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Research on Collaborative Innovation of Integrated Circuit Industry Supply Chain in Guangdong Province under the Dual Circulation Pattern

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Abstract: In order to cope with the challenges of the global economy, my country has vigorously promoted the new development pattern of "dual circulation" and strengthened the domestic demand-driven economy. At present, my country's integrated circuit industry is plagued by development bottlenecks and urgently needs to improve its independent innovation capabilities. As one of the important integrated circuit industry bases in China, Guangdong Province focuses on the local situation, builds a supply chain collaborative innovation model for the government, enterprises, scientific research institutions and suppliers, integrates resources from all parties through trial and error application platforms, improves technological innovation capabilities, and builds a collaborative innovation performance evaluation index system for the integrated circuit industry supply chain in our province to verify the effectiveness. Finally, based on the research results, policy recommendations for improving the innovation model are proposed, aiming to promote the innovative development of the integrated circuit industry in Guangdong Province, provide suggestions for the empowerment of government-enterprise collaboration industries, and help Guangdong build the third pole of the national integrated circuit industry.

1. Introduction

With the vigorous development of the integrated circuit industry chain, the expansion of scale, and the improvement of technological innovation capabilities, China has become one of the world's largest integrated circuit markets, but the demand for high-end chips still relies on imports, and the self-sufficiency rate is low. With frequent interruptions to the international supply chain, shortages of key technologies or obstructed supply of parts, China faces the challenge of being "stuck in the neck" by developed countries, and long-term "low-end lock-in" restricts industrial upgrading. Under the new development pattern, we emphasize the domestic and international "dual circulation" and industrial chain security, and promote scientific and technological self-reliance. As a major province in the integrated circuit industry, Guangdong Province needs to break the situation and reshape its advantages, and combine the provincial party committee's "1310" deployment to develop key technologies and supply chain collaborative innovation. Because the current industry is at the middle and low end and lacks trial and error scenarios, it is necessary to strengthen government-enterprise cooperation, upstream and downstream collaborative innovation, establish an innovation consortium, reduce R&D costs, enhance independent innovation capabilities, optimize resource allocation, and promote the province's integrated circuit industry to move towards high-end.

2. Literature Review

In order to strengthen the cooperation between government and enterprises, this paper proposes to establish the Guangdong Integrated Circuit Technology Innovation Consortium model. At present, relevant research results at home and abroad focus on collaborative innovation. Focusing on innovation performance and innovation sustainability, the research on collaborative innovation of industrial supply chain is divided into three aspects, namely mechanism, impact and performance evaluation.

In terms of mechanism, Chang Jie and Jin Bo proposed a digital supply chain architecture, building four major mechanisms: information communication, collaborative decision-making, cooperative innovation, and risk control[1]. Nilsson and Göransson proposed a sustainable supply chain model based on social, environmental, economic and innovative design dimensions[2]. In terms of influencing factors, scholars have mostly explored the impact of activities, knowledge sharing, capabilities, relationship quality, learning ability and value innovation on innovation performance from the perspective of collaborative innovation performance. Construct the I-P-O model: the influencing factors are input (I), the mediating factors are process (P), and the innovation results are output (O)[3]. Wang and Hu found that collaborative innovation activities, knowledge sharing and collaborative innovation capabilities promote enterprise innovation performance. Knowledge sharing is an intermediary link, and collaborative innovation capabilities regulate the relationship between innovation activities and innovation performance[4]. In terms of performance evaluation, Cai Tingting and Zhang Bo constructed an evaluation index system based on innovation input, innovation output and innovation environment, and used the entropy method to objectively and comprehensively evaluate the innovation performance of enterprises[5]. Zaman et al. used the grey decision-making method to evaluate the supply chain cost and its synergy factors from the perspective of supply chain finance, and pointed out that digitalization, information sharing, collaborative communication, incentive consistency and information quality are the main influencing factors[6].

