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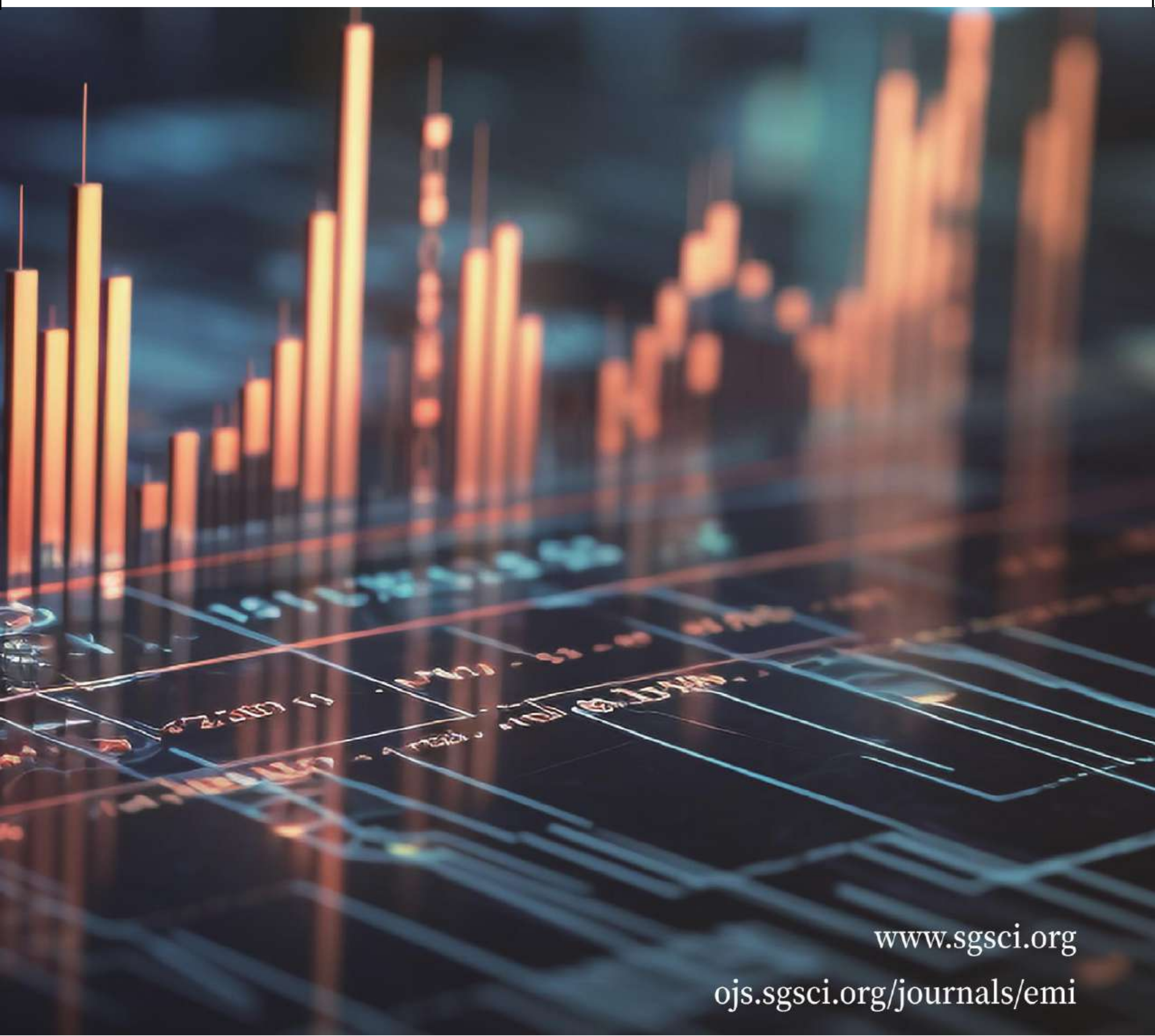

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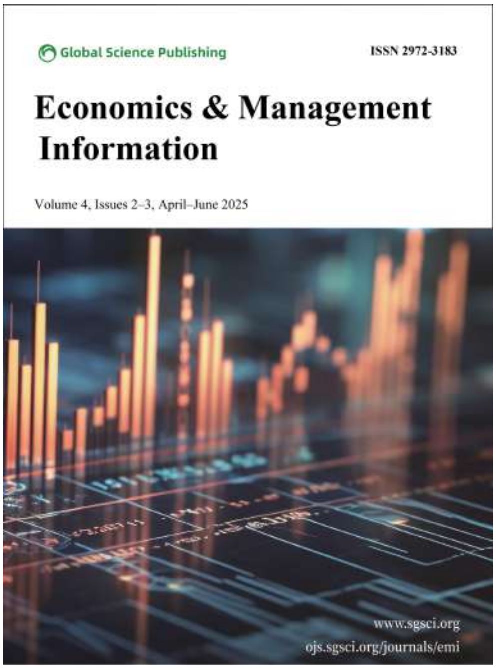

Aims & Scope

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Article

Research on Carbon Tariff Rate Forecasting Based on EU Carbon Border Adjustment Mechanism

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Abstract: The current international trade rules are facing profound changes, green trade barriers represented by carbon tariffs and their impact have become an important issue in the evolution of global trade. Some countries are reshaping international trade rules with green standards. These measures put pressure on high-carbon emitting industries in developing countries and have an impact on their trade competitiveness. Based on this background, this paper studies the future carbon tariff level and discusses the impact of international trade and industrial competition pattern. The GTAP-E model was used to simulate the implementation of carbon tariffs in different scenarios to study the impact of carbon tariffs on trade in various industries and some countries and economic organizations. The study found that high-carbon industries will face a greater impact, while low-carbon industries will be relatively less affected. Therefore, developing countries should actively participate in the formulation of global green trade rules and build their own discourse system. Optimize the industrial structure, promote the transformation of high-carbon industries to low-carbon, and enhance the innovation capacity of green technology; Improve the carbon accounting system and carbon trading market, better adapt to the international green trade environment, and jointly write a new chapter of green trade rules.

Keywords: international trade; carbon tariff; CBAM; GTAP-E

1. Introduction

The "green" development trend of international trade rules is obvious, and adapting to absorb and participate in the construction of low-carbon international economic and trade rules will become an important direction of international trade work of countries in the future. Major developed countries and economies have formulated corresponding policies to promote the development of green international trade rules. In September 2022, the Inflation Reduction Actof 2022 was passed into law. The bill supports the development of domestic green industry and low-carbon economy through subsidies, tax credits and other ways, which will form a comparative advantage over low-carbon products in the global region, and the proposal on carbon tariffs in the United States has taken shape. In July 2021, the EU issued the "Climate change Package" around the "European Green Agreement", which proposed to establish a Carbon Border Adjustment Mechanism (CBAM). The plan aims to reduce carbon emissions by imposing additional charges on green products exported from countries and regions that are lagging behind in low-carbon development. In May 2023, the EU CBAM passed legislation, which refers to the use of greenhouse gas emissions as a unit of pricing in international trade, combined with carbon price spreads, by importing countries to levy carbon emission tariffs on the country of origin. According

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to the "Brussels Effect", the EU and other important countries that first formulate green trade rules in the international market are enough to convert their national standards into global standards with their own market power, and then export their own low-carbon product import and export standards through the trade import and export process, changing the global market trade rules. In this context, it is of practical significance to predict the tax rate of carbon tariff.

2. Literature Review

2.1. Research on Carbon Tariff and Its Impact

Some scholars discussed different scenarios of Carbon Tariffs from the perspective of Western countries [1]. Arguing that this policy will weaken the competitiveness of national industries that are more dependent on high-carbon industries and exacerbate trade disputes [2]. This negative impact on competitiveness is seen in countries at different levels of development. More often, the imposition of carbon tariffs is a strategy to ease the competitive pressure faced by the industries of the taxing countries and protect the position of their own energy industries in international trade [3]; Carbon tariffs help to improve the relative competitive disadvantage of energy-intensive industries caused by carbon prices and protect domestic energy-intensive products [4]. will help secure global climate leadership [5]. Given the decline in import demand in the countries where carbon tariffs are imposed, carbon tariffs may become a coercive strategic trade policy, disrupting the balance of trade competitiveness and triggering trade conflicts.

2.2. Research on CBAM and Its Influence

Luo Bixiong (2023) used the global multi-regional recursive dynamic computable general equilibrium model to study the impact of carbon border adjustment mechanism on GDP, exports and industries of major economies in the world and the development trend of international industries under this scenario. The conclusion shows that because Russia exports more steel products to the EU, its total exports will decline significantly; EU GDP would rise; In the specific industries of the EU, the exports to the industries related to the carbon border adjustment mechanism all increased; Russia, Turkey and China and other economies of steel, non-metal, non-ferrous metals and chemical industry output exports have been affected to varying degrees, China's non-ferrous metal industry's international market share will tend to rise with its competitive advantages. The output of global key industries shows a trend of transferring from developing economies with a large proportion of high-carbon products exports to developed economies or developing economies with strong international competitiveness [6]. Dong Kangyin et al. (2023) established a CGE model including 12 sub-regions of the world based on the theory of general equilibrium model. The model has five modules, namely, production, income, expenditure, investment and international trade. It is found that the carbon tariff policy mainly driven by Europe and the United States has resulted in the loss of China's GDP and residents' welfare to a certain extent, and has a large negative effect on the export of commodities with high carbon density, but has little impact on China's overall emission reduction. The carbon tariff policies in Europe and the United States have no obvious effect on their own carbon emission reduction, which belongs to the behavior of "harming others and not benefiting themselves". To some extent, China's export tax rebate policy can mitigate the negative impact of carbon tariff policies implemented by Europe and the United States on China's economy [7]. According to Tu Xinquan et al. (2023), developed countries and developing countries are on opposite sides in the issue of carbon tariff regulation mechanism, the essence of which is the dispute over the right to development in green trade. In recent years, developed countries have continuously competed for the international right to speak on climate governance standards, and by virtue of their advantages in green technology and climate standards, they have accelerated the establishment of a "climate club" and constructed green trade barriers, with the aim of curbing the trade and economic development of countries with low levels of green economic development and reshaping the global green economic and trade pattern. In terms of products only initially covered by carbon tariffs, China is the top target, followed by India and Russia. When the carbon tariff mechanism covers all products under the EUETS, the amount of carbon tariffs paid by China is much lower than that of Russia. On the other hand, CBAM causes changes in terms of trade and relative trade competitiveness among countries, reshaping the pattern of trade advantages. Sectors with higher carbon intensity and greater trade exposure (such as mining, metals, etc.) and countries (Russia, China, India) will be greatly affected [8].

3. Analysis of the Status Quo of Green Trade Barriers

3.1. EU Carbon Border Regulation Mechanism

The EU has always been a global “leader” in the fight against climate change. In December 2019, the European Commission proposed the Green Deal (“Green New Deal”) to combat climate change and promote sustainable development. In July 2021, the EU proposed “Fit for 55” (emission reduction “package”), aiming to achieve the climate action goal of reducing greenhouse gas emissions by 55% compared with 1990 by the end of 2030, covering a total of 12 emission reduction measures in energy, industry, transport, buildings and other fields, including to avoid the risk of “carbon leakage”. We plan to implement the Carbon Border Adjustment Mechanism (CBAM). CBAM, the first global carbon tariff scheme, is a charge on the carbon emissions of goods imported into the EU. The EU believes that if its own climate targets are too high, it may lead to the transfer of high-carbon emission industries to countries and regions with relatively loose climate policies, affecting the competitiveness of local carbon-intensive commodities. In this context, the implementation of CBAM will not only help to better protect enterprises in the EU in the context of trade globalization, but also encourage other countries to increase emission reduction efforts.

CBAM has mainly made adjustments to the following provisions in the new draft. One is to delay the formal implementation by one year. From 2023 to 2026, enterprises are not required to pay CBAM fees, but they are required to submit a report to the CBAM management authority every quarter, which mainly includes: the total amount of imported products in the quarter by category (indicating the manufacturer), the direct and indirect emissions of each type of product, and the carbon emissions cost paid by the product emissions in the country of origin. Starting from 2027, CBAM fees will be paid based on the carbon emissions of imported products. The second is to expand the scope of application of CBAM. On the basis of the five major industries of cement, electricity, fertilizer, steel and aluminum, organic chemicals, hydrogen, ammonia and plastic products are included. The third is to accelerate the exit process of free allowances from the EU Emissions Trading System (EU ETS). The original plan was to reduce the free quota by 10% per year from 2026, and to withdraw completely by 2035. It is proposed that from 2027 to 2032, the proportion of ETS carbon tariff free allowances will be reduced to 93%, 84%, 69%, 50%, 25% and 0, respectively, that is, the withdrawal of free allowances will be completed three years in advance. Fourth, expand the scope of carbon emission calculation for carbon tariffs. In the March 2022 draft, the category of carbon tariffs only includes “direct emissions,” that is, carbon emissions directly generated by the production of products. In order to better reflect the carbon cost of the European industrial sector and be compatible with the relevant WTO principles, the new draft proposes to include “indirect emissions”, that is, the carbon emissions generated by the electricity consumed in the production of products, into the total emissions accounting, which means that the carbon emissions generated by the purchase of electricity from the manufacturing industry will also be subject to carbon tariffs. The fifth is to set up a unified executive body at the EU level. The aim is to ensure the effectiveness of the subsequent implementation of the CBAM mechanism and to use the carbon tax to support the decarbonization of manufacturing in LDCS. The sixth is to clarify the relevant punishment mechanism and fine amount. In case of failure to submit CBAM-related certificates or false information to the CBAM authority before May 31 of each year, a penalty of three times the average price of the CBAM certificate in the preceding year shall be imposed along with the replacement of the outstanding number of CBAM certificates.

3.2. The American Clean Act

Since the end of the 21st century, the United States has actively tried to put forward a series of proposals on carbon border regulation, cap-and-trade, and carbon tax systems at the federal level. However, due to the lack of a greenhouse gas emissions trading system similar to the EU ETS, and the lack of uniform carbon pricing at the federal level, the United States has never formally introduced a national carbon tax document. With the proposal and continuous promotion of the EU CBAM, the relevant legislation of carbon pricing and carbon border adjustment was more active during the 116th and 117th U.S. Congress. In June 2022, U.S. Democratic Senator Whitehouse, together with three other Democratic senators, formally submitted a bill called the Clean Competition Act (CCA) to the Senate Finance Committee.

The CCA does not follow the European Union in imposing a carbon price tax, but instead imposes a carbon fee on products that contain more carbon than the industry average. In other words, the EU's carbon tax standard is to see whether the country's carbon price is "expensive", and the United States' tax standard is to measure the "green" of imported products. This design cleverly avoids the current situation of the United States without a unified carbon market and a unified carbon price, and successfully realizes the shift from punishing low carbon prices to punishing high carbon content. CCA's practice is to take the average carbon content of US products as the base line, for imported products and US products with carbon content higher than the base line, it charges a carbon fee of US $55 per ton, and it increases by 5% per year considering inflation. Of this, 75% of carbon tax revenue is used to fund competitive grant programs for carbon-intensive industries, and 25% is used to help developing countries decarbonize and achieve net zero emissions. Although CCA and CBAM are both punitive tariffs, the former reflects its idea of transforming into a mature carbon tax system, such as the carbon content baseline set will be calculated based on the emissions, electricity consumption and production reported by US enterprises to the Treasury Department, and has transitional characteristics: From 2025 to 2028, the baseline carbon content will be lowered by 2.5% per year, and from 2029 by 5% per year and eventually to zero. However, on 14 October 2024, the United States comprehensively raised the tariffs on Chinese trams exported to it, and the tariff increase was finally fixed at 100%, which seems that the United States has to implement this move.

4. Data and Model Processing

4.1. Data Processing

This article analyzes the 11A database using GTAP, which is the latest version of the GTAP database with data updated to 2017. The database covers a total of 160 countries and 65 production sectors. Before using the database, countries, regions and production sectors need to be classified according to the research content. The country setting (Table 1) takes into account information from the EU's major trading partners, the EU carbon border Adjustment Mechanism, the European Emissions Trading System, the development direction of China's export industry and relevant economic cooperation organizations. The production sector setting (Table 2) is combined with China's "Classification of National Economic Industries" (GB/T 4754-2017), the EU carbon border adjustment mechanism Act document "Regulation of the European Parliament and the Council on the establishment of carbon border adjustment mechanism (EU) 2023/956" and the European emissions Trading System document "Commission Regulation (EU) 2024/873" included in the carbon tariff-related industries as well as the quality improvement and carbon reduction path of China's export products The CONTENT.

