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The Semiconductor Industry and High-Quality Economic Development: An International Perspective*

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Abstract

Purpose – This paper is an empirical investigation of the mediation effect of innovation activity in industry transformation considering the relationship between the semiconductor industry and high-quality economic development. The research questions are whether the semiconductor industry drives high-quality economic development and if so, what is the semiconductor industry's role in high-quality development? We found that the semiconductor industry has clearly improved the quality of economic development, and its comparative advantage has significantly increased per capita national incomes. Furthermore, innovation activity proved to be an intermediary factor for the semiconductor industry to promote high-quality economic development. The world economy should aim to reasonably develop the international semiconductor industry and cultivate innovation markets.

Design/methodology – Our empirical model considers the relationship between the semiconductor industry, innovation activity, and high-quality economic development. We constructed an analysis framework based on data from 199 World Bank economies between 1995 and 2019, and we used a mediation effect method to calculate the total effect of the semiconductor industry on promoting high-quality economic development, the indirect effect of the semiconductor industry on promoting innovation activity, and the mediation effect of these innovation activities on the promotion of high-quality economic development.

Findings – The results show that the semiconductor industry has significantly promoted high-quality economic development. This is true even after the robustness test of grouping and alternative variables was applied. An analysis of the mechanism shows that promoting patents, scientific research, efficient government, and urban management innovation are important mechanisms for the semiconductor industry to release high-quality development dividends.

Originality/value – Although it has been shown that specific industries like semiconductors can affect high-quality economic development through industrial upgrading, few researchers have attempted to empirically test the impact of the semiconductor industry on high-quality economic development. In this paper, we use a mediation effect model, alternative variables and a grouping test to find the internal mechanisms of the comparative advantage of the semiconductor industry in high-quality economic development from the perspective of innovation activity.

Keywords: Semiconductor Industry, High-Quality Economic Development, Mediation Effect Model
JEL Classifications: D69, F40, O40

1. Introduction

For a long time, the development of the semiconductor industry and its associated

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innovation activities have played an important role in helping countries create jobs, develop a modern production system and promote economic growth. We have entered an era characterized by high levels of intellectual labor, along with expanding knowledge and information-based economies. The level of innovation activity is deeply reflected in the structural changes of the economic society. Resolving the dilemmas created by economic growth requires consistent innovation, the process of commercializing innovative elements (such as new products, new markets, and new methods) and ultimately transforming them into market values. Innovation activity is a measure of innovation value and efficiency. Innovation activity is highly situational in that different industrial structures will lead to different levels of innovation activity in different economies.

With this in mind, this paper uses the perspective of the semiconductor industry to investigate how governments can affect the innovation activity level of economies and promote national economic growth through industrial policy arrangements and other macro environmental conditions surrounding innovation and entrepreneurship.

"High-quality economy development" is a new development concept consisting of innovation, coordination, greenness, openness, and sharing. It involves all fields of a social economy. The literature on high-quality development is related to attracting multinational talents (Hasgall and Ahituv, 2018), supporting education and research (Sen, 2018), building an efficient government (Kim et al., 2017), promoting urbanization (Yang and Zhao, 2020), narrowing the gap between rich and poor (Frederiksen, 2019) and developing patented technologies in the semiconductor industry (Sapra et al., 2014). In particular, the semiconductor industry affects the innovation activities of economies through its technological and management innovation activities. At the same time, considering the technology spillover effect and the industrial first mover advantage of the semiconductor industry, its impact on promoting high-quality economic development could also show economic cycle spillover characteristics and have spatial spillover effects (Lacasa et al., 2019).

The semiconductor industry continues to expand its integration with various economic and social fields and plays an important role in stimulating technological innovation and investment and creating employment. Here the following research questions arise: Does the semiconductor industry drive high-quality economic development, and if so, by what mechanism? Prior research has examined the impact of semiconductors on high-quality economic development. At the micro level, emerging technologies such as semiconductors can form an economic environment with economies of scale, scope, and long-tail effects. To better match supply and demand, researchers built a more complete price mechanism, thereby improving the equilibrium level of the economy (Broekel et al., 2018). At the macro level, innovation activity promotes high-quality economic development through technological inputs, resource allocation efficiencies, and total factor productivity (Cao, 2018).

However, researchers are yet to uncover any patterns in the semiconductor industry's impact on high-quality economic development. We therefore adopted a time-series approach to studying 199 global economies from 1995 to 2019 to estimate the mediation effect of innovation activity in industry transformation considering the relationship between the semiconductor industry and high-quality economic development. Although we cannot estimate the effect of individual innovation activities, the essence of the approach chosen here is to find an appropriate theoretical analysis framework. Various econometric methods, such as OLS regression, group regression, and mediation effect models, were used to empirically test the impacts of the semiconductor industry on high-quality economic development and its mechanism.

The research results show that the semiconductor industry has significantly promoted high-quality economic development and that increasing innovation activity is an important influence mechanism. These conclusions are still valid after the robustness tests of categorical grouping and variable substitution. This study takes an international perspective as we used economic data from 199 economies of the World Bank between 1995 and 2019. Furthermore, in terms of international research theory, this paper adopts the latest product space theory of a Harvard University research team (Hausmann and Klinger, 2006). Finally, this paper adopts an intermediary effect model in its empirical model of internationalization, which is more advanced in the current empirical field.