Based on the research results of many scholars, supply chain collaborative innovation mainly focuses on supply chain innovation performance, knowledge sharing mechanism, collaborative innovation benefits and innovation efficiency evaluation. This article will combine the development status of the local integrated circuit industry in Guangdong Province to explore how the domestic supply chain can effectively carry out collaborative innovation under the domestic and international dual circulation pattern, and provide a reference for government policy implementation through the innovation performance evaluation system.

3. Construction of Innovation Performance Evaluation Index System

3.1. Principles for Constructing an Innovation Performance Evaluation Index System

The innovation performance evaluation index system in this paper mainly follows the principles of multi-dimensional theory, combination of comprehensiveness and importance, combination of qualitative and quantitative, scientificity, dynamism and operability.

3.2. Selection of Innovation Performance Evaluation Indicators

The mainstream enterprise innovation performance evaluation indicators include multiple dimensions such as innovation input, innovation output and innovation environment. Combining the supply chain collaboration studied in this paper and the above research status, this paper adds the talent development and information collaboration dimensions to the existing innovation input, innovation output and innovation environment dimensions, so as to comprehensively consider the innovation capability and the degree of collaboration between upstream and downstream enterprises[5].

(1) Talent development. Talent investment is the core driving force for the continuous progress and competitiveness of enterprises.

(2) Innovation input. R&D investment is mainly measured by the intensity of an enterprise's R&D expenses.

(3) Innovation output. Innovation outputs include but are not limited to new products, new technologies, new patents, new services, etc.

(4) Innovation environment. The innovation environment reflects the support of the external social environment for enterprise innovation. In my country, it is mainly reflected in government subsidies and tax incentives.

(5) Information collaboration. The accuracy and timeliness of information transmission directly become key factors affecting the effectiveness of innovation activities. When the accuracy of information within the supply chain is high, it reflects the high efficiency and closeness of collaboration among supply chain members.

Evaluation indicators include quantitative and qualitative indicators with different attributes. Quantitative indicators are directly obtained through data calculation and statistical methods, and qualitative indicators are obtained through questionnaires, interviews with corporate employees and experts, etc. This article summarizes the information obtained and uses the fuzzy comprehensive evaluation method to divide the comment set into five layers to quantify the evaluation. The enterprise collaborative innovation performance evaluation system created in this paper is shown in Table 1[5,7,8].

Table 1: Hierarchical model of enterprise collaborative innovation performance evaluation system

Target layer	Criteria layer	Indicator layer	Indicator calculation formula or description
Enterprise innovation performance	Talent development	Number of R&D personnel	Number of R&D personnel in the enterprise (person)
		R&D personnel ratio	R&D personnel ratio = number of R&D personnel / total number of employees
		Number of R&D personnel with postgraduate degree or above	Number of R&D personnel with a master's degree or above in the enterprise (person)
	Innovation input	R&D investment intensity	R&D investment intensity = R&D investment/operating income
		Year-on-year growth rate of R&D investment	Year-on-year growth rate of R&D investment = (R&D investment in this period - R&D investment in the previous period) / R&D investment in the previous period

		Proportion of investment in innovative equipment	Innovation equipment investment ratio = enterprise R&D equipment cost / operating cost
	Innovation output	Changes in intangible assets	Changes in corporate innovation activities during the period, including patents, trademarks, copyrights, etc., changes in intangible assets = intangible asset value at the end of the period - intangible asset value at the beginning of the period (100 million yuan)
		New product market situation	Obtained through the "Management Discussion and Analysis" section of the annual report
		Number of patent authorizations	Cumulative number of enterprise patent authorizations (items)
		Gross profit margin	Gross profit margin = (operating income - operating costs) / operating income
	Innovation environment	Government subsidy ratio	Government subsidy ratio = government subsidy / operating income
		Tax ratio	Tax ratio = current accrued taxes payable / operating income
	Information collaboration	Information sharing between enterprises	The closeness of cooperation between upstream and downstream adjacent enterprise nodes
		Timely delivery of information	Timeliness of information transmission = number of accurate information transmission times / total number of transmission times
		Accuracy of information transmission	Accuracy of information transmission = number of timely information transmission/total number of transmissions

