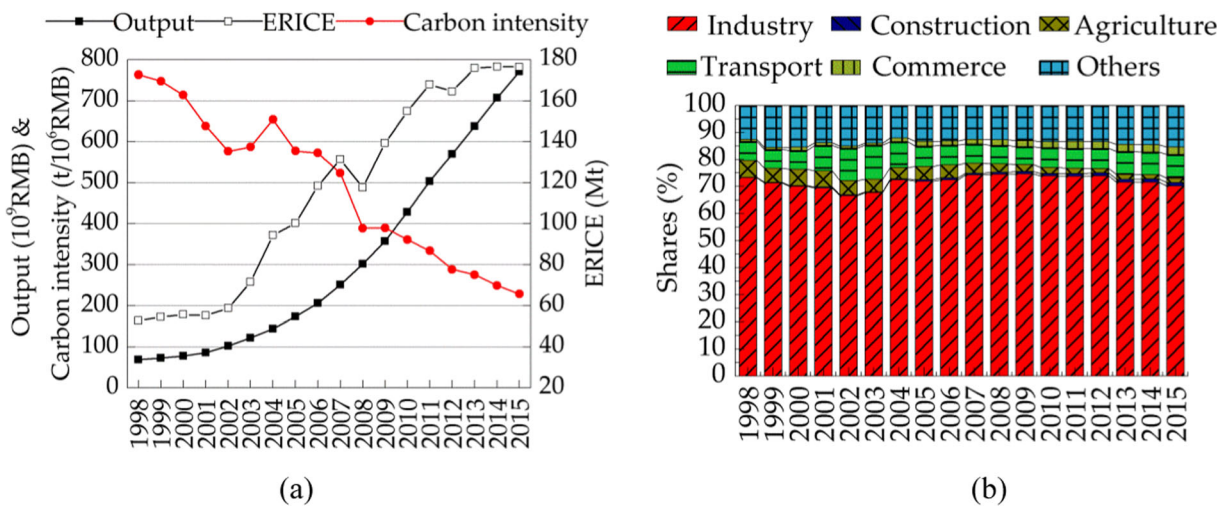


Fig. 1 The energy-related industrial carbon emissions (ERICE), industrial output, carbon intensity (a), and the structure of total energy-related CO₂ in Jiangxi (b)

Therefore, the carbon intensity of Jiangxi overall had a decrease during 1998–2015, because of the higher increasing rate of the industrial output (15.25%) than that of the ERICE (7.35%). There was an exceptional change of the growth rate during 2003–2004, which might have been the result of the break out of “SARS”. Similarly, the stable situation in 2008–2009 might have been the result of the “financial crisis” at that time.

It is very noteworthy that the industrial sector share has always remained at 70% ($\pm 4\%$) in the total energy-related CO₂ of Jiangxi from all the production sectors such as construction, agriculture, and transport (Fig. 1b). Thus, we can also conclude that the Jiangxi’s energy consumption in the industrial sector and the ERICE might play a vital and decisive role in its economic growth. Particularly, the multiplicative decomposition results of Jiangxi’s ERICE change in three “Five-Year Plan” periods and the entire period as are presented in Appendix Fig. 14. The corresponding additive decomposition results are shown in Fig. 2. Their detailed results are shown in Appendix Tables 7 and 8. Overall, Jiangxi’s ERICE experienced an increasing trend. It increased by 123.59 Mt from 1998 to 2015 (Fig. 2 and Appendix Table 8), with a growth rate of 234.2% (Appendix Table 7). The ERICE also presented an increasing trend during the three consecutive “Five-Year Plan” stages (Fig. 2 and Appendix Table 7).

During the 10th “Five-Year Plan” period (2000–2005), the ERICE growth was 44.61 Mt. However, in the 11th “Five-Year Plan” period (2005–2010), the

ERICE had a larger rise of 54.66 Mt. The reason can be attributed to the acceleration of industrialization in Jiangxi reflected by the quick rise of the proportion of industry output from 35.9% in 2005 to 45.5% in 2010. During the 12th “Five-Year Plan” period (2010–2015), Jiangxi’s ERICE had a smaller rise than the previous two periods, with only a growth of 21.43 Mt and the lowest rate of increase rate (13.8%), which might be closely related to the industrial structural transformation. As we know, the global financial crisis began in 2008. After that, the sustainable development of the social economy received increasing attention and the transformation of the industrial structure naturally received great impetus arising from some effective emission-reduction actions of government. As a result, the proportion of tertiary industry output increased from 33.0% in 2010 to 39.1% in 2015. Therefore, we found that these emission-reduction efforts such as industrial structure updating surely had a positive effect of mitigating the ERICE growth.

Next, the contributions of various factors to the ERICE changes are listed in Table 3. From this data, we can easily see that with contributions from high to low orders during 1998–2015, the promotion factors of the ERICE in Jiangxi were output (564.6%), R&D intensity (162.1%), investment intensity (71.4%), and energy structure (0.3%), while the mitigating factors of the ERICE were R&D efficiency (−233.5%), energy intensity (−198.1%), and industrial structure (−132.7%). The total promotional effects (564.6% + 162.1% + 71.4% +

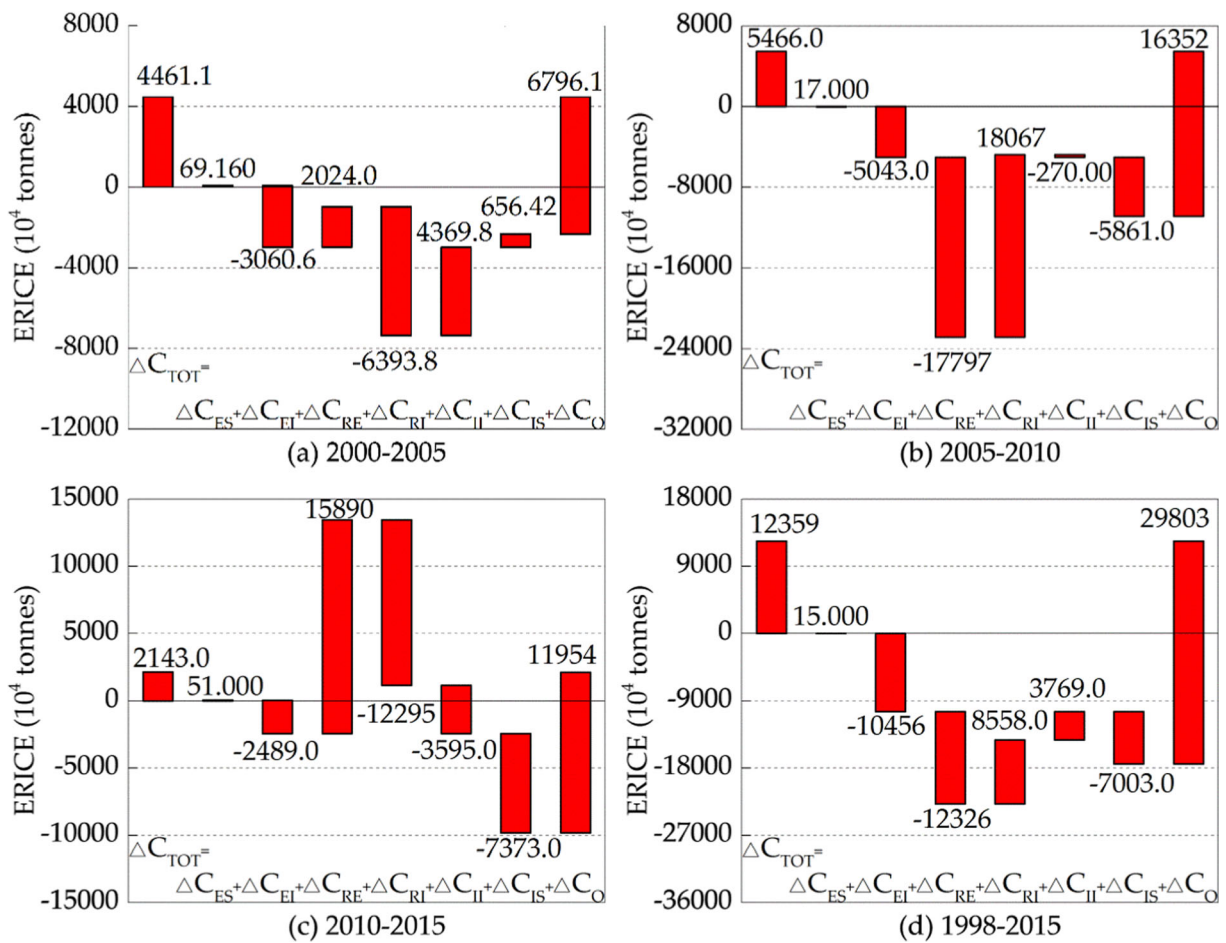


Fig. 2 Additive decomposition results of Jiangxi’s ERICE changes in the three “Five-Year Plan” periods and the entire period (ΔC_{ES} , ΔC_{EI} , ΔC_{RE} , ΔC_{RI} , ΔC_{II} , ΔC_{IS} , and ΔC_O denote the effects of energy structure, energy intensity, R&D efficiency, R&D

intensity, investment intensity, industrial structure, and output on the ERICE changes, respectively). **a** 2000–2005. **b** 2005–2010. **c** 2010–2015. **d** 1998–2015

0.3% = 798.4%) were much greater than the total mitigating effects (233.5% + 198.1% + 132.7% = 564.3%), which caused a remarkable increase of 234.2% (= 798.4 – 564.3%) in the total ERICE over the period of 1998–2015 (Table 3). Particularly, the multiplicative and additive decomposition results of the output were 18.34 and 298.03 Mt (Appendix Fig. 14d and Fig. 3d), respectively, indicating that the output was the largest driver of the ERICE growth (Fig. 3).

