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Development of New Products and Energy Consumption in Industrial Production: Relationship and Evidence From China

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Will energy consumption decrease when producers implement some innovative activities in industrial production? As a special but important innovation, how development of new products impacts energy consumption is a valuable issue. This study proposes a model to analyze the relationship of energy consumption and development of new products and finds that development of new products and production probably increases total energy consumption and energy intensity by output simultaneously since the productivity of producing new products may be lower than those existing goods with mature processes in industrial production. Producers develop new products with cleaner technology by saving energy or/and with higher initial productivity is possible to decrease energy consumption. After theoretical analysis, this study empirically tests the correlation between development of new products and energy consumption by using 2016–2019 data of Chinese industry and reveals that development of new products and production increased total energy consumption and energy intensity by output in industrial production, but decreased the usage and intensity of a special final energy product as gasoline. These findings indicate that the Chinese industrial sector developed new products with cleaner technology by only saving gasoline. The effect of total energy saving by implementing innovative activities with new product development in industrial production was very limited in China. Chinese industry consumes huge amounts of energy and spends a lot of money on development of new products; policy makers with the vision of innovative and green development need to balance development of new products and energy consumption.

Keywords: development of new products, energy consumption, industrial production, innovative activity, sustainable development

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INTRODUCTION

Earth, as a home where humans live together, provides many natural resources for production and operation in any economy. Fossil fuels are a limited natural resource and humankind has used a large quantity of energy from the Earth. In China, huge energy consumption and some associated public problems have attracted worldwide attention, with the United States and India being the top three consumers of energy in the world (Wang et al., 2020). As a public resource, fossil fuels in some regions are likely to be overexploited, and concerns of energy sustainability are leading to policy makers implementing some strict regulations. Natural resources are an important gift from the Earth. Some ancient Chinese philosophers discovered that people often overuse these natural resources. For example, *The Works of Mencius* was an important Chinese classic and stated, "The trees of the New Mountain were once beautiful. Being situated, however, in the borders of a large state, they were hewn down with axes and bills; and could they retain their beautiful? Still through the activity of the vegetative life day and night, and the nourishing influence of the rain and dew, they were not without buds and sprouts springing forth, but then came the cattle and goats and browsed upon them."[1] In many economic analyses, the case of the tragedy of the commons could explain how some shared public resources are overused when individuals cannot prevent other people's use (Park, 2010). Policy makers in ancient China also found various disorders, including the overuse of public resources, under conditions of unclear property rights, such as in another Chinese classic *The Book of Lord Shang*, in which Gong-sun Yang said, "That a hundred men will chase after a single hare that runs away, is not for the sake of the hare, for when they are sold everywhere on the market, even a thief does not dare to take one away, because their legal title is definite."[2] Fossil fuels are owned by the state as defined by the country's constitution and other laws, which indicated that Chinese policy makers have some significant powers to prevent fossil fuel overexploitation in local China after 1 October 1949. However, due to total fossil energy consumption steadily increasing with the rapidly increasing usage of new energy in China (Cang et al., 2021), a single restriction on energy production will seriously lead to an imbalance between supply and demand in China's local energy markets, and policy makers should implement an appropriate plan of energy supply and demand in the future (Qiu et al., 2021). Rehman et al. (2021a) indicated that greenhouse gas emissions and coal energy, respectively, have an adversative association with economic growth based on evidence from Pakistan. The growing energy consumption in the Chinese economy has also slowed the process of carbon reduction like in the building sector (Li et al., 2022). From a bibliometric review, the building sector with large energy consumption and carbon emissions impacts the goal of carbon peak and carbon neutrality (Sun et al., 2022). To ease our climate change crisis, Xiang et al. (2022a) developed a calculation tool, named Python-LMDI, for index decomposition analysis, which could quickly obtain results to analyze some issues of building carbon emissions. Although consuming fossil energy will produce carbon emissions and other atmospheric pollutants such as sulfur dioxide and nitrogen oxides (Wang et al., 2019), policy makers cannot directly reduce energy consumption because energy usage is a proxy to measure people's living standards in China (Ma et al., 2021) and, like other economies, that energy is a necessary input in production (Kosemania and Bamgboye, 2021). The economy had to import huge amounts of energy from foreign energy markets in China (Kong et al., 2019).

Energy is mainly consumed in the sector of industry in China (Tang and Peng, 2017). Thus, some public policies that delay the growth rate of energy consumption should focus on adjusting the structure and pattern of industrial production. As a special type of factor, energy consumption per unit output should decrease when technological progress or efficiency improvement appears in production. Energy intensity by GDP, that is, energy consumption per unit of GDP was usually measured as energy efficiency (Zhang et al., 2019) and decreased gradually in China after 2005 based on the information from the *China Energy Statistical Yearbook* 2020. In recent years, China's economy has become increasingly productive on the whole because top designers in the country paid more attention to innovation of technology and science. Hence, the Chinese economy with lower energy intensity by GDP has benefited from some activities with raising economic productivity such as R & D (Huang and Chen, 2020). R & D activities implemented by industrial producers could cut more energy intensity than that of independent R & D institution and higher education (Chen et al., 2019). In the level of total energy usage, Tang et al. (2018) indicated that energy consumption increases with output growth when an economy becomes more productive by proposing a model with a nonlinear market structure characterized by C. E. S based on the framework of Melitz (2003). According to the relationship between energy consumption and carbon emissions, the effect of innovation on CO_2 emission is complicated. Zhu et al. (2022) studied the influence of positive and negative shocks of innovation on CO_2 emissions based on evidence from some developing economies. Carbon dioxide is emitted in the process of some final energy products' production. Murshed et al. (2022) indicated that fossil fuel dependency within power sector impacts the environment like in Argentina since energy production–based carbon emission was large. For economic growth, energy including fossil fuel energy, nuclear energy, and renewable energy has different and dynamic effects (Rehman et al., 2022). In order to coordinate energy consumption and demand, an economy, including developed and developing economies, should forecast production and consumption of some energy products. Manigandan et al. (2021) forecasted the production and consumption of natural gas in the United States, which could provide effective information for policy makers. In the stage of China's development, total energy usage increases and energy consumption per unit of GDP reduces simultaneously when the economy has a higher productivity in production. The requirements of innovative and green development were two important components when China's policy makers implemented a new vision for development in a new era. The relationship between energy consumption and productivity in the whole economy of China was quite clear as described above, but how developing and producing new products impact energy consumption is relatively complicated in economic operation.

Under the condition that the energy supply may not meet the energy demand in many economies, it is of great value to study the impact of some special innovative activities on energy

[1]This is the English version published by *Liaoning People's Publishing House* in 2017 and originally translated by a Scottish sinologist named James Legge (1815–1897).