Table 1. GTAP 11A database country Settings.

National and Regional Establishment	The Initial Country in the Database
chn	China
EU_27	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden
usa	United States of America

Table 1. Cont.

National and Regional Establishment	The Initial Country in the Database
uk	United Kingdom
can	Canada
RCEP_otr	Australia, New Zealand, Japan, Korea, Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Philippines, Singapore, Thailand, Viet Nam
e&s_a	Rest of East Asia, Rest of South Asia
br_otr	India, Brazil, Russian Federation, South Africa
eu_ets'otr	Switzerland, Norway, Rest of EFTA
xtw	Other countries and regions listed in the database in addition to the above countries and regions

Source: Compiled by GTAP 11A database.

Table 2. GTAP 11A database production department Settings.

Production Department Setting	Original Production Department Category in the Database
agr	paddy rice, wheat, cereal graints nec, vegetables/fruit/nuts, oil seeds, sugar cane/sugar beat, plant-based fibers, crops nec, forestry, fishing
fop	bovine cattle/sheep/goats, animal products nec, raw milk, wool/silk-worm cocoons, bovine meat products, meat products net, vegetable oil and fats, dairy products, processed rice, sugar, food products nec, beverages and tobacco products
clo	textiles, wearing apparel, leather products
li_ind	wood products, paper products/publishing
che	chemical products, rubber and plastic products
min	minerals nec, mineral products nec, water
coa	coal
oil	oil
gas	gas, gas manufacture/distribution
o_p	petroleum/coal products
elc	electricity
met	ferrous metals, metals nec, metal products
new_tec	electrical equipment, machinery and equipment, manufacturess nec
mech_m	motor vechicles and parts, transport equipment nec
trans_m	basic pharmaceutical products, computer/electronic/optic
cns	construction
trd	trade
trans_sup	water transport, air transport, transport nec, warehousing and support activic
com_ser	communication, financial services nec, insurance, real estate activities, business services nec, accommodation/food servic, dwellings
otr_ser	recreational and other service, public administration and defe, education, human health and social word activities

Source: Compiled by GTAP 11A database.

4.2. Carbon Tariff Rate Setting

The carbon tariff imposed in the GTAP model is AD valorem tax, and the EU carbon border regulation mechanism actually collects AD valorem tax. We need to convert the AD valorem tax into AD valorem tax according to a certain formula, and then input it into the model for discussion. The formula for calculating the AD valorem tax rate of carbon tariff is:

$$\tau' = \tau * VCIF_i * \xi_i / VPM_i * 100\%$$

τ' is the AD valorem rate of carbon tariff, and the unit is percentage; τ is the specific carbon tariff rate, the unit is USD/ton; VCIFi is the CIF price of product *i* from the exporting country to the country where the carbon tariff is imposed, in millions of US dollars; ξ_i is the implied carbon emission intensity of product *i*, expressed in tons/USD; VPMi is the market value of product *i* exported to the taxing country in millions of US dollars.

4.3. Simulation Scenario Setting

Based on a detailed simulation of carbon tariffs based on a dynamic GTAP-E model, we set up a simulation scenario covering different tax entities, applicable industries and tax rates (USD/ton) to analyze the potential impact of carbon tariff policies. Simulation scenarios are divided into three main categories: basic scenario, industry-wide levy and countermeasures, each containing multiple simulation scenarios. The tax rate is $60/ton and $120/ton respectively.

In the base scenario, the carbon tax is mainly levied by the EU and applies to certain high-carbon emitting industries. S01 includes power, cement, steel, hydrogen, aluminum, fertilizer, and S02 includes power, cement, steel, hydrogen, aluminum, fertilizer, organic chemistry, heat, oil refining, metals, lime, glass, ceramics, paper products, aviation, and Marine. In the S02 phase, the scope of the EU carbon tax has been further expanded, adding organic chemicals, thermal energy, oil refining, metals, lime, glass, ceramics, paper products, aviation, shipping and other industries.

In the S1 scenario, the EU is aligned with the EU-ETS standard, which no longer limits taxes on specific sectors, but imposes carbon taxes on all sectors. The S11 carbon tariff rate is $60/ton, and the S12 carbon tariff rate is increased to $120/ton.

In the S2 scenario, China and other non-Chinese economic organizations jointly retaliate by imposing reciprocal carbon tariffs. The EU will not be the only country to impose carbon tariffs. S21 took countermeasures only for China. The EU and other EU-ETS participating countries impose carbon tariffs on all sectors. In the S22 scenario, China and other economic organizations other than China impose carbon tariffs at the same level as the EU and EU-ETS participating countries, with the EU and EU_ETS jointly imposing two levels of carbon tariffs on all sectors.

In summary, we simulated carbon tariff policies in different scenarios, and the industry setting took into account the EU carbon border regulation mechanism and EU-ETS related act documents. Includes a carbon tariff with two tax levels ($60/ton and $120/ton). The scenarios take into account a broader global carbon tax policy, including the participation of China and international cooperation organizations in taking countermeasures. These simulations help to assess the potential impact of different carbon tariff policies on the global economy, industrial competitiveness and international trade flows.

5. Prediction and Analysis of Carbon Tariff Rate

5.1. EU Carbon Tariff Rates for China

Table 3 shows the AD valorem carbon tariff rates imposed by the EU on different industries in China under different simulation scenarios. We will discuss the potential impact of the implementation of the EU's carbon border adjustment mechanism on various industries in China in the future. Overall, the manufacturing industry is under the most pressure from carbon tariffs, especially the machinery and equipment manufacturing industry, chemical industry, metal mining and processing industry, among which the machinery and equipment manufacturing industry has a tax rate of 31.40% under S02 and S04 scenarios, and the chemical industry has a tax rate of more than 23% under S02, S04 and S12 scenarios. The metal mining and processing industry is also taxed at around 13%. Due to their high carbon emissions, these industries face stricter carbon emission reduction requirements and greater cost pressure. For example, the tax rate of the transportation manufacturing industry and commercial commodity service industry is 8.90% in the S02 scenario, while the tax rate of the commercial commodity service industry is as high as 13.31% in the S12 scenario. With the expansion of the scope of the EU carbon tariff collection industry, the industry will be more affected. Agriculture, food manufacturing, textiles, wood manufacturing, construction, trade and other service industries may face a lower carbon tariff rate and be relatively less affected, among which the construction industry has the lowest tax rate, the carbon tariff rate ranges from 0.70% to 2.36%, and the tax rate of trade industry does not exceed 7.46% under most scenarios. Other services are even as low as 1.10%. This shows that the EU's carbon tariff policy is mainly aimed at high-carbon emission industries to promote the transformation of high-energy consumption industries to green and low-carbon, while the impact on low-carbon industries is relatively small. At the same time, the changes in tax rates under different scenarios reflect the uncertainty of policies, which may bring different degrees of impact due to the adjustment of EU policies in the future, and relevant industries should pay close attention to and take positive countermeasures.

Table 3. AD valorem carbon tariff rates of the EU against China under different scenarios%.

Sector	S01	S02	S03	S04	S11	S12	S2
agr					2.40	4.79	2.87
fop					2.30	4.60	2.13
clo					2.67	5.33	1.69
li_ind			3.48	6.95	3.48	6.95	2.83
che	11.70	23.40	11.70	23.39	11.70	23.39	5.75
min	6.88	13.80	6.88	13.77	6.88	13.77	3.75
met	6.7	13.60	6.79	13.58	6.79	13.58	3.42
new_tec	15.69	31.40	15.69	31.39	15.69	31.39	6.72
mech_m	4.43	8.90	4.43	8.86	4.43	8.86	1.91
trans_m	0.70	1.40	0.70	1.40	0.70	1.40	2.36
cns			7.60	15.20	7.60	15.20	3.84
trd			6.85	13.70	6.85	13.70	1.26
trans_sup					1.37	2.73	7.46
com_ser					6.65	13.31	4.90
otr_ser					1.15	2.31	1.10

Source: Compiled by GTAP 11A database.

5.2. EU Carbon Tariff Rates for Other RCEP Countries

From Table 4, it can be seen that from the first to the third stage, the AD valorem carbon tariff rates of the EU on different production sectors of RCEP countries have a large span, and high-carbon emission industries will generally face higher tax rates, while low-carbon industries will be relatively little affected. The transportation manufacturing industry, chemical industry, metal mining and processing industry are the main targets of the carbon tax policy. At the level of 120 US dollars/ton, the carbon tariff of the transportation manufacturing industry is as high as 25.40%, the carbon tariff of the chemical industry is 22.77%, and the carbon tariff of the metal mining and processing industry is 8.94%. Machinery and equipment manufacturing is also among the most affected industries, with a carbon tariff rate of 9.88%. These industries will be more affected due to their high carbon emission characteristics, indicating that the EU carbon tariff policy aims to exert greater carbon cost pressure on high-polluting industries and promote their transition to green and low-carbon. In contrast, agriculture, food manufacturing, textiles, wood manufacturing, construction, trade and other services will face lower carbon tariffs and be relatively unaffected. In the S12 scenario, the tax rate of agriculture, forestry, animal husbandry and fishery is 3.41%, the highest rate of food manufacturing is 4.05%, the highest rate of textiles is 4.59%, the highest rate of construction is 4.94%, the highest rate of trade industry is 15.41%, and the carbon tariff rate of commercial commodity service industry is 15.25%, and the lowest rate is only 7.62%. Cross-industry comparison, other services will face a carbon tariff rate of up to 3.77% and a minimum of 1.10%, which is the least affected of all industries. Low-carbon industries are less directly affected by the EU's carbon tariff policy, and the overall tax rate is kept at a low level.

In the fourth stage, except for the EU, China and the Economic Cooperation Organization jointly adopted countermeasures to impose the same carbon tariff, and the carbon tariff rate of all industries was significantly reduced, the tax rate of transportation manufacturing was reduced to 6.88%, the chemical industry was reduced to 6.27%, the machinery and equipment manufacturing industry was reduced to 4.09%, and the metal mining and processing industry was reduced to 4.80%. The tax rates for agriculture, food, construction, trade and services are also further reduced in this scenario, to 2.95% for agriculture, 2.25% for food manufacturing, 2.10% for construction and 6.76% for trade. This suggests that taking countermeasures would reduce the overall negative impact of carbon tariffs on other RCEP countries. Under different scenarios, the fluctuations in tax rates by industry reflect the uncertainty of the EU's carbon tariff policy, which may have different impacts in the future due to international policy changes or adjustments to industry carbon emission standards. Therefore, high-carbon industries should actively take carbon emission reduction measures to reduce potential tax costs, while low-carbon industries should also pay attention to policy changes, and appropriate countermeasures can be taken to build international trade rules and order.

Table 4. AD valorem carbon tariff rates of the EU against RCEP under different scenarios%.

Sector	S01	S02	S03	S04	S11	S12	S2
agr					1.71	3.41	2.95
fop					2.03	4.05	2.25
clo					2.30	4.59	1.80
li_ind			3.01	6.03	3.01	6.03	2.93
che	11.38	22.77	11.38	22.77	11.38	22.77	6.27
min	2.30	4.59	2.30	4.59	2.30	4.59	3.66
met	4.47	8.94	4.47	8.94	4.47	8.94	4.80
new_tec	4.94	9.88	4.94	9.88	4.94	9.88	4.09
mech_m	12.70	25.40	12.70	25.40	12.70	25.40	6.88
trans_m	2.47	4.94	2.47	4.94	2.47	4.94	2.10
cns			1.56	3.11	1.56	3.11	2.30
trd			1.98	3.96	1.98	3.96	1.25
trans_sup					7.70	15.41	6.76
com_ser					7.62	15.25	4.90
otr_ser					1.89	3.77	1.10

Source: Compiled by GTAP 11A database.

5.3. EU Carbon Tariff Rates for Other BRICS Countries

Table 5 shows the AD valorem carbon tariff rates imposed by the EU on other BRICS countries under different scenarios. On the whole, the carbon tariff rate of the high-carbon emission industry is much higher than the carbon tariff rate of the low-carbon industry. Among them, the transportation manufacturing industry, the chemical industry, metal mining and processing industry has the highest tax rate, and will face more severe carbon tariff pressure. The carbon tariff rate of the transportation manufacturing industry is 21.07% at the level of $60/ton, and 42.13% at the level of $120/ton, more than double, which shows the high carbon emissions of the industry and the great impact of the EU carbon border adjustment mechanism policy. The carbon tariff rate of the chemical industry is 14.84% at the level of $60/ton and 29.67% at the level of $120/ton, and the increase in carbon price will greatly increase the carbon emission cost of the industry. In addition, the metal mining and processing industry also faces a higher carbon tax burden, with carbon prices rising, it faces a carbon tariff rate increased from 13.48% to 26.97%. Although the carbon tax rate of the machinery and equipment manufacturing industry, construction industry and other mineral resources industry is lower than the above industries, but will still face not low carbon tariffs, high carbon price level, the tax rate of machinery and equipment manufacturing industry reached 16.29%, the tax rate of the construction industry is 11.60%, and the tax rate of other mineral resources industry is 9.56%. At the same time, agriculture, food manufacturing, textiles, wood manufacturing, high-tech industries, transportation and ancillary industries, trade and services face relatively low carbon tariff rates and less pressure on carbon emissions costs. At the high carbon price level, agriculture, forestry, animal husbandry and fishery accounted for 7.10%, food manufacturing 5.38%, textiles 5.18%, and high-tech industries 6.41%. The tax rate for trade and commercial goods services increases under the S12 scenario to 15.27% and 17.94% respectively, but the overall level is lower than that for high-carbon industries.

In the fourth phase, the carbon tax rates for all sectors were significantly reduced, indicating that the implementation of countermeasures by China and other economic organizations will have a significant impact on the adjustment of the EU's carbon tariff policy. The tax rate of the transportation manufacturing industry was reduced to 7.15%, the chemical industry to 6.41%, the machinery and equipment manufacturing industry to 4.30%, the metal mining and processing industry to 4.31%, the other mineral resources industry to 4.04%, and the construction industry fell more sharply and dropped to 2.13%. In addition, the tax rates for agriculture, food manufacturing, textiles and wood manufacturing have been reduced to 2.96 percent, 2.34 percent, 1.89 percent and 2.96 percent respectively. It is worth noting that although the level of carbon tariffs in trade and commercial goods services has also decreased, the level is relatively high, 9.44% and 5.21%, respectively, meaning that even in a looser policy environment, these industries still need to bear a higher carbon tax cost. To sum up, the overall tax rate in the S2 scenario is reduced, and considering that more countries take countermeasures, the EU will adjust its carbon tariff policy.

6. Policy Recommendations

In order to further reduce the trade pressure on those countries that are most affected by green trade barriers, this paper proposes the following policy recommendations:

First, countries need to break out of the climate trade discourse system dominated by western regimes such as the EU, build their own green trade response strategies and logical structures, and negotiate with other countries and economic organizations in an orderly manner while negotiating with the EU, so as to explore contractual methods to deal with unfair green competition. While conducting international trade, multilateral dialogue and cooperation mechanisms should be used to formulate reasonable countermeasures. Countries that affect free trade due to unilateral discriminatory policies should work together to improve export conditions and face risks together.

Second, developing countries should take this opportunity to update, better and more accurately design the export pattern and micro-ecology of their industries, continue to give full play to their export advantages in textiles and light processing, help the export products of the construction industry expand overseas business, encourage machinery and equipment, ships, automobiles and other large equipment or whole parts to expand into the field of energy conservation and environmental protection, and give full play to the advantages of the service industry. Extend the industrial chain value chain and construct a multi-level supply chain system; Seize the good opportunity of international cooperation and the Belt and Road Initiative to leverage our comparative advantages; Optimize the green export industry system, solid soil, to cope with the new pattern of international trade in the future.

Third, we need to continuously improve the carbon accounting and carbon trading system, so that products

Table 5. AD valorem carbon tariff rates imposed by the EU on other BRICS countries under different scenarios%.