Considering that cumulative decomposition results stabilize the short-term fluctuant effects of the various factors to provide a more credible comparison (Ma and Stern 2008; Shao et al. 2016), they are listed in Appendix Table 9 and depicted in Fig. 3. Here, the term “cumulative” means the following. Let us suppose that

the decomposition results of all the ERICE change indices in 1998 were 1. The cumulative decomposition results of 1999 are the corresponding multiplicative values of 1998–1999. Then, the cumulative decomposition results in 2000 are the multiplicative values of 1998–1999 multiplied by the multiplicative values of 1999–2000 and so on. It should be noted that we separately drew the results of RI, II, and RE in Fig. 3b to clearly present them due to their high fluctuations.

Over the 1998–2015 period, among the five macroeconomic factors shown in Fig. 3a, only the output always had a positive effect on the ERICE and presented a sharp upward trend. This result is consistent with the information presented in Fig. 2d and means that the output expansion is the dominant effect for ERICE growth. The other macroeconomic factors had trivial

Table 3 Contributions of the various factors to the ERICE changes (unit: %)

Stage	Changes	Energy structure	Energy intensity	R&D efficiency	R&D intensity	Investment intensity	Industrial structure	Output
1998–1999	3.26	-1.22	-3.03	3.79	17.76	-21.54	10.99	-3.48
1999–2000	2.14	-0.23	-4.14	-108.78	95.95	12.83	-1.52	8.03
2000–2001	-0.93	0.21	0.58	-14.90	-9.98	24.88	1.39	-3.10
2001–2002	6.69	0.09	-16.37	-84.61	80.77	3.84	8.55	14.41
2002–2003	21.67	-0.02	3.18	3.48	-37.33	33.86	-5.21	23.72
2003–2004	31.83	0.59	-13.75	130.07	-122.51	-7.56	7.94	37.04
2004–2005	6.25	0.12	-16.90	8.44	-11.13	2.69	-3.52	26.54
2005–2006	18.00	0.04	-3.60	-58.63	103.98	-45.35	-10.74	32.30
2006–2007	11.04	0.28	-7.10	6.78	-34.86	28.08	-15.54	33.40
2007–2008	1.67	-0.15	-15.02	-65.91	37.28	28.63	-5.40	22.23
2008–2009	4.39	0.02	-6.88	-37.74	18.40	19.33	-8.77	20.02
2009–2010	11.11	-0.04	-10.32	8.47	28.36	-36.83	-7.42	28.89
2010–2011	8.42	0.36	-2.21	142.81	-144.05	1.24	-6.58	16.85
2011–2012	-2.00	-0.06	-8.87	6.71	10.42	-17.13	-8.16	15.09
2012–2013	6.85	0.07	-1.12	93.48	-102.52	9.05	-8.57	16.47
2013–2014	0.38	0.25	-4.42	-46.04	44.72	1.32	-11.31	15.86
2014–2015	-0.11	-0.32	1.79	-91.24	107.40	-16.16	-10.52	8.93
2000–2005	80.13	1.24	-54.97	36.36	-114.85	78.49	11.79	122.07
2005–2010	54.50	0.17	-50.28	-177.46	180.15	-2.69	-58.44	163.05
2010–2015	13.83	0.33	-16.06	102.53	-79.33	-23.20	-47.57	77.13
1998–2015	234.15	0.29	-198.09	-233.53	162.13	71.40	-132.67	564.62

Note: “-” denotes the positive (favorable) contribution of reducing the ERICE

effects on the ERICE. Among them, energy intensity had the strongest emission-mitigating effect. Industrial structure followed it. With respect to the other three

microeconomic factors, the R&D efficiency showed frequent fluctuations, with a circuitous downward trend (mitigating effects). Inversely, the investment intensity

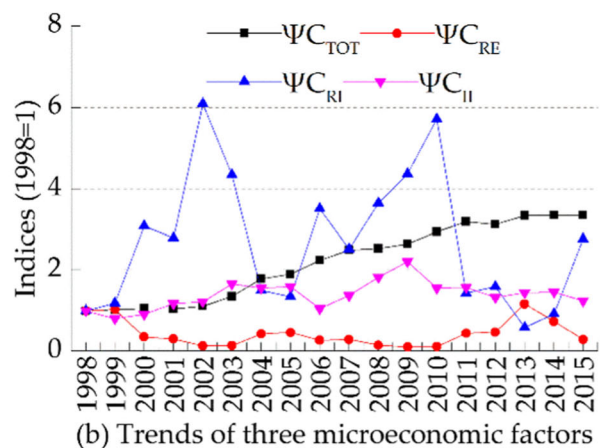
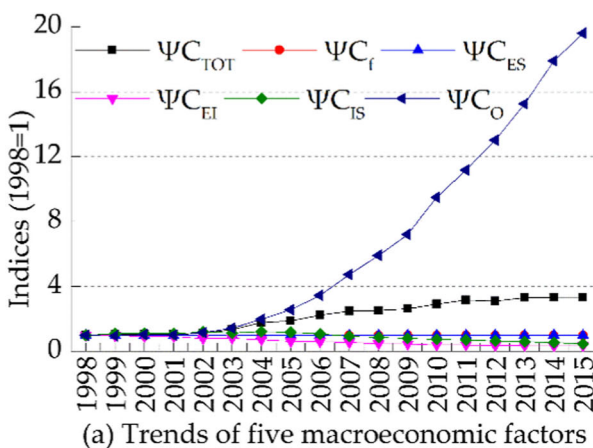


Fig. 3 Indices’ trends of the cumulative decomposition results of the ERICE changes (1998 = 1) ($\Psi_{C_{TOT}}$, Ψ_{C_f} , $\Psi_{C_{ES}}$, $\Psi_{C_{EI}}$, $\Psi_{C_{IS}}$, Ψ_{C_O} , $\Psi_{C_{RI}}$, $\Psi_{C_{II}}$, and $\Psi_{C_{RE}}$ denote the total changes and the effects’ indices of emission coefficient, energy structure,

energy intensity, industrial structure, output, R&D intensity, investment intensity, and R&D efficiency on the ERICE changes, respectively). **a** Trends of the five macroeconomic factors. **b** Trends of the three microeconomic factors

also showed frequent fluctuations, but with a circuitous upward trend (driving effects). Similarly, the R&D intensity presented the most prominent fluctuations and had a major driving effect on the ERICE (Fig. 3b). Overall, all the three microeconomic factors exerted the most significant effects on the ERICE changes (Appendix Fig. 14d, and Figs. 2d and 3b). Therefore, it is necessary to take into account the investment and the R&D behaviors of enterprises when further examining the drivers of the ERICE changes.

Drivers' changes of different scales at continuous four stages

Drivers of the macroeconomic scale

As mentioned above, to further explore the characteristics and reasons behind the ERICE changes here, the entire studied period of 1998–2015 was divided into four stages by the “Five-Year Plan” and the decomposition results from each stage were compared as follows. For convenience, the end of the 9th “Five-Year Plan” (1998–2000) was designated as the first stage. Table 4 and Fig. 4 present the corresponding results and changing trends of each factor, respectively.

Output effect The output effect had the largest average annual contribution rate (33.212%). It was much larger than the others (Table 4), and always had a positive effect in all four stages (Fig. 4). This means that the industrial output growth was the most prominent driving factor for ERICE growth. This finding is consistent with the results obtained above and the conclusions of most related studies (Ren et al. 2012; Shao et al. 2011,

2016). This was because energy is considered to be the most basic production factor and economic development is characterized by industrialization and urbanization, which induce substantial energy consumption and the corresponding increases of the ERICE (Ren et al. 2012; Shao et al. 2016). Therefore, the ERICE's rise is a concomitant outcome of the economic development and increasing industrial output of Jiangxi. For example, the industrial output of Jiangxi had an obvious upward trend with an increase of approximately 10.16 times from 69.12 billion RMB in 1998 to 771.31 billion RMB in 2015. Its average annual growth rate during this period was 15.25% (Fig. 1a). As a result, the ERICE also increased (by 3.34 times) and climbed from 52.78 Mt in 1998 to 176.37 Mt in 2015 with an average annual growth rate of 7.35%. Particularly, the ERICE's increases resulting from output were 2.55, 67.96, 163.52, and 119.54 Mt with average annual growth rates of 2.32%, 29.02%, 53.50%, and 21.20% in the four stages, respectively, as shown in Fig. 2 and Appendix Tables 8 and 9. This is consistent with the changing trends of the contributions from the output to the ERICE's growth shown in Fig. 4.