[2]This is the English version published by *The Commercial Press* in 2006 and originally translated by Jan Julius Lodewijk Duyvendak (1889–1954) who was a Dutchman.

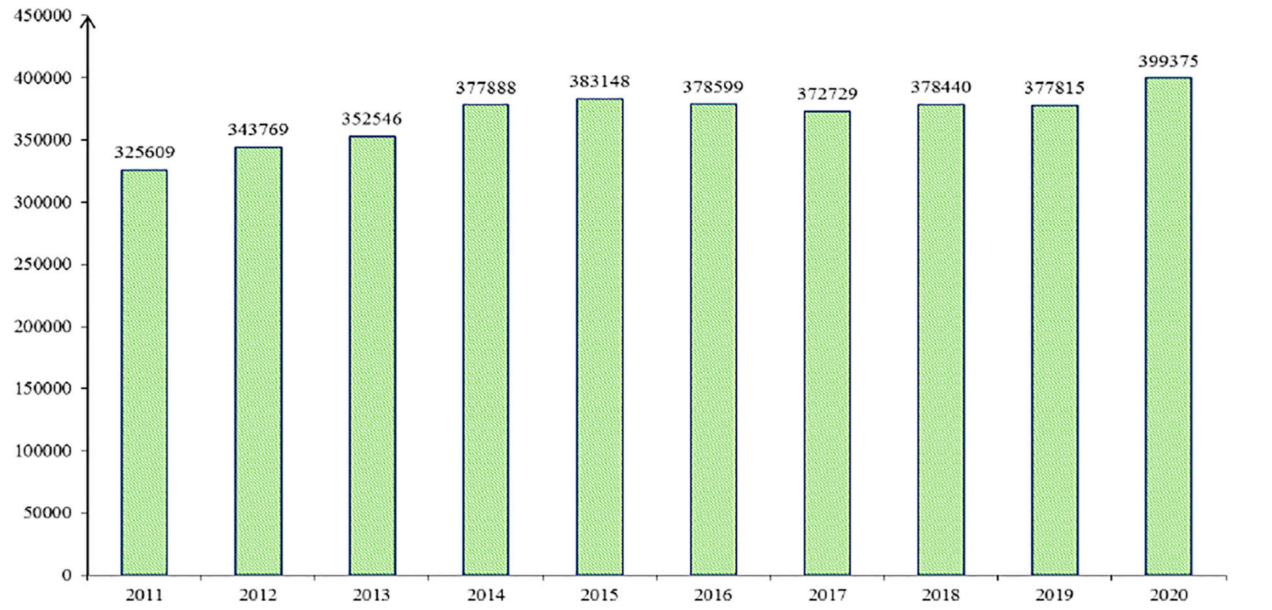

FIGURE 1 | Numbers of industrial enterprises above designated size in China during 2011–2020 (unit). Source: The author searched for the information from the *China Statistical Yearbook* (2012–2021). Note: According to the brief introduction from the *China Statistical Yearbook* 2021, data of main indicators of industrial enterprises above designated size are not comparable with previous years since 2017 based on many reasons. Hence, this figure only provided roughly a trend about the numbers of these enterprises, which was what this study needed.

consumption. Development of new products is a special but important innovative activity, and how it impacts energy consumption in industrial production is a valuable issue which should be addressed in this study. The current knowledge mainly focused on studying how innovative input such as R & D costs impacts energy consumption and its intensity and indicated that energy intensity will be lower along with innovative activities. Producers develop new products to pursue more profits. Energy intensity by output may increase since the process of new product production probably has lower productivity than that of existing goods. This study aims at analyzing the relationship between development of new products and energy consumption and introducing some policy implications with the vision of innovative and green development.

This article will be organized in the following sections as follows: "Basic facts" mainly introduces some associated information in China. I will develop a simple model to analyze how development of new products impacts energy consumption and its intensity in "Theoretical analysis." "Empirical analysis" empirically tests the issue of development of new products and energy consumption based on Chinese evidence. After theoretical and empirical analysis, I will discuss my results and introduce some policy implications in "Discussion." Finally, "Conclusion" is also contained.

BASIC FACTS

To analyze theoretically and test empirically the relationship between energy consumption and development of new products in industrial production, this article first presents and discusses some associated basic facts about China. In the Chinese local economy, the industry sector plays a significant role in economic growth and employment. Industry was subdivided into three industrial segments based on the new version of national standard of industry classification 2017 in China as follows: mining sector with seven smaller sectors, manufacturing sector with 31 smaller sectors, and production and supply of electricity, gas, and water sector with three smaller sectors. Along with economic development, the Chinese statistical authority only recorded sales revenue above 20 million yuan for industrial enterprises which it has named *Industrial Enterprises above Designated Size* since 2011. **Figure 1** shows the numbers of industrial enterprises in China during 2011–2020, and it indicates that the quantity of industrial enterprises above designated size was very large in the economy. Particularly, the quantity of industrial enterprises above designated size in China 2020 was about 400 thousand and more than that in 2019. The global economy declined significantly due to COVID-19 (Mofijur et al., 2021), and Chinese policy makers implemented some supporting policies to help market entities out of business difficulties, and the number of these enterprises increased instead of decreasing in China in 2020. In other words, Chinese industrial production and industrial entities will not be strictly constrained in the short term, even if huge fossil energy is consumed and great pollutants are emitted in the industrial sector.

Increasing total energy consumption in the Chinese local economy has lasted many years, and energy usage in the industrial sector accounts for the largest share based on the information from the *China Energy Statistical Yearbook* 2020.