Sector	S01	S02	S03	S04	S11	S12	S2
agr					3.55	7.10	2.96
fop					2.69	5.38	2.34
clo					2.59	5.18	1.89
li_ind			3.75	7.49	3.75	7.49	2.96
che	14.84	29.67	14.84	29.67	14.84	29.67	6.41
min	4.78	9.56	4.78	9.56	4.78	9.56	4.04
met	13.48	26.97	13.48	26.97	13.48	26.97	4.31
new_tec	8.15	16.29	8.15	16.29	8.15	16.29	4.30
mech_m	21.07	42.13	21.07	42.13	21.07	42.13	7.15
trans_m	5.80	11.60	5.80	11.60	5.80	11.60	2.13
cns			3.21	6.41	3.21	6.41	2.42
trd			1.94	3.88	1.94	3.88	1.34
trans_sup					7.64	15.27	9.44
com_ser					8.97	17.94	5.21
otr_ser					1.80	3.60	1.14

Source: Compiled by GTAP 11A database.

can better integrate into the green trade chain. Improve the hidden carbon emission accounting system for the whole life cycle of products from enterprise production, product molding, transportation and other links, so that carbon accounting is accurate and scientific, so that carbon footprint covers the industrial chain system completely. Promote the construction of carbon emission trading systems and carbon markets to safeguard the real economy involved in export trade and the goal of carbon neutrality in trade.

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Article

Macroeconomic Regulation: A Third Way beyond Keynesianism and Monetarism

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Abstract: In addressing economic downturns, there are two primary approaches in Western macroeconomics: central bank money issuance and government debt issuance. The former is known as monetarism, and the latter is called Keynesianism. In fact, there is a "third path" apart from these two methods, which is to "stimulate the credit-creation ability of commercial banks". This is a new solution proposed in this paper. "Expanding the credit creation of commercial banks" can also generate a large amount of money for investment without incurring any costs and without leaving any sequelae of economic stimulus.

Keywords: macroeconomic regulation; third path; paradox of monetary policy; monetary hedging; depression caused by a collapse in the rate of return on capital

1. Limitations of Government Bond Issuance and Central Bank Money Creation

The government's investment through bond issuance is a proposition of the Keynesian school. Government bond issuance without prior tax reform will not only lead to a government debt trap but also transmit its negative impacts to the entire economy through the suppressing effect of government debt on interest rates [1]. The author has proposed the theory of the "government debt-central bank interest rate spiral": government bond issuance will suppress the central bank's interest rates, and the central bank's low-interest rates, in turn, will boost government bond issuance. Eventually, this will only result in continuously lower central bank interest rates and ever-increasing government debt. Moreover, the harm of government bond issuance will be transmitted to the entire financial system through the central bank's low-interest rates, ultimately endangering the entire economy. The central bank's money creation is a proposition of the monetarist school, and its scale is also quite limited.

2. Expand the Huge Scope for Commercial Banks to Enhance Their Credit Creation Capabilities

The amount of money created by expanding the credit creation capacity of commercial banks will be far greater than that created by the above two methods. By expanding the credit creation capacity of commercial banks, hundreds of trillions or even over a million trillion of investment capital can be created. For example, in China, the amount of base money is about 40 trillion. If the money multiplier doubles, it means an additional 40 trillion; if it triples, it means an additional 80 trillion. Even in an economic environment with a very sluggish financial sector, with 40 trillion in base money, a "total social financing scale" of over 400 trillion can be

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created, among which about 360 trillion is credit money created by commercial banks [2].

Since the birth of commercial banks, the proportion of central bank money in the total effectively-circulating money in society has been quite small. More than 90% of the effectively-circulating money in society is created through the credit of commercial banks. Keynes discovered this rule when he wrote *A Treatise on Money* last century and explained it clearly [3].

What we often hear as "lack of funds for investment" actually refers to the insufficient credit creation of commercial banks, rather than a real shortage of money. Investment is sourced from money, and money ultimately comes from the credit creation of commercial banks. To address the issue of the lack of funds for investment, the most crucial aspect is to solve the problem of commercial banks' credit creation. Only by expanding the credit creation capacity of commercial banks can a large amount of corporate investment capital be generated. Therefore, we propose that "a country's investment capacity is actually a function of the currency credit creation capacity of commercial banks". Compared with the currency credit creation of commercial banks, government bond issuance and central bank money-creation are not even in the same order of magnitude. Moreover, the vast majority of the money created through commercial banks' credit creation is invested in the real economy, and there are basically no sequelae from economic stimulus.

3. The "Paradox of Monetary Policy" and the Issue of "Monetary Hedging"

Since expanding the credit-creation capacity of commercial banks has an immediate effect on rescuing the economy, why is this approach rarely adopted worldwide? Firstly, central banks around the globe formulate monetary policies within the constraints of the quantity theory of money. *A Monetary History of the United States* also emphasizes "printing money to save the economy" rather than motivating the credit-creation of commercial banks [4]. Currently, the theory of "printing money to save the economy" has become the most mainstream theory in contemporary macroeconomics after being developed by Milton Friedman and Ben Bernanke. Although it has been opposed by scholars from the Post-Keynesian endogenous money school and the McKinnon "financial deepening" school, it still maintains its dominant position.

However, the approach of "printing money to save the economy" advocated by the monetarist school has shown poor results in reality. Printing money not only fails to stimulate the credit-creation of commercial banks but also destroys it. Moreover, it creates a "paradox of monetary policy". When the central bank intends to implement an expansionary monetary policy, the actual "effectively-circulating money" decreases. This is due to the issue of "monetary hedging". The principle and logic behind "monetary hedging" are that the central bank's expansionary monetary policy is incompatible with the incentives of credit-based financial institutions. That is, there is an incentive conflict between the central bank's monetary policy and commercial banks. At this time, the enthusiasm of credit-based financial institutions for lending declines, and their credit-creation capacity drops significantly, resulting in a decrease in the total amount of effectively-circulating money in society. As a result, instead of experiencing excessive liquidity, the overall economy falls into a liquidity trap.

In the era of low-interest rates, the decline in the credit-creation capacity of credit-based financial institutions is not only due to the decrease in their enthusiasm but also because the "narrow interest-spread" leads to a decline in their risk-resistance ability. For banks to lend out money, they have to relax risk control. However, the precondition for relaxing risk control is to widen the interest-spread. The narrower the interest-spread, the stricter the bank's risk control and the higher the loan threshold. In the low-interest-rate era, the loan threshold of banks actually increases, and banks are unable to lend out money even if they have funds. When the interest-spread of commercial banks is lower than their natural bad-debt rate, how can banks dare to issue loans?

The credit-creation capacity of banks is directly proportional to the "interest-spread" of banks. In the era when the central bank implements high-interest-rate policies, the interest-spread of banks is high, and their credit-creation capacity is strong, thus a large amount of investment capital will be created. Once the central bank starts to implement low-interest-rate policies, the credit-creation capacity of commercial banks will decline. When the bank's interest-spread is lower than its "natural bad-debt rate", theoretically, the bank's credit-creation capacity will become zero. At this time, each loan issued by the bank will result in a loss. Therefore, to expand the lending capacity of banks, interest rates must be raised. As a result, the quantitative easing monetary policy destroys the credit-creation capacity of banks rather than strengthening it. A loose monetary policy is not a good way to rescue banks from a crisis.

The long-term implementation of loose monetary policy will lead to a decrease in the effectively circulating money. Although the central bank increases the issuance of currency and adds one or two trillion yuan of base money, due to the decline in the credit creation ability of commercial banks, it will result in a loss of hundreds of trillions of yuan in effectively circulating money. This is also the reason why loose monetary policy not only fails to rescue the economy but also causes an economic downturn.

4. Conflicts in Monetary Policy Orientations between the Quantity Theory of Money and the Theory of Monetary Credit Creation

The theoretical basis behind the loose monetary policy is the “quantity theory of money”. In essence, economic policies formulated based on the quantity theory of money and the theory of monetary credit creation are in conflict. According to the quantity theory of money, the more money there is, the better. This will inevitably lead to low interest rates. However, according to the theory of monetary credit creation, only “moderately high interest rates” can effectively stimulate the credit creation ability of commercial banks.

Although Ben Shalom Bernanke proposed the “financial accelerator” theory and noticed the role of the banking crisis in the economic crisis, he failed to come up with a new theory. Moreover, his solutions reverted to those of Milton Friedman. In the end, Bernanke did not stand on the right side of history.

5. The “Quantity Theory of Money” Is the Greatest Obstacle to Emancipating the Mind

The greatest enemy of modern economics is the “quantity theory of money” [5]. The quantity theory of money advocates printing money when the economy faces deflation and withdrawing money when there is inflation. This wrong way of thinking has severely restricted people’s decision-making. As can be known from our previous analysis, the central bank’s money-printing conflicts with the credit creation ability of commercial banks. The central bank’s money-printing will not lead to an increase in the total amount of effectively circulating money in society but rather a decrease, thus causing the money-printing policy to fail. Therefore, Milton Friedman’s monetary proposition is wrong. Since the emergence of the credit creation of commercial banks, the quantity theory of money has actually long become ineffective.

However, in reality, there are too few economists who have grasped the concept of monetary credit creation. Even those economists who understand the idea of credit creation have not linked credit creation with interest rates. So when formulating policies, there is an almost one-sided inclination towards the thinking of the quantity theory of money.

6. The Consequence of the Prevalence of the Quantity Theory of Money Is the “Collapse-Style Depression of Capital Returns”

When a country’s credit interest rate drops to a certain level, a “collapse-style depression of capital returns” will occur. This kind of depression mainly has four major characteristics: “banks have no profits, enterprises have no funds to use, the public has no money to spend, and the government has no tax revenue”. These four situations are interlinked. If banks have no profits, enterprises will lack funds. Without sufficient funds, enterprises won’t expand, and as a result, the public’s income won’t grow, and they will have no money to spend. If corporate investment and public income don’t increase, the national tax revenue won’t grow either; instead, it may even decline.

Japan was the first country in the world to implement the “quantitative easing” monetary policy, and its economy was also the first to fall into the “collapse-style depression of capital returns”. The society under such a depression is a society without desires. The United States also implemented quantitative easing for a long time and was on the verge of falling into the “collapse-style depression of capital returns”. However, due to the severe inflation in the US after the Russia-Ukraine conflict, it then quickly entered an interest-rate hike cycle and finally managed to avoid the depression. This has provided humanity with a case of getting out of the "collapse-style depression of capital returns". The phenomenon that the US economy thrives as interest rates rise is difficult to explain from the perspective of modern economics, but it can be perfectly explained by the author's economic theory. Currently, the Chinese economy is at risk of sliding into the "collapse-style depression of capital returns".

7. The "Optimal Central Bank Monetary Interest Rate" Is an Interest Rate that Is Moderately High

In modern economies, there is no shortage of credit demand. Instead, there is a lack of incentives for credit-based financial institutions to explore such demand. In modern society, the supply of credit lags far behind the demand. As long as credit institutions are adequately incentivized, more credit demands will be uncovered and met, and the total social financing scale will increase. Therefore, monetary policy stimulus should be implemented from the supply-side of money, that is, by stimulating credit institutions rather than using low-interest rates to stimulate enterprises.

For modern economies, capital is the engine of the economy, and real-sector enterprises are the wheels. When the economy slows down, we should promptly restore the power of the engine rather than directly push the wheels.

Only when the "optimal central bank monetary interest rate" is implemented can the social financing scale be maximized, the quantity of effectively-operating money be maximized, and finance support the real economy to the greatest extent. If a country wants to maintain high-speed economic growth, it should implement "financial deepening" rather than "financial repression". Of course, financial deepening is not the financial liberalization advocated by scholars like McKinnon in the United States. Instead, the central bank should fix the monetary interest rate at the "optimal central bank monetary interest rate".

8. Conclusions

Given that the Keynesian and monetarist economic policies we have grown accustomed to using have become ineffective, it might be worth adopting the third approach proposed in this paper. That is, by setting the optimal central-bank monetary interest rate to enhance the credit-creation capacity of commercial banks, we can break out of the economic dilemma and maximize economic growth.

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Data Availability Statement

The data presented in this study are openly available via the links provided in the data section. More detailed information can be obtained upon request to the corresponding authors.

Conflicts of Interest

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Article

Optimizing China's Fertility Policies: Strategies Informed by International Practices

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Abstract: This paper mainly discusses how to solve the problem of declining fertility rate in China. On the basis of combing through the current fertility situation in China, it is found that there are problems such as insufficient fertility subsidies, inconsistent standards, employment discrimination for women of childbearing age, backward marriage and childbearing culture in some areas, and imperfect child care system. Some countermeasures were put forward, such as increasing fertility subsidies, unifying subsidy standards, formulating policies to eliminate discrimination against women in employment, building a civilized marriage and childbearing culture, and further improving the child-care system. It is hoped that the financial support and policy incentives provided by the state can reduce the burden of child-rearing.

Keywords: fertility policies; maternity allowance; nursery system

1. Introduction

According to a Reuters report on September 24, Vyacheslav Volodin, Chairman of the Russian State Duma, stated that the Russian parliament plans to enact a law prohibiting behaviors deemed by the government as "harmful propaganda of a childless lifestyle" and imposing heavy fines for such acts. This news highlights that encouraging and safeguarding national fertility has become a critical long-term policy for ensuring stable development in countries worldwide. To maintain stable population growth in China and continuously improve the fertility environment, coordinated efforts across economic, social, and cultural domains are essential.

In recent years, in response to the aging population and declining fertility, China began to implement the "universal two-child policy" in October 2015, and the "universal three-child policy" began to be implemented in May 2021 with the "Decision on Optimizing the Fertility Policy to Promote Long-term and Balanced Population Development". However, according to the data of the National Bureau of Statistics, in 2022, China's population has experienced negative growth for the first time, reducing 850,000 people, and the total fertility rate has fallen below 1.1 (the international warning line is 1.5), and the population fertility issue has become a major proposition before the Party and the country. Further optimizing and improving the fertility system, cracking the "stuck points" and "stuck points" of the fertility policy, and continuously releasing the national fertility potential are of great significance for adapting to the new changes in the population situation and promoting high-quality development.

2. The Historical Evolution of Our Country Birth Policy

Since 1949, China's family policy has experienced from encouraging birth to birth control to strict family

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planning and then to relax family planning and other stages, as follows.

2.1. The First Stage: 1949–1952, the Stage of Encouraging Fertility

In the early days of the founding of the People's Republic of China, the country's population and fertility rate both rose sharply as the country's leaders put forward the slogan "there is strength in numbers". In four years, the population grew from 540 million to 570 million.

2.2. The Second Stage: From 1953 to 1961, the Stage of Birth Control

According to the data of the first population census (1953.6–1954.11), China's total population reached 600 million, accounting for nearly a quarter of the world's total population. The population base is large and the growth momentum is fierce, which leads to the shortage of educational resources and the shortage of residents' housing. In this context, the orientation of the national fertility policy changed from "not opposed to birth control" to "in favor of appropriate birth control", which is the bud of the family planning policy. In nine years, the population grew by only 70 million from 580 million to 650 million.

2.3. The Third Stage: From 1962 to 1979, the Stage of Advocating Family Planning

In December 1962, the Directive on Conscientiously Promoting Family Planning was issued, proposing "to promote birth control in cities and densely populated rural areas, to properly control the natural growth rate of the population, so that the birth problem will gradually move from a state of no planning to a state of planning". This is a landmark document in the formulation of China's family planning policy, thus opening the era of family planning for half a century. In 18 years, the population has increased by only 300 million from 670 million to 970 million, and the family planning policy has had obvious effects.

2.4. The Fourth Stage: From 1980 to 2013, the Strict Family Planning Stage

In 1980, China issued the famous "Open Letter to All Communist Party Members and Communist Youth League Members on Controlling China's Population Growth", which marked the full implementation of the rigid family planning policy. On 9 February 1982, China's "Directives on Further Improving the Work of Family Planning" stated: "Government officials, workers and urban residents, except in special circumstances approved, each couple shall have only one child. It is generally advocated in rural areas that a couple should have only one child, and if some people really have difficulties in requesting a second child, they can make planned arrangements after examination and approval. No matter what the circumstances, can not have three children, "this is long known as the "current birth policy" "one child policy". In September 1982, it was determined that "the practice of family planning is a basic state policy of our country" and established the legal status of family planning, and China entered a period of strict family planning for more than 30 years. Zhang Yue and Chen Dan (2020) [1], and other scholars believe that the family planning policy of strictly carry out the policies of the showed great effect. According to census data, China's population grew by less than 400 million in 34 years from 980 million in 1980 to 1.36 billion in 2013. China's total fertility rate dropped sharply, from 3 before the implementation of the policy to below 2.1 in the 1990s, and then remained at a low level for a long time and continued to decline, reaching the lowest value of 1.49 in 1999, far below the internationally recognized replacement level of 2.1.

2.5. The Fifth Stage: Since 2014, the Birth Stage Has Been Conditionally Released

2.5.1. Implementation Phase of the "Two Children Alone" Policy (January 2013–December 2015)

On 30 December 2013, China issued the "Opinions on Adjusting and Improving the Birth Policy", which stipulates that couples can have two children if one of them is an only child, marking the official launch of China's birth policy adjustment. At the beginning of 2014, provinces across the country successively implemented the "two children alone" policy, and the new population in that year was 16.87 million, 470,000 more than in 2013, and the short-term effect of the policy was prominent [2].