Industrial structure effect The industrial structure adjustment presented an overall mitigating effect (the average annual contribution rate was -7.804% , as shown in Table 4) on the ERICE during the four stages, especially in 11th and 12th “Five-Year Plan” stages. This means that the industrial structure adjustment in Jiangxi was effective in mitigating CO₂ emissions although it was not an obvious or even a driving effect in the initial 9th and 10th “Five-Year Plan” stages as shown in Fig. 4 and Table 4. This concept “adjustment” indicates that

Table 4 Contribution types and trends of the four stages and average annual contribution rates from various scale factors

Scale	Type	Decomposition factor	Trend ^a	Average annual contribution rate (%)
Macro-economy	Output effect	Output	++++	33.212
	Structure effect	Energy structure	-+++	0.017
		Industrial structure	+- - -	-7.804
Micro-economy	Intensity effect	Energy intensity	----	-11.652
		Investment intensity	-+ - -	4.200
	Efficiency effect	R&D intensity	+ - + -	9.537
		R&D efficiency	- + - +	-13.737

^a The sequence of trends was at the end of the 9th “Five-Year Plan” (1998–2000), the 10th “Five-Year Plan” (2000–2005), the 11th “Five-Year Plan” (2005–2010), and the 12th “Five-Year Plan”; + and - stand for positive and negative effects on the ERICE changes, respectively

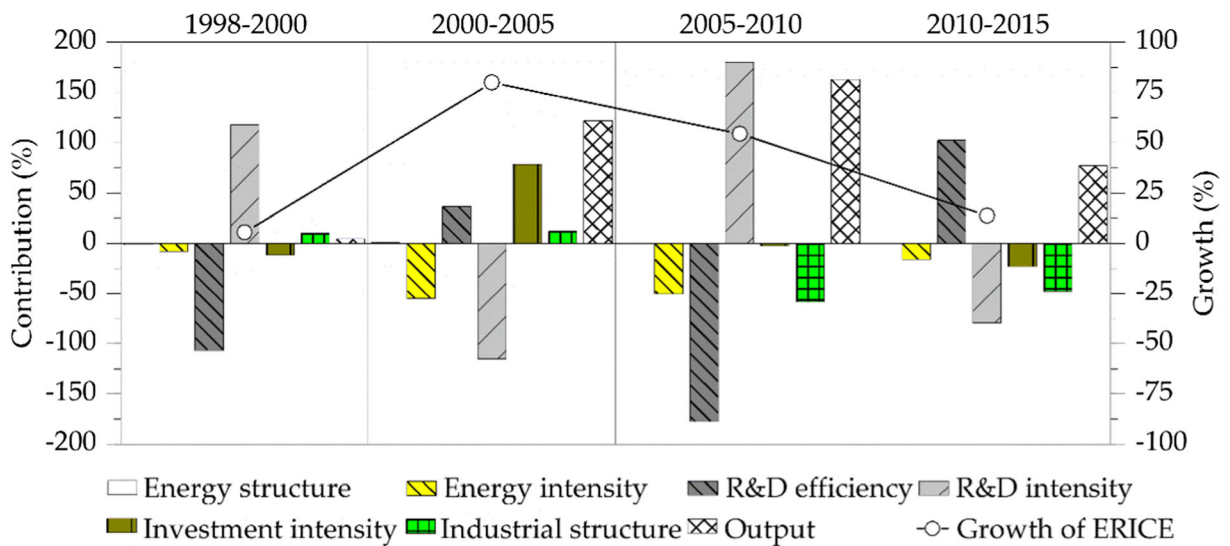


Fig. 4 Growth of the ERICE and contributions of its decomposition factors at four stages (i.e., the end of the 9th “Five-Year Plan” (1998–2000), the 10th “Five-Year Plan” (2000–2005), the 11th “Five-Year Plan” (2005–2010), and the 12th “Five-Year Plan” (2010–2011))

production resources were reallocated among industrial sectors with different technologies, efficiencies, and profits, thus inducing the changes of output share among the different sectors (Ren et al. 2012). According to neoclassical growth theory, structural adjustment is an important source of sustainable growth and a radical approach to transform the development pattern (Ren et al. 2012; Shao et al. 2011, 2016). Similarly, here, we consider that the industrial structural adjustment is the flow of production factors between industrial sectors with low energy consumption and CO₂ emissions. With the development and opening of the Honggutan new district since the beginning of the twenty-first century, Jiangxi’s industrial structure has gradually been transformed from raw material processing and manufacturing with high energy use and high pollutant emissions to a new phase with a more reasonable industrial structure. In this new phase, high-tech industries with low energy use and CO₂ emissions, such as photovoltaic, electronic, solar, and information technology, have rapidly developed in Jiangxi. As depicted in Fig. 5a, the output share of this low emission group continuously increased while that of the high emission group symmetrically decreased during 1998–2015. Although the share of the former had slight decreases in 2003 and 2011, its share continued to rise from 21.50% in 1998 to 38.52% in 2015, with an annual average increase of approximately 3.49%. Therefore, the contribution of industrial structure adjustment to mitigate the ERICE was effective and dominant overall. The ERICE changes resulting from

the industrial structural adjustment were 4.98, 6.56, –58.61, and –73.73 Mt with the average annual decrease rates of 4.88%, 1.81%, –7.46%, and –7.19% in the four stages, respectively, as shown in Figs. 2 and 4 and Appendix Tables 8 and 9. This indicates that production resource reallocation among different sectors could drive the reduction of the ERICE and that a structural bonus also existed in Jiangxi over the long run.

Energy structure effect The effect of the energy structure was the weakest and could almost be neglected (0.017%, Table 4). Most relevant studies also drew similar conclusions and argued that it could be attributed to the coal-dominated energy resources and consumption structures in China (Ren et al. 2012; Shao et al. 2011, 2016). The CO₂ emission coefficient of coal is higher than those of oil and gas. Hence, unlike other countries or regions, the long-term coal-dependent energy structure determined that most energy-related CO₂ emissions in the Jiangxi Province of China have come from coal burning. As depicted in Fig. 5b, the share of coal-type fuel use had decreased slightly from 73.3% in 1998 to 66.8% in 2015. This implies that although the energy consumption structure in Jiangxi, to some extent, has been improved, the coal-type fuel is still the main source of Jiangxi’s ERICE. Particularly, the average annual ERICE changes resulting from energy structural adjustments were –0.39, 0.14, 0.03, and 0.10 Mt at the four stages, respectively (Appendix Table 8). This indicates that the impact of the energy

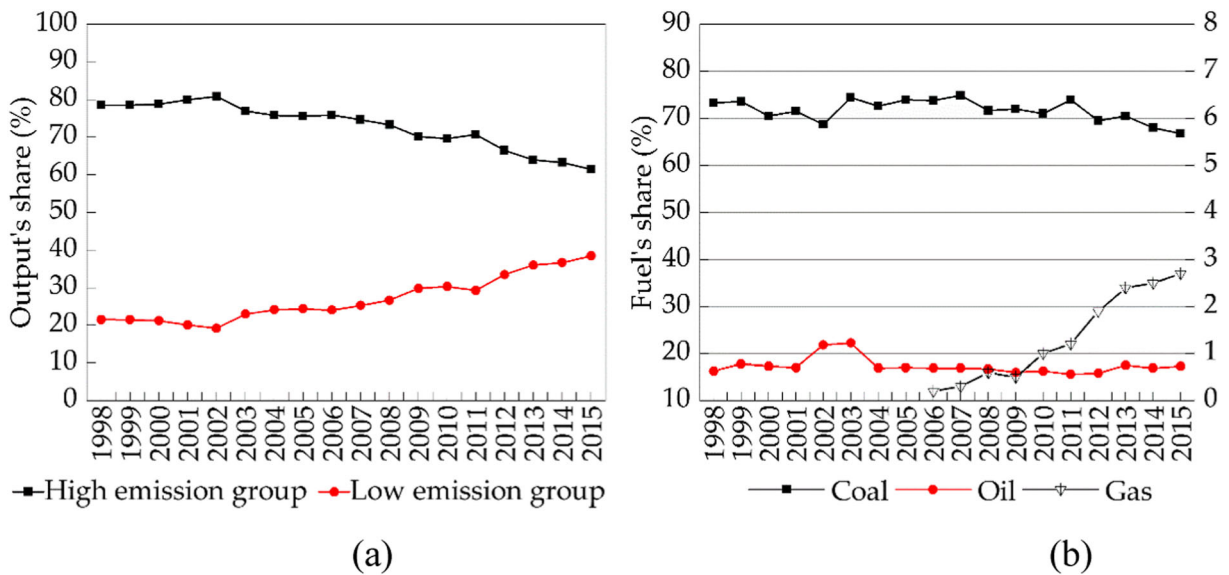


Fig. 5 **a** Output share's change of the high and low emission groups in Jiangxi (according to the ranking of the annual average ERICE over the period of 1998–2015, the high emission group

corresponds to the top half of the subsectors, and low emission group to the lower half of the subsectors). **b** Fuel share's change of the ERICE for the entire industry of Jiangxi

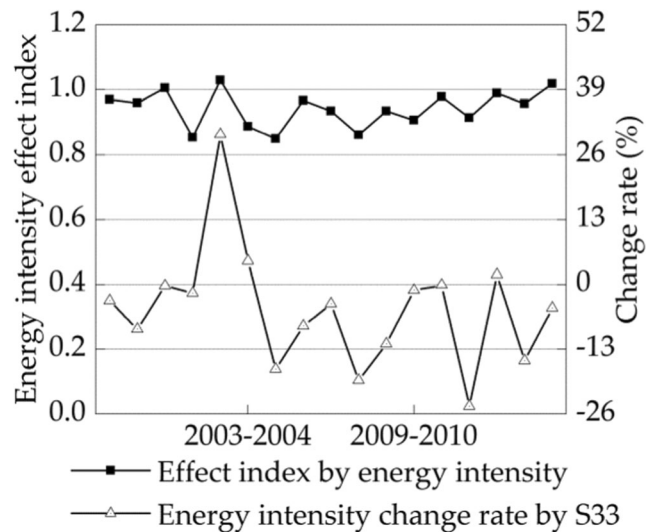
structural adjustment on the ERICE was relatively marginal. In fact, it is also difficult to mitigate the ERICE by altering the traditional coal-dominant energy structure in Jiangxi over the short term. In other words, the low-carbon pathway of energy structure adjustment requires a longer time and more effort.