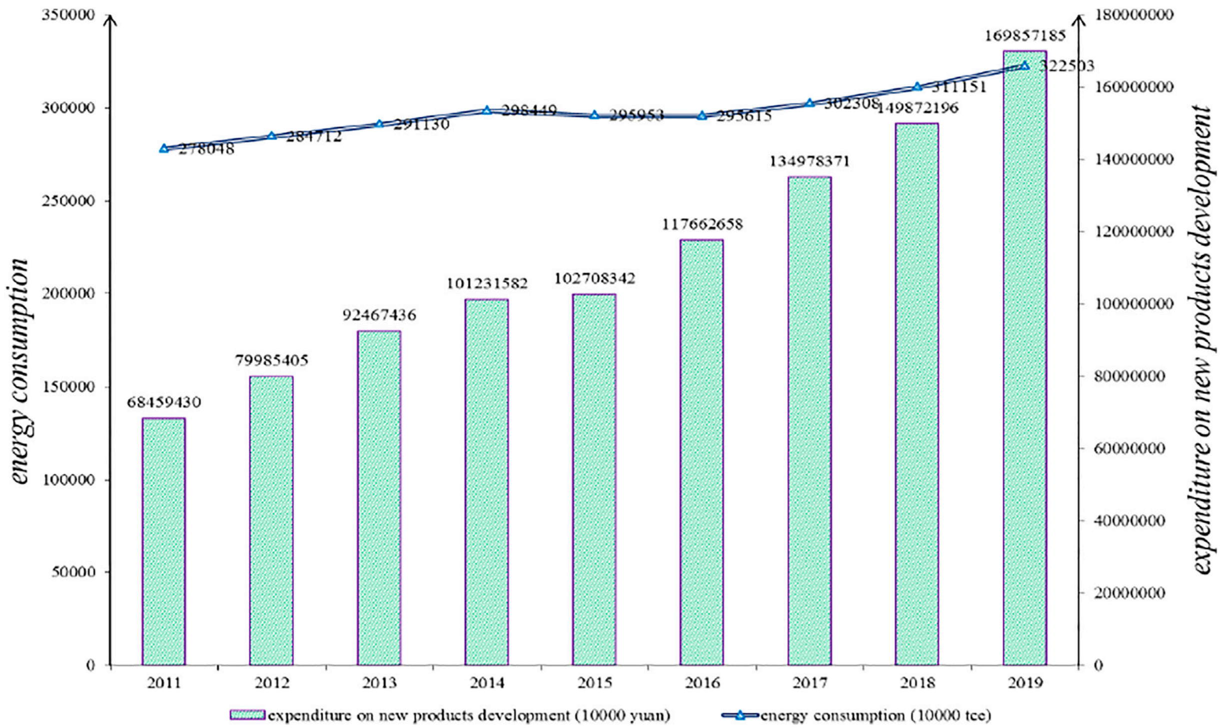

FIGURE 2 | Total energy consumption and expenditure on development of new products by the industrial sector in China during 2011–2019. Source: The author obtained the information from the *China Statistical Yearbook* and the *China Energy Statistical Yearbook* in the relevant years.

Total energy consumption in industry increased on the whole in China during 2011–2019 but declined in 2015 and 2016 compared to the previous years, as shown in **Figure 2**. Even if China's industrial output rapidly increased with technological progress in production, energy consumption in the sector of industry with slight fluctuation indicated that higher productivity could reduce the total energy usage in this sector in some specific years. The total energy consumption must increase when an economy becomes more productive at the developing stage characterized by Tang et al. (2018). As a component in an economy, energy consumption in the industrial sector was easily impacted by technological progress compared to the total energy usage in the economy. Although energy usage in the industrial sector declined in China during 2014–2016, its energy consumption has increased again since 2017.

To develop new products, enterprises have to input a great deal of resources. **Figure 2** also shows the total expenditure on development of new products by the industrial sector in China during 2011–2019, and it indicates that the cost of developing new products rapidly increased in production. Total energy consumption increased with slight fluctuations and total expenditure on development of new products strictly expanded in the industrial sector, indicating that their relationship is not simple.

Industrial enterprises are the basic entities in the process of production; the average energy consumption and expenditure on development of new products among these enterprises could give more information to study some associated issues. **Table 1** shows enterprises' average energy consumption in the smaller 41 industrial sectors in China during 2016–2019 and summarizes the change trend, respectively. Some information that can be found in **Table 1** is as follows: Energy usage per firm changed considerably in different industrial sectors, which indicated that energy played different roles in their production. Enterprises' average energy consumption in 15 sectors strictly increased with five sectors declining during this time, and 18 sectors fluctuating. Particularly, there were three industrial sectors, including manufacture of furniture, printing, reproduction of recording media, and manufacture of electrical machinery and apparatus, that had a basically unchanged average energy consumption for their enterprises in production. For these three industrial sectors, production technology with energy use should be very steady and mature.

For 38 industrial sectors with recorded data, **Table 2** calculates the enterprises' average expenditure on development of new products and indicates that the numbers increased in 26 sectors, the other 12 sectors fluctuated, and no sectors strictly declined. Compared to **Table 1**, all five sectors with reducing average energy consumption had increased average expenditure on development of new products. Of course, there were many sectors with increasing average energy consumption which also had more average expenditure on development of new products. Additionally, the average cost of developing new products in different industrial sectors had a wide variation; in other words, producers in some industrial sectors emphasized new products' innovation more than managers in other sectors.

TABLE 1 | Enterprises' average energy consumption by industrial sector in China during 2016–2019 **(**10^4 tce/unit**)**.

Industrial sector	2016	2017	2018	2019	Trend
Mining and washing of coal	1.87	2.17	2.22	2.38	↑
Extraction of petroleum and natural gas	28.79	31.90	31.04	31.55	~
Mining and processing of ferrous metal ores	0.78	1.01	1.02	1.43	↑
Mining and processing of non-ferrous metal ores	0.65	0.76	0.86	1.02	↑
Mining and processing of nonmetal ores	0.35	0.36	0.39	0.42	↑
Support activities for mining/professional and support activities for mining	1.70	1.76	2.49	1.84	~
Mining of other ores	13.12	17.35	27.81	63.30	↑
Processing of food from agricultural products	0.16	0.17	0.16	0.19	~
Manufacture of foods	0.22	0.22	0.22	0.25	↑
Manufacture of liquor, beverages, and refined tea	0.21	0.21	0.19	0.23	~
Manufacture of tobacco	1.61	1.64	1.71	1.79	↑
Manufacture of textile	0.37	0.40	0.39	0.41	~
Manufacture of textile, wearing apparel, and accessories	0.06	0.06	0.06	0.07	↑
Manufacture of leather, fur, feather, and related products and footwear	0.07	0.07	0.06	0.06	↓
Processing of timber and manufacture of wood, bamboo, rattan, palm, and straw products	0.13	0.12	0.12	0.11	↓
Manufacture of furniture	0.06	0.06	0.06	0.06	-
Manufacture of paper and paper products	0.62	0.65	0.61	0.58	~
Printing, reproduction of recording media	0.09	0.09	0.09	0.09	-
Manufacture of articles for culture, education, arts and crafts, sport, and entertainment activities	0.04	0.05	0.05	0.06	↑
Processing of petroleum, coking and processing of nucleus fuel/processing of petroleum, coal and other fuels	12.88	14.78	14.34	16.29	~
Manufacture of raw chemical materials and chemical products	2.02	2.11	2.18	2.47	↑
Manufacture of medicines	0.31	0.30	0.29	0.29	↓
Manufacture of chemical fibers	1.14	1.23	1.27	1.28	↑
Manufacture of rubber and plastics products	0.25	0.26	0.26	0.25	~
Manufacture of non-metallic mineral products	0.99	0.97	0.94	0.92	↓
Smelting and pressing of ferrous metals	7.40	8.15	12.12	12.79	↑
Smelting and pressing of non-ferrous metals	3.00	3.36	3.55	3.37	~
Manufacture of metal products	0.24	0.31	0.26	0.27	~
Manufacture of general purpose machinery	0.15	0.15	0.16	0.15	~
Manufacture of special purpose machinery	0.10	0.10	0.09	0.10	~
Manufacture of automobiles	0.23	0.23	0.24	0.24	↑
Manufacture of railway, ship, aerospace, and other transport equipment	0.18	0.20	0.38	0.18	~
Manufacture of electrical machinery and apparatus	0.11	0.11	0.11	0.11	-
Manufacture of computers, communication, and other electronic equipment	0.22	0.23	0.28	0.27	~
Manufacture of measuring instruments and machinery	0.07	0.07	0.06	0.05	↓
Other manufacture	0.90	0.90	0.97	1.07	↑
Utilization of waste resources	0.14	0.14	0.23	0.33	↑
Repair service of metal products, machinery, and equipment	0.14	0.21	0.20	0.15	~
Production and supply of electric power and heat power	3.86	3.83	3.98	3.53	~
Production and supply of gas	0.49	0.58	0.68	0.57	~
Production and supply of water	0.78	0.78	0.82	0.73	~