The structure of the article is as follows: In section 2, we briefly review the literature for the empirical framework and hypothesis, and in section 3, we explain the econometric approach and the underlying data. In section 4, we present the test results, which represent the core of the findings on the impact of innovation activity in industry transformation. Finally, in section 5, we summarize the analysis and present the research implications.

2. Empirical Framework and Hypothesis

At the core of high-quality economic development is innovation, coordination, greenness, openness and sharing. This involves all fields of social economy. This research has shown that the semiconductor industry's inherent advantages and essential characteristics, such as intensive patented technology, attracting transnational talents, supporting education and research, building an efficient government, and promoting urbanization, have effectively eliminated the contradiction between supply and demand of factors for high-quality development among economies, the restriction of economic activity space, and the imbalance between fairness and efficiency. In addition to the direct impact of the industry's own characteristics and the nature of high-quality development, the semiconductor industry can also affect the innovation activities of the economy. Through technological and management innovation activities, it has an indirect impact on the high-quality development of the economy. At the same time, considering the "technology spillover effect" and "industry first mover advantage" of the semiconductor industry, its impact on promoting high-quality economic development may also show the characteristics of economic cycle spillover and spatial spillover effects. This paper will mainly study and demonstrate three aspects of the semiconductor industry: the effects of the industry on high-quality economic development, its promotion of innovation activity, and the intermediary effect of this innovation activity.

2.1. The semiconductor industry and high-quality economic development

In terms of industrial structure theory, previous research has established the product space theoretical framework and introduced a product comparative advantage index. Specifically, we proposed that the semiconductor industry’s comparative advantage in promoting national economic development could have been brought about by the so-called first mover advantage (Hausmann and Linger, 2006). Furthermore, we found that the comparative advantage degree of some industries, for example the textile industry (Huang, 2006), can have a “resource curse effect”. There is also evidence that the comparative advantages of some low-end products and human resource-intensive products in the industry chain are very fragile, meaning the related industries decline very rapidly. However, light industrial and high-tech semiconductor industries have been shown to promote high-quality economic development (Carbonell and Werner, 2017; Siaw et al., 2018; Kumar and Yalew, 2012). Previous research has used US metal export data from 1993 to 2006 to empirically test the product export advantages that promote economic growth (Erkan and Yildirimci, 2015). Other studies have used the "technical catch-up theory" to analyze the development trend of the global semiconductor industry, finding it to be an important foundation of the digital society that is not only related to international economic growth but also directly affects nations' political and economic security (Lee, 2001). Based on the above findings, we propose the following research hypothesis:

H1: The semiconductor industry promotes high-quality economic development.

2.2. Semiconductor industry and innovation activity

Immigrant attraction, common technology, a low-carbon economy, and industrial characteristics are important factors in how the semiconductor industry promotes innovation activity. One research group used 1990–2014 World Bank data to test the relationship between semiconductor exports and the number of immigrants. They empirically determined that the development of the semiconductor industry increases the attraction of transnational skilled immigrants, and the net inflow of skilled immigrants can increase the number of patent applications (Caporale et al., 2015). Furthermore, based on case studies of three R&D alliances: VLSI, SEMAT-ECH, and IMEC, a comparative analysis concluded that the semiconductor industry enhances regional innovation and increases innovation activity through common technology research and development (Fang and Wang, 2010).

Other researchers used data from the 1952–2010 China Statistical Yearbooks to construct a Solow growth model to investigate whether the development of a low-carbon economy is conducive to improving total factor productivity and promoting innovation efficiency (Lin and Sun, 2011). Some researchers analyzed the priority strategies of heavy industry development and concluded that urbanization processes need to prioritize the development of light industry and high-tech industries like semiconductors and promote the development of urban innovation spaces (Arndt, 1990).

In addition to the above factors, the semiconductor industry has also been shown to promote high-quality economic development through labor transfer, urbanization, industrial transformation, and government guidance. A previous study analyzed urbanization and innovation activity and showed that its mechanism is to absorb the transfer of rural labor and promote the development of urban modernization (Rana, 2011). Another study looked at 1962–2014 commodity trade data and concluded that those traditional labor-intensive industries should increase market exit efforts to avoid restraining the innovation ability of technology-intensive industries (Ferrarlni and Scaramozzino, 2015). One research group reported on the current situation of the world semiconductor industry and innovation capacity cultivation based on dynamic game theory and found that a government's integration of semiconductor industry clusters and construction of domestic clusters can improve the independent research and development of technology, absorption, transformation, and innovation (Renko et al., 2001). Based on these findings, we proposed the following research hypothesis:

H2: The semiconductor industry promotes innovation activity.

2.3. Mediating effect of innovation activity

In a study about innovation to promote high-quality economic development using World Bank data from 1960 to 2002, researchers considered technical talents, education, and scientific research as independent variables, and GDP growth rate as the dependent variable. Through empirical analysis, they determined that human capital, education, and scientific research have lagging effects on national economic growth but also have significant long-term effects. They also showed that technical talents, education, and scientific research are important indicators of innovation activity (Blanchard and Giavazzi, 2003). Some researchers took the legal framework and financial markets as independent variables and national income as the dependent variable and determined that a fair legal and policy environment promotes healthy national income distribution and economic growth; a fair legal environment is an important factor in the government's ability to manage innovation (Allen et al., 2005).