2.5.2. Implementation Phase of Universal Two-Child Policy (January 2016–May 2021)

In October 2015, China decided to "fully implement the policy of allowing one couple to have two children and actively carry out actions to cope with the aging population". This is the second adjustment to the birth policy after the "two-child" policy. The move signals an end to China's more than three-decade-old one-child policy. In 2016, there were 17.86 million new births, 1.31 million more than in 2015. The universal two-child policy has a significant effect on population growth.

2.5.3. Implementation Phase of the "Universal Three-Child" Policy (May 2021–Present)

In order to continue to cope with the declining birth rate and increasing aging, on 31 May 2021, China reviewed the Decision on Optimizing the Fertility Policy to Promote Long-term and Balanced Population Development and began to implement the policy of allowing a couple to have three children and supporting measures. China has officially entered the "three-child era", but the effect is not satisfactory. The birth rate in 2021 will be 10.62 million, more than 1.4 million fewer than the 12.02 million in 2020; In 2022, the birth rate was 9.56 million, again more than 1 million less than the previous year, and it fell below 10 million for the first time since the founding of the People's Republic of China. In 2023, the birth rate is 9.02 million, that is, three years after the three-child policy was lifted, and the birth rate is declining every year, even the natural population growth rate has become −1.48‰. This indicates that the fertility accumulation effect has basically ended and the policy stimulus is weak.

3. Current Shortcomings in China's Fertility Policies

The shortcomings of China's birth policy are mainly reflected in the following three dimensions:

Firstly, the formation process of the policy is not scientific. China's family planning policy has its specific historical background, and the policy of "one child per couple" has not gone through in-depth scientific research and procedural demonstration. One of the motivations for this policy was to set population targets with economic goals, mistakenly believing that China's population must be controlled within 1.2 billion at the end of the 20th century in order to achieve the economic goal of quadrupling per capita GNP. Population control targets are also uncertain and there is no consensus. In addition, the legal basis for implementing the strict one-child policy is insufficient. The Population and Family Planning Law "encourages" a couple to have one child, not "forces" it, which means that the strict one-child policy in cities and towns lacks the support of the upper level law.

Scendly, there is a lack of fairness in the implementation of policies. The core of the "current birth policy" that has been implemented in China for a long time is actually the one-child policy, but in the specific implementation process, it is divided into one child policy, one child and a half policy, two child policy and other types, among which, the "one child and a half policy" means that rural couples can have another child if the first child is a girl. To some extent, the policy reinforced son preference, inadvertently reinforced the idea of "son preference", labeled those families with only daughters as "vulnerable", and was artificially distorted into a policy of "letting farmers have sons". In addition to gender inequality, this policy also reflects the unfairness of urban and rural fertility policies to a certain extent.

Thirdly, Policy adjustment is not timely enough. According to the research of Mu Guangzong (2016) [3], as early as the fifth national census conducted in 2000, the total fertility rate (TFR) of China fell to 1.22, which has fallen into the "ultra-low fertility trap". However, in the document issued in the same year, it is still proposed to "do everything possible to stabilize the low fertility level" such as family planning inertia measures. China's total fertility rate fell from about 6 before the 1970s to about 2 in 1990, then to about 1.5 after 2010, and only 1.15 in 2021, 1.09 in 2022, and 1.0 in 2023, less than half of the generation replacement level (2.1) and the lowest in the world. At present, China's population crisis is in a severe form, but it has not attracted enough attention. It can be seen that the adjustment of China's birth policy is not timely, and the rapid changes in the birth situation do not match, and there is a serious path dependence on the existing policy.

To be specific, China's policy deficiencies are reflected in four aspects.

3.1. Inconsistent Local Fertility Subsidy Policies

Birth subsidy is an important means to reduce the cost of family birth. In recent years, in order to encourage fertility, many provinces and cities have introduced relevant policies to provide financial subsidies to childbearing families. However, due to the different financial status of different places, the lack of subsidies at the policy level and the non-uniform subsidy standards are prominent. For example, in April 2023, the "Notice of the Implementation Plan of Shenyang to issue three-child childcare Subsidies (Trial)" issued by Shenyang City stipulates that "for local household registration families where both husband and wife jointly bear three children according to law, the three-child childcare subsidy will be paid 500 yuan per month until the child is 3 years old". The "Hefei Childcare Subsidy Implementation Plan" issued by Hefei City in 2024 stipulates that "the birth of the second child will be given a one-time subsidy of 2000 yuan; A one-time allowance of 5000 yuan is given for the birth of the third child." It can be seen that the standards and quotas of local government maternity subsidy policies vary greatly.

3.2. Workplace Discrimination against Women of Childbearing Age

In our national family, women often have to bear the important responsibility of childbearing and rearing. In reality, many women have not yet married and had children at the age of marriage, and women have become a "soft spot" in employment when they enter the childbearing age. According to the survey report on the status of Chinese Women in the Workplace in 2023, 57 percent of women believe that the main reason for unfair treatment in the workplace is childbearing. Some cases of employment discrimination against women of childbearing age in the workplace may even rise into legal cases. According to a news released by the Chinese Court network, in 2019, Ms. Fan of Zhuhai entered a property company for less than two months, but was fired on the day she was pregnant. After several unsuccessful negotiations with the property company, Ms. Fan filed a lawsuit on the grounds of equal employment rights dispute. The Zhuhai Xiangzhou Court made a first-instance judgment on the case, finding that the property company had infringed on Ms. Fan's right to equal employment, and ordered the property company to make a written apology and financial compensation to Ms. Fan. This case is the first judicial practice of "equal employment right dispute" for women of childbearing age in Guangdong Province.

3.3. Harmful Marriage and Fertility Practices

Good marriage and family culture is the "soil" to shape the correct marriage and family values of the people. However, in recent years, the high bride price, the trend of comparison, and the "non-marriage" emphasizing personal consumption are easy to produce wrong value guidance for the marriageable people. According to a related news report by the People's Daily Online in 2024, in some counties of Shandong, Henan and Gansu, there are sayings such as "colorful red and green" and "motionless", among which "colorful red and green" is a popular saying according to the color of RMB banknotes, including 10,000 5 yuan, 1000 100 yuan and some 50 yuan banknotes, and the face value of the banknotes is more than 150,000 yuan; "Move" refers to a car, "motionless" refers to a house in the city, the high price of these counties can be seen. The high price of dowry not only corrupts the social atmosphere, but also produces a large number of judicial disputes. In December 2023, at the press conference held by the Supreme People's Court, the Ministry of Civil Affairs and the All-China Women's Federation on "Promoting the change of customs and customs to control high bride price", Chen Yifang, president of the First People's Court of the Supreme People's Court, said that the number of bride price disputes in recent years has been on the rise.

3.4. Inadequate Childcare Services

Infant care service is an important part of improving people's livelihood and concerns thousands of families. Modern families often cannot provide enough care time due to work reasons, but the current social care service system is insufficient in effective supply, public institutions are in short supply, private institutions charge high and mixed, and infant care services lack of official guidance and industry norms, resulting in many families feel pressure in the care process. In 2020, a news report from Anhui Network reflected the current problem of “it is easy to enroll and difficult to drop out” in some early education institutions. Ms. Chen, a citizen, spent more than 20,000 yuan for her children to attend a one-year course in an early education institution located in the economic development District. After the child took a day of class, she found through monitoring that the child’s class experience was poor, and thought that the teacher was not responsible enough, so she planned to withdraw from the class, but was repeatedly delayed by the early education agency. To this end, Ms. Chen complained about the early education agency to the Consumer Complaints Reporting Center of the Market Supervision Bureau.

4. International Experiences in Addressing Fertility Challenges

Compared with China, western developed countries such as Germany and France entered the aging and low fertility society earlier, and gained some policy experience for reference in solving the problem of national population fertility.

4.1. Linking Childcare Benefits to Parental Leave

France’s parental leave policy is more representative, according to the relevant provisions of the French Social Security Code amended in 2008, France sets a statutory 16 weeks of maternity leave, if the number of children or multiple births, maternity leave can be up to 46 weeks. All payments during maternity leave are made by the French Social Security Agency, and the employer is not responsible for wages. In addition, French parents can also enjoy a year of paid parental leave, which can be extended up to two times, and receive a basic subsidy of about 429 euros/month. As a high welfare state, Germany provides high maternity allowances for parents and infants to encourage fertility. In 2006, Germany introduced the Federal Parental Allowance and Parental Leave Act, which stipulates that birth parents can receive parental allowance and parental allowance within 14 months after the birth of their child. Parents who did not work before giving birth can receive a monthly allowance of 300 euros, and those who worked before can receive a maximum allowance of 1800 euros. In addition, Germany also provides subsidies for newborns to cover the cost of raising, all newborns before the age of 18 can receive a subsidy of 250 euros/month, about 37% of the cost of raising.

4.2. Legal Protections for Women’s Employment Rights

As early as 1983, France issued the “Labor Code” to protect the employment rights and interests of women of childbearing age, which stipulates that enterprises shall not specify the gender and marital status of recruitment candidates in recruitment advertisements, employers shall not refuse to recruit or transfer women because of pregnancy, and employers shall not ask about the pregnancy of candidates. In 2018, Germany’s revised Maternity Protection Law specifically protects the employment rights of pregnant women and new mothers, stipulating that from the beginning of pregnancy until four months after delivery, employers cannot dismiss pregnant women and new mothers, and this law also applies to pregnant women who have miscarried more than 12 weeks of pregnancy.

4.3. Promoting Pro-Family Values via Media

Another major measure to solve the fertility problem in developed countries is to publicize the importance of fertility and family through TV, social media and public advertisements, and actively shape the mainstream values of marriage and childbearing in society. For example, in June 2024, the German government opened a special column on the most-watched “Recent News” program to provide positive guidance for the blind psychology of many people who believe that over the age of 30, they miss the best childbearing age and therefore give up their family planning. The feature argues that women over 30 accumulate more social resources and invest more time and money in raising children, and that children born to women over 30 have higher grades and better emotional and social behavior.

5. Recommendations for Optimizing Fertility Policies

In order to cope with the changing trend of population fertility in China, it is necessary to enhance the national fertility willingness and promote the long-term balanced development of population. It is necessary to strengthen top-level design and improve the population development strategy and related policy systems such as finance, employment and social security.

5.1. We Made Timely Adjustments to the Policy and Fully Lifted Restrictions on Family Planning

The universal two-child policy is less than expected, and the effect of the three-child policy has not shown, failing to reverse the declining trend of China's birth population. Experts such as Ren Zeping and Liang Jianzhang suggested that China fully liberalize family planning restrictions, formulate policies to encourage and support birth, and remove the cap of "the only country in the world that still implements birth restrictions" [4,5].

5.2. Establish a Comprehensive Financial Support System

In terms of encouraging fertility, it is necessary to further improve the "central-local" fertility allowance subsidy policy, and introduce relevant fertility allowance subsidy policies and establish special funds for fertility allowance subsidies at the national level. We will further clarify the standards and scope of maternity allowances and establish a comprehensive reward system for central and local maternity allowances. The relevant departments of human resources and social Security, health, Statistics Bureau and other departments may, on the basis of the data of the average cost of childbearing and rearing of a household from local population censuses or sample surveys of households, reasonably formulate the standards of maternity allowances and subsidies, and provide subsidies according to a certain proportion of the average cost of childbearing and rearing of a household, and implement stepped subsidies according to the number of newborns in a family. In terms of supporting parenting, it is necessary to fully consider the main household consumption costs such as housing rental costs, nutrition costs, and custody fees of child-rearing families, and encourage places where conditions permit to subsidize rental, purchase, and meal costs for families with two or three children.

5.3. Strengthen Legal Safeguards for Employment and Leave

In the aspect of marriage and childbearing employment, referring to the experience of the legal protection of women of childbearing age in developed countries, the relevant laws and regulations for the protection of women of childbearing age are formulated in line with the actual situation in China, and the employment rights and interests of women before and after marriage and childbearing are protected by legislation. The main contents of relevant laws and regulations on the protection of women of childbearing age should focus on prohibiting enterprises and public institutions from discriminating against women of childbearing age in terms of marriage, age, pregnancy and other aspects in recruitment, and prohibiting enterprises and public institutions from taking improper actions such as forced job change, pay reduction, and dismissal of women of childbearing age or female employees with newborn babies at work. Further strengthen the punishment of enterprises and public institutions for illegal employment of women of childbearing age. In terms of maternity leave, it is proposed to formally incorporate paid parental leave into the scope of the law, and legislate to ensure that parents have enough time and stable income to care for their infants and young children through the establishment of paternity leave for fathers, the guarantee of on-duty pay for parents, and the appropriate extension of parental leave for families with two or three children.

5.4. Promote Healthy Marriage and Fertility Values

Make full use of TV, Internet, social media platforms, we-media and other media channels to increase the publicity of the correct values of marriage and childbearing, such as marriage and family social responsibility, love focus on communication and understanding, and build a public opinion propaganda "matrix" with diverse subjects and diverse ways to advocate a new type of marriage and childbearing culture. Through short videos, suicide live dramas, public interviews, special comments and other communication methods, the narrative content of innovative publicity of new marriage and childbearing culture is enriched, and a series of “vane” cultural products are formed to publicize the correct values of marriage and childbearing. The Women’s Federation, the Youth League Committee, the Ministry of Education, the Publicity Department and other relevant departments should vigorously carry out the main propaganda activities of the “three steps” of the new marriage and childbearing culture into the community, into the campus and into the unit, and strengthen the correct guidance of the contemporary youth’s marriage and love concept of family.

5.5. Improve Childcare Service Systems

Encourage local people’s societies, health and other relevant departments to introduce service norms and industry standards for infant and child care service institutions, standardize the operation qualification and service content of the territorial infant and child care service institutions, and promote the childcare service personnel to work with certificates. Support the establishment of local associations of infant and child care service agencies, assist local governments to implement self-regulatory management of infant and child care service agencies, formulate a standard system for evaluation of childcare services and a “white list” of institutional service quality, and establish a corresponding “exit mechanism” for institutions with irregular operations and inadequate services. Local governments with relatively good financial status can use fiscal subsidies, service consumption vouchers and other financial means to provide appropriate operation subsidies to private infant and child care service institutions with certain universality, relatively standardized operation and good service quality, so as to effectively reduce the expenditure on family childcare services.

5.6. We Will Strengthen Support for Families with Children in Areas Such as Housing, Education, Taxation, and Social Security

In terms of housing, we can explore a trial “children’s housing allowance”, such as each family can get 50, 000 yuan/child housing construction or purchase subsidies. In terms of education, on the one hand, we can explore the policy of free secondary school public education for new children in the pilot areas, and on the other hand, we can promote the cancellation of the policy of general employment separation after junior middle school, so as to effectively alleviate parents’ anxiety about education. In terms of tax revenue, the amount of personal income tax deduction for families with children will be increased. In terms of subsidies for starting businesses, we will increase support for people with children to start businesses. In the field of social security, the “family insurance” policy can be introduced for low-income families, one person works and one person pays, and the whole family can benefit; In the field of commercial insurance, childless policy holders aged 26 and above are required to pay a certain amount of additional premium for childless insurance.

6. Conclusions and Discussion

In fact, the fertility problem is not only a Chinese problem, but also a global problem. Changes in global geopolitics, intense economic competition, increasing pressure in life, changing ideas about marriage and childbearing among the younger generation, and even problems such as air pollution and food safety may be the reasons why young people are less likely to get married and have children. There is a long way to go to change this phenomenon, but we are aware of the seriousness of the problem and are trying to make a change. China’s top-down efforts to solve its fertility conundrum are showing results. On the basis of sorting out the domestic fertility policy, this paper actively learns the excellent experience of France and Germany, which reflects our determination to change.

The shortcoming of this paper is that the survey data come from the National Bureau of Statistics. Future research can also conduct detailed investigation and research on a specific region or community, and design a 3–5 years longitudinal follow-up investigation and research to obtain more real and detailed data and cases, so as to increase the rigor of the research.