Source: The author searched for some information from the China Statistical Yearbook *and the* China Energy Statistical Yearbook*, and calculated these numbers based on the raw data respectively.*

Note: The symbols "↑" and "↓" respectively indicate a strictly increased and decreased trend, and "-" and "~" represented basically unchanged and fluctuated trends respectively in the table. The sector "processing of petroleum, coking and processing of nucleus fuel" was renamed "processing of petroleum, coal and other fuels" with slight change since 2018 and did not impact analysis in this paper. Additionally, the sector "support activities for mining" was also renamed "professional and support activities for mining".

According to these basic facts about energy consumption and development of new products in industrial sectors from China, this article could study their relationship more clearly.

THEORETICAL ANALYSIS

Producers produce goods, including new products, in industrial production to sell in the market, and to obtain the most profit. For demand characteristics, a representative consumer has a utility function $U = \sum_i \frac{1}{\theta} x_i^{\theta}$ with $0 < \theta < 1$, the demand and the price of any good i is x_i and p_i, respectively, and the consumer's budget constraint with the shadow price is λ, that is, the marginal utility of income characterized by Krugman (1980). Hence, the consumer utility maximization option meets the following condition:

$$\frac{\partial U}{\partial x_i} = \lambda p_i \Rightarrow x_i^{\theta-1} = \lambda p_i \tag{1}$$

In the good i market, price elasticity of demand is $\frac{dx_i}{dp_i}\frac{p_i}{x_i} = \frac{1}{\theta-1} < 0$, to analyze as common manner, and the absolute value of elasticity is $|\frac{1}{\theta-1}| = \frac{1}{1-\theta} > 1$ with $0 < \theta < 1$. When a firm produces good i with marginal cost MC_i, the profit-maximizing price p_i adopts the cost-plus pricing method as follows:

TABLE 2 | Enterprises' average expenditure on new products' development by industrial sector in China during 2016–2019 (10^4 yuan/unit**)**.

Industrial sector	2016	2017	2018	2019	Trend
Mining and washing of coal	131	170	161	110	~
Extraction of petroleum and natural gas	1,326	1,285	1,492	1994	~
Mining and processing of ferrous metal ores	31	41	29	88	~
Mining and processing of non-ferrous metal ores	76	93	94	87	~
Mining and processing of nonmetal ores	21	30	26	42	~
Processing of food from agricultural products	105	122	113	137	~
Manufacture of foods	175	188	196	243	↑
Manufacture of liquor, beverages, and refined tea	129	155	170	193	↑
Manufacture of tobacco	1824	2,194	2,494	2,746	↑
Manufacture of textile	113	127	141	166	↑
Manufacture of textile, wearing apparel, and accessories	77	87	84	95	~
Manufacture of leather, fur, feather, and related products and footwear	82	95	104	116	↑
Processing of timber and manufacture of wood, bamboo, rattan, palm, and straw products	56	66	66	75	↑
Manufacture of furniture	98	111	133	157	↑
Manufacture of paper and paper products	178	220	250	280	↑
Printing, reproduction of recording media	85	107	128	170	↑
Manufacture of articles for culture, education, arts and crafts, sport, and entertainment activities	117	135	140	169	↑
Processing of petroleum, coking and processing of nucleus fuel/processing of petroleum, coal and other fuels	417	505	504	611	~
Manufacture of raw chemical materials and chemical products	303	348	351	407	↑
Manufacture of medicines	660	781	860	991	↑
Manufacture of chemical fibers	540	683	715	854	↑
Manufacture of rubber and plastics products	168	198	218	239	↑
Manufacture of non-metallic mineral products	87	107	121	153	↑
Smelting and pressing of ferrous metals	597	790	1,480	1870	↑
Smelting and pressing of non-ferrous metals	470	549	588	590	↑
Manufacture of metal products	163	187	195	232	↑
Manufacture of general purpose machinery	308	335	369	415	↑
Manufacture of special purpose machinery	356	428	466	508	↑
Manufacture of automobiles	874	980	1,089	1,121	↑
Manufacture of railway, ship, aerospace, and other transport equipment	985	1,056	993	1,150	~
Manufacture of electrical machinery and apparatus	551	627	697	698	↑
Manufacture of computers, communication, and other electronic equipment	1,543	1,676	1869	1964	↑
Manufacture of measuring instruments and machinery	509	589	635	660	↑
Other manufacture	163	184	245	258	↑
Repair service of metal products, machinery, and equipment	497	435	420	499	~
Production and supply of electric power and heat power	66	96	80	101	~
Production and supply of gas	29	44	69	55	~
Production and supply of water	23	31	42	46	↑

Source: The author obtained some information from the China Statistical Yearbook *and the* China Statistical Yearbook on Science and Technology, *and calculated these numbers based on the raw data respectively.*

Note: The sectors of professional and support activities for mining, mining of other ores, and utilization of waste resources were not contained in the China Statistical Yearbook on Science and Technology, *thus, the author did not search information about new products innovation in these three sectors. The symbols "↑" and "~" represent the same content as* ***Table 1****.*

$$p_i = \frac{MC_i}{1 - 1\Big/\left(\frac{1}{1-\theta}\right)} = \frac{MC_i}{1 - (1-\theta)} = \frac{1}{\theta} MC_i \tag{2}$$