Based on global financial data from 2010 to 2011, researchers used OLS regression analysis to conclude that a positive and significant relationship between innovation activities and key economic security factors promotes national economic growth (Lee et al., 2011). Another study used 2006–2011 World Bank data and concluded that a good industrial policy environment promotes technological innovation and interactively increases the gross national product (Valencia et al., 2012). Elsewhere, Lin et al. (2014) showed that innovative activities were stable despite changes in government efficiency. They found that this had a significant positive effect on improving China's competitiveness based on 2013 data on the country's innovative enterprises.

Tang et al. (2014) constructed a broad dynamic panel matrix based on the data of 28 provinces and regions in China from 1996 to 2011 and determined that the foreign technology spillover and imitation effects of the semiconductor industry were conducive to intensifying economic growth and promoting high-quality economic development. Wan and Wang (2016) confirmed that technological innovation and social capital together promote national economic growth and that large-scale investment in semiconductor enterprises has this same attribute. Researchers who studied customs data from 30 provinces in China identified that the complexity of semiconductor product export technology presents the characteristics of agglomeration in developed coastal areas and has a significant driving coefficient on per capita national income (Wu and Wang, 2019). Indeed, broader research has shown that government expenditure on scientific research and innovation can increase the overall returns for society (Miao et al., 2019). Based on these findings, we proposed the following research hypothesis:

H3: Innovation activity has a mediation effect on the semiconductor industry's promotion of high-quality economic development.

3. Methodology and Data

3.1. Variables and Data

For this article, we use data from 1995 to 2019 on the 199 economies gathered from the World Bank database and Harvard University. To avoid data selectivity bias, the data includes not only the name of the economy, year, per capita national income, industrial structure coordination coefficient, and economic complexity but also the export comparative advantage of the semiconductor industry, patent innovation, scientific research innovation, government management innovation, urban management innovation and other indicators (Kirby et al., 2015). To allow us to effectively explore the related issues from multiple perspectives, the database for this article also contains binary numerical variables such as the degree of economic development, economic cycle and resource type. In short, the data used in this article are representative and credible.

The indicators we use to describe the status quo of the semiconductor industry are the relative value index of export comparative advantage (RCAEL) (Wen et al., 2012; Fan and Liu, 2020) and the innovation activity index (Forsman, 2011; Frederiksen, 2019). The existing research commonly selected four additional innovation capability indices: innovation input capability (EDUC), innovation output capability (PATE), innovation environment support (CITY), and innovation sustainability (GOVE). Researchers then described the constructs in terms of the logarithm of the per capita national income (LNGNI), the industrial structure coordination coefficient (COI), and economic complexity (ECI) (Watanabe et al., 2018; Valeriani and Peluso, 2011; Zuo et al., 2021). The definitions of the related variables are shown in Table 1.

The intermediary effect model consists of the independent variable, intermediary variable, and dependent variable. If the independent variable has an impact on the dependent variable through a certain variable, that variable is called the intermediary variable of the independent variable and dependent variable. The mediation effect model can link our observations to the original research on the same phenomenon to find the reasons behind said phenomenon. To improve the accuracy of the data, the sample data are processed as follows. Narrowing the degree of difference in the data range between variables is specifically manifested in the logarithmic processing of the per capita national income of the dependent variable, as shown in equation (1):

$$Y^* = \mathrm{Ln}(y_i) \tag{1}$$

where Y^* indicates high-quality economic development and y_i represents per capita national income.

Then the data is processed for the independent, intermediate, and control variables, as shown in equation (2):

$$\mu_\mathrm{i} = \frac{\mathrm{T}-\bar{\mathrm{x}}}{\mathrm{s}} \tag{2}$$

where T indicates the value of the variable; x indicates the mean of the variable; and s represents the standard deviation.

Specifically, the comparative advantage index is the most convincing index of the competitiveness of a country's industries in the international market; it aims to quantitatively describe the relative export performance of an economy's industry, in this case, the semiconductor industry (Pfluger and Tabuchi, 2019). The RCAEL can be used to determine whether an economy's semiconductor industry has export competitiveness, thereby revealing the economy's comparative advantage in international trade, following equation (3):

$$RCAEL_{c,i,t} = \frac{exp_{c,i,t}/\sum_{i,t} exp_{c,i,t}}{\sum_{c,t} exp_{c,i,t}/\sum_{c,i,t} exp_{c,i,t}} \tag{3}$$

where $RCAEL_{c,i,t}$ indicates the comparative advantage index of the semiconductor industry i of a certain economy c in the period t, $exp_{c,i,t}$ indicates the amount of semiconductor exports of a certain economy in period t, $\sum_{i,t} exp_{c,i,t}$ indicates the export value of all products of a certain economy in period t, $\sum_{c,t} exp_{c,i,t}$ represents the global export value of semiconductors in period t, and $\sum_{c,i,t} exp_{c,i,t}$ represents the total export value of all products in the global period t. Generally, RCA = 1 indicates a comparative advantage, and RCA > 1 indicates a significant advantage.