3.3. Weight Assignment of Innovation Performance Evaluation Indicators

This paper will select the hierarchical analysis method to calculate the indicator weights, combine qualitative and quantitative methods to analyze the problem by building a hierarchical structure model. A hierarchical model is established, as shown in Table 1, so that experts can make comparative judgments on the relative importance of each factor in the criterion layer. A judgment matrix is constructed, and the proportions and meanings of the judgment matrix are shown in Table 2:

Table 2: Judgment matrix proportion and its meaning

Scale value	Meaning
1	Element *c* is as important as element *d*
3	Compared with element *c*, element *d* is slightly more important
5	Compared with element *c*, element *c* is obviously more important than element *d*
7	Compared with element *c*, element *c* is strongly more important than *d*
9	Compared with element *c*, element *c* is absolutely more important than *d*
2, 4, 6, 8	The middle value of the above pairwise judgment
Reciprocal	The importance ratio of element *c* to element *d* is the reciprocal of the above value

After expert investigation, the judgment matrices at the criterion level and indicator level were obtained, as shown in Table 3, Table 4, Table 5, Table 6, Table 7, and Table 8.

Table 3: Criteria layer judgment matrix

Enterprise innovation performance	Talent development	Innovation input	Innovation output	Innovation environment	Information collaboration	Wi
Talent development	1	0.1667	0.1429	0.25	0.3333	0.0457
Innovation input	6	1	0.5	0.5	3	0.2169
Innovation output	7	2	1	2	4	0.3945
Innovation environment	4	2	0.5	1	2	0.2384
Information collaboration	3	0.3333	0.25	0.5	1	0.1045
max=5.1633, CR=0.0365						

Table 4: Judgment matrix for talent development

Talent development	Number of R&D personnel	R&D personnel ratio	Number of R&D personnel with postgraduate degree or above	Wi
Number of R&D personnel	1	3	4	0.608
R&D personnel ratio	0.3333	1	3	0.2721
Number of R&D personnel with postgraduate degree or above	0.25	0.3333	1	0.1199
λmax=3.0741; CR=0.0713				

Table 5: Innovation investment judgment matrix

Innovation input	R&D investment intensity	Year-on-year growth rate of R&D investment	Proportion of investment in innovative equipment	Wi
R&D investment intensity	1	5	4	0.6768
Year-on-year growth rate of R&D investment	0.2	1	2	0.1925
Proportion of investment in innovative equipment	0.25	0.5	1	0.1307
λmax=3.0956; CR=0.0919				

Table 6: Innovation output judgment matrix

Innovation output	Changes in intangible assets	New product market situation	Number of patent authorizations	Gross profit margin	Wi
Changes in intangible assets	1	0.3333	1	0.3333	0.1191
New product market situation	3	1	5	1	0.4028
Number of patent authorizations	1	0.2	1	0.25	0.0979
Gross profit margin	3	1	4	1	0.3801
λmax=4.0248; CR=0.0919					

Table 7: Innovation environment judgment matrix

Innovation environment	Government subsidy ratio	Tax ratio	Wi
Government subsidy ratio	1	5	0.8333
Tax ratio	0.2	1	0.1667
λmax=2; CR=0			

Table 8: Judgment matrix of information collaboration

Information collaboration	Information sharing between enterprises	Timely delivery of information	Accuracy of information transmission	Wi
Information sharing between enterprises	1	4	3	0.6327
Timely delivery of information	0.25	1	1	0.1749
Accuracy of information transmission	0.3333	1	1	0.1924
λmax=3.0092; CR=0.0089				

The yaahp software was used to calculate the relative weight of each indicator in the judgment matrix to the indicator in the previous layer, and the sum-product method was used to normalize each judgment matrix to obtain the indicator weight coefficient, as shown in Table 3 to Table 8.