Energy intensity effect The energy intensity has always had a mitigating effect on the ERICE (Fig. 4 and Table 4). The energy intensity had a slight mitigating effect on the ERICE during the first stage (1998–2000). This effect increased obviously in the second and third stages (2000–2005, 2005–2010). The average annual contribution rate of energy intensity to the ERICE was -11.652% . This means that the mitigation of Jiangxi's ERICE is largely dependent upon the decline of the energy intensity, which implies that an improvement of energy efficiency or level of technology. This is consistent with the finding of most of the related studies (Ren et al. 2012; Shao et al. 2011, 2016). The energy intensity of the entire industry in Jiangxi had an obvious decrease from $2.09 \text{ tce}/10^4 \text{ RMB}$ in 1998 to $0.77 \text{ tce}/10^4 \text{ RMB}$ in 2015, which means that there was a continuous improvement of the energy efficiency.

As expected, the energy intensity had a visible mitigating effect on the ERICE in most years. However, in some ambiguous years, e.g., 2001, 2003, and 2015, the energy intensity also had a decline,

but the decline induced a promotional effect on the ERICE (Table 3). The paradox could be clarified by the following two aspects. First, following related studies (Ren et al. 2012; Shao et al. 2011, 2016), the impact of the energy intensity on CO_2 emissions implicated an industrial structure effect, i.e., the energy intensity change of the largest CO_2 emission subsector largely determined the influential direction of energy intensity of the entire industry on the ERICE. With respect to Jiangxi, the average annual ERICE of S33 (production and supply of electric power and heat power, Table 2) was 34.07 Mt and this was much larger than the values of the other sectors, with a nearly 30% share of the total ERICE. The trend of S33's energy intensity change was very close to that of the multiplicative decomposition index of the energy intensity factor (Fig. 6). This indicates that the influential direction of the energy intensity on the ERICE changes largely depends on S33's energy intensity change. Second, the rebound effect mentioned above could be used to illuminate this “paradox”. In these years, the energy intensity declined, which means that the energy efficiency had a certain increase. So, if the investment and R&D activities were targeting production expansion, then the energy consumption and carbon emissions were added and augmented. Thus, a promotional effect on the ERICE appeared. Some scholars (Ren

Fig. 6 Trends of the energy intensity change rate of the S33 subsector and multiplicative decomposition index of the energy intensity factor



et al. 2012; Shao et al. 2011, 2016) have argued that a rebound phenomenon has surely existed in China. Therefore, it can be inferred that the efforts of reducing energy intensity also did not always decrease energy consumption and CO₂ emissions in Jiangxi. However, overall, the energy intensity had a prominent mitigating (negative) effect on the ERICE. However, our results indicate that the energy intensity was not the most effective factor for mitigating the ERICE and its contribution was less than that of the R&D efficiency in the light of both the average annual contribution rate and the overall contribution over the period of 1998–2015 (Tables 4 and 8). This difference can be explained by the following text on the basis of the microeconomic scale.

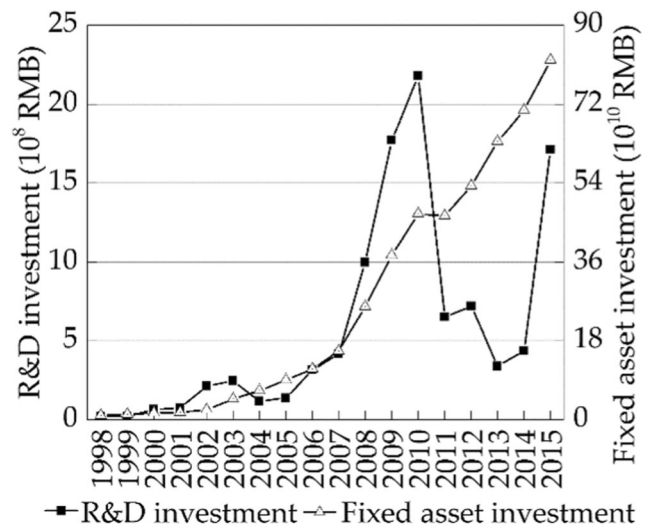
Drivers of microeconomic scale

An enterprise's investment behavior is an important research object of microeconomics. Therefore, the investment intensity was also considered as a potential driver to the ERICE and introduced in the LMDI decomposition progress during this investigation. This is the so-called investment intensity effect. Moreover, the R&D expenditure among the investment was employed as a proxy for technological progress. Generally, technological progress can be considered to be a crucial factor for driving the promotion of energy efficiency. However, it is an intangible characteristic and is difficult to measure directly. Therefore, there was a certain practical and guiding significance for us to adopt the R&D

expenditure to represent the technology progress indicator. For decomposition convenience, here, we built two indicators (R&D intensity and R&D efficiency) to jointly reflect the effect of the R&D expenditures. In other words, the R&D effect was divided into a R&D intensity effect and a R&D efficiency effect.

Investment intensity effect The investment intensity had an overall promotional effect on the ERICE of Jiangxi (4.200%, Table 4). The average annual ERICE changes induced by the investment intensity were -2.19, 8.74, -0.54, and -7.19 Mt with the corresponding change rates of -4.08%, 15.59%, -0.43%, and -3.91% for the four stages (Figs. 2 and 4, and Appendix Tables 8 and 9), respectively. This indicates that there was a duality and an indirect improvement trend of its impact on the ERICE of Jiangxi. As depicted in Figs. 7 and 8, the investment amount of Jiangxi's entire industry experienced a steady upward trend, but the evolution of investment intensity was irregular. The increase in the absolute investment amount meant a new round of output growth, which could or could not cause a relevant increase of the energy demand and the ERICE. On one hand, the increasing investment intensity could augment the ERICE through productivity expansion. On the other hand, it could improve energy utilization efficiency in the production processes to partially abate the ERICE through the upgrading production equipment. For example, some scholars (Ren et al.

Fig. 7 Trends of the R&D investment and fixed asset investment of the entire industry of Jiangxi



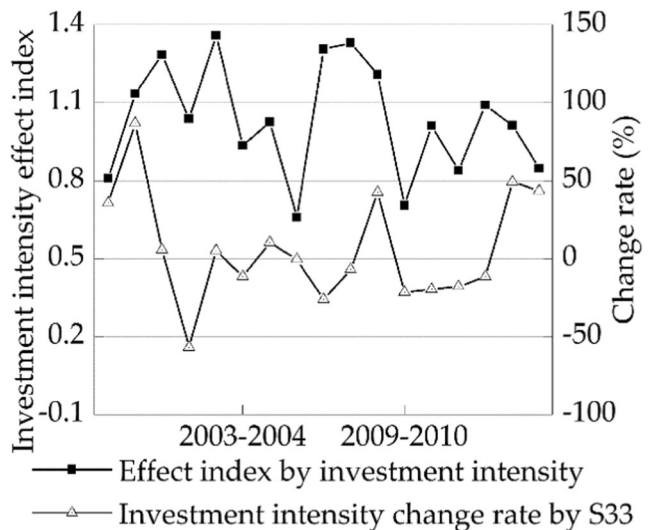
2012; Shao et al. 2011, 2016) have argued that investment in information and communication technology (ICT) equipment played a significant role in improving the energy efficiency in some developed countries and in China.

Consequently, the fact that the influential direction of investment intensity turned positive during the 10th “Five-Year Plan” indicates that the investment was mainly used to augment productivity during the 2000–2005 stage. However, the influential direction of investment intensity turned extremely negative at the 12th “Five-Year Plan”. This indicates that Jiangxi’s industrial enterprises had changed their investment direction towards production equipment with higher energy efficiency under the guidance of the energy-saving and

emission-reduction policy. This finding is consistent with the fact of the social-economic development in Jiangxi. In the end, the S33’s investment intensity change could, to some extent, explain the direction change of the investment intensity effect on the ERICE. This was because the S33’s change rate and effect index had very similar trends, although the latter had a more intensive fluctuation as depicted in Fig. 8.