For production, Krugman (1980) and Melitz (2003) both assumed that there was only one factor, labor. In order to analyze some issues about natural resource usage, including energy consumption, in the framework of Melitz (2003), this study also assumes a combined factor "resource" s characterized by Tang et al. (2018), which contained labor, capital, natural resources like land and water, and energy. For expositional simplicity, the ratio of energy on the resource s_i for producing good i is assumed to be δ_i, that is, one unit resource s_i contains δ_i unit energy under the associated technology in industrial production. Energy, as a factor in production, input more steadily than other factors such as labor and capital. Based on **Table 1**, energy used by industrial enterprises was relatively stable, even if enterprises' average energy consumption in three sectors was unchanged in 4 years (2016–2019) in China. In other words, producers could use more capital instead of labor to produce, but it is difficult to translate the type of inputting factors by directly changing energy in production. For example, to increase output by directly enlarging energy consumption under the condition of other factors, maintaining unchanged status is difficult to achieve. Hence, producing a given product i with unchanged ratio δ_i is a relatively rational assumption based on the reality of industrial production.

To study how the development of new products impacts the energy usage in production, this study assumes firms produce and operate in two stages. In the first stage, a firm produces good i with productivity φ_t^i and develops a new good j in the period t. In the second stage, the firm has developed the new good j with productivity φ_{t+1}^j, and decides to produce good i or/and good j in the period $t+1$. Additionally, as the economy becomes more and more productive, the good i with productivity $\varphi^i_{t+1} = (1+g)\varphi^i_t$ where $g > 0$ is assumed in the period $t+1$. For the input resource s, good i with unchanged energy input ratio δ_i in the two periods as described above, the new good j with ratio δ_j in the period $t+1$. For the ratio δ_i and δ_j, these three situations as $\delta_i > \delta_j$, $\delta_i < \delta_j$, and $\delta_i = \delta_j$ may occur and represent different implications. In industrial production, energy consumption of each industrial sector has its own characteristics and holds relatively steady as described by China's evidence in **Table 1**. The firm produced good i and good j simultaneously in the period $t+1$; the gap between δ_i and δ_j should not be too large in production. However, δ_j may be greatly lower than δ_i when the firm developed a new product by adopting cleaner technology with declining energy usage in the beginning.

In the first stage, the firm production function characterized by Melitz (2003) as $s_i = \frac{q^i_t}{\varphi^i_t}$ with the same fixed cost $f > 0$, which does not contain energy for all products' production, and assumes the unit price of resource s_i is unchanged ζ_i and not affected by the firm. Hence, the cost of the firm producing good i in the period t is as follows:

$$C_t = \zeta_i s_i + f = \frac{\zeta_i}{\varphi^i_t} q^i_t + f \tag{3}$$

According to **Eq. 3**, the firm's marginal cost is $MC_t = \frac{dC_t}{dq^i_t} = \frac{\zeta_i}{\varphi^i_t}$. Based on **Eq. 2**, the price of good i in the period t is as follows:

$$p^i_t = \frac{\zeta_i}{\theta \varphi^i_t} \tag{4}$$

Combining **Eq. 1–4**, the output of good i produced by the firm in the period t is[3] as follows:

$$q^i_t = \left(\lambda p^i_t\right)^{\frac{1}{\theta-1}} = \left(\lambda \frac{\zeta_i}{\theta \varphi^i_t}\right)^{\frac{1}{\theta-1}} = \left(\frac{\theta \varphi^i_t}{\lambda \zeta_i}\right)^{\frac{1}{1-\theta}} \tag{5}$$

Hence, the firm uses the resource s_i as follows:

$$s_i = \frac{q^i_t}{\varphi^i_t} = \left(\frac{\theta}{\lambda \zeta_i}\right)^{\frac{1}{1-\theta}} \left(\varphi^i_t\right)^{\frac{\theta}{1-\theta}} \tag{6}$$

As good i with unchanged energy input ratio δ_i, energy consumption in the firm production in the period t is as follows:

$$E_t = E^i_t = \delta_i s_i = \delta_i \left(\frac{\theta}{\lambda \zeta_i}\right)^{\frac{1}{1-\theta}} \left(\varphi^i_t\right)^{\frac{\theta}{1-\theta}} \tag{7}$$

In the period $t+1$, if the firm continues to produce good i, energy consumption for this good production is as follows:

$$E^i_{t+1} = \delta_i \left(\frac{\theta}{\lambda \zeta_i}\right)^{\frac{1}{1-\theta}} \left[(1+g)\varphi^i_t\right]^{\frac{\theta}{1-\theta}} = (1+g)^{\frac{\theta}{1-\theta}} E^i_t \tag{8}$$

[3]There is a fixed cost f in production; the firm may not obtain positive profit and not produce any products characterized by Melitz (2003). For simplicity, this study does not consider the situation and does not impact theoretical analysis about energy consumption.

The firm's productivity of producing good i rises with the growth rate g, and energy consumption also increases $(1+g)^{\frac{\theta}{1-\theta}} - 1 > 0$ in the next period. In the developing stage characterized by Tang et al. (2018), the economy consumes more energy with higher productivity since resource usage with output increases. Although energy consumption per unit output declines with productivity raises in industrial production, total energy consumption increases when the firm produces more "old" products.

The firm produces the new good j with energy consumption as follows:

$$E^j_{t+1} = \delta_j \left(\frac{\theta}{\lambda \zeta_j}\right)^{\frac{1}{1-\theta}} \left(\varphi^j_{t+1}\right)^{\frac{\theta}{1-\theta}} \tag{9}$$

The firm consumes the total energy in the period $t+1$ as follows:

$$E_{t+1} = E^i_{t+1} + E^j_{t+1} \tag{10}$$

Energy consumption will increase in the production of "old" good i, that is, $E^i_{t+1} > E^i_t$, and energy usage must increase more in the additional production of the new good j. Hence, development of new products and production will increase energy consumption when producing the new product only as an extra production. Energy usage per unit output increase or decrease may occur with production of new and "old" products co-existing, although energy consumption per unit for "old" output declines with the productivity growth.