In order to verify the rationality of the weight values obtained by the judgment matrix, the above judgment matrix is subjected to consistency test. The formula is:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{1}$$

Where CI is the consistency index, λ_{max} is the maximum characteristic root, *n* is the order, and *c* is the element of each judgment matrix:

$$\mathrm{CI} = \frac{\lambda_{\max}-\mathrm{n}}{\mathrm{n}-1} \tag{2}$$

$$\lambda_{\max} = \frac{\sum(\mathrm{cWi})}{\mathrm{nWi}} \tag{3}$$

When CR < 0.1, the judgment matrix is considered to have satisfactory consistency. As shown in

Table 3 to Table 8, all judgment matrices passed the consistency test.

The weights of the criterion layer and the indicator layer (rounded to two decimal places) are shown in Table 9:

Table 9: Weight values of the criterion layer and indicator layer

Criteria layer	Weight	Indicator layer	Weight
Talent development	0.05	Number of R&D personnel	0.03
		R&D personnel ratio	0.01
		Number of R&D personnel with postgraduate degree or above	0.01
Innovation input	0.22	R&D investment intensity	0.15
		Year-on-year growth rate of R&D investment	0.05
		Proportion of investment in innovative equipment	0.03
Innovation output	0.40	Changes in intangible assets	0.05
		New product market situation	0.16
		Number of patent authorizations	0.04
		Gross profit margin	0.15
Innovation environment	0.24	Government subsidy ratio	0.20
		Tax ratio	0.04
Information collaboration	0.10	Information sharing between enterprises	0.07
		Timely delivery of information	0.02
		Accuracy of information transmission	0.02

3.4. Case Verification of Innovation Performance Evaluation Index System

The object of evaluation in this paper is the supply chain with integrated circuit enterprises in Guangdong Province as the core. Therefore, this paper selects 10 integrated circuit enterprises in Guangdong Province to evaluate their innovation performance. The sample data comes from the annual reports of each enterprise and interviews with enterprise employees. Because innovation capability is continuous and cumulative, the survey data selection time is the whole year of 2023. The statistical data (rounded to two decimal places) are shown in Table 10.

The values of qualitative indicators are fuzzy comprehensive evaluation quantitative indicators. The comment set is V={V1, V2, V3, V4, V5}={poor, relatively poor, average, good, excellent}, and the corresponding scores are 1, 2, 3, 4, 5.

The values of qualitative indicators are fuzzy comprehensive evaluation quantitative indicators, and the comment set is V={V1, V2, V3, V4, V5}={poor, poor, general, good, excellent}, and the corresponding scores are 1, 2, 3, 4, 5. Each evaluation indicator has different units, dimensions, and orders of magnitude. In order to unify the standards and facilitate data processing, all evaluation indicator values must be standardized to become dimensionless and order-of-magnitude standard scores. The larger the value of the evaluation index atmosphere index, the better the benefit-type index, and the smaller the value of the index, the better the cost-type index. Except for the proportion of innovative equipment investment and the proportion of taxes and fees, which are cost-type indicators, the rest are benefit-type indicators. Benefit indicators are processed positively:

$$x_i = \frac{x - x_{min}}{x_{max} - x_{min}} \quad (4)$$

Cost indicators are treated negatively:

$$x_i = \frac{x_{max} - x}{x_{max} - x_{min}} \quad (5)$$

The standardized data are shown in

Enterprise	A	B	C	D	E	F	G	H	I	J
Number of R&D personnel (person)	3656	986	1245	683	632	216	440	183	360	508
R&D personnel ratio	30.44%	33.10%	82.67%	37.45%	81.13%	78.55%	71.08%	74.39%	36.92%	58.46%
Number of R&D personnel with postgraduate degree or above (person)	2436	273	726	110	280	40	113	107	101	33
R&D investment intensity	19.97%	5.86%	30.59%	6.96%	29.14%	11.35%	25.18%	11.90%	31.66%	25.94%
Year-on-year growth rate of R&D investment	23.66%	66.74%	24.99%	97.77%	16.48%	49.30%	83.32%	-3.88%	-6.61%	19.29%
Proportion of investment in innovative equipment	99.86%	85.23%	100.00%	93.88%	71.18%	92.40%	77.38%	81.58%	94.44%	73.37%
Changes in intangible assets (100 million yuan)	5.44	1.81	-0.91	0.13	-0.36	-0.07	-0.05	0.01	-0.16	-0.01
New product market situation	4	3	3	2	4	4	3	2	3	5
Number of patent authorizations	470	414	350	334	386	107	154	64	396	176
Gross profit margin	41.10%	8.19%	40.46%	-17.39%	0.22%	22.56%	31.29%	20.01%	2.06%	8.55%
Government subsidy ratio	1.65%	0.24%	0.74%	0.30%	1.14%	1.49%	1.23%	1.19%	2.38%	1.42%
Tax ratio	0.76%	0.11%	0.65%	0.19%	0.54%	0.38%	0.46%	0.13%	0.67%	0.12%
Information sharing between enterprises	3	4	5	2	4	1	3	5	2	4
Timely delivery of information	87.56%	92.34%	76.89%	94.12%	69.78%	81.23%	89.45%	73.67%	90.01%	75.32%
Accuracy of information transmission	96.45%	89.78%	92.34%	97.12%	85.67%	90.23%	94.56%	87.90%	93.01%	88.76%

Table 11.

Table 10: Statistical data of 10 companies

Enterprise	A	B	C	D	E	F	G	H	I	J
Number of R&D personnel (person)	3656	986	1245	683	632	216	440	183	360	508
R&D personnel ratio	30.44%	33.10%	82.67%	37.45%	81.13%	78.55%	71.08%	74.39%	36.92%	58.46%
Number of R&D personnel with postgraduate degree or above (person)	2436	273	726	110	280	40	113	107	101	33
R&D investment intensity	19.97%	5.86%	30.59%	6.96%	29.14%	11.35%	25.18%	11.90%	31.66%	25.94%
Year-on-year growth rate of R&D investment	23.66%	66.74%	24.99%	97.77%	16.48%	49.30%	83.32%	-3.88%	-6.61%	19.29%
Proportion of investment in innovative equipment	99.86%	85.23%	100.00%	93.88%	71.18%	92.40%	77.38%	81.58%	94.44%	73.37%
Changes in intangible assets (100 million yuan)	5.44	1.81	-0.91	0.13	-0.36	-0.07	-0.05	0.01	-0.16	-0.01
New product market situation	4	3	3	2	4	4	3	2	3	5
Number of patent authorizations	470	414	350	334	386	107	154	64	396	176
Gross profit margin	41.10%	8.19%	40.46%	-17.39%	0.22%	22.56%	31.29%	20.01%	2.06%	8.55%
Government subsidy ratio	1.65%	0.24%	0.74%	0.30%	1.14%	1.49%	1.23%	1.19%	2.38%	1.42%
Tax ratio	0.76%	0.11%	0.65%	0.19%	0.54%	0.38%	0.46%	0.13%	0.67%	0.12%
Information sharing between enterprises	3	4	5	2	4	1	3	5	2	4
Timely delivery of information	87.56%	92.34%	76.89%	94.12%	69.78%	81.23%	89.45%	73.67%	90.01%	75.32%
Accuracy of information transmission	96.45%	89.78%	92.34%	97.12%	85.67%	90.23%	94.56%	87.90%	93.01%	88.76%