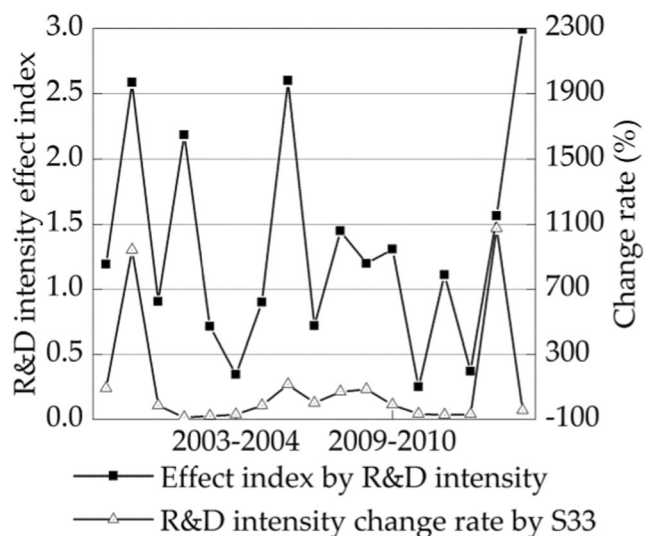
R&D intensity effect The actual contribution of R&D activities to reduce the ERICE largely depends on whether R&D activities were typically targeted at energy saving and emission reduction. Therefore, like the investment intensity, R&D intensity and its induced technological progress could bring either a positive or a negative effect

Fig. 8 Trends of the investment intensity change rates of S33 and the multiplicative decomposition index of the investment intensity effect on the ERICE



on mitigating the ERICE. If the R&D activities were mainly made to develop energy-saving and emission-reduction technologies or cleaner production technologies, then the induced technological progress would promote energy efficiency, carbon productivity, and the utilization of renewable-energy sources to facilitate the abatement of CO₂ emissions. In this case, the technological progress was entitled as green technological progress, which is regarded as the permanent driving force of energy saving and emission reduction (Ren et al. 2012; Shao et al. 2011, 2016). Conversely, if the R&D activities were mainly exerted to develop new products and improve the productivity of input factors, especially physical capital, then the induced technological progress would cause the expansion of production and increases of the input factors, including energy. This goes against the achievement of energy saving and emission reduction. As expected, the R&D intensity had a mitigating effect on the ERICE in some years, but it also had a positive effect in some other years (Table 3 and Fig. 2). During the four stages, the R&D intensity had an obvious fluctuating effect on the ERICE. Particularly, the average annual ERICE changes resulting from the R&D intensity effect were 30.88, -12.79, 36.13, and -24.59 Mt (Fig. 2 and Appendix Table 8), respectively. The reason behind the changes can be found in the comparison between the two trends of R&D intensity change rates of S33 and that of the multiplicative decomposition index of the entire R&D intensity (Fig. 9). As the largest ERICE subsector, S33's R&D intensity change, to some extent, determined the influential direction of entire R&D intensity on the ERICE.

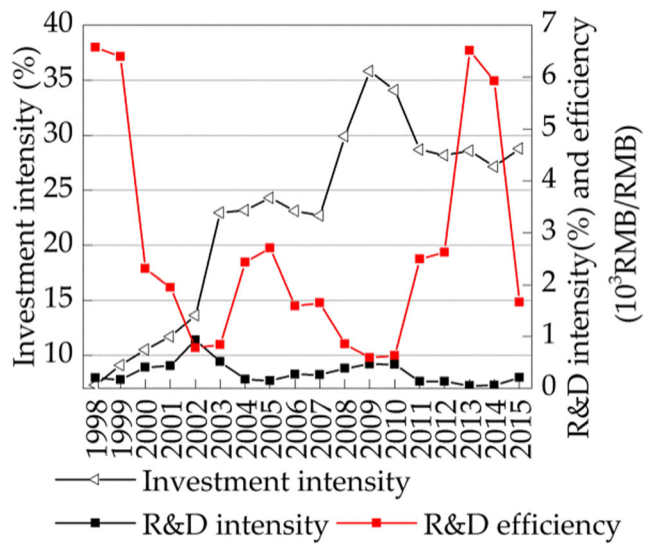
Fig. 9 Trends of the R&D intensity change rates of S33 and the multiplicative decomposition index of the R&D intensity effect on the ERICE



In fact, the R&D intensity itself also experienced similar but smaller fluctuations. It increased from 0.21% in 1998 to 0.41% in 2000, then, decreased to 0.15% in 2005, with a peak value in 2002. After that, the R&D intensity increased to 0.46% in 2010 and decreased again to 0.21% in 2015 (Fig. 10). The total R&D expenditure had relatively obvious fluctuations and a total growth from 22.01 million RMB in 1998 to 1.71 billion RMB in 2015 (Fig. 7). However, at the same time, the fixed asset investment had a steady increase from 10.60 billion RMB in 1998 to 820.67 billion RMB in 2015 and had no obvious fluctuations (Fig. 7). The difference between the increase rates of these two indices was not obvious, as the fluctuations of the R&D intensity were small (Fig. 10). However, so far, a satisfactory explanation of the R&D intensity effect on the ERICE has not been determined. For example, the total contribution of the R&D intensity to the ERICE was a positive 162.13% during the period of 1998–2015 (Table 3). This would be much clearer if the R&D efficiency and the R&D intensity were put together for a comprehensive analysis.

R&D efficiency effect The average annual ERICE changes resulting from the R&D efficiency effect were -28.69, 4.05, -35.59, and 31.78 Mt with the corresponding change rates of -32.34%, 6.12%, -15.15%, and 32.26% at the four stages (Figs. 2 and 4; Appendix Tables 8 and 9), respectively. Such results also imply an unstable effect of the R&D efficiency on the ERICE. As discussed above, this factor is closely related to the focus of the R&D effort from industrial enterprises,

Fig. 10 Trends of the R&D intensity, the investment intensity, and the R&D efficiency of entire industry in Jiangxi

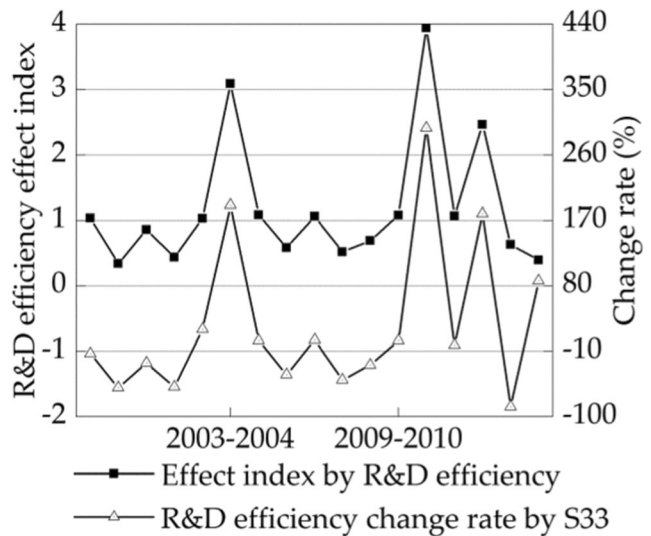


whose R&D activities are not always conducted for energy savings and emission reductions. Only when the R&D investment is used for improving energy efficiency and reducing emission, can the ERICE be mitigated. This is similar to the investment intensity, the clue behind the changes could also be found in the comparison between the two trends of the R&D efficiency change rates of S33 and of the multiplicative decomposition index of the entire R&D efficiency (Fig. 11). As the largest ERICE subsector, S33’s R&D efficiency change, to some extent, determines the influential direction of entire R&D efficiency on the ERICE.

It is noteworthy that the R&D efficiency is presented an evidently fluctuating, which was just opposite of the

R&D intensity (Fig. 10). For example, during the first stage (1998–2000), the contribution of the R&D intensity to the ERICE was obviously positive, but the corresponding contribution of the R&D efficiency was evidently negative (Table 4 and Fig. 4). The positive effect of the R&D intensity means that the R&D expenditures of Jiangxi might have been mainly exerted to develop new technology and improve the utilization efficiency for energy savings and emission reductions during 1998–2000. Thus, the R&D expenditures used to expand products’ amount were smaller and smaller. The corresponding output and the ERICE were also smaller and smaller. Therefore, the mitigating effect of the R&D efficiency on the ERICE was more and more obvious

Fig. 11 Trends of the R&D efficiency change rates of S33 and the multiplicative decomposition index of the R&D efficiency effect on the ERICE



(the negative effect of the R&D efficiency). Then, it can also be seen in Table 3 that the total contributions of the R&D intensity and the R&D efficiency were 162.13% and -233.52%, respectively. The average annual contribution rates of these two factors were 9.537% and -13.737% (Table 4), respectively. This means that the aggregated R&D effect (intensity effect and efficiency effect) would still be mitigating (negative, $162.13 - 233.52\% = -71.39\%$, $9.537 - 13.737\% = -4.200\%$) to the ERICE. In other words, the technological progress reflected by these two indicators is still a prominent factor for abating the ERICE in Jiangxi. This is consistent with most of the related studies (Ren et al. 2012; Shao et al. 2011, 2016). Thus, we can say that the R&D intensity and R&D efficiency should be considered comprehensively when decomposing the ERICE changes, because they can commonly reflect the direction of the R&D activities or technological progress.

Strategies for reducing the ERICE

Based on these results discussed above, some particular strategies or measures for reducing the ERICE of Jiangxi Province are proposed as follows. These strategies can also undoubtedly improve the energy use efficiency of the local government. First, industrial output is the most prominent driving force for the ERICE growth in this region (33.212%), but it is not feasible to abate the ERICE by decelerating industrial development and inhibiting the need for a better life for people. Therefore, the Jiangxi's government has to seek a trade-off between economic development and emission reductions. Emission-reduction policies should contribute to counteract the output effect by activating compositional and technological effects. In other words, Jiangxi also has to experience a structural and technological emission reduction process. This goal can come true only by transforming the pattern of Jiangxi's economic growth. For example, a circular economy should be promoted so that the total consumption of fossil fuels and raw materials, and the corresponding ERICE can be minimized. As a result, the energy use efficiency of the local government can also be greatly improved.