If the firm only produces the new good j in the period $t+1$, the ratio $\frac{E_{t+1}}{E_t}$ represents the total energy consumption changes in the two periods and as follows:

$$\begin{aligned}\frac{E_{t+1}}{E_t} &= \left[\delta_j \left(\frac{\theta}{\lambda \zeta_j}\right)^{\frac{1}{1-\theta}} \left(\varphi^j_{t+1}\right)^{\frac{\theta}{1-\theta}}\right] \Big/ \left[\delta_i \left(\frac{\theta}{\lambda \zeta_i}\right)^{\frac{1}{1-\theta}} \left(\varphi^i_t\right)^{\frac{\theta}{1-\theta}}\right] \\ &= \frac{\delta_j}{\delta_i} \left(\frac{\zeta_i}{\zeta_j}\right)^{\frac{1}{1-\theta}} \left(\frac{\varphi^j_{t+1}}{\varphi^i_t}\right)^{\frac{\theta}{1-\theta}}\end{aligned} \tag{11}$$

If the firm attached great importance to cleaner technology with saving energy in the process of developing new products, that is, the number δ_j is relatively lower, total energy consumption may decline. If the per unit cost of resource for producing new products is higher, that is, the number ζ_j is relatively larger, total energy consumption may reduce when the output is relatively less with cost increase. Additionally, total energy consumption by producing new products is relatively lower under the condition that the productivity of producing new goods is relatively lower than that of producing "old" products with more skilled technology, and the lower output of new products is the main reason. However, the energy consumption per unit output in production of new products is probably higher than that in "old" products.

Based on the above theoretical analyses, this study mainly finds that total energy consumption must increase when the firm continues to produce the existing products and the new product was only an extra good in industrial production. If the firm directly replaces "old" products with new goods in production, the total energy consumption probably declines when the firm develops new products by emphasizing cleaner technology and saving energy. The production technology in "old" products is relatively advanced; thus, energy consumption per unit for "old" product output is probably less than that in new products. These findings contribute to further empirically studying the relationship between energy consumption and development of new products.

EMPIRICAL ANALYSIS

To empirically analyze the relationship between energy consumption and development of new products in industrial production, this study uses these 38 industrial sectors with recorded data as described in **Table 2** to test. According to the raw data from the *China Statistical Yearbook*, the *China Energy Statistical Yearbook*, and the *China Statistical Yearbook on Science and Technology*, the author selected the period 2016–2019 and built strongly balanced panel data about Chinese industrial sectors during 2016–2019.

First, this study tests how new products' development and production influence total energy consumption in Chinese industrial production. The raw materials recorded total energy consumption with standard quantity, coal consumption, gasoline consumption, and electricity consumption with physical quantity for these sectors during the periods. Using natural logarithmic transformation conventionally for these variables[4], these dependent variables Ln_energy, Ln_coal, $Ln\_gasoline$, and $Ln\_electricity$ were obtained to test, respectively.

The raw data contained sales revenue of new products from these industrial sectors in the period and also uses natural logarithmic transformation and obtains the independent variable Ln_new_sales. For other control variables, the "old" products' output is an important impact factor based on the theoretical analysis. Constraint with the materials notwithstanding, the author uses the business income[5] recorded in the yearbook to approximately measure all products, including "old" products' production for testing empirically. The control variable Ln_bus_inc could be built by using natural logarithmic transformation for these sectors' business income. Energy, as a production factor with labor and capital, new products' development, and sales value were also impacted by labor and capital, so the two variables should be included in control variables. The variables Ln_labor and $Ln\_capital$ could be measured by the logarithm of average number of employees and total assets by industrial sectors, respectively. Profitability in industrial production may impact these sectors' selection of cleaner technology for saving energy. Because some sectors show negative profit, that is, operating loss in some times, the author built a control variable Ln_profit as follows: $Ln\_profit = \text{sgn}(profit) \cdot \ln[\text{sgn}(profit) \cdot profit]$, where $profit$ indicated the total profit in the industrial sector and $\text{sgn}(\cdot)$ was a symbolic function in mathematics.

After building these variables, including dependent variables, the independent variable, and control variables, the author tested these four equations by using fixed effect regression of the strongly balanced panel data, respectively, and recorded the results in **Table 3**.

$$\begin{aligned} Y_{it} &= C + \beta_1 Ln\_new\_sales_{it} + \beta_2 Ln\_bus\_inc_{it} \\ &+ \beta_3 Ln\_labor_{it} + \beta_4 Ln\_capital_{it} + \beta_5 Ln\_profit_{it} + \mu_i + \varepsilon_{it} \end{aligned} \quad (12)$$

where Y_{it} represents Ln_energy_{it}, Ln_coal_{it}, $Ln\_gasoline_{it}$, and $Ln\_electricity_{it}$, respectively.

Based on the results in **Table 3**, the Chinese industrial sector with more new products will consume more energy under the condition of maintaining business income unchanged. In other words, total energy consumption increased with developing and producing new products in Chinese industrial production. For the three special energy products, coal, gasoline, and electricity, new products' development with the industrial sector had a positive but not significant effect on total coal and electricity consumption, but had a significantly negative effect on total gasoline consumption. According to the energy reserves in China, industrial producers developing new products using less gasoline, which are given the status of crude oil or petroleum, are relatively scarce.

In order to test empirically how new products' development and production impact energy consumption per unit output, the author built the dependent variables Per_energy, Per_coal, $Per\_gasoline$, and $Per\_electricity$ by using the ratio of total energy consumption, total coal consumption, total gasoline consumption, and total electricity consumption to business income, respectively. Then, the author continues to test the following equations by using the panel data as follows:

$$\begin{aligned} Y_{it} &= C + \beta_1 Ln\_new\_sales_{it} + \beta_2 Ln\_labor_{it} \\ &+ \beta_3 Ln\_capital_{it} + \beta_4 Ln\_profit_{it} + \mu_i + \varepsilon_{it} \end{aligned} \quad (13)$$

which is more similar to **Eq. 12**, where Y_{it} represents Per_energy_{it}, Per_coal_{it}, $Per\_gasoline_{it}$, and $Per\_electricity_{it}$, respectively. **Eq. 13** does not contain the control variable Ln_bus_inc. The results of fixed effect regression by testing the strongly balanced panel data are recorded in **Table 4**.

According to the results in **Table 4**, for the industrial sector with more new products, its energy intensity by output (energy consumption per unit business income) was higher based on the first test. The last three results in **Table 4** mainly revealed the relationship between development of new products and intensity of special energy product including coal, gasoline, and electricity. Based on the results, the quantity of new products had a positive but not significant effect on coal intensity by output, had a significantly negative effect on gasoline intensity by output,

[4]Other energy products such as coke, crude oil, kerosene, diesel oil, fuel oil, natural gas, and so on were also recorded in the *China Energy Statistical Yearbook*, but this study does not test these since industrial sectors used these extremely unevenly or almost never consumed them. Additionally, the sector of repair service of metal products, machinery, and equipment did not have coal consumption in 2018 and 2019. Thus, the variable $Ln\_coal = \ln(coal + 1)$, where *coal* indicates the quantity of coal consumption.