Table 11: Standardized data

Enterprise	A	B	C	D	E	F	G	H	I	J
Number of R&D personnel (person)	1	0.23	0.31	0.14	0.13	0.01	0.07	0	0.05	0.09
R&D personnel ratio	0	0.05	1	0.13	0.97	0.92	0.78	0.84	0.12	0.54
Number of R&D personnel with postgraduate degree or above (person)	1	0.1	0.29	0.03	0.1	0	0.03	0.03	0.03	0
R&D investment intensity	0.55	0	0.96	0.04	0.9	0.21	0.75	0.23	1	0.78
Year-on-year growth rate of R&D investment	0.29	0.7	0.3	1	0.22	0.54	0.86	0.03	0	0.25
Proportion of investment in innovative equipment	0	0.51	0	0.21	1	0.26	0.78	0.64	0.19	0.92
Changes in intangible assets (100 million yuan)	1	0.43	0	0.16	0.09	0.13	0.14	0.14	0.12	0.14
New product market situation	0.67	0.33	0.33	0	0.67	0.67	0.33	0	0.33	1
Number of patent authorizations	1	0.86	0.7	0.67	0.79	0.11	0.22	0	0.82	0.28
Gross profit margin	1	0.44	0.99	0	0.3	0.68	0.83	0.64	0.33	0.44
Government subsidy ratio	0.66	0	0.24	0.03	0.42	0.58	0.46	0.44	1	0.55
Tax ratio	0	1	0.16	0.87	0.34	0.58	0.46	0.97	0.14	0.98
Information sharing between enterprises	0.5	0.75	1	0.25	0.75	0	0.5	1	0.25	0.75
Timely delivery of information	0.73	0.93	0.29	1	0	0.47	0.81	0.16	0.83	0.23
Accuracy of information transmission	0.94	0.36	0.58	1	0	0.4	0.78	0.19	0.64	0.27

According to the above evaluation index system, the comprehensive score S of each enterprise's innovation performance is calculated using the following formula:

$$S = \sum_{i=1}^{15} p_i \times x_i \quad (6)$$

Among them, p_i is the corresponding weight value of each indicator layer, and x_i is the standardized statistical data value of the indicator layer. The larger the S value, the higher the innovation performance of the enterprise and the stronger the innovation ability, which can be used to compare the innovation ability of each enterprise. The comprehensive scores and rankings of the 10 companies are shown in Table 12:

From the ranking of enterprise scores, we can see that enterprises A and J, which have higher R&D investment intensity, higher market popularity of new products, considerable corporate gross profit margin, larger proportion of government subsidies and higher information sharing synergy among enterprises, have higher comprehensive scores, while enterprises B and D, which have fewer R&D personnel, lower R&D investment intensity, lower market popularity of new products, less government subsidies and higher taxes, rank lower in comprehensive scores. Therefore, it can be seen that R&D investment and government subsidy support are very important for corporate innovation and talent development.

Table 12: Comprehensive scores and rankings of innovation performance of 10 companies

Enterprise	Comprehensive score	Ranking
A	0.684	1
B	0.352	9
C	0.552	5
D	0.202	10
E	0.529	6
F	0.453	7
G	0.561	3
H	0.372	8
I	0.553	4
J	0.622	2

By scoring the enterprises, we can comprehensively evaluate the capabilities of the enterprises in all aspects, assess the creativity of the enterprises, and help the government to judge the development of enterprises and provide reference for the market potential of products, so as to promote the introduction of more feasible talents and the implementation of policies for the integrated circuit industry. By evaluating the innovation performance of enterprises in the integrated circuit industry in Guangdong Province, the government can use this evaluation mechanism to promote the innovative development of enterprises, optimize the innovation environment, improve service efficiency, and enhance the competitiveness of the regional economy.

4. Conclusions

Based on the current situation of the integrated circuit industry in Guangdong Province, this study proposes the need to build a supply chain collaborative innovation model for the development of the integrated circuit industry in Guangdong Province. By integrating the resources of the government, upstream and downstream enterprises in the supply chain, scientific research institutions and universities, we jointly establish a technology innovation consortium and a trial and error application center, and carry out technology and management innovation within the platform to enhance the independent innovation capabilities of core enterprises. To this end, we constructed a performance evaluation index system for collaborative innovation of the integrated circuit industry supply chain in our province and combined it with case verification. Finally, we put forward policy recommendations for collaborative innovation of the integrated circuit industry supply chain in Guangdong Province, which provides a scientific basis and practical experience for our province to build an integrated circuit industry innovation model that meets the requirements of the new development stage under the "dual circulation" pattern, and also provides a reference for the exploration of industrial innovation models in other regions.

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