Then, following output, R&D intensity and investment intensity also extremely drive the growth of the ERICE. Their average annual contribution rates were 9.537% and 4.200%, respectively. In addition, their promotional effects had obvious fluctuations. However, like the output, it is also not feasible to abate the ERICE

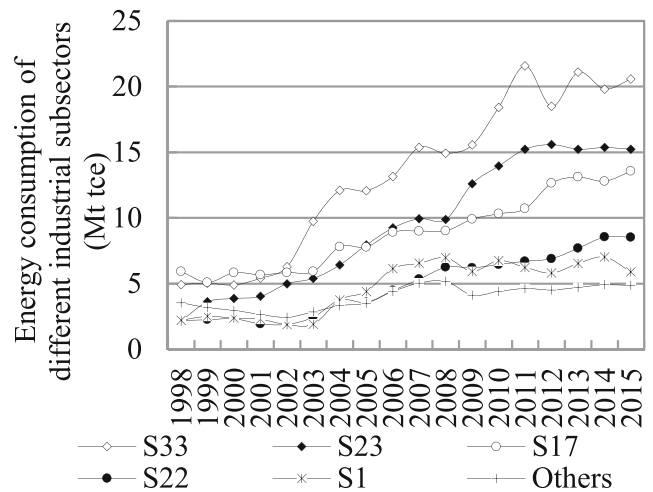
by decelerating the corresponding activities of these two drivers. Thus, the same routes or measures for improving the energy use efficiency of Jiangxi can also be used, as discussed above, to reduce the regional ERICE.

In addition, the effect of the energy structure on the ERICE is also positive, and it is the weakest factor with an average annual contribution rate of 0.017%. This indicates that the energy structure adjustment toward improving energy efficiency to abate the ERICE is still an arduous process in Jiangxi in the short term. However, the energy structure adjustment has a large potential for improving the energy use efficiency of the local government through a reasonable design of green energy policies, etc. (Shao et al. 2016). In other words, we cannot ignore the potential role of energy structure optimization in improving energy efficiency and reducing the ERICE's absolute amount in the long run.

However, the R&D efficiency of industrial enterprises plays a crucial role in mitigating the ERICE (-13.737%). As mentioned above, the enterprises' R&D investment decisions also often tended to focus on expanding production amount, which went against the emission reduction efforts. Therefore, the government should enhance the promotional effect of some fiscal policies so that enterprises will pay more attention to converting their investment direction towards energy savings and emission reductions. For example, some regulatory policy instruments, such as a carbon-reduction liability, carbon emission audits, and carbon labels could be implemented to encourage industrial firms to improve their energy efficiency and carbon emission performance.

The energy intensity is also one of the key factors in abating the ERICE in Jiangxi (-11.625%), which was slightly less than the expected value ($11.652\% < 13.737\%$), due to the rebound effect. Thus, in Jiangxi, the effects of energy intensity could bring desired emission-reduction only if the rebound effect was effectively restricted. Therefore, a more rational policy design should fully consider the potential rebound effect and restrict it through a market-oriented policy mix, especially the marketization reform of energy pricing. To sum up, as found in the studied period of 1998–2015, to reduce the energy intensity unceasingly of the entire industry to improve the corresponding energy use efficiency, while inhibiting the possible rebound effect, will also serve as a long-term development strategy for the local government.

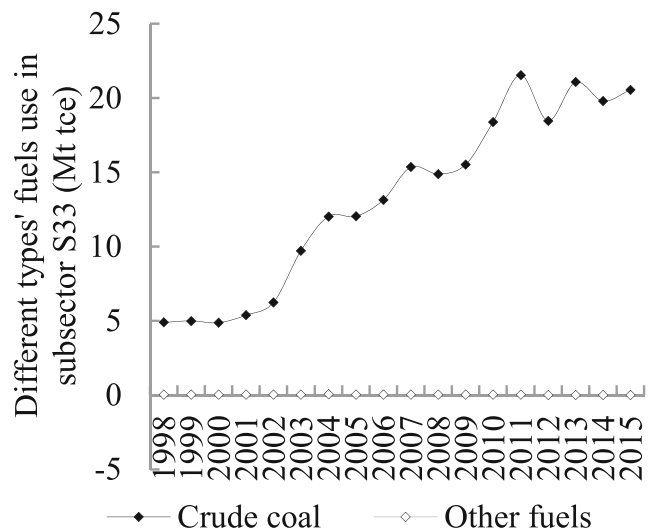
Fig. 12 Dynamics' changes of energy consumption of industrial subsectors in Jiangxi



Industrial structure adjustment presented an overall mitigating effect on the ERICE (−7.804%), which indicates that production resources' reallocation among different subsectors can drive the ERICE reduction over the long run. For example, these subsectors' development of light and advanced manufacturing with low energy consumptions and high added value should be the focus. In addition, the development of clean and renewable-energy subsectors such as the photovoltaic battery industry, and the solar power generation industry should also be promoted. Meanwhile, those energy-intensive industries with obsolete technologies and efficiencies should be gradually phased out. Particularly, for a more in depth analysis of the carbon reduction focus or the direction of industrial structure adjustment in

Jiangxi, the data dynamic changes of the energy consumption in different subsectors were drawn and are shown in Fig. 12. The top five energy-intensive subsectors in Jiangxi were S33, S23 (Smelting and Pressing of Ferrous Metals), S17 (Processing of Petroleum, Coking, Processing of Nuclear Fuel), S22 (Manufacture of Non-metallic Mineral Products), and S1 (Mining and Washing of Coal). The highest energy-intensive subsector was S33. These results are consistent with those discussed above. Thus, these five energy-intensive subsectors should be given priority when designing related ERICE reduction policies. Similarly, the changes of different types of fuels used in subsector S33 were also drawn and are shown in Fig. 13. It can easily be seen that the energy consumption of

Fig. 13 Different types' fuels use in subsector S33



S33 was almost entirely composed of crude coal use and the use of other fuels was almost equal to zero (Fig. 13). In reality, the energy consumptions of subsectors S23, S17, S22 and S1 had a structure similar to that of S33 but were omitted for saving space. Therefore, in Jiangxi, the government should positively implement the utilization of clean-coal technology, greatly promote the development of renewable-energy, etc. to ultimately improve the efficiency of energy use. These results are also consistent with those discussed above.

Conclusions

So far, there have been few scientists who have analyzed the ERICE drivers from both the macroeconomic and the microeconomic scales, especially for underdeveloped regions. Hence, in this investigation, taking the Jiangxi Province of China as the study case, we computed the ERICE and decomposed its drivers from both of these scales by using an extended LMDI model. In this model, we not only decomposed the ERICE changes of Jiangxi over the period of 1998–2015 into four conventional factors from the macroeconomic scale but also introduced specifically three novel factors from the microeconomic scale. Particularly, the macroeconomic factors were output, industrial structure, energy intensity and energy structure. In addition, the microeconomic factors were investment intensity, R&D intensity and R&D efficiency.

The numerical results showed: among the promotion factors of the ERICE, output growth was the most prominent driving force due to rapid industrialization and urbanization in the most recent 20 years. Its average annual contribution rate was 33.212%. Following this factor, R&D intensity had the next highest effect on the growth of the ERICE. The next promotion factor was investment intensity. Their promotional effects had obvious fluctuations and the average annual contribution rates were 9.537% and 4.200%, respectively. The effect of the energy structure on the ERICE was also positive, and it was the weakest factor with an average annual contribution rate of 0.017%. In contrast, the R&D efficiency presented the most obvious mitigating effect on the ERICE (−13.737%). Energy intensity and industrial structure followed this factor. Their average annual contribution rates were −11.652% and −7.804%, respectively.

Thus, it was found that, to improve the energy efficiency of Jiangxi and reduce the ERICE, the local government had to transform the pattern of economic growth, e.g., a circular economy should be promoted. Then, people could not ignore the potential role of energy structure optimization over the long run. Third, some regulatory policy instruments related to R&D investment, such as carbon-reduction liability, carbon emission audits, and carbon labels could be implemented to encourage industrial firms to improve their energy efficiency and carbon emission performance. Fourth, as in the studied period of 1998–2015, reducing the energy intensity unceasingly while inhibiting the possible rebound effect should serve as a long-term strategy for the local government. The industrial development of light and advanced manufacturing with low energy consumption and high added values should be promoted. Meanwhile, those energy-intensive industries with obsolete technologies and efficiencies should be gradually phased out. Particularly, the top five energy-intensive subsectors (S33, S23, S17, S22, and S1) should be given priority when designing related ERICE reduction policies. Last, the government should positively implement the utilization of clean-coal technology and greatly promote the development of renewable-energy, etc.