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Article

Multi-Perspective Research on the Mechanism of Venture Capital in Driving Innovation Development

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Abstract: This study empirically examines the impact and mechanisms of venture capital on innovation-driven development using a Panel Vector Autoregressive (PVAR) model with three proxy variables: total factor productivity (TFP), industrial upgrading, and technological progress. The findings demonstrate that venture capital significantly promotes innovation-driven economic development overall. Specifically, while the scale of venture capital investment shows a significant positive correlation with industrial upgrading, it fails to significantly enhance either TFP growth or technological advancement. In contrast, increasing the proportion of venture capital in aggregate social financing significantly drives technological progress. These results suggest that to fully realize high-quality, innovation-driven development through venture capital, policymakers must simultaneously expand the scale of venture capital investment and restructure regional financing systems by increasing the share of direct financing. Based on these conclusions, the study proposes policy recommendations including reforming the social financing structure, improving the multi-tier capital market system, and optimizing exit mechanisms for venture capital funds.

Keywords: venture capital; innovation-driven development; industrial upgrading; financing structure; technological progress

1. Introduction

With the advent of the digital era, major economies such as the United States, Europe, and China are transitioning from factor-driven to innovation-driven economic models. Innovation development has become a key indicator for measuring economic growth quality across major countries and regions. Given that venture capital plays a crucial role in fostering innovation incubation, optimizing resource allocation, and accelerating factor mobility, many nations and regions have introduced or established venture capital mechanisms as a catalyst for economic innovation.

However, despite the rapid expansion of venture capital, existing research on its mechanisms in driving innovation remains relatively narrow in perspective. Innovation development manifests at three levels: (1) macro-level, as an improvement in total factor productivity (TFP); (2) meso-level, as industrial structure upgrading; and (3) micro-level, as technological progress and innovation output [1]. Yet, most studies focus solely on the relationship between venture capital and firm-level innovation output [2], with only a few recent works touching upon venture capital's role in industrial structure advancement [3]. Notably, there is a lack of theoretical research examining the impact of venture capital on total factor productivity.

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To address this gap, this study incorporates proxy variables for economic innovation—total factor productivity (TFP), industrial upgrading, and technological progress—into a unified analytical framework. By adopting a multi-dimensional perspective, we systematically investigate the mechanisms and pathways through which venture capital influences economic innovation development.

2. Literature Review

The theoretical foundation of venture capital's role in accelerating innovation-driven growth originates from research on the relationship between industrial upgrading and economic growth. Variations in productivity growth rates and demand expansion across industries imply that resource allocation cannot remain optimally efficient across sectors indefinitely. When industrial upgrading aligns with shifts in demand and improvements in technological utilization efficiency, production factors (e. g., labor and capital) flow toward sectors with higher productivity or productivity growth rates, thereby enhancing economic growth [4]. Peneder's (2003) research further demonstrates that technological progress drives industrial upgrading, and the resulting factor reallocation elevates societal productivity, sustaining economic growth [5]. Thus, technological progress serves as the primary pathway through which industrial upgrading spurs economic growth—a process summarized as technological progress → industrial upgrading → economic growth [6].

However, technological progress itself depends on capital-driven mechanisms. A defining feature of global technological advancement is that "innovation begins with technology but thrives through capital" [7]. Venture capital facilitates rapid profitability for innovative firms [8] and mitigates pervasive underinvestment in corporate innovation [9]. In this process, venture capital promotes industrial upgrading by accelerating technological progress, ultimately driving economic growth—a causal chain encapsulated as "venture capital → technological progress → industrial upgrading → economic growth".

Given venture capital's direct impact on technological progress, much theoretical research focuses on its relationship with firm-level innovation output. Empirical studies globally confirm that equity-based financing instruments like venture capital constitute the most critical external funding source for corporate R&D [10]. Scholars have also identified a significant positive correlation between venture capital investment and patent grants [11]. Analyses of China's earliest major venture capital initiative—the Innovation Fund for Technology-based SMEs—reveal its substantial effects on firm-level innovation output, with economic growth further amplifying these effects [12].

Early theoretical frameworks posit that venture capital indirectly drives industrial upgrading through technological progress, prompting later scholars to expand their focus from innovation output to structural economic transformation. Chen Feiqiong et al. (2015) employed empirical models to investigate venture capital's mechanisms in industrial restructuring, using multi-group structural equation modeling (SEM). Their findings indicate that venture capital significantly enhances value creation and R&D investment at the micro level but exhibits negligible effects on macro-level capital accumulation or employment [13]. Subsequent studies introduced heterogeneity analyses of venture capital's role in industrial upgrading. For instance, Zijing Wu et al. (2019) applied PVAR regression to provincial panel data, concluding that venture capital lacks an initiation mechanism but possesses an acceleration mechanism for industrial upgrading [14].

Existing research predominantly examines venture capital's effects on technological progress and industrial upgrading, with scant attention to its role in total factor productivity (TFP) growth. Levine and Zervos (1998) pioneered this inquiry through financial development theory, empirically demonstrating that direct financing instruments (including venture capital) significantly boost TFP despite limited impacts on aggregate economic growth [15]. Notably, China-specific studies rarely address venture capital's TFP mechanisms, and none integrate TFP, industrial upgrading, and technological progress into a unified analytical framework.

To address these gaps, this study employs panel vector autoregression (PVAR) models to empirically analyze venture capital's innovation-driving mechanisms across three dimensions: total factor productivity, industrial upgrading, and technological progress.

3. Measurement and Indicator Decomposition of TFP

Total Factor Productivity (TFP) refers to the ratio of total output to total input factors in an economic system, serving as a crucial tool for analyzing the sources and pathways of economic growth. It helps identify whether current economic growth is input-driven or efficiency-driven, thereby assessing the sustainability of economic system growth.

The measurement approaches for TFP primarily include parametric and non-parametric methods: (1) parametric methods, mainly based on Solow residual theory, estimate production functions and derive results by calculating the residual value after deducting factor input growth from output growth; (2) non-parametric methods, primarily employing Data Envelopment Analysis (DEA model), compute production frontiers through linear programming. This approach offers the advantage of being unaffected by the measurement units of input-output indicators since it doesn't require constructing specific production function models.

In this study, we adopt the DEA approach to measure TFP and decompose its indicators by calculating the Malmquist-Luenberger index (ML index).

3.1. Methodology and Variables

The Malmquist index constructs the production possibility frontier of an economic system and employs directional distance functions to measure the distance between each decision-making unit (DMU) and this frontier, thereby calculating the input-output efficiency of DMUs. The ML productivity index can be decomposed into an efficiency index (*Effch*) and a technological progress index (*Techch*), indicating that TFP growth stems from both efficiency improvement and technological advancement. The model specifications are as follows:

$$ML_i^{t+1}(x_i^{t+1}, y_i^{t+1}, x_i^t, y_i^t) = \frac{d_i^{t+1}(x_i^{t+1}, y_i^{t+1})}{d_i^t(x_i^t, y_i^t)} \times \sqrt{\frac{d_i^t(x_i^{t+1}, y_i^{t+1})}{d_i^{t+1}(x_i^{t+1}, y_i^{t+1})} \times \frac{d_i^t(x_i^t, y_i^t)}{d_i^{t+1}(x_i^t, y_i^t)}} \tag{1}$$

$$Effch_i^{t+1} = \frac{d_i^{t+1}(x_i^{t+1}, y_i^{t+1})}{d_i^t(x_i^t, y_i^t)} \tag{2}$$

$$Techch_i^{t+1} = \sqrt{\frac{d_i^t(x_i^{t+1}, y_i^{t+1})}{d_i^{t+1}(x_i^{t+1}, y_i^{t+1})} \times \frac{d_i^t(x_i^t, y_i^t)}{d_i^{t+1}(x_i^t, y_i^t)}} \tag{3}$$

where *i* and *t* denote the DMU and time period respectively, while *x* and *y* represent inputs and outputs. Thus, d_t^i (x_t^i, y_t^i) and d_t^i (x_{t+1}^i, y_{t+1}^i) represent the distance functions for DMU *i* at periods *t* and *t* + 1 relative to the period *t* production frontier. In Equations (2) and (3), *Effch* measures efficiency change and *Techch* captures technological progress change for DMU *i* between *t* and *t* + 1.

However, under real-world conditions of variable returns to scale (VRS), efficiency changes may not solely reflect pure technical efficiency changes but could also include scale efficiency effects. Therefore, the Malmquist-Luenberger productivity index under VRS can be reformulated as:

$$ML_i^{t+1}(x_i^{t+1}, y_i^{t+1}, x_i^t, y_i^t) = Pech_{\mathrm{i}}^{t+1} \times Sech_i^{t+1} \times Techch_i^{t+1} \tag{4}$$

$$Pech_i^{t+1} = \frac{d_i^{t+1}(x_i^{t+1}, y_i^{t+1})_{/VRS}}{d_i^t(x_i^t, y_i^t)_{/VRS}} \tag{5}$$

$$Sech_i^{t+1} = \frac{d_i^t(x_i^t, y_i^t)_{/VRS}}{d_i^t(x_i^t, y_i^t)_{/CRS}} \Bigg/ \frac{d_i^{t+1}(x_i^{t+1}, y_i^{t+1})_{/VRS}}{d_i^{t+1}(x_i^{t+1}, y_i^{t+1})_{/CRS}} \tag{6}$$

$$Techch_i^{t+1} = \frac{d_i^t(x_i^t, y_i^t)_{/CRS}}{d_i^{t+1}(x_i^t, y_i^t)_{/CRS}} \times \frac{d_i^t(x_i^{t+1}, y_i^{t+1})_{/CRS}}{d_i^{t+1}(x_i^{t+1}, y_i^{t+1})_{/CRS}} \tag{7}$$

Equation (4) decomposes efficiency change into pure technical efficiency change (*Pech*) and scale efficiency change (*Sech*). The notations VRS and CRS distinguish between variable and constant returns to scale scenarios.

This DEA framework demonstrates that TFP growth (*TFPch*) derives from three components: technological progress (*Techch*), pure technical efficiency improvement (*Pech*), and scale efficiency change (*Sech*). While TFP growth broadly captures new drivers of macroeconomic growth, technological progress (*Techch*) more precisely reflects the micro-level "innovation-driven" development paradigm.

For ML index measurement, input factors primarily include capital and labor:

Capital input: Calculated using perpetual inventory method with fixed asset investment data: $C_{i\,t} = I_{i\,t} + (1 - \delta)$ Ci_{t-1}, where $C_{i\,t}$ is capital stock for province i in quarter t, $I_{i\,t}$ is fixed asset investment, and δ is the depreciation rate (annual 6%, quarterly 1.5%).

Labor input: Total employment, summing registered urban employees and private/individual workers.

The output measure is regional GDP. This study examines venture capital's impact on TFP using Chinese provincial data. Since regional statistics on venture capital became more complete post-2020, we employ 16 quarters of data (2021–2024) for panel VAR analysis. GDP and fixed asset investment data come from CEIC, while labor data is sourced from China Economic Net.

3.2. Results and Analysis

Using DEAP 2.1 software, we measured the total factor productivity (TFP) index and decomposed its components for panel data covering 30 Chinese provinces over 16 quarters by employing the DEA-Malmquist index model under variable returns to scale (VRS). The results are presented in Table 1.

Table 1. TFP of China: Measurement and Component Analysis.

Time (Quarter)	*Effch*	*Techch*	*Pech*	*Sech*	*TFPch*
2021-Q2	1.0070	0.9850	0.9900	1.0160	0.9920
2021-Q3	1.0500	0.8200	1.0530	0.9970	0.8610
2021-Q4	0.8780	1.1630	0.9430	0.9300	1.0210
2022-Q1	0.8790	0.7400	0.8400	1.0460	0.6510
2022-Q2	1.0010	1.0340	1.0150	0.9860	1.0360
2022-Q3	1.0440	0.9470	1.0530	0.9910	0.9880
2022-Q4	0.9150	1.1450	0.9740	0.9400	1.0480
2023-Q1	0.8680	0.8320	0.8660	1.0030	0.7220
2023-Q2	1.1030	0.9900	1.0740	1.0270	1.0920
2023-Q3	0.9820	1.0790	1.0310	0.9520	1.0590
2023-Q4	0.9550	1.0820	0.9850	0.9700	1.0340
2024-Q1	0.8750	0.8620	0.8800	0.9950	0.7550
2024-Q2	1.1200	0.9880	1.0870	1.0300	1.1070
2024-Q3	1.0080	1.0180	1.0320	0.9760	1.0260
2024-Q4	0.9920	1.1140	1.0200	0.9720	1.1040
Mean	0.9750	0.9790	0.9870	0.9880	0.9550

The mean value of TFP growth rate changes was 0.955, indicating an average quarterly decline of 4.5% in TFP growth between 2021 and 2024 (16 quarters). Decomposition analysis reveals that when TFP growth is disaggregated into efficiency change (*Effch*) and technological progress (*Techch*), the year-on-year TFP growth rate remained consistently above 5% from 2022 through Q3 2023. However, beginning in Q4 2023, TFP growth approached zero, with occasional quarters showing negative growth. This phenomenon can be partially attributed to: the lagged scarring effects of COVID-19 pandemic-induced economic contraction in 2023 and systemic contraction in China's real estate market leading to reduced aggregate social financing.

Notably, the observed TFP fluctuations were primarily driven by technological progress rather than efficiency changes, suggesting that: (1) the productivity slowdown reflected innovation capacity constraints rather than operational inefficiencies; (2) the economic shocks disproportionately affected frontier technology adoption rather than existing production practices.

4. Empirical Analysis by PVAR

4.1. Data and Variables

This study examines the impact of venture capital on innovation-driven development, which is measured through three dimensions: total factor productivity (TFP) growth, industrial upgrading, and technological progress. To analyze the dynamic mechanisms, we employ a Panel Vector Autoregressive (PVAR) model to investigate how venture capital influences these three pathways.

While existing studies predominantly use venture capital investment size as the proxy variable, we recognize that aggregate social financing also significantly drives regional industrial upgrading. To distinguish venture capital's unique effects from other financial instruments, we additionally introduce venture capital weight (the ratio of venture capital investment to total social financing) as a complementary proxy variable.

(1) **Venture Capital Investment Size** (denoted as $Fund_{it}$). Common measures include investment amount, number of investees, and investment frequency. The distinction between investees and frequency arises because multiple funds may invest in the same project or a single fund may invest in the same project multiple times. For model parsimony, we select investment amount (denoted as $Fund_{it}$) as the primary proxy, as internal fund allocation structures do not affect our aggregate conclusions.

(2) **Venture Capital Weight** (denoted as $FundEntropy_{it}$). Empirical evidence confirms that equity-based direct financing instruments (like venture capital) contribute more substantially to industrial upgrading than indirect instruments (e.g., medium/long-term credit). As venture capital represents the dominant form of equity investment, its weight in total social financing reflects regional capital structure efficiency:

$$FundEntropy_{it} = Fund_{it}/SocFinance_{it} \tag{8}$$

where $Fund_{it}$ is the size of venture capital investment and $SocFinance_{it}$ denotes total social financing.

(3) **Industrial Upgrading** (denoted as Ser_{it}). Industrial upgrading manifests as the transition from lower- to higher-value-added sectors. Early studies used the non-primary industry share of GDP, but this fails to capture China's current transition from manufacturing to service-oriented industries [16]. We instead adopt the service-industrialization ratio:

$$Ser_{it} = S_{it}/I_{it} \tag{9}$$

where S_{it} and I_{it} represent output values of tertiary and secondary sectors, respectively, for province i at time t.

(4) **TFP Growth Rate** (denoted as $TFPch_{it}$). As a macroeconomic proxy for innovation-driven development, TFP measures output growth unexplained by labor or capital inputs. We focus on TFP growth rate ($TFPch_{it}$) rather than its absolute level to assess dynamic improvements.

(5) **Technological Progress** (denoted as $Techch_{it}$) and **Scale Efficiency Change** (denoted as $Sech_{it}$). TFP decomposition reveals two components: (1) Technological progress ($Techch_{it}$) is our proxy for innovation capacity because that innovation output stems from technological progress at the micro level; (2) Scale efficiency change, further split into pure technical efficiency and scale efficiency change ($Sech_{it}$) including which in the PVAR model controls for non-technological factors affecting TFP [17] (as shown in Table 2).

Table 2. Variable Definitions and Descriptive Statistics.

Variable	Definition	Min	Max	Mean	St. Dev
TFPch	TFP Growth Rate	−0.707	1.163	−0.018	0.222
Techch	Technological Progress Rate	−1.000	0.230	−0.014	0.137
Sech	Scale Efficiency Change	−0.203	0.194	−0.009	0.054
Ser	Industrial Upgrading Level	0.615	4.762	1.308	0.746
Fund	VC Investment Scale	0.000	1907.31	52.772	173.512
FundEntropy	VC Investment Weight	0.000	0.816	0.025	0.080

The industrial upgrading variables in the model are sourced from the CEIC database, while venture capital related data and aggregate social financing figures are obtained from the WIND database and China Economic

Net. To ensure stationarity in the PVAR model, all variables except VC investment scale ($Fund_{it}$) are ratio-based measures, so we apply a natural logarithm transformation (denoted as ln $Fund_{it}$) for the empirical analysis.