Table 1. Variables and Calculation Method

Type	Name	Symbol	Calculation Method
Dependent variable: high-quality economic growth (**GROW**)	Per capita national income	LNGNI	The logarithm of the economy's per capita national income from 1995 to 2019
	Industrial structure coordination	COI	The coefficient of industrial structure coordination of the economy from 1995 to 2019
	Economic complexity	ECI	The economic complexity coefficient of the economy from 1995 to 2019
Independent variable: Semiconductor industry (**SEMI**)	Comparative advantage	RCAEL	The degree of comparative advantage of the export of semiconductor products in the economy from 1995 to 2019
Intermediary variable: Innovation activity (**INNO**)	Patent innovation	PATE	The number of patent applications by residents of the economy from 1995 to 2019
	Research innovation	EDUC	The proportion of scientific research investment in the economy from 1995 to 2019
	Government management innovation	GOVE	The conversion coefficient of the number of days a business has been open in an economy from 1995 to 2019 is shown in equation (4)
	City management innovation	CITY	Economy 1995-2019 urban population growth rate
Control variable: (**CLAS**)	Development level	DEVE	Whether the economy is a developed country from 1995 to 2019 (= 1 if yes and 0 if not)
	Economic cycle	CYCL	The data for the economy from 2007 to 2019 is 1, and the data for the economy from 1995 to 2006 is 0
	Resource Type	RESO	Whether the economy is technology-intensive from 1995 to 2019 (= 1 if yes and 0 if not); see equations (5) and (6)

Source: World Bank (2022).

To maintain the consistency of the regression coefficient direction, government innovation management is calculated as shown in equation (4):

$$GOVE = MAXGOVE_t - GOVE_{it} \tag{4}$$

where $GOVE$ is the converted coefficient, $MAXGOVE_{it}$ for the maximum number of days a company could be open during period t of the global economy, and $GOVE_{it}$ is the number of days that the business of economy i was open during period t.

In terms of resource type, *RESO*, we draw on the Harvard University Atlas database and divide the world trade products into nine categories: textiles, agriculture, diamonds, minerals, metals, chemicals, automobiles, machinery, and electronics. Equation (5) calculates whether an economy is technology-intensive:

$$RESO_{c,i,t} = \frac{\exp{(CHEM+VEHI+MACH+ELEC)_{c,i,t}}}{\sum_{i,t} exp_{c,i,t}} \tag{5}$$

where exp $(CHEM + VEHI + MACH + ELEC)_{c,i,t}$ is the total export volume of chemicals, automobiles, machinery, and electronics of a certain economy i in the period t and $\sum_{i,t} exp_{c,i,t}$ is the total export value of a certain economy i in period t. The criterion is shown in equation (6):

$$x_{c,j,t} = \begin{bmatrix} 1, & RESO_{c,i,t} > MEAN_{c,t} \\ 0, & RESO_{c,i,t} \leq MEAN_{c,t} \end{bmatrix} \tag{6}$$

where $x_{c,j,t}$ is the coefficient of determination, $RESO_{c,i,t}$ is the proportion of technological resource exports of a certain economy i in period t, and $MEAN_{c,t}$ is the average value of the technology resource exports of the global economy in the period t. If the value of the economy exceeds the global average, it is judged to be a technology-intensive economy.

The descriptive statistics of the related variables are shown in Table 2. The peak of the variable data is generally greater than 0, indicating that the overall data distribution is steeper than the normal distribution and on a sharp peak. The skewness of variable data is generally between -0.11 and 1.70, indicating that the data distribution pattern does not deviate much from the normal distribution.

Table 2. Variable Descriptive Statistics

Variable	Number	Mean	Median	Standard Error	Kurtosis	Skewness	Minimum	Max
LNGNI	4894	8.31	8.29	1.59	0.93	0.01	4.63	12.09
COI	4894	0.003	0.017	0.83	0.47	0.26	-3.68	2.96
ECI	4894	-0.04	-0.11	1.46	1.56	2.98	-3.1	2.91
RCAEL	4894	0.41	0.09	0.85	156.14	1.70	0.01	20.18
PATE	4894	6317	67	52325	36.28	1.17	1	1393815
EDUC	4894	28.24	21.00	24.94	0.04	0.93	0.13	136.06
GOVE	4894	222.95	233	38.10	10.58	0.76	0	260
CITY	4894	56.58	56.46	23.69	1.03	-0.04	7.21	100
DEVE	4894	0.19	0	0.39	0.32	1.52	0	1
CYCL	4894	0.52	1	0.49	1.98	-0.11	0	1
RESO	4894	0.34	0	0.47	1.55	0.66	0	1

Source: World Bank (2021).

3.2. Model construction

For this paper, we constructed a mediation effect model to examine the total effect, direct effect, indirect effect, and intermediary effect as follows:

To test research hypothesis H1, the overall effect of the semiconductor industry in promoting high-quality economic development, we constructed the basic model as shown in equation (7) to observe whether the coefficient c was significant:

$$GROW_i = \beta_0 + c * SEMI_i + \varepsilon_i \tag{7}$$

where $GROW_i$ is the category of high-quality economic development; β_0 is the intercept; c is the total effect coefficient; $SEMI_i$ for the semiconductor industry category; and ε_i is the residual.

To test H2, we constructed equation (8) to measure the influence on the promotion of innovation activity in the semiconductor industry and observe whether the coefficient was significant:

$$INNO_i = \gamma_0 + a * SEMI_i + \varepsilon_i \tag{8}$$

where $INNO_i$ is innovation activity; γ_0 is the intercept; a is the indirect effect coefficient; $SEMI_i$ is the semiconductor industry category; and ε_i is the residual.