[5]The database recorded main business income in 2016 and 2017 with business income in 2018 and 2019 from the *China Statistical Yearbook*.

TABLE 3 | Empirical test results (1).

Variables	Ln_energy	Ln_coal	Ln_gasoline	Ln_electricity
C	5.9640*** (0.9389)	−13.1496** (6.3242)	−2.5820 (2.4513)	3.8818*** (0.6844)
Ln_new_sales	0.1131*** (0.0395)	0.0078 (0.2661)	−0.2106** (0.1031)	0.0388 (0.0288)
Ln_bus_inc	0.1231 (0.1029)	1.4978** (0.6931)	1.3705*** (0.2686)	−0.0128 (0.0750)
Ln_labor	−0.2111* (0.1119)	1.5579** (0.7540)	1.2814*** (0.2922)	−0.4479*** (0.0816)
Ln_capital	−0.0121 (0.1315)	−0.3018 (0.8859)	−1.1921*** (0.3434)	0.4154*** (0.0959)
Ln_profit	−0.0085 (0.0086)	−0.0466 (0.0580)	−0.0374* (0.0225)	−0.0072 (0.0063)
R^2	0.1528	0.2678	0.6350	0.4700
F test	Prob > F = 0.0000	Prob > F = 0.0000	Prob > F = 0.0000	Prob > F = 0000
Number of obs	152	152	152	152

*Note: Standard errors are recorded in brackets; ***, **, and * represent statistically significant at the level of 1, 5, and 10%, respectively.*

TABLE 4 | Empirical test results (2).

Variables	Per_energy	Per_coal	Per_gasoline	Per_electricity
C	2.5418*** (0.3584)	0.1073 (0.3787)	0.0047*** (0.0010)	0.6884*** (0.1082)
Ln_new_sales	0.0306** (0.0151)	0.0106 (0.0160)	−0.00016*** (0.00004)	0.0103** (0.0046)
Ln_bus_inc				
Ln_labor	−0.1796*** (0.0304)	0.0545* (0.0322)	0.0005*** (0.0001)	−0.0555*** (0.0092)
Ln_capital	−0.1838*** (0.0461)	−0.0335 (0.0487)	−0.0004*** (0.0001)	−0.0529*** (0.0139)
Ln_profit	−0.0151*** (0.0030)	−0.0017 (0.0032)	−0.00004*** (8.06e-06)	−0.0026*** (0.0009)
R^2	0.5146	0.0273	0.5033	0.4736
F test	Prob > F = 0.0000	Prob > F = 0.0000	Prob > F = 0.0000	Prob > F = 0.0000
Number of obs	152	152	152	152

*Note: Standard errors are recorded in brackets; ***, **, and * represent statistically significant at the level of 1, 5, and 10%, respectively.*

and had a significantly positive effect on electricity intensity by output, respectively. Especially, the significantly negative effect of development and production of new products on gasoline intensity by output in the third result in **Table 4** indicated that Chinese industrial producers developed new products mainly focused on saving gasoline.

Combined with the results in **Tables 3**, **4**, the industrial sector develops and produces new products that may simultaneously increase energy consumption and energy intensity by output in China, but decrease gasoline consumption in both total level and per output level. In other words, new products' development in Chinese industrial sectors has no energy saving effect, but has the obvious effect of saving gasoline. In the following section, it is necessary to discuss the empirical results with theoretical findings and introduce some policy implications.

DISCUSSION

Natural resources, including fuel energy, as an input factor, are necessary in industrial production. In the process of economic progress, different energies, including hydroelectric energy, thermal energy, and nuclear energy, have different effects (Rehman et al., 2021b). For total energy consumption, expanding production in the industrial sector often leads to consuming more energy. In the developing stage, as in China, reducing the energy consumption by directly and greatly decreasing industrial production is not a feasible way, because the sector of industry plays an important role in development and employment. In other words, the output in industrial production is difficult to decrease and is expected to increase in the long term in China. Under the condition that the production of the industrial sector gradually expands, decreasing the total energy consumption is only achieved by reducing energy usage per unit output. The latter is a necessary but not sufficient condition to realize the former, that is, total energy consumption may also increase with total output increases when energy intensity by output in industrial production declines, which is similar to what was characterized by Tang et al. (2018). To reduce energy usage per unit output in the sector of industry, obtaining a high level of productivity for declining input resources, including energy, is the main method. Policymakers, producers, and researchers are trying to pursue some methods to improve productivity, and they believe that technological progress from some innovative activities can achieve the goal. To achieve sustainable development, the tendency to use energy greatly while neglecting environmental and ecological protection in industrial production must shift. China's top designer proposed a new vision for development, including green and innovation, and accurately indicated that the Chinese economy has entered a stage of high-quality development from a phase of rapid growth in a new era. Hence, treating the huge energy consumption in the sector of industry becomes an important goal of public policies in the future. As described above, some innovative activities in the sector of industry may reduce energy usage by raising the productivity in industrial production, giving China's policy-makers a reason to support innovation from industrial enterprises. In order to solve the circle of "environmental pollution–economic development," implementing green technology innovation is a key method (Guo et al., 2018). After the reform and opening-up in 1978, marketization has become the main reform orientation in China. As a result, enterprises are the main players for technological innovation. According to the *China Statistical Yearbook on Science and Technology* 2020, China's local economy had 7,129,256 persons of total R & D personnel in 2019. For the total number of R & D personnel, enterprises had 5,177,353 persons, so the share of the total was 72.6%. Additionally, industrial enterprises above the designated size had 4,440,550 persons and the share of the total was about 62.3%. In a word, China's technologically innovative activities mainly focus on industrial production. If industrial sectors could significantly reduce energy consumption by implementing innovative activities, the goal of green development by saving energy could be achieved to a certain degree.