4.2. Methodology and Empirical Analysis

To investigate the mechanism through which venture capital affects total factor productivity (TFP), industrial upgrading, and technological progress, we construct a Panel Vector Autoregressive (PVAR) model using quarterly data from 30 provinces spanning 2021 to 2024. The PVAR framework combines the advantages of both time-series and panel data approaches, enabling a multidimensional analysis of the dynamic evolution of venture capital's impact on industrial upgrading. The empirical model is specified as follows:

$$Y_{it} = \alpha_{it} + \gamma_t + \sum_{t=1}^{n} \prod\nolimits_{nt} Y_{i,t-n} + \varepsilon_{it} \qquad (10)$$

where Y_{it} represents the vector of endogenous variables, comprising six dimensions as $TFPch_{it}$, $Techch_{it}$, $Sech_{it}$, Ser_{it}, $Fund_{it}$, and $FundEntropy_{it}$. $\{Y_{it}\}^{i}_{t=1}$ represents cross-sectional data for province i across all quarters and $\{Y_{it}\}^{t}_{i=1}$ represents time-series data for all provinces in quarter t. Π_{it} is the parameter matrix to be estimated, n denotes the lag order, ε represents random disturbances with identical distribution and no serial correlation, α captures province fixed effects accounting for cross-sectional heterogeneity and γ represents time effects reflecting common temporal trends.

Our dataset consists of 16 quarterly observations across 30 provinces, characteristic of "wide panel, short time series" data that can be treated as stationary. Stationarity tests confirm this property, with all variables' characteristic roots lying within the unit circle (Figure 1), satisfying the PVAR model's stability conditions.

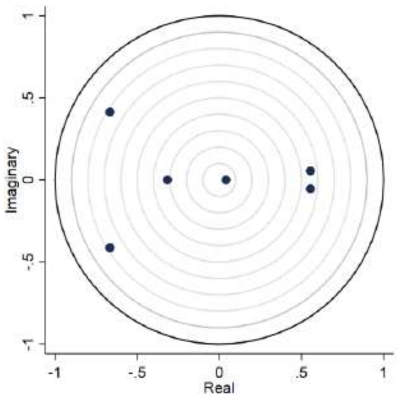

Figure 1. Inverse Roots of the Companion Matrix Test (Unit Circle Test).

Prior to PVAR estimation, we determine the optimal lag length using Hansen's J statistic and three information criteria: MAIC, MBIC, and MQIC. As shown in Table 3, all criteria (AIC, BIC, and HQIC) unanimously select one lag as optimal. Consequently, we specify a first-order lag structure for our PVAR model examining the initiation mechanism of venture capital's impact on industrial upgrading.

Table 3. Determination of Optimal Lags in PVAR Model.

Lags	MBIC	MAIC	MQIC
1	−412.5754	−85.9963	−218.6641
2	−258.6806	−40.9612	−129.4064
3	−121.7665	−12.90678	−57.12938

The PVAR model offers distinct advantages by enabling the decomposition of each shock's effect on endogenous variables through orthogonalized impulse responses, while holding other variables constant. However, the presence of fixed effects in the model violates the strict exogeneity assumption of classical linear regression. To address this, we employ forward mean differencing (Helmert transformation) to eliminate the mean of future observations for each individual, thereby preventing correlation between explanatory variables and the error term.

To mitigate endogeneity concerns, we utilize first-order lagged terms as instrumental variables (IVs) in system generalized method of moments (GMM) estimation. This approach yields consistent and efficient estimates for the parameter matrix *Π*. While additional time periods provide supplementary moment conditions and instruments, they may also lead to instrument proliferation. Consequently, we conduct an overidentification test using Hansen's J-statistic after GMM estimation to verify the orthogonality of instruments and ensure the validity of the IV set.

Using the system GMM estimation approach, in Table 4 we obtain the PVAR model estimates for the relationships among TFP growth rate (*TFPch*), technological progress (*Techch*), scale efficiency change (*Sech*), industrial upgrading (*Ser*), venture capital investment scale (ln*Fund*), and venture capital investment weight (*FundEntropy*). The Hansen's J statistic fails to reject the null hypothesis, indicating no overidentification issues with the instrumental variables and validating the estimation results.

The PVAR model reveals divergent patterns among the three key variables characterizing innovation-driven development: industrial upgrading (*Ser*) shows a significantly positive correlation with technological progress (*Techch*), however, TFP growth (*TFPch*) exhibits negative correlations with both industrial upgrading (*Ser*) and technological progress (*Techch*), suggesting that TFP—which incorporates scale efficiency effects—may not be the optimal proxy for "innovation-driven" development due to its composite nature.

Table 4. PVAR-GMM Estimation Results.

Variables	*TFPch*	*Techch*	*Sech*	*Ser*	ln*Fund*	*FundEntropy*
$TFPch_{t-1}$	−0.475*** (0.092)	−0.376*** (0.057)	0.058 (0.059)	−0.139*** (0.036)	0.120 (0.174)	0.094 (0.095)
$Techch_{t-1}$	0.120 (0.106)	−0.011 (0.090)	−0.314*** (0.067)	0.258*** (0.089)	−2.411*** (0.512)	−0.156 (0.160)
$Sech_{t-1}$	−0.088 (0.210)	1.347*** (0.290)	−0.926*** (0.145)	0.091 (0.163)	2.169* (1.155)	−0.220 (0.304)
Ser_{t-1}	0.422*** (0.138)	1.118*** (0.095)	−0.012 (0.063)	0.353*** (0.088)	6.959*** (0.927)	−0.197* (0.115)
$\ln Fund_{t-1}$	−0.011* (0.007)	−0.024*** (0.008)	0.008* (0.004)	0.019*** (0.006)	0.095* (0.051)	−0.003 (0.006)
$FundEntropy_{t-1}$	0.437*** (0.157)	0.512** (0.202)	0.001 (0.167)	0.064 (0.170)	0.080 (0.805)	0.467** (0.186)
Hansen's J	84.144118 (*p* Value = 0.244)					

Note: ***, ** and * represent significance at the 1%, 5% and 10% levels, respectively. Standard deviation in parentheses.

The results in Table 4 also show the key findings on venture capital effects:

VC investment scale (ln*Fund*): (1) positive correlation with industrial upgrading (*Ser*), confirming that venture capital accelerates industrial upgrading and advanced industrial structures attract more venture capital; (2) negative correlation with *TFPch*, as increased capital inputs mechanically reduce TFP's relative contribution; (3) positive correlation with scale efficiency change (*Sech*), indicating improved returns-to-scale.

VC investment weight (*FundEntropy*): (1) significantly promotes both TFP growth and technological progress (*Techch*); (2) highlights the importance of capital structure optimization beyond mere scale expansion.

The above results demonstrate that while industrial upgrading attracts venture capital, simply expanding fund investments without rebalancing regional capital structures (e.g., reducing indirect financing ratio) proves insufficient for fostering genuine innovation-driven development.

4.3. Granger Causality Tests, Impulse Response and Variance Decomposition

The Granger causality tests (in Table 5) on the PVAR model reveal a bidirectional causal relationship between industrial upgrading and venture capital investment. Specifically:

(1) Mutual Reinforcement Effect: Increased venture capital investment accelerates industrial upgrading. Meanwhile, the advanced industrial structures simultaneously attract more venture capital (reverse causality).

(2) Differential Effects on Productivity Growth: Both venture capital scale (ln*Fund*) and weight (*FundEntropy*) demonstrate Granger causality with TFP growth (*TFPch*) and technological progress (*Techch*). However, their coefficients in the PVAR model show opposite signs, indicating that mere increases in VC investment volume may crowd out other productivity-enhancing factors but also by rebalancing regional financing structures (reducing indirect financing ratio while increasing VC scale) can venture capital effectively drive innovation-led development.

The impulse response functions (IRFs) trace the dynamic effects of a one-standard-deviation shock to the stochastic disturbance term on current and future values of variables in the VAR system, effectively capturing the temporal relationships and interaction intensities among variables. Figure 2 shows the venture capital's impact on innovation-driven development, examining how the shocks of VC scale (ln*Fund*) and weight (*FundEntropy*) affect the TFP growth (*TFPch*), technological progress (*Techch*) and industrial upgrading (*Ser*) over a 10-period horizon. The left-side variables represent shock sources, while the right-side variables show responses, with the X-axis indicating time periods and Y-axis response magnitudes.

The impulse response analysis in Figure 2 reveals distinct dynamic patterns:

(1) Capital Structure Effects (Row 1): The response of TFP growth (*TFPch*) and technological progress (*Techch*) to a one-standard-deviation shock in venture capital investment weight (*FundEntropy*) reaches its peak positive effect at 2–3 quarters before gradually converging to zero by quarter 5. This indicates that rebalancing the social financing structure by increasing direct financing ratio generates that the strong innovation-driven effects emerging within 2–3 quarters (half year) and the persistent impacts lasting approximately 5 quarters (over one year).

(2) Investment Scale Effects (Row 2): The industrial upgrading (*Ser*) response to venture capital scale (ln*Fund*) shocks shows that the significant positive effects during quarters 1–4 and the gradual dissipation by quarter 5. However, technological progress (*Techch*) exhibits the initial negative impact in quarter 1 and positive turnaround from quarter 2 onward, peaking subsequently.

This dual pattern suggests that: (a) Venture capital predominantly invests in emerging tertiary industries through equity financing, leading to the immediate increases in tertiary sector share (industrial upgrading) and short-term capital deepening effects that initially crowd out R&D inputs (negative *Techch* in Q1; (b) The equity investment mechanism subsequently enhances firm innovation capacity through governance and resource allocation and generates delayed but sustained technological progress (positive *Techch* from Q2).

Through forecast error variance decomposition (FEVD), we quantify the relative contribution of orthogonalized shocks from all variables to the forecast mean squared error of each individual variable, thereby providing deeper insights into their interrelationships [18]. Table 6 presents the FEVD results based on 300 Monte Carlo simulations of shocks to innovation-related proxy variables, showing decomposition outcomes for periods 5 and 10.

The variance decomposition analysis reveals three key findings: First, industrial upgrading (*Ser*) and technological progress (*Techch*) exhibit significant bidirectional interactions, with variance contribution rates of 20.1% and 11.5% respectively, confirming their dual role as primary proxies for innovation-driven development. Second, venture capital demonstrates differential impacts, with investment scale (ln*Fund*) contributing 3.7% to technological progress (*Techch*) and 5.2% to industrial upgrading (*Ser*), while investment weight (*FundEntropy*) accounts for approximately 2.4% to both TFP growth (*TFPch*) and technological progress (*Techch*). Third, while venture capital shows statistically significant effects on innovation development, the results suggest it operates as a secondary driver rather than the dominant force, as structural factors (embodied in *Ser*-*Techch* interactions) account for greater variance, though capital structure optimization (*FundEntropy*) demonstrates comparable importance to absolute investment volume (ln*Fund*).

Table 5. Granger Causality Test.

Variable	χ^2 Value	DF	*p*-Value	Test Conclusion
TFPch ← *Techch*	1.270	1	0.260	Do not reject H_0: No Granger causation
TFPch ← *Sech*	0.178	1	0.673	Do not reject H_0: No Granger causation
TFPch ← *Ser*	9.365	1	0.002	Reject H_0: Significant Granger causation
TFPch ← ln*Fund*	2.998	1	0.083	Reject H_0: Significant Granger causation
TFPch ← *FundEntropy*	7.733	1	0.005	Reject H_0: Significant Granger causation
TFPch ← *All*	21.970	5	0.001	Reject H_0: Significant Granger causation
Techch ← *TFPch*	43.924	1	0.000	Reject H_0: Significant Granger causation
Techch ← *Sech*	21.571	1	0.000	Reject H_0: Significant Granger causation
Techch ← *Ser*	137.547	1	0.000	Reject H_0: Significant Granger causation
Techch ← ln*Fund*	9.460	1	0.002	Reject H_0: Significant Granger causation
Techch ← *FundEntropy*	6.395	1	0.011	Reject H_0: Significant Granger causation
Techch ← *All*	248.191	5	0.000	Reject H_0: Significant Granger causation
Sech ← *TFPch*	0.960	1	0.327	Do not reject H_0: No Granger causation
Sech ← *Techch*	22.295	1	0.000	Reject H_0: Significant Granger causation
Sech ← *Ser*	0.037	1	0.847	Do not reject H_0: No Granger causation
Sech ← ln*Fund*	2.997	1	0.083	Reject H_0: Significant Granger causation
Sech ← *FundEntropy*	0.000	1	0.996	Do not reject H_0: No Granger causation
Sech ← *All*	85.242	5	0.022	Reject H_0: Significant Granger causation
Ser ← *TFPch*	15.265	1	0.000	Reject H_0: Significant Granger causation
Ser ← *Techch*	8.492	1	0.004	Reject H_0: Significant Granger causation
Ser ← *Sech*	0.311	1	0.577	Do not reject H_0: No Granger causation
Ser ← ln*Fund*	9.822	1	0.002	Reject H_0: Significant Granger causation
Ser ← *FundEntropy*	0.142	1	0.707	Do not reject H_0: No Granger causation
Ser ← *All*	39.528	5	0.000	Reject H_0: Significant Granger causation
ln*Fund* ← *TFPch*	0.481	1	0.488	Do not reject H_0: No Granger causation
ln*Fund* ← *Techch*	22.189	1	0.000	Reject H_0: Significant Granger causation
ln*Fund* ← *Sech*	3.527	1	0.060	Reject H_0: Significant Granger causation
ln*Fund* ← *Ser*	56.402	1	0.000	Reject H_0: Significant Granger causation
ln*Fund* ← *FundEntropy*	0.010	1	0.921	Do not reject H_0: No Granger causation
ln*Fund* ← *All*	118.759	5	0.000	Reject H_0: Significant Granger causation
FundEntropy ← *TFPch*	0.970	1	0.325	Do not reject H_0: No Granger causation
FundEntropy ← *Techch*	0.953	1	0.329	Do not reject H_0: No Granger causation
FundEntropy ← *Sech*	0.524	1	0.469	Do not reject H_0: No Granger causation
FundEntropy ← *Ser*	2.923	1	0.087	Reject H_0: Significant Granger causation
FundEntropy ← ln*Fund*	0.245	1	0.621	Do not reject H_0: No Granger causation
FundEntropy ← *All*	9.961	5	0.076	Reject H_0: Significant Granger causation

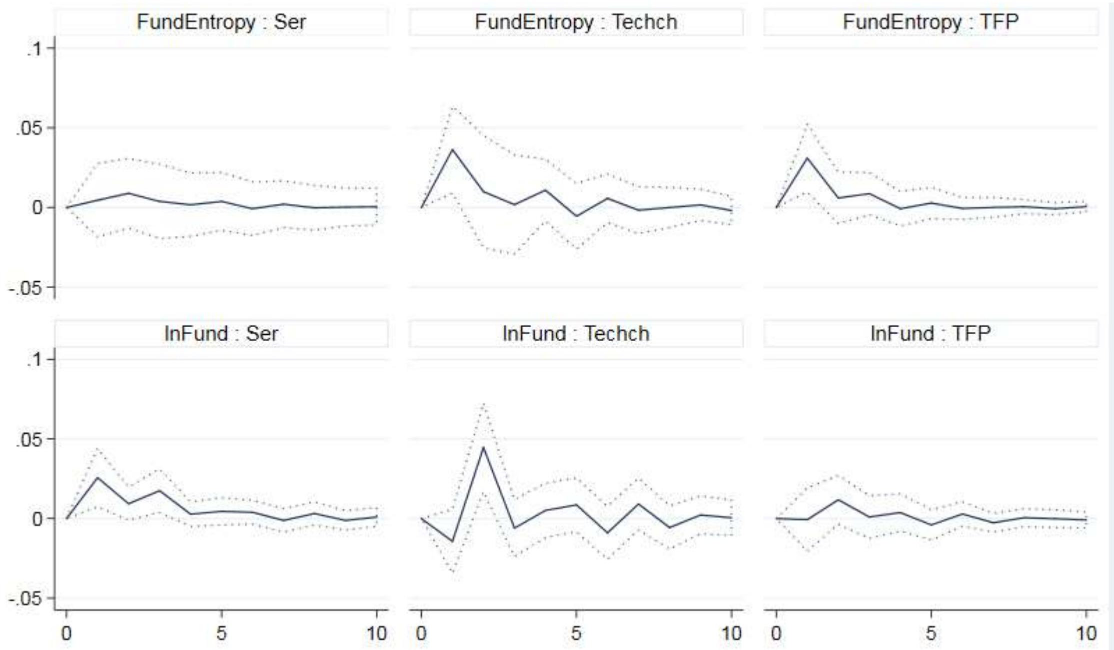

Figure 2. Impulse Response of the PVAR Model.