To test H3 on a mediating effect of research innovation activity in the semiconductor industry's promotion of high-quality economic development, we constructed the model shown in equation (9) to examine whether the direct effect coefficient c' and the indirect coefficient b were significant:

$$GROW_i = \delta_0 + c' * SEMI_i + b * INNO_i + \varepsilon_i \tag{9}$$

where $GROW_i$ is high-quality economic development; δ_0 is the intercept; c' is the direct effect coefficient; b is the indirect effect coefficient; $SEMI_i$ is the semiconductor industry category; $INNO_i$ is the category of innovation activity; and ε_i is the residual.

Coefficient c' determines whether there is a mediating effect. If c is significant but c' is not, the innovation activity has a complete mediating effect. If $c' < c$, the innovation activity has a partial mediating effect, and the effect size is $a \times b$, as shown in equation (10):

$$c - c' = a \times b \tag{10}$$

Furthermore, we calculated the Pearson's correlation coefficient for each variable in the main effects regression equation (9). The coefficients of the main variables were all 0.3 or lower, which proves that there was no obvious multicollinearity problem between the variables and regression analysis could be performed. The results are shown in Table 3.

Table 3. Pearson's Correlation Coefficients of the Study Variables

Classification	RCAEL	PATE	EDUC	GOVE	CITY
RCAEL	1				
PATE	0.17*	1			
EDUC	0.18*	0.15*	1		
GOVE	0.08*	0.06*	0.28*	1	
CITY	0.11*	0.08*	0.14*	0.15*	1

Note: A coefficient below 0.3 reflects low correlation and is indicated by *.

4. Empirical Test

4.1. Benchmark regression results

Table 4 reports the significance of the coefficient c and the estimated results of the semiconductor industry's impact on a country's high-quality economic development. The extent to which the export comparative advantage of the semiconductor industry promotes per capita national income, industrial structure coordination, and economic complexity is significant. The OLS regression F is significant, indicating that the equation has not been wrongly assumed, and the conclusion supports H1: The semiconductor industry promotes high-quality economic development.

Table 4. The Semiconductor Industry Affects High-Quality Development

Dependent Variable		GROW Formula (7)		
		LNGNI	COI	ECI
Independent variable SEMI	RCAEL	0.36*** (13.91)	0.22*** (16.67)	0.42*** (28.44)
intercept		8.16*** (329.22)	-0.08*** (-6.89)	-0.23*** (-16.60)
F		193.73***	277.95***	809.27***
Observations		4894	4894	4894

Notes: $*p < 0.1$, $**p < 0.05$, $***p < 0.001$.

Table 5 reports the significance of the coefficient and the estimated results of the semiconductor industry's promotion of innovation activity. The export comparative advantage of the semiconductor industry significantly promotes technological innovation, scientific research innovation, government management innovation, and urban management innovation. The OLS regression model's F is significant, indicating that the equation has not been wrongly assumed, and the conclusion supports H2: The semiconductor industry promotes innovation activity.

Table 5. The Semiconductor Industry Promotes Innovation Activity

Dependent Variable		INNO Formula (8)			
		PATE	EDUC	GOVE	CITY
Independent variable SEMI	RCAEL	10933.38*** (12.76)	5.33*** (13.07)	3.77*** (5.98)	3.08*** (7.86)
intercept		1825.79** (2.23)	26.05*** (67.04)	221.40*** (368.04)	55.32*** (148.24)
F		162.90***	170.96***	35.77***	61.80***
Observations		4894	4894	4894	4894

Notes: $*p < 0.1$, $**p < 0.05$, $***p < 0.001$.

Table 6 reports the significance of b and c', as well as the estimated results of the mediating effect of innovation activity in promoting high-quality economic development. The comparative advantage of the semiconductor industry has a positive effect on per capita national income, industrial structure coordination, and economic complexity and is significant. Innovation activity has a positive effect on per capita national income, industrial structure coordination, and economic complexity and is significant. This conclusion supports H3: Innovation activity has a mediation effect on the semiconductor industry's promotion of high-quality economic development.

Table 6. Mediating Effects of Innovation Activity

Dependent Variable		GROW Formula (9)		
		LNGNI	**COI**	**ECI**
Independent variable SEMI	RCAEL	0.12*** (7.67)	0.16*** (12.88)	0.29*** (24.01)
Intermediary variable INNO	PATE	0.00000027*** (3.06)	-0.00000065*** (-3.12)	0.0000017*** (8.63)
	EDUC	0.018*** (26.53)	0.012*** (22.60)	0.013*** (26.54)
	GOVE	0.0051*** (13.39)	0.0011*** (3.96)	0.0022*** (7.87)
	CITY	0.035*** (50.42)	-0.0013*** (2.41)	0.0096*** (18.88)
intercept		4.54*** (51.01)	-0.59*** (-8.67)	-1.61*** (-25.02)
F		1578.63***	214.63	809.11***
Observations		4894	4894	4894

Notes: *$p < 0.1$, ** $p < 0.05$, *** $p < 0.001$.

Furthermore, Table 7 reports the results of the mediation effect of innovation activity. The semiconductor industry significantly promotes per capita national income, industrial structure coordination, and economic complexity; the total effect coefficients are 0.36, 0.22, and 0.42, respectively. The direct effect coefficients of the semiconductor industry in promoting high-quality economic development are 0.12, 0.16, and 0.29, and the mediation effect are 66.67%, 27.27%, and 30.95%, also respectively.