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Authors' contributions Junsong Jia and Chundi Chen designed the research; Huiyong Jian performed it and analyzed the result with the help of Dongming Xie; Junsong Jia wrote almost all the text of first submission with the help of Zhongyu Gu; Zhihai Gong completed the second and third revisions under the direction of Junsong Jia. All authors read and approved the final manuscript.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Appendix

Fig. 14 Multiplicative decomposition results of Jiangxi's ERICE changes in the three "Five-Year Plan" periods and the entire period (Ψ_{C_f} , $\Psi_{C_{ES}}$, $\Psi_{C_{EI}}$, $\Psi_{C_{RE}}$, $\Psi_{C_{RI}}$, $\Psi_{C_{II}}$, $\Psi_{C_{IS}}$, and Ψ_{C_O} denoted the effects of emission coefficient, energy structure, energy intensity, R&D efficiency, R&D intensity, investment intensity, industrial structure, and output on the ERICE changes, respectively). **a** 2000–2005. **b** 2005–2010. **c** 2010–2015. **d** 1998–2015

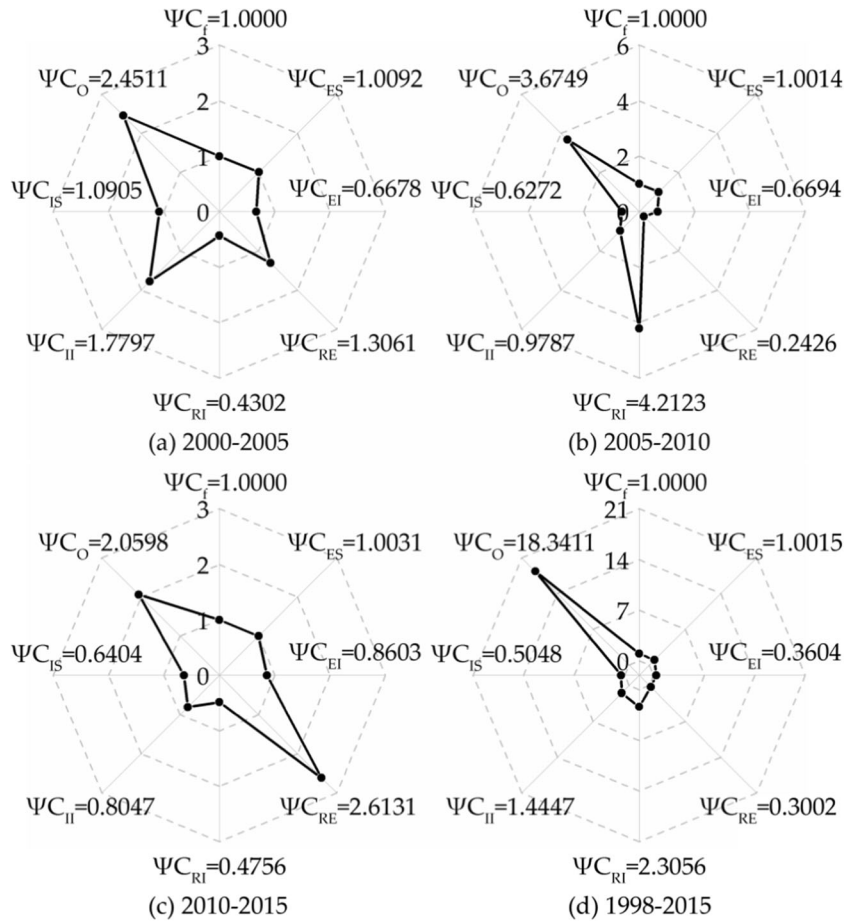


Table 5 Emission coefficients of nine energy sources

Fuel	Net calorific value (TJ/Gg) ^a	Carbon content (kg/GJ) ^a	Carbon oxidation rate (%) ^b	Emission coefficient (unit: 10 ⁴ t CO ₂ /10 ⁴ t or 10 ⁴ t CO ₂ /10 ⁸ m ³ (for gas))
Raw coal	20.908	26.1	91.6	1.8300
Cleanedcoal	26.344	25.8	98.0	2.4423
Other cleaned coal	8.400	25.8	99.8	0.7890
Coke	28.435	29.2	92.8	2.8252
Crude oil	41.816	20.0	97.9	3.0021
Gasoline	43.070	18.9	98.0	2.9251
Kerosene	43.070	19.6	98.6	3.0520
Diesel	42.652	20.2	98.2	3.1022
Fuel oil	41.816	21.1	98.5	3.1866

^a The value is from the IPCC recommended value

^b The value is from Ren et al. (2012) and Shao et al. (2011, 2016); 1TJ = 10³ GJ = 10¹² J

Table 6 The ERICE results of various subsectors in Jiangxi during 1998–2015 (unit: 10⁴ t)

Sector	1998	1999	2000	2001	2002	2003	2004	2005	2006
S1	565.00	641.18	607.47	583.03	479.80	488.14	964.73	1128.06	1578.52
S2	0.08	0.16	0.12	0.05	0.06	0.28	4.48	4.67	13.63
S3	10.38	9.80	9.17	7.65	7.51	6.22	14.61	7.89	12.23
S4	39.59	35.13	38.55	25.47	18.81	43.20	5.53	18.38	41.43
S5	2.11	1.50	0.71	0.85	0.25	12.01	12.17	10.95	17.63
S6	39.63	42.73	30.18	20.89	19.84	27.34	66.53	88.49	136.94
S7	8.65	11.66	12.37	11.63	9.08	16.90	19.21	24.24	26.00
S8	3.08	3.80	4.00	5.66	5.24	4.87	5.80	6.32	11.95
S9	48.35	53.18	55.80	46.72	38.13	40.27	33.96	45.23	47.67
S10	0.64	0.38	0.10	0.25	0.21	0.23	0.84	4.96	6.75
S11	1.41	1.07	1.09	0.76	0.39	1.05	0.96	1.17	1.90
S12	28.48	27.36	30.55	31.16	28.74	19.73	23.72	17.41	15.28
S13	0.43	0.71	0.18	0.04	1.05	0.02	0.07	0.58	1.10
S14	71.99	82.38	86.12	79.77	45.32	33.18	36.97	30.53	130.23
S15	0.78	0.84	0.66	0.66	0.58	0.47	0.46	2.28	2.35
S16	0.10	0.09	0.21	0.00	0.43	0.31	0.12	0.84	0.87
S17	1365.63	1127.38	1276.90	1253.52	1297.17	1309.69	1770.47	1780.95	2040.51
S18	396.34	313.53	286.77	276.92	271.96	257.56	370.02	305.47	285.22
S19	43.67	33.50	31.42	26.01	28.45	50.68	41.52	46.94	47.39
S20	47.38	45.85	34.35	25.30	29.03	87.89	52.72	124.84	110.36
S21	5.33	10.47	5.00	10.54	4.66	5.64	13.28	12.42	12.75
S22	560.04	574.10	592.28	496.22	485.18	626.88	962.32	914.13	1144.62
S23	611.18	1009.26	1078.58	1121.91	1391.62	1509.55	1801.02	2219.96	2583.99
S24	65.14	61.83	60.17	58.91	57.39	66.61	80.28	77.49	121.17
S25	7.95	4.34	5.03	2.56	3.88	5.30	7.01	6.42	9.09
S26	22.82	12.71	11.65	6.60	8.06	5.29	16.12	7.84	11.20
S27	7.07	5.25	4.73	1.49	3.41	3.02	2.34	3.61	4.03
S28	14.22	16.12	14.93	14.10	19.97	18.48	19.69	22.20	22.39
S29	12.49	6.92	4.66	3.60	3.60	3.08	5.01	7.94	10.71
S30	5.09	2.00	1.67	1.57	1.32	1.01	0.57	1.39	2.82
S31	2.39	1.46	1.59	1.38	1.49	1.34	1.02	0.61	1.01
S32	25.42	23.40	23.98	11.25	10.49	12.07	4.52	7.24	7.19
S33	1261.90	1287.03	1253.06	1384.68	1606.54	2497.62	3094.22	3091.62	3371.06
S34	3.37	2.51	3.12	4.25	3.44	3.54	6.16	5.08	1.77
S35	0.14	0.94	0.17	0.14	1.52	0.14	0.19	0.27	1.45
Total	5278.27	5450.54	5567.35	5515.52	5884.61	7159.60	9438.65	10,028.41	11,833.19
Sector	2007	2008	2009	2010	2011	2012	2013	2014	2015
S1	1683.06	1794.37	1527.27	1738.72	1607.57	1485.18	1675.15	1798.05	1509.89
S2	13.80	16.53	12.28	15.32	14.57	13.33	15.33	12.45	10.51
S3	21.34	16.49	10.54	11.05	8.52	9.28	6.52	6.78	5.53
S4	48.99	70.17	69.86	52.72	34.59	34.54	138.04	132.16	103.89
S5	22.97	31.02	27.79	22.20	25.96	38.04	39.87	33.75	34.85
S6	155.24	196.29	165.98	164.24	171.18	170.79	80.14	80.13	91.15
S7	31.79	33.71	23.64	22.58	19.30	18.49	21.22	17.09	16.17
S8	4.57	3.31	3.54	3.25	3.19	3.32	3.94	2.24	1.67

Table 6 (continued)