Table 6. Variance Decomposition Results of the PVAR Model.

Variable	S	*TFPch*	*Techch*	*Sech*	*Ser*
TFPch	5	0.909	0.097	0.058	0.031
Techch	5	0.009	0.505	0.311	0.110
Sech	5	0.136	0.142	0.464	0.035
Ser	5	0.039	0.196	0.134	0.768
ln*Fund*	5	0.003	0.036	0.019	0.051
FundEntropy	5	0.024	0.024	0.011	0.006
TFPch	10	0.903	0.101	0.063	0.033
Techch	10	0.012	0.495	0.302	0.115
Sech	10	0.015	0.142	0.459	0.039
Ser	10	0.041	0.201	0.138	0.756
ln*Fund*	10	0.004	0.037	0.021	0.052
FundEntropy	10	0.024	0.025	0.012	0.006

5. Conclusions and Implications

The empirical analysis employing provincial quarterly panel data from 2021 to 2024 within a panel vector autoregressive (PVAR) framework demonstrates that venture capital exerts significant positive effects on innovation-driven economic development overall. When decomposing venture capital into investment scale and investment weight while using total factor productivity, industrial upgrading and technological progress as distinct proxies for innovation development, the results reveal a bidirectional relationship between industrial upgrading and venture capital: industrial upgrading attracts venture capital while increased venture capital scale simultaneously drives industrial upgrading. However, the analysis shows that merely expanding investment scale without improving the proportion of direct financing in the social financing structure fails to significantly promote technological progress. These findings suggest that comprehensive promotion of innovation-driven development requires coordinated policies that simultaneously increase venture capital investment scale and optimize regional financing structures by enhancing direct financing ratio.

Based on the theoretical framework and empirical findings of this study, the following policy implications are proposed:

(1) Promote venture capital development and restructure social financing channels. The results demonstrate that while expanding venture capital investment scale significantly drives industrial upgrading, it shows limited effects on enhancing total factor productivity (TFP) or technological progress. Conversely, increasing the proportion of direct financing in social financing structures exerts significantly positive impacts on TFP growth, industrial upgrading, and technological advancement. Therefore, policymakers should not merely focus on scaling up venture capital funds, but rather prioritize restructuring the social financing system through institutional development, policy guidance, and investment incentives. This includes encouraging enterprises to increase direct financing ratio and motivating financial institutions to innovate diversified, flexible direct financing instruments, thereby gradually reducing indirect financing ratio while meeting corporate financing needs.

(2) Improve the multi-tier capital market system to enhance exit flexibility for venture capital. As the primary platform for direct financing and crucial exit channel for venture capital, the capital market system's development is essential [19]. Given that venture capital primarily realizes returns through exit mechanisms, insufficient or narrow exit options significantly dampen investment incentives. We recommend deepening capital market reforms beyond stock market expansion, including developing innovative market mechanisms and strengthening alternative exit channels such as mergers and acquisitions. These measures would accelerate capital recycling towards promising enterprises, generating synergistic effects between industrial and financial development.

(3) Implement coordinated policies to foster innovation-driven growth. The study reveals that although venture capital significantly contributes to innovation development, it alone cannot serve as the primary driving force. Regional innovation requires comprehensive strategies combining talent recruitment, business environment optimization, and technology commercialization, complemented by venture capital investments. Furthermore, the research identifies a virtuous cycle wherein industrial upgrading attracts venture capital, which in turn accelerates further upgrading—creating a reinforcing feedback mechanism. This dynamic consolidates regional industrial transformation by sustaining upgrading processes and maintaining structural advantages.

(4) Establish differentiated policies based on regional characteristics. The effectiveness of venture capital varies significantly across regions with different financial development levels and industrial structures. Policymakers should adopt tailored approaches: developed regions should focus on optimizing capital structures and exit mechanisms, while developing regions may prioritize basic scale expansion and market infrastructure building. This spatial differentiation ensures optimal resource allocation and maximizes policy impacts according to local conditions.

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Article

Research on the Composition of Talent Competencies for Digital Transformation of Industrial Enterprise Management

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Abstract: Management digital transformation is a necessary path for industrial enterprise management upgrading. But industrial enterprises can implement the management of digital transformation and upgrading of the number of talents required for the level and quality level is relatively low, which largely limits the speed and process of China's industrial enterprises management of digital transformation road. Focusing on the direction of digital transformation of industrial enterprise management, considering the reasons for the shortage of talents for management digital transformation needs, starting from the four aspects of comprehensive ability, professional knowledge, technical skills, engineering practice, the establishment of a digital talent training system for management, the division of talent competency level, aiming at the digital upgrading of industrial enterprises to provide the talent competency and job setup standards for the enterprise to cultivate with management and digital knowledge to provide the direction. The aim is to provide standards for talent ability and job setting for the digitalization upgrade of industrial enterprises, and to provide directions for enterprises to cultivate compound talents with management and digital knowledge.

Keywords: digital transformation; talent development; management digitization; composite talent

1. Introduction

In recent years, the State Council, the Ministry of Industry and Information Technology (MIIT) and local governments have introduced a series of policies and measures to promote the digital transformation of enterprises. For the digital transformation of small and medium-sized enterprises (SMEs), Shi Yupeng [1] and others mentioned in their research that the difficulties of digital transformation of SMEs include "insufficient digital knowledge reserves of management and employees", and the focus is on "solving the talent problem in a variety of ways". Zhu Wenmei [2] scholars in the digital development path of state-owned enterprises pointed out that the digital talent team is an important guarantee for the realization of the digital transformation of state-owned enterprises, enterprises should do a good job in the recruitment of external talent and internal talent training focus. Zhu Wenjing scholars pointed out [3], for small and medium-sized enterprises, talent structure, organizational structure and other aspects of adaptive adjustment is closely related to the digital transformation of enterprises, if the talent, organizational adaptive adjustment can not be followed up, the digital transformation of enterprises will be greatly hindered. The State Council's "14th Five-Year" Digital Economy Development Plan and the Ministry of Industry and Information Technology's "Guide to Digital Transformation of Small and

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Medium-sized Enterprises" both emphasize that digital talent is the core element to crack the "can't turn" and "don't dare to turn" conundrum. The core elements of the difficult problem. It can be seen that the shortage of digital transformation talent is a major barrier on the road of enterprise digital transformation. Liu Junmei and Tao Limin [4] scholars believe that the update of the education concept and training mode of universities, as well as the construction of the social system is to grasp the opportunities for the development of digital talent key initiatives. In addition, many scholars focus on overseas countries and enterprises [5, 6], research and interpretation of the digital capacity of other enterprises, and based on this, summed up the effective countermeasures for the training of digital talents suitable for the characteristics of China's enterprises. After summarizing the above research can be found, from the current education system, the main reasons for the shortage of digital transformation composite talents are:

(1) The singularity of talent training objectives leads to a mismatch between talent capabilities and enterprise digital transformation needs;

(2) The disciplinary barriers have not been broken, and the knowledge structure and practice content are based on a single discipline and training;

(3) The curriculum content lags behind, and the digital transformation demand is limited.

Comprehensive view, academic research on the training of talents for digital transformation of industrial enterprises is relatively small, the lack of a complete set of "training-assessment-improvement" digital talent training system, IE and IT theoretical system of digital talent training system is even less. There are even fewer digital talent training systems that combine the theoretical systems of IE and IT.

2. Managing Digital Transformation Meanings

In the deepening stage of digital transformation, enterprise management digitalization has been upgraded from the application of tools to systematic change. Management digitization emphasizes management thinking as the kernel, through digital technology empowerment to achieve operational efficiency leap. At present, although industrial enterprises have access to advanced technology, there is a lack of composite talents who "understand management + technology", and the phenomenon of "two skins" often occurs when technology and processes are disconnected.

Adhering to the idea that "the digital transformation and upgrading of industrial enterprises needs to be oriented to management, led by industrial enterprises, and integrate digital technology with management theory", we introduce the professional knowledge system of industrial engineering, systematically strengthen and complete the knowledge of talents in management and technology, and set up the talent ability and job standards for the digitalization of industrial enterprise management. It helps enterprises to cultivate compound talents with both management and digitalization capabilities.

3. Definition of Talent Competencies Required to Manage Digital Transformation

3.1. Digital transformation Talent Capabilities

The essence of digital transformation is to realize the systematic upgrading of management through digital technology, and its core lies in the deep integration of management ideas and digital tools. In the rapid iteration of technology, but the management of the value of the transformation of the contradiction lags behind, enterprises are in urgent need of both lean management, industrial engineering (IE) program and other methodologies, but also master the data modeling and system architecture technology of the composite talent. However, the technical ability can be acquired through training, but the management thinking needs to be long-term practice accumulation, IT talent is stronger than technology but lack of industrial site knowledge, IE talent is good at management but weak in the application of digital technology, the disciplinary barriers lead to digitalization projects are often caught in the technical solutions and business needs of the misalignment of the predicament.

Industrial engineering (IE) has the advantages of strong synthesis, multidisciplinary integration, engineering method orientation, and strong practicability, which is an important technical and theoretical support for industrial enterprise management. From the point of view of IE and IT training programs and curricula in China's colleges and universities, the IE professional training system pays more attention to the cultivation of students' systematic thinking, interdisciplinary integration, and management ability, etc., which prompts students with IE background to be more prominent in the overall view, interdisciplinary integration, and management perspective than those with IT background; however, the cultivation of the IE knowledge system is comprehensive but not precise, and the cultivation of its special IT knowledge is slightly weaker. Weakness in the cultivation of IT-specific knowledge [7,8].

In order to meet the management upgrading under the digital transformation of industrial enterprises, enterprises need the support of IT and IE talents, but the difference in disciplines leads to the problem of cognitive bias between the two types of talents in the practice of digital transformation. As a result, it is proposed to combine information technology (IT) and industrial engineering (IE) to establish a management digital talent training system, break the cognitive barriers between IT and IE, improve the comprehensiveness and completeness of digital talent training, and meet the needs of digital transformation of enterprises. The knowledge of IE can supplement the thinking and management ability of management digital talents, and help the digital transformation talents to realize the effective combination of the manufacturing site and digital technology, while the knowledge of IT can supplement the data of the talents. IE knowledge can supplement the thinking and management ability of management digital talents, and help digital transformation talents realize the effective combination of manufacturing site and digital technology, while IT knowledge can supplement their data modeling and intelligent algorithm development ability, and provide a technical realization path for process optimization.

3.2. Managing Digital Transformation Talent Competency Structures and Knowledge Systems

3.2.1. Managing Digital Talent Determination Principles

"Knowing, believing and acting" incorporates 'believing' on the basis of Wang Yangming's theory of 'unity of knowledge and action' [9]. From the perspective of cognitive sequence, knowing, believing, and acting are not linear progression, but the deepening of cognition is promoted through dialectics, knowledge strengthens the belief through practice, and the belief feeds the exploration of new knowledge and practical innovation, which forms the internal and external cognitive double cycle and promotes the learner's cognition and mastery of the things (as in Figure 1). "Knowing" refers to knowing about knowledge; 'Believing' refers to believing in knowledge, establishing correct cognition, and internalizing it into insights; 'Acting' refers to action and practice. This logic echoes Katz's model of managerial skills, in which managers at the grassroots level rely on technical skills-acting, those at the middle level focus on interpersonal skills-knowing, and those at the top level need conceptual skills-believing, which together constitute the cognitive component of managerial competence progression. Together, they form the cognitive foundation for the advancement of management skills. In the digital transformation scenario of industrial enterprises, talents with different cognitive paths are matched with differentiated management:

Grassroots managers: Knowing → Acting → Believing is the cognitive path. This type of talent can internalize knowledge into beliefs and concepts through practice in the actual work, but they are easy to be low-skilled, so they are more suitable for training as field-level management talents.

Middle-level managers: Actions→knowledge→belief as the cognitive order, with a certain management ability and strong action, but management ideas and concepts are slightly deficient, need to master knowledge and establish concepts through practice, easy to limit the development of cognitive level, lack of high-level talent of the overall situation and strategic view, more suitable for the training of management personnel as a business-level management personnel;

Senior managers: those who take faith→action→knowledge as the order of cognition have the quality of overcoming difficulties and innovation, have strong faith, have a global view and a strategic view, and are able to discover and master new knowledge with the support of faith and action, which is more suitable for training as management talents.

The essential law of digital talent training is to forge “digital arms and legs” based on technical implementation at the grassroots level, cultivate “digital nerves” based on systematic thinking at the middle level, and shape “digital brain” based on strategic beliefs at the top level. The top management takes strategic beliefs as the nucleus to shape the “digital brain”. The layered training mechanism not only follows the law of cognition, but also meets the demand for competence advancement, providing a talent support framework for cracking the pain points of digital transformation, such as strategic overhang and faulty execution.

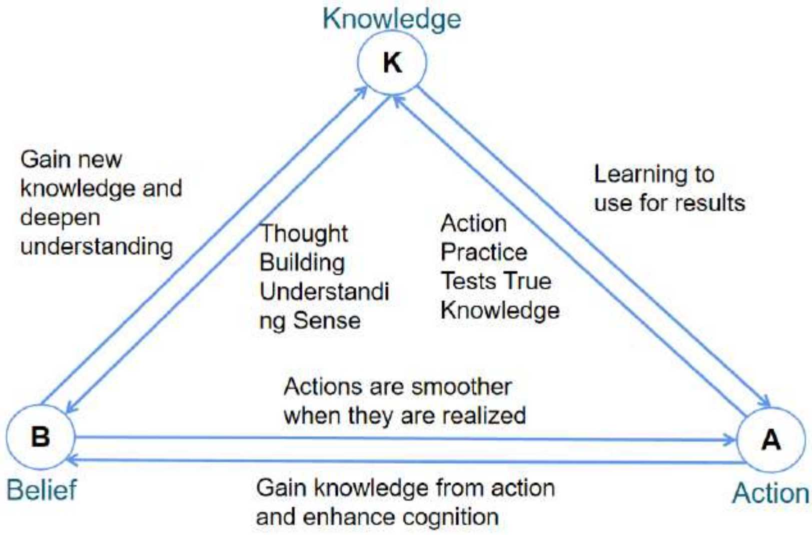

Figure 1. Mechanism diagram of the relationship between knowledge, belief and behavior.

3.2.2. Talent Competency Definition

Digital transformation requires talents to form a competency structure of “technical experts who understand business and business talents who understand technology”. Facing the dual challenges of technology iteration and business complexity, the ability of digital talents is deconstructed into a 4-dimensional model: comprehensive ability is the underlying qualities to cope with the dynamic environment, covering learning adaptability, cross-discipline communication, and the ability to analyze business scenarios; professional knowledge builds a cognitive framework, bridging the cognitive gap between management and technology, including the industry standard, general knowledge of safety regulations, IE and IT monographs, etc., and technical skills focusing on the application of digital tools. Technical skills focus on the application of digital tools, including data analysis, software development and other skills, emphasizing the ability to transform theory into solutions; engineering practice to measure the ability to implement the project, through the accumulation of experience in the whole process of demand analysis, system design to value delivery. The four-dimensional capabilities form a two-way strengthening of cognitive + practical closed loop, through the professional depth and cross-border integration, to crack the traditional talent training of technology suspension and ability to break the dilemma.

Differentiated training for different levels of talents based on job characteristics. Field-level talents build their foundation with professional knowledge, focusing on mastering industrial engineering standards and digital tools to ensure that technology is put into practice; operation-level talents strengthen engineering practice and enhance systematic problem-solving ability based on existing professional knowledge; and management-level talents deepen strategic thinking and enhance the top-level design ability of digital construction through complex project management and professional knowledge iteration.

The layered training mechanism not only follows the law of capability development, but also meets the management advancement needs of the field layer, where the standard execution of the field layer is precipitated into the practice foundation of the operation layer, and the strategic decision-making ability of the operation layer is sublimated through the integration of the first two layers of capabilities, which ultimately forms a three-dimensional capability matrix to support the digital transformation of the enterprise. 4-dimensional model breaks through the boundaries of disciplines, integrates the IE systematic methodology with the IT technology, which makes up for the technical shortcomings of the traditional IE talents, and gives the IT talents management thinking, and also gives the IT talents management thinking. The 4-dimensional model breaks through the disciplinary boundaries and integrates IE system methodology with IT technology, which not only makes up for the technical shortcomings of traditional IE talents, but also empowers IT talents with managerial thinking, cultivates a new type of digitalization leader who is well versed in the language of management and the logic of technology, and realizes the change from tool application to management.