The horizontal comparison of the mediation effect shows the largest effect for innovation activity in promoting the increase of per capita national income at 66.67%. In terms of detailed indicators, scientific research and innovation have the most obvious effect on high-quality economic development, reaching 39.97%, 106.61% and 53.50%, followed by urban management innovation, technological innovation, and government management innovation. Special attention should be paid to the fact that urban management innovation has a negative mediating effect on the coordination coefficient of industrial structure. This conclusion can explain the problem of "innovation space congestion." Industry policymakers need to avoid the repeated construction of urban innovation spaces and the short-term negative effects caused by intensified urban competition (Zhang, 2020).

Table 7. Mediating Effects of Innovation Activity

Variable		Total Effect (c)	Direct Effect (c')	Effect (a)	Effect (b)	Indirect Effect (ab)	Mediation Effect (%)
				LNGNI			
RCAEL		0.36	0.12			0.24	66.67
RCAEL	PATE			10933.38	0.00000027	0.0029	12.30
	EDUC			5.33	0.018	0.095	39.97
	GOVE			3.77	0.0051	0.019	8.01
	CITY			3.08	0.035	0.11	44.91
Variable					**COI**		
		Total Effect (c)	**Direct Effect (c')**	**Effect (a)**	**Effect (b)**	**Indirect Effect (ab)**	**Mediation Effect (%)**
RCAEL		0.22	0.16			0.06	27.27
RCAEL	PATE			10933.38	-0.00000065	-0.0071	11.84
	EDUC			5.33	0.012	0.063	106.61
	GOVE			3.77	0.0011	0.0041	6.91
	CITY			3.08	-0.0013	-0.0041	-6.67
Variable					**ECI**		
		Total Effect (c)	**Direct Effect (c')**	**Effect (a)**	**Effect (b)**	**Indirect Effect (ab)**	**Mediation Effect (%)**
RCAEL		0.42	0.29			0.13	30.95
RCAEL	PATE			10933.38	0.0000017	0.018	14.29
	EDUC			5.33	0.013	0.069	53.3
	GOVE			3.77	0.0022	0.0082	6.38
	CITY			3.08	0.0096	0.029	22.74

Source: World Bank (2021).

3.2. Robustness test

Using the robustness test method of combining subsamples and surrogate variables, we extracted the data for South Korea, Japan, the United States, and China (including Hong Kong and Macau, excluding Taiwan), which have the highest comparative advantage in the semiconductor industry, and used the volume of semiconductor exports as a substitute independent variable for comparative advantage to examine the semiconductor industry. The purpose of this exercise was to test whether the conclusions on innovation activity and economic complexity were stable (Mirakyan, 2021) as calculated with equation (11):

$$Y_{ECI} = -1.51 + 0.0000091 * ELECLO_{it} + 0.0000072 * PATE_{it} + 0.0081 * EDUC_{it} + 0.0025 * GOVE_{it} + 0.066 * CITY_{it} + 0.31 * DEVE_{it} + 0.20 * CYCL_{it} + 0.78 * RESO_{it} + \varepsilon_{it} \quad (11)$$

where Y_{ECI} is the country's economic complexity, and $ELECLO_{it}$ replaces the independent variable and represents the semiconductor export volume of economy i in period t. The definitions of the other variables remain the same as in the previous article. Table 8 reports the results of the robustness test.

Each 1% increase in the export volume of the semiconductor industry increases the economic complexity by 0.000009; each 1% increase in the number of resident patent applications increases the economic complexity by 0.000072; each 1% increase in scientific research and innovation increases the economic complexity by 0.008; each 1% increase in government management innovation increases the economic complexity by 0.0025; and each 1% increase in the city's innovation capability increases the economic complexity by 0.066.

Table 8. Robustness Test Results

Dependent variable		ECI Formula (11)		
		coefficient	Standard error	P
Independent variable SEMI	ELECLO	0.0000090***	0.00000092	0.0001
Intermediary variable INNO	PATE	0.0000072***	0.0000026	0.0060
	EDUC	0.0080***	0.00049	0.0001
	GOVE	0.0025***	0.00024	0.0001
	CITY	0.0066***	0.00045	0.0001
Control variable INNO	DEVE	0.30***	0.028	0.0001
	CYCL	0.20***	0.018	0.0001
	RESO	0.78***	0.021	0.0001
intercept			-1.51*** (-26.83)	
F			835.92***	
Observations			4744	

Notes: *$p < 0.1$, **$p < 0.05$, ***$p < 0.001$.

5. Summary and conclusion

With this paper, we present the impact of the semiconductor industry on the high-quality economic development and its internal mechanisms in 199 world economies using 1995–2019 economic data from the World Bank and Harvard Atlas databases. To do this, we calculated a comparative advantage index and an economic high-quality development index for the semiconductor industry in each country and constructed a mediation effect model for multidimensional empirical testing.

The empirical test findings show that the semiconductor industry has clearly improved the quality of economic development worldwide, and its comparative advantage has significantly increased per capita national incomes. The high-quality economic development of the semiconductor industry has had obvious industry spillover effects that have effectively improved the coordination ability of the industrial structure. Not only can the domestic semiconductor industrial production meet strong domestic demand, but it can also meet the broader technology needs of electronics and equipment industries in international markets, ultimately achieving national economic development.