S9	46.25	38.36	24.28	24.08	21.85	15.76	13.41	11.79	11.96
S10	7.14	7.48	5.86	7.46	3.83	5.23	4.84	3.81	3.37
S11	1.93	1.81	1.93	2.80	2.19	3.28	3.89	3.76	3.72
S12	15.08	13.19	9.28	6.83	4.20	2.52	2.60	2.02	1.62
S13	1.07	2.00	1.66	0.85	1.13	1.18	0.79	1.00	1.25
S14	129.93	122.40	85.74	116.54	115.73	111.62	113.09	156.24	161.60
S15	1.41	1.18	1.01	1.02	0.87	0.74	2.76	2.96	3.08
S16	1.25	1.34	1.16	1.32	2.07	3.23	5.00	4.43	3.45
S17	2086.20	2069.06	2278.69	2375.57	2515.89	2976.87	3089.27	3056.16	3186.74
S18	298.60	373.24	277.49	293.36	344.74	301.92	338.76	384.53	381.75
S19	51.13	51.87	37.60	39.25	37.68	42.93	39.80	41.05	45.22
S20	171.77	53.40	45.55	52.42	88.12	105.52	114.87	103.71	115.38
S21	18.96	21.13	20.28	19.04	13.01	12.67	13.08	13.42	15.03
S22	1365.23	1598.08	1588.27	1650.04	1717.04	1765.68	1968.24	2184.41	2182.47
S23	2789.40	2768.47	3531.28	3899.28	4264.32	4358.56	4259.93	4297.74	4255.43
S24	157.90	175.57	145.96	162.98	164.49	178.22	172.43	174.47	172.85
S25	9.83	11.49	9.41	8.76	7.79	7.63	7.15	7.34	7.44
S26	14.13	14.30	9.79	10.14	9.75	7.83	8.13	6.34	6.12
S27	4.72	4.65	4.97	4.40	4.02	5.82	6.38	8.43	9.37
S28	21.90	21.81	21.69	28.72	29.23	23.35	20.52	16.19	8.41
S29	9.72	16.00	14.15	16.39	14.71	20.09	17.85	16.41	14.21
S30	2.52	3.45	2.73	2.63	1.75	1.56	2.01	2.33	1.23
S31	1.17	1.07	0.23	0.42	0.35	0.10	0.09	0.07	0.13
S32	9.37	3.39	2.61	3.06	2.25	1.58	0.74	0.86	1.05
S33	3938.49	3820.28	3982.11	4718.22	5527.17	4734.72	5403.67	5074.55	5270.22
S34	1.94	1.95	0.37	18.09	19.64	0.44	0.31	0.30	0.29
S35	0.37	0.35	0.36	0.36	0.22	0.22	0.26	0.28	0.38
Total	13,139.20	13,359.20	13,945.38	15,494.11	16,798.91	16,462.24	17,590.09	17,657.22	17,637.41

Table 7 Detailed multiplicative decomposition results of the ERICE changes

Stage	$\Psi_{C_{TOT}}$	$\Psi_{C_{ES}}$	$\Psi_{C_{EI}}$	$\Psi_{C_{RE}}$	$\Psi_{C_{RI}}$	$\Psi_{C_{II}}$	$\Psi_{C_{IS}}$	$\Psi_{C_{O}}$
1998–1999	1.0326	0.9880	0.9706	1.0380	1.1912	0.8088	1.1144	0.9663
1999–2000	1.0214	0.9977	0.9598	0.3403	2.5876	1.1355	0.9850	1.0828
2000–2001	0.9907	1.0021	1.0058	0.8608	0.9045	1.2844	1.0140	0.9693
2001–2002	1.0669	1.0008	0.8535	0.4408	2.1859	1.0379	1.0864	1.1498
2002–2003	1.2167	0.9998	1.0292	1.0320	0.7133	1.3585	0.9540	1.2394
2003–2004	1.3183	1.0052	0.8875	3.0935	0.3452	0.9365	1.0714	1.3793
2004–2005	1.0625	1.0012	0.8489	1.0853	0.8977	1.0264	0.9665	1.2936
2005–2006	1.18	1.0004	0.9674	0.5833	2.6011	0.6591	0.9060	1.3458
2006–2007	1.1104	1.0027	0.9349	1.0664	0.7185	1.3051	0.8630	1.3726
2007–2008	1.0167	0.9985	0.8613	0.5192	1.4488	1.3294	0.9478	1.2474
2008–2009	1.0439	1.0002	0.9349	0.6913	1.1972	1.2082	0.9178	1.2163
2009–2010	1.1111	0.9996	0.9068	1.0836	1.3084	0.7053	0.9321	1.3151
2010–2011	1.0842	1.0035	0.9790	3.9408	0.2508	1.0120	0.9388	1.1756
2011–2012	0.98	0.9994	0.9141	1.0703	1.1112	0.8408	0.9208	1.1650
2012–2013	1.0685	1.0007	0.9892	2.4701	0.3709	1.0914	0.9205	1.1727
2013–2014	1.0038	1.0025	0.9567	0.6304	1.5655	1.0133	0.8929	1.1723
2014–2015	0.9989	0.9968	1.0184	0.3943	2.9906	0.8480	0.8983	1.0954
2000–2005	1.8013	1.0092	0.6678	1.3061	0.4302	1.7797	1.0905	2.4511
2005–2010	1.545	1.0014	0.6694	0.2426	4.2123	0.9787	0.6272	3.6749
2010–2015	1.1383	1.0031	0.8603	2.6131	0.4756	0.8047	0.6404	2.0598
1998–2015	3.3415	1.0015	0.3604	0.3002	2.3056	1.4447	0.5048	18.3411

Table 8 Detailed additive decomposition results of the ERICE changes (unit: 10^4 t)

Stage	ΔC_{TOT}	ΔC_{ES}	ΔC_{EI}	ΔC_{RE}	ΔC_{RI}	ΔC_{II}	ΔC_{IS}	ΔC_O
1998–1999	172.28	-64.56	-160.26	200.07	938.48	-1138.55	580.84	-183.75
1999–2000	116.81	-12.59	-225.84	-5937.61	5237.41	700.20	-83.23	438.47
2000–2001	-51.83	11.45	32.31	-830.39	-556.44	1386.83	77.19	-172.79
2001–2002	369.10	4.77	-902.92	-4668.20	4456.09	212.11	471.95	795.30
2002–2003	1274.98	-1.06	187.06	204.57	-2196.50	1991.94	-306.35	1395.34
2003–2004	2279.06	42.51	-984.25	9313.12	-8772.16	-540.96	568.57	2652.22
2004–2005	589.76	11.46	-1594.41	796.80	-1050.28	253.48	-331.90	2504.62
2005–2006	1804.78	4.12	-361.14	-5878.24	10,425.28	-4547.03	-1077.12	3238.92
2006–2007	1306.00	33.34	-840.14	802.06	-4123.77	3321.71	-1838.06	3950.86
2007–2008	220.01	-19.25	-1978.92	-8683.63	4911.52	3772.11	-710.81	2928.98
2008–2009	586.18	2.99	-918.92	-5038.81	2457.35	2581.46	-1170.99	2673.10
2009–2010	1548.72	-5.19	-1439.04	1180.44	3953.23	-5133.68	-1034.83	4027.78
2010–2011	1304.80	55.93	-341.71	22,130.82	-22,323.02	192.20	-1019.92	2610.50
2011–2012	-336.67	-10.33	-1493.79	1129.11	1753.84	-2882.95	-1372.92	2540.36
2012–2013	1127.85	11.67	-184.93	15,390.66	-16,879.94	1489.28	-1410.60	2711.73
2013–2014	67.12	44.43	-781.00	-8131.88	7898.67	233.21	-1997.31	2801.00
2014–2015	-19.80	-57.24	322.53	-16,423.33	19,332.38	-2909.05	-1893.15	1608.05
2000–2005	4461.06	69.16	-3060.59	2024.03	-6393.81	4369.78	656.42	6796.07
2005–2010	5465.69	17.30	-5042.66	-17,796.64	18,066.88	-270.24	-5860.91	16,351.97
2010–2015	2143.31	51.14	-2488.76	15,890.05	-12,294.86	-3595.18	-7372.90	11,953.83
1998–2015	12,359.15	15.05	-10,455.79	-12,326.24	8557.61	3768.63	-7002.70	29,802.59

Table 9 Cumulative decomposition results of the ERICE changes (1998 = 1)

Year	ΨC_{TOT}	ΨC_{ES}	ΨC_{EI}	ΨC_{RE}	ΨC_{RI}	ΨC_{II}	ΨC_{IS}	ΨC_O
1999	1.0326	0.9880	0.9706	1.0380	1.1912	0.8088	1.1144	0.9663
2000	1.055	0.9857	0.9316	0.3532	3.0823	0.9184	1.0977	1.0463
2001	1.045	0.9878	0.9370	0.3041	2.7880	1.1796	1.1131	1.0142
2002	1.115	0.9886	0.7997	0.1340	6.0943	1.2243	1.2092	1.1661
2003	1.356	0.9884	0.8231	0.1383	4.3470	1.6632	1.1536	1.4453
2004	1.788	0.9935	0.7305	0.4279	1.5006	1.5576	1.2360	1.9935
2005	1.900	0.9947	0.6201	0.4644	1.3471	1.5987	1.1946	2.5788
2006	2.242	0.9951	0.5999	0.2709	3.5039	1.0537	1.0823	3.4705
2007	2.489	0.9978	0.5608	0.2889	2.5176	1.3752	0.9340	4.7636
2008	2.531	0.9963	0.4830	0.1500	3.6474	1.8282	0.8852	5.9421
2009	2.642	0.9965	0.4516	0.1037	4.3667	2.2088	0.8125	7.2274
2010	2.936	0.9961	0.4095	0.1123	5.7134	1.5579	0.7573	9.5048
2011	3.183	0.9996	0.4009	0.4427	1.4329	1.5766	0.7110	11.1738
2012	3.119	0.9990	0.3665	0.4739	1.5923	1.3256	0.6547	13.0175
2013	3.333	0.9997	0.3625	1.1705	0.5906	1.4467	0.6026	15.2656
2014	3.345	1.0022	0.3468	0.7379	0.9245	1.4660	0.5381	17.8958
2015	3.3417	0.9990	0.3532	0.2909	2.7649	1.2431	0.4833	19.6031

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