3.2.3. Definition of Competency Dimensions under Talent Levels

Bloom's theory of classification of educational objectives classifies learning objectives in the cognitive domain into memorization, comprehension, application, analysis, evaluation and creation [10], providing a systematic framework for teaching design and effect evaluation. Following Bloom's theory, on the basis of the 4-dimensional competence of talents, the competence of talents is divided into three levels of beginner, intermediate and advanced according to the needs of talents, and combined with the elements of competence, the digital talents of different levels are positioned in terms of their competence and responsibilities. In the process of leaping from industrial civilization to digital civilization, the enterprise has evolved into a digital life form with evolutionary ability, and the construction of its neural network requires the integration and development of digital talents and organizational levels. In order to realize the goal of digital technology penetration of production relations, the junior, middle and senior digital talents correspond to the enterprise grass-roots managers, middle managers and senior managers respectively.

Beginning, middle and senior management digital talents of their corresponding positions, responsibilities determine the degree of mastery of the three dimensions of the 4-dimensional capabilities of each dimension of the ability to focus on the division of knowledge capabilities for the beginning, middle and senior talents.

(1) Comprehensive ability.

As grassroots managers, the core of junior management digital talents is to ensure the physical implementation of digitalization through communication, coordination and execution, so they focus on the development of basic communication, teamwork and task execution capabilities at the executive level, and have a sense of responsibility, learning ability and stress resistance.

Intermediate management digital talents have the ability to manage both upper and lower levels, emphasizing risk prediction and strategic awareness in project operation, while combining the abilities of junior management digital talents.

Senior management digital talent focuses on the development of overall coordination ability, including strategic decision-making, business negotiation, and the enhancement of emotional quotient and adversity quotient.

(2) Expertise is divided on the basis of ease of knowledge understanding and application.

Elementary management digital talents need to master the basic principles of digital architecture design, and be able to use basic algorithms to solve on-site problems.

Intermediate management digital talents are the same as junior management digital talents in mastering and designing digital algorithms and structure development methods, with the difference that they need to deepen their digital transformation ability and focus on the application of advanced knowledge in architecture design.

Senior management digital talents focus on management digital ideology training, focusing on the whole system digital construction, requiring proficiency in enterprise strategy management, with platform architecture design and implementation capabilities.

(3) Technical skills: divided by the ability to apply engineering, office software operation, and methodology practice.

Elementary management digital talents need to be skilled in the application of digital system analysis methods, with the ability to diagnose basic problems.

Intermediate management digital talents need to break through the primary ability to cultivate systematic architecture construction thinking, break through the limitations of a single technology application.

Senior digital talents master decision support tools, strengthen the digital ecosystem construction technology application.

(4) Engineering practice: engineering practice ability is reflected in the primary focus on task execution, intermediate strengthening of system management, and senior focus on strategy implementation, through the integration of the first three elements of ability, and practical verification of the ability to achieve the degree of each level.

Based on the above, the talent cultivation capability model is shown in Figure 2.

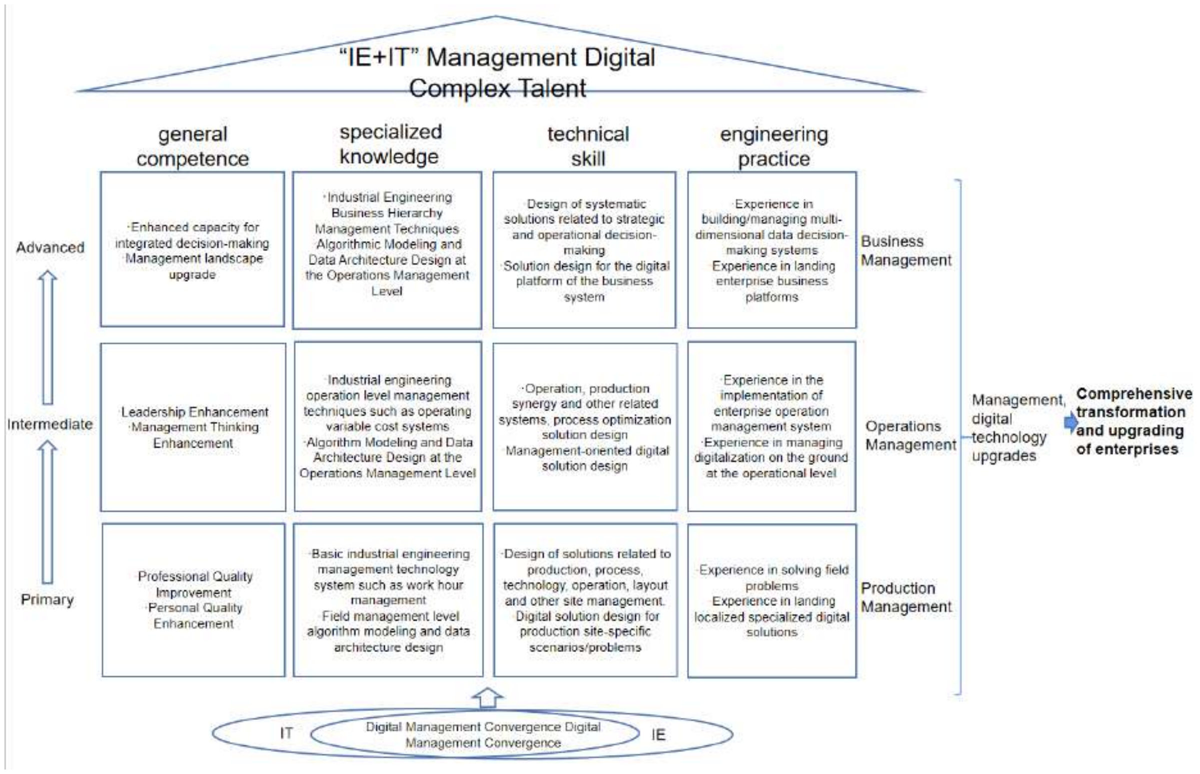

Figure 2. Digital Talent Competency Graded Training Model.

3.2.4. Competency Dimension—Specialized Knowledge Structure Division

The management of digitalized talents takes the industrial site as the cornerstone. Industrial site management to plan for the control program, production execution for the process control hand, quality control for the "all customer-centric" landing point, layout planning and equipment management for production to achieve the basic security, operational changes in cost control for the core competitiveness. Based on this, the management of digital talents need to master the 8 core disciplines. Process management to ensure the optimization and standardization of the production process; production planning and control to coordinate resources to ensure product delivery; production execution will be planned into actual production; total quality management to build a closed loop quality; facilities planning and logistics to optimize the efficiency of the use of space; full equipment management to protect the effectiveness of the equipment; cost control to reduce the cost of production; supply chain management to coordinate upstream and downstream resources. These disciplines collaborate with each other, together constitute the production and operation system of industrial enterprises, to ensure efficient and stable operation of enterprises, with industry and enterprise characteristics, is where the talent cognitive barriers.

The essence of digital software is the algorithmic encapsulation of management knowledge, process management system development relies on process management, APS development relies on production planning and control, MES development relies on production execution, quality analysis system development relies on quality management, layout simulation relies on facilities planning and logistics, equipment data mining and analysis development relies on full equipment management and maintenance, job cost system development relies on cost control, supply chain management Supply chain management platform development relies on supply chain management. Digital software to management knowledge first, the deconstruction and analysis of the industrial site after the corresponding software development, based on management knowledge, supplemented by knowledge modeling, digital technology can help enterprises achieve high-level management analysis and rationale for upgrading.

Figure 3 shows the role of 8 major disciplines in enterprise manufacturing, is the core support for the efficient and stable operation of the enterprise production system, strengthen the management of digital talents in the mastery of these 8 major knowledge, not only to break down the barriers of industrial cognition, but also to cultivate their scene deconstruction and digital modeling capabilities, driving the experience of algorithms to feed the management of upgrading.

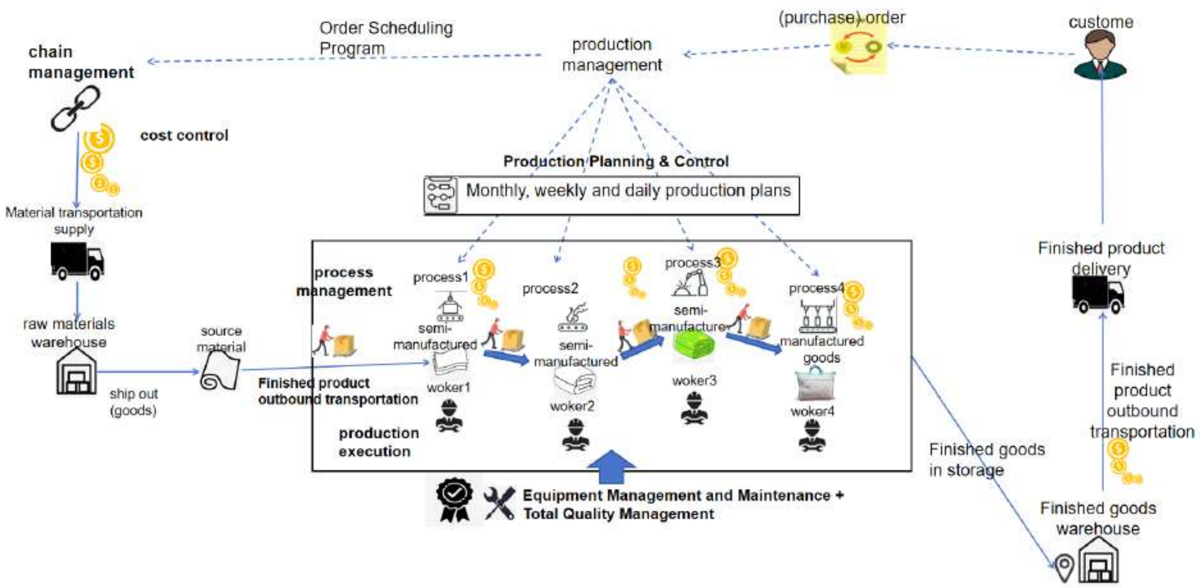

Figure 3. Mechanism map of expertise dimensions.

4. Digital Talent Job Competency Evaluation Standards

Differentiated assessment plans are formulated based on competency levels, clarifying the requirements of talents at various levels in the dimensions of technology application, process optimization, strategic decision-making, etc., supporting the precise training and management upgrading of talents.

4.1. Evaluation Weights of the Competency Level of the Management of Digital Talents' Positions

Based on the hierarchical ability cultivation model, we determine the focus of comprehensive ability, professional knowledge, technical skills and engineering practice of talents at all levels, and establish a mechanism for talent promotion and ability level evaluation and assessment.

Junior talents focus on professional knowledge to build a foundation, focusing on the construction of theoretical systems, and engineering practice requirements account for the lowest proportion, because they are in the cognitive accumulation stage, and need to lay the foundation for ability leap through standardized knowledge learning.

Intermediate talents strengthen engineering practice and comprehensive ability. As an organizational hub, they need to improve cross-sectoral coordination ability, and the weight of professional knowledge and technical skills is adjusted downward, highlighting the core ability of theory transformation + system implementation.

Senior talents balance strategic vision and practical depth, and emphasize both professional knowledge and engineering practice. Through complex project management, they can realize the synergy between management decision-making and technological innovation, and drive the digital transformation strategy to the ground.

To sum up, the evaluation weights of management digital talents are shown in Table 1. Primary level constructs cognitive framework with knowledge input, intermediate level opens up the fault between technology and management with practice, and senior level realizes value creation with strategic integration.

Table 1. Weighting table for evaluation of the competency level of management of digital talents' positions.

Evaluation Dimension	**General Competence**	**Specialized Knowledge**	**Technical Skill**	**Engineering Practice**
Job Level	**Weighting of Points**	**Weighting of Points**	**Weighting of Points**	**Weighting of Points**
inferior	20%	45%	20%	15%
mid-level	25%	25%	20%	30%
high level	20%	30%	20%	30%

Note: The total evaluation score is 100 points, which is obtained from the total weighted score of the four evaluation dimensions: general ability, professional knowledge, technical skills, and engineering practice.

4.2. Managing the Digital Talent Cultivation Inspection Path

Based on the above cultivation and evaluation system, we design a pathway for the cultivation of digital talents. First of all, the corresponding professional knowledge courses are formulated, through which the students can systematically master the digitalization and management related professional knowledge and establish relevant cognition. At the same time, a practice platform is set up to transform knowledge into problem-solving ability through project practice, realizing the closed loop from learning to application. After completing the preliminary professional learning and practice, based on a certain degree of professionalism, students can choose the appropriate initial, intermediate and advanced certification examination according to their own ability, and can be promoted after the examination to meet the requirements. The specific training path is shown in Figure 4.

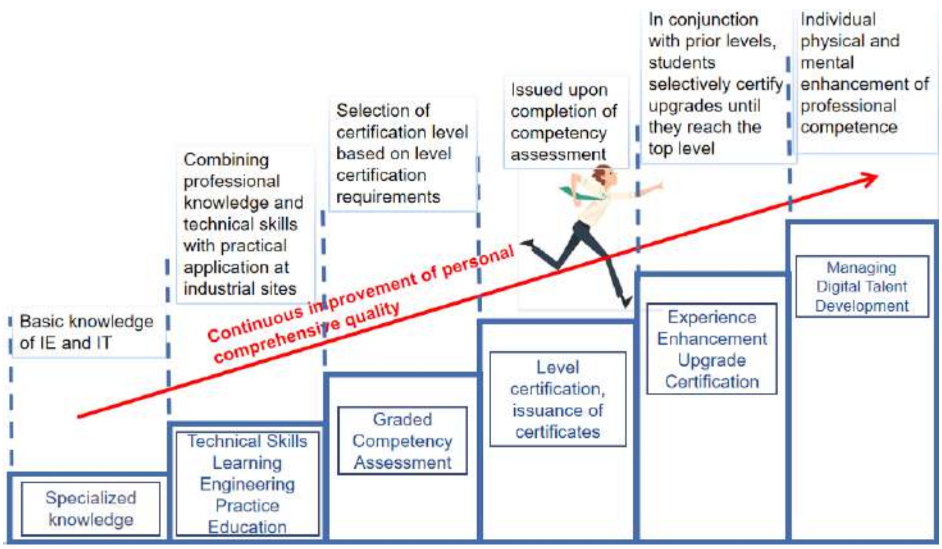

Figure 4. Digital Talent Development Examination Path.

5. Conclusions

The essence of digital transformation of industrial enterprises is the systematic reconstruction of management thinking and talent ability. This study provides a systematic solution to crack the digital "talent shortage", and builds a set of digital talent training program that covers four dimensions of competency definition, three competency levels, eight disciplines of professional knowledge, three levels of evaluation standards and the overall cultivation path, which is adapted to industrial scenarios. On the basis of analyzing the demand for talents for digital transformation of industrial enterprises, we reveal the core contradiction of "interdisciplinary competence disconnection and imperfect cultivation system" in the shortage of talents. Combining the importance of IE and IT to the digital operation of industrial enterprise management, integrating the dual knowledge system of IE and IT, constructing a 4-dimensional competency model of "comprehensive ability, professional knowledge, technical skills and engineering practice", and introducing the "know, believe and act" model of "cognitive theory and Katz management skills". Cognitive theory and Katz management skills model are combined to define the competency standards of junior, middle and senior talents. Finally, combining job requirements and competency weights, the program establishes a talent evaluation mechanism and cultivation path.

Through the quantification of competency standards and visualization of training paths, the program has solved the drawbacks of "focusing on technology but not management" in education and "fragmentation" in enterprise training. Enterprises can carry out internal talent promotion and external recruitment based on the three-level evaluation standard, and universities can optimize the curriculum system with reference to the knowledge map, realizing the precise docking between industry and education.

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Author Contributions

J.N. participated in the writing of the project grant document for this dissertation. and was responsible for the conceptualization and design, model construction, analysis, and interpretation of this study. The authors also drafted the manuscript and approved the final version as submitted. J.L. as the instructor, led the implementation of this grant program and guided the identification and writing of the content related to this article. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

This study did not involve any human or animal subjects and therefore did not require ethics approval.

Data Availability Statement

All data used in the study were obtained from publicly available sources.

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Conflicts of Interest

The authors declare no conflict of interest. There are no financial or personal relationships that could have influenced the research presented in this manuscript.

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