The semiconductor industry's spatial spillover effect and technology knowledge spillover effects have been confirmed. The group inspection of the degree of development, business cycle, and resource type show that the semiconductor industry can help form regional coordination. Innovation capability in the government, industry, schools, and among the public is the mechanism whereby the semiconductor industry enables high-quality economic development. The results suggest that the semiconductor innovation model of government–industry–university collaboration is of great significance for achieving high-quality economic development. The semiconductor industry increases investment in patents and scientific research and innovation, and the proportion of scientific and technological funding to local fiscal expenditures. Investment guarantees the output capacity of innovative resources, improves and develop the technology trading system and market, increases the technology diffusion capacity, and builds environmental support for independent innovation, starting from the two aspects of government management innovation and urban management innovation.

In addition to providing a body of empirical evidence for the semiconductor industry's promotion of high-quality economic development, the conclusions have several policy implications. First, the semiconductor industry can become a new driving force to promote high-quality economic development, increasing investment in patent innovation and scientific research innovation, and expanding the proportion of national financial expenditure allocated to science and technology. At the same time, decision makers can ensure the output capacity of innovation resources, improve and develop technology trading systems and markets, increase the economy's technology diffusion capacity, and build an environmental support for independent innovation. This starts from two aspects: government management innovation and urban management innovation, including the proportion of scientific and technological loans from financial institutions, the legal efficiency of the government, and the urban green economy.

Second, the semiconductor industry can promote an "official industry university research" cooperation strategy by establishing an innovation pooling fund and setting up the semiconductor official industry university research special plan. This plan would give priority to supporting enterprises, universities and research institutes that jointly undertake semiconductor technology research tasks. The strategy could also adopt the approach of "horizontal projects", matching "vertical funds" at a fixed proportion to provide strong environmental support for enterprises' technological innovation ability, management innovation ability and product research and development ability.

Third, as innovation activity is an intermediary factor for the semiconductor industry to promote high-quality economic development, it is extremely important for the world economy to rationally undertake the expansion of the international semiconductor industry by cultivating innovation markets. This would include undertaking the transfer of the world semiconductor industry to developing economies. While improving semiconductor technology, efforts should be made to improve the business environment and policy environment and attract foreign direct investment in the semiconductor sector.

We recommend that the existing government–industry–university collaborations continue and that semiconductor industry innovation coordination funds be established that support enterprises and research institutes that jointly undertake semiconductor technology research. This coordinated collaboration will provide strong environmental support for enterprises' technological innovation, management innovation, and product development capabilities.

References

Allen, F, Qian, J and Qian M. (2005), "Law, Finance, and Economic Growth in China", *Journal of Financial Economics*, 1, 57-116.

Arndt, S.W. (1990)," Industrial Structure, Competitiveness, and Trade", *North American Review of Economics and Finance*, 2, 217-224.

Broekel, T., Rogge,N. and Brenner,T. (2018), "The Innovation Efficiency of German Regions – A Shared-Input DEA Approach", *Review of Regional Research*, 4, 77-109.

Cao, Zheng-Yong. (2018), "Research on the New Manufacturing Model to Promote High-Quality Development of China's Industry under the Background of Digital Economy", *Theoretical Investigation*, 2, 99-104.

Caporale, G.M., Sova, A. and Sova R. (2015), "Trade Flows and Trade Specialisation: The case of China", *China Economic Review*, 3, 261-273.

Carbonell, J.B. and Werner, R.A. (2017), "Does Foreign Direct Investment Generate Economic Growth? A New Empirical Approach Applied to Spain", *Economic Geography*, 4, 425-456.

Erkan, B. and Yildirimci, E. (2015), "Economic Complexity and Export Competitiveness: The Case of Turkey", *Procedia-Social and Behavioral Sciences*, 3, 524-533.

Fan, Xu and Liu, Wei. (2020), "The choice of semiconductor innovation policy tools under Sino-US trade conflict", *Studies in Science of Science*, 7, 1176-1184.

Fang, Rong-Gui and Wang, Min. (2010), "Study on Supply of Generic Technology in Semiconductor Industry: Based on Case Comparison of Typical Generic Technology R&D Alliances in Japan, U.S. and Europe", *Journal of Technology Economics*, 11, 47-54.

Ferrarlni, B. and Scaramozzino, P. (2015), "The Product Space Revisited: China's Trade Profile", *The World Economy*, 9, 1368-1386.

Forsman,H. (2011), "Innovation Capacity and Innovation Development in Small Enterprises. A Comparison between the Manufacturing and Service Sectors", *Research Policy*, 5, 739-750.

Frederiksen, T. (2019), "Political Settlements, The Mining Industry and Corporate Social Responsibility in Developing Countries", *The Extractive Industries and Society*, 1, 162-170.

Hasgall, A. and Ahituv, N. (2018), "Implementing Continuous Adaptation to Technology Innovation in Complex Adaptive Organizations", *The Journal of High Technology Management Research*, 1, 35-45.

Huang, Xin-Nian. (2006), "The Poverty Growth of Chinese Textile and Garment Export Enterprises Stems from the Excessive Reliance on the Comparative Advantage Strategy", *Journal of International Trade*, 3, 40-45.

Kim, Sung-Hyun, Jang, Si-Young and Yang, Kyung-Hoon (2017), "Analysis of the Determinants of Software-as-a-Service Adoption in Small Businesses: Risks, Benefits, and Organizational and Environmental Factors", *Journal of Small Business Management*, 2, 303-325.