In analysis, if we only study how the total input of innovation as R & D cost influences energy consumption and its intensity by output, the results often revealed that innovative activities could reduce energy usage pressure, especially significantly decrease energy intensity by output. For innovative activities, new products' development is an important activity in applied research and experimental development in any economy. The traditional economic model of welfare and product differentiation characterized by Spence (1976) was very enlightening, and Chen et al. (2020) proved that product differentiation impacted social welfare and was restricted by other factors such as capacity constraints or sharing. Developing new products with higher performance and better function can improve the quality of people's life; policy-makers support and encourage enterprises to innovate new products in many developing and developed economies. China's enterprises, especially industrial enterprises, paid more attention to developing new products in technologically innovative activities. For example, enterprises' average expenditure on development of new products increased in most industrial sectors based on **Table 2**. Production of new products may have some productivity disadvantages compared to the existing products, because the production process of the latter is more mature than that of new products. Hence, developing new products, as an innovative activity, to reduce energy consumption or energy intensity by output, is not primarily through raising productivity in industrial production. To decrease energy consumption, producers should emphasize the introduction of cleaner technology with saving energy when developing the new products. Based on the empirical analysis, development of new products in Chinese industrial production does not have the effect of saving energy and even intensifies energy consumption on the whole. Sustainable development needs to properly plan production and consumption, especially that of the limited fossil fuels and other natural resources. In the process of globalization, energy use and trade impact ecological footprint, and globalization has negative effect on biodiversity (Rehman et al., 2021c). Producers want to trade new products to foreign markets for pursuing more profit, which expands the production of new products and increases energy usage. However, development of new products and production will consume more energy and is not the evidence to prevent the innovative activity of developing new products. First, even if the sector of industry does not develop new products, energy consumption may also increase with expanding production of the existing "old" goods. Second, more new products will increase the consuming quality at the level of public demands, and its development cannot be completely constrained just because of the energy consumption issues. Finally, productivity from producing new products will become higher and higher gradually and reduce energy consumption per unit output in the future, that is, the new product will become an "old" product with a growth rate of productivity.

The Chinese industrial sector developed new products in production that will increase the total energy consumption and coal and electricity usage based on the empirical tests, respectively. However, total gasoline consumption and gasoline intensity by output significantly declined by developing and producing new products, that is, China's industrial new products' development contained the characteristic of saving gasoline. According to the reserve, with regard to the production and consumption status of natural resources, especially fossil fuels in China, the shortage of petroleum is very obvious. The industrial sector developed new products with less usage of gasoline to meet the forced mechanism of petroleum constraints. Producers should understand that other energy products in China will also be lacking in the future and self-select to develop new products with less all-consuming energy products. Additionally, energy consumption per enterprise in some energy industries, such as the sector of extraction of petroleum and natural gas and processing of petroleum, coking, and processing of nucleus fuel/processing of petroleum, coal, and other fuels, is relatively larger than other sectors based on the information from **Table 1**. This finding indicated that losses during energy transformation and other losses of energy transport, distribution, and storage may be quite large in China. If energy industries develop new products, reducing these energy losses will have a significant effect in energy-saving. Overall, to reduce energy consumption by developing new products in industrial production is possible to achieve, such as how gasoline consumption has declined with development of new products in China and has some potential and feasible methods. This is a long-term process under the visions of innovative and green development in China, especially given that total energy consumption and energy intensity by output still increases with development of new products and production at present.

To avoid simply studying the relationship between the whole innovative input as R & D cost and energy consumption, this study mainly analyzed theoretically and empirically how development of new products impacts energy consumption and its intensity by output, which has some significant policy implications with the vision of innovative and green development. Development characterized by innovation and green is an important goal pursued by policy makers, and they often believe that inputting more resources to innovation could also achieve the goal of green development. Energy consumption increasing with development of new products indicated that policy makers should comprehensively evaluate the goal of innovative and green development. For policy instruments, in the practice of macro-controlling industrial production, evidence has shown that developing a new product with a characteristic of massive use of energy and other natural resources should be more strongly regulated. Fiscal policy should help industrial entities to develop new products with cleaner technology by saving energy. Additionally, enterprises should emphasize the initial productivity of producing new products to reduce the disadvantages of energy intensity with the existing products. Additionally, the vision of green development contains the definitions of both energy saving and emission reducing. In response to climate change, controlling carbon dioxide emissions becomes a main goal in public policy in many economies, like in China. Energy consumption could produce carbon dioxide emissions, so strictly implementing the policy of controlling carbon dioxide emissions could force energy usage to decline. Carbon emission reduction in Chinese commercial buildings will have a significant effect on the goal of carbon peak and carbon neutrality (Xiang et al., 2022b), which may slow the growth of energy consumption in practice. Under the policy with the vision of green development, industrial producers will pay more attention to saving energy and reducing emission when they develop new products in production.

CONCLUSION

The limitation of fuel energy attracted Chinese policy-makers to pay attention to huge energy consumption and some associated issues in the production of the industrial sector. Sustainable development needs to reduce the growth rate of energy consumption in the future. Energy, as a necessary input factor in production, raises the productivity by implementing some innovative activities that could decrease energy intensity by output. Development of new products in industrial production, as an important innovative activity, impacts energy consumption and is relatively complicated. This study simply developed a model to analyze the relationship between new products' development and energy consumption and found the following: 1) New products' production must increase total energy consumption when these new products are extra products with the existing "old" goods in production. 2) When new products directly replace the existing goods in industrial production, total energy consumption may increase or decline, and the possibility of it increasing is relatively greater since the productivity of new products' production is commonly lower than that of the existing products. For the same reason, energy intensity by output in industrial production also increases when producers develop and produce new products. 3) Developing new products with cleaner technology by saving energy or with higher initial productivity is more likely to decrease total energy consumption and energy intensity by output in industrial production, which more greatly fits the needs of sustainable development.

This study empirically tests energy consumption and development of new products based on China's evidence after theoretical analysis and obtains some interesting findings, which are as follows: 1) Industrial sector with larger new products' production consumed more total energy and had higher energy intensity by output, and these results were statistically significant at common standards. 2) For special energy products, the industrial sector will consume more coal and electricity and have higher coal intensity and electricity intensity by output when it develops and produces new products, but these results were not statistically significant except for electricity intensity which was statistically significant at the level of 5%. However, new products' development and production was statistically significant at the common level to reduce total gasoline consumption and gasoline intensity by output in Chinese industrial production. In a word, the Chinese industrial sector developed new products that have no energy-saving effect on the whole, but the new products' development with cleaner technology by saving the special energy as gasoline is strongly supported by empirical evidence. For policy recommendation, not just petroleum but all fossil fuel reserves are limited in the Earth, so developing new products with cleaner technology by saving all energy rather than only saving gasoline will be more in accordance with sustainable development in China and all over the world. Policy makers should support the development of new products characterized by energy conservation and emission reduction in producers' production process.

For industrial production, producers' micro decisions impact the development of new products and energy consumption, respectively. The limitations of this study are mainly embodied in empirical analysis in the macro level. It is difficult to empirically test how development of new products impact energy usage in the micro level on condition that lacking of the information of micro enterprises' energy consumption and new products developing status. According to the correlation between energy consumption and pollution emission along with the key findings in this study, the research direction, by analyzing some associated issues with development of new products and environmental quality in industrial production, is also significant in the future.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

ET made all contributions to this manuscript.

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