Kirby, W.C., Chen, M.C and Wong, K. (2015), "Taiwan Semiconductor Manufacturing Company Limited: A Global Company's China Strategy", *Harvard Business School Case*, 1, 308-357.

Kumar, S. and Yalew, A.W. (2012), "Economic Impacts of Climate Change on Secondary Activities: A Literature Review", *Low Carbon Economy*, 2, 39-48.

Lacasa, I.D., et al. (2019), "Paths of Technology Upgrading in the BRICS Economies", *Research Policy*, 1, 262-280.

Lee, E.K, Lee, B.T. and Chae, M.S. (2011), "Herding Behavior In Online P2P Lending: An Empirical Investigation", *PACIS 2011 Proceedings*, 105.

Lee, Y.H. (2001), "Supply Chain Model for the Semiconductor Industry of Global Market", *Journal of Systems Integration*,10, 189–206.

Lin, Bo-Qiang and Sun, Chuan-Wang. (2011), "How Can China Achieve Its Carbon Emission Reduction Target while Sustaining Economic Growth?", *Social Sciences in China*, 1, 64-76+221.

Lin, Zhou-Yu., Lin, Han-Chuang and Deng, Xin-Hua. (2014), "What Determines the Right to

Speak in the Formulation of National Standards: Technological Innovation or Political Relations”, *The Journal of World Economy*, 12, 140-161.

Miao, Wen-Long., He, De-Xu and Zhou, Chao. (2019), “The Difference in Enterprise Innovation Behavior and the Effect of Government Technological Innovation Expenditure”, *Economic Research Journal*, 1, 85-100.

Mirakyan, D.G. (2021),”Digitalization Processes Development in ASEAN Regional Integration Association”, *International Trade and Trade Policy*, 7, 101-112.

Blanchard, O and Giavazzi, F. (2003), “Macroeconomic Effects of Regulation and in Goods and Labor Markets”, *Quarterly Journal of Economics*, 8, 879-907.

Pfluger, M and Tabuchi, T. (2019),” Comparative Advantage, Agglomeration Economies and Trade Costs”, *Journal of Urban Economics*, 1, 1-13.

Rana, M.M.P. (2011),” Urbanization and Sustainability: Challenges and Strategies for Sustainable Urban Development in Bangladesh”, *Environment, Development and Sustainability*, 13, 237-256.

Renko, H.Y., Autio, E and Sapienza, H.J. (2001),” Social Capital, Knowledge Acquisition, and Knowledge Exploitation in Young Technology-Based Firms”, *Strategic Management Journal*, 6, 587-613.

Hausmann, R and Klinger, B. (2006), “Structural Transformation and Patterns of Comparative Advantage in the Product Space”, *CID Working Paper*, 8, 1-39.

Sen, Shu-Bin. (2018), “International Comparative Study on the Relationship Between China's Higher Education Growth and Economic Growth”, *Journal of Liaoning University (Natural Science)*, 4, 350-357.

Siaw, A., et al.(2018),” Agricultural Exports and Economic Growth: A Disaggregated Analysis for Ghana”, *Theoretical Economics Letters*, 8, 2251-2270.

Tang, Wei-Bin., Fu, Yuan-Hai and Wang, Zhan-Xiang. (2014), “Technological Innovation, Technology Introduction and the Transformation of Economic Growth Mode”, *Economic Research Journal*, 7, 31-43.

Valencia, V. S. , et al. (2012), “Corporate Governance and Innovation”, *Journal of Financial and Quantitative Analysis*, 2, 397-413.

Valeriani, E. and Peluso, S. (2011), “The Impact Of Institutional Quality On Economic Growth And Development: An Empirical Study”, *Journal of Knowledge Management, Economics and Information Technology*, 6, 1-25.

Wan, Jian-Xiang and Wang, Shou-Yang. (2016), “Interprovincial Economic Integration, Technical Complexity of Provincial Product Export and Regional Coordinated Development”, *The Journal of Quantitative & Technical Economics*, 12, 76-89.

Watanabe, C., et al. (2018), “Measuring GDP in the Digital Economy: Increasing Dependence on Uncaptured GDP”, *Technological Forecasting and Social Change*, 7, 226-240.

Wen, H.C., Huang, J.H and Cheng, Y.L. (2012), “What Japanese Semiconductor Enterprises Can Learn from the Asset-Light Business Model for Sustainable Competitive Advantage”, *Asian Business Management*, 11, 615–649.

Wu, Cu-Hao and Wang, Su-Li. (2019), “Provincial-level Economic Integration, Technical Complexity of Provincial-level Product Export and Regional Coordinated Development”, *Quantitative Economics and Technical Economic Research*, 11, 121-139.

Yang, Q.P and Zhao, J.K. (2020), “Study on China’s Economic Development From The Perspective of Strong Sustainability”, The Singapore Economic Review, 1, 161-192.

Zhang, Zhen-Hua. (2020), “Research on Government Subsidy Effect and Research Efficiency of Semiconductor Display Industry in China”, *Journal of Industrial Technological Economics*, 2, 151-160.

Zuo, Peng-Fei., Jiang, Qi-Ping and Chen, Jin. (2021), “Digital Economy with Economic Growth from the Perspective of High-Quality Development”, *Research on Financial and Economic Issues*, 6, 1-10.