Analysis of the scientific and technological innovation efficiency and regional differences of the land–sea coordination in China's coastal areas

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ABSTRACT

The overall strategy for land-sea coordination is important for scientific and technological innovation efficiency in China's coastal areas. In this paper, the country's mixed land and sea regions were selected for study, including two land and ocean subsystems with input and output index systems. Based on the variation coefficient method, the global Malmquist–Luenberger (GML) index was used to calculate the scientific and technological development efficiency of coordinated plans for China's coastal land and sea areas from 2006 to 2015 and to analyze the regional differences among these plans. The conclusions are as follows. First, the total factor productivity growth rate of science and technology innovation efficiency in China's coastal areas is primarily larger than 1 and at the frontier of efficiency. The efficiency of mixed areas is higher than that of separated land and sea areas, and the differences in regional technological innovation efficiencies have gradually narrowed. The change in technical efficiency is consistent with changes in the GML index, and the financial crisis of 2008–2009 had a significant positive impact on pure technical efficiency. Second, the coordinated plans for land and sea areas are realized and spatial differences in scientific and technological innovation efficiency in China's coastal areas are classified according to scientific and technological innovation in China's coastal areas. Hebei and Liaoning are classified according to the land efficiency type; Jiangsu and Zhejiang are classified as the marine efficiency-driven type; and the Shandong, Tianjin, Shanghai, and Pan-Pearl River Delta regions are classified as the efficiency of mixed land and sea areas type. Drivers of regional differences mainly include economic development levels, differences in industry structure, the personnel structure of scientific and technological systems, and the state of production and the influence of the government.

1. Introduction

The ocean will be an important driver of economic growth in China in the 21st century and is expected to become a main source of competition in the region (A Road map to 2050, 2010) that will be influenced by scientific and technological innovation and the strength of international marine initiatives. The “One Belt One Road Initiative” requires scientific and technological innovation. Thus, China's marine strategy and initiatives for future development should focus on scientific and technological innovation as basic strategies, strengthening original technological research with respect to ocean development with innovative technology.

Many national and international studies have considered technological innovation efficiency; however, few studies have focused on scientific and technological innovation efficiency in marine areas; of those studies that have, this topic has been mainly investigated with a focus on the following aspects: (1) Marine scientific and technological innovation strategies—several scholars have analyzed China’s marine technology strategy, present situation, and trends in and incubation mechanisms of new high-technology industries (Qi, 2003; Yang, 1999; Ye, 1999); (2) Marine scientific and technological innovation industries—several scholars have suggested that marine scientific and technological innovation should rely on the competitive advantages of coastal cities and that a cluster for the marine scientific and technological industry should be developed to realize coordinated development and chain reactions (Yu and Chen, 2000; Han and We, 2004; Zhang and Nong, 2010); (3) The ability and performance of marine scientific and technological innovation—some scholars have performed a horizontal or vertical comparison of the regional differences of scientific and technological innovation efficiency in coastal provinces (Liu et al.,...
2. Materials and methods

2.1. The theoretical premise

The regional mixed technological system of land and sea is complex, with an endless exchange of material energy between the scientific and technological subsystems on land and marine scientific and technological subsystems when developing coordinated plans. The regional mixed technological system of land and sea is a scientific and technological regional system in which the technologies and factors of production are promoted to flow and effectively allocate resources in certain regions by two subsystems. The production and exchange of the two types of subsystems are possible owing to the differences among the scientific and technological subsystems on land and sea with respect to natural resources, development stage, economic basis, and management experience. Logically, the regional mixed technological system of land and sea is a function of the scientific and technological subsystem of the land and marine scientific and technological subsystem:

\[ S = (L, M, \alpha), \]

where \( S \) is the regional mixed technological system on land and sea; \( L \) represents the scientific and technological subsystem on land, \( M \) is the marine scientific and technological subsystem, and \( \alpha \) represents the collection of selected relationships between the two subsystems.

2.2. Evaluation method

2.2.1. The coefficient of variation method

The coefficient of variation method directly uses the information contained in its indicators; it is an objective method of empowerment, calculating the weight of the index. Owing to the different dimensions of indicators in the evaluation index system, the extent of the difference should not be directly compared. To eliminate the influence of the different dimensions of the indexes, the degree of differences of each index should be measured using the coefficient of variation of the indicators (Shechtman, 2013). The variation coefficient equation of indicators is:

\[ V_i = \frac{\bar{x}_i}{x_i} \quad (i = 1, 2, \ldots, n), \]

where \( V_i \) is the coefficient of variation of the \( i \)-th index, also known as the standard deviation coefficient; \( \bar{x}_i \) is the standard deviation of the \( i \)-th indicator; and \( x_i \) is the average of the \( i \)-th indicator. The weight of each index can be calculated by:

\[ W_i = \frac{V_i}{\sum_{i=1}^{n} V_i} \]

2.2.2. Global Malmquist-Luenberger index

The growth rate of the total factor production reflects the dynamic level of the economic growth efficiency change with respect to the input–output analysis and shows that the same level of input in the same period, obtaining more than the previous total output to reflect the total factor production dynamic incremental level (Farrell, 1957). This paper adopts a non-radial and non-angle efficiency evaluation model, which can effectively avoid problems; for example, the radial DEA will overvalue the efficiency and lead to inaccurate results because the input or output is ignored. Furthermore, traditional problems, such as any solutions in ML linear programming, will not occur when using the GML index (Tone, 2004; Fukuyama and Weber, 2009). This paper provides a more accurate measurement of the effect of each factor by extracting the changes in the efficiency factor from the total factor productivity growth rate and clearing the source of the total factor productivity growth and characteristics of regional differences.

To evaluate the relationship between the total factor productivity and technical efficiency change, we consider that the total factor
production growth index is based on the output-oriented Malmquist–Luenberger (ML) index according to Chung et al. (1997) methods:

\[
ML_{it}^{+1} = \left( \frac{M{I}_I^{+1}}{M{I}^{+1}_{i0}} \right)^{\frac{1}{2}}
\]

\[
= \left( \frac{1 + \frac{1}{2} \frac{D_{vG}(x', y', b', y', \omega')}{1 + \frac{1}{2} \frac{D_{v}(x', y', b', y', \omega')}{}\times\frac{D_{G}(x', y', b', y', \omega')}{}\times\frac{D_{I}(x', y', b', y', \omega')}}{}}{1 + \frac{1}{2} \frac{D_{vG}(x', y', b', y', \omega')}{1 + \frac{1}{2} \frac{D_{v}(x', y', b', y', \omega')}{}\times\frac{D_{G}(x', y', b', y', \omega')}{}\times\frac{D_{I}(x', y', b', y', \omega')}}{}}\right)^{\frac{1}{2}}
\]

\[
= M_{L} E F C_{i0}^{+1} \times M L T E C_{i}^{+1}
\] (4)

The ML productivity is decomposed into: the technical progress index (MLTEC_{i}^{+1}) and efficiency change index (MLEFFC_{i}^{+1}); ML, MLTEC, and MLEFFC values larger than 1 (less than 1) represent total factor growth (decline), technological progress (regression), and efficiency improvement (deterioration).

Oh (2010) built the Global-Malmquist-Luenberger (GML) index to avoid the “technical retrogression” phenomenon; the specific equation is:

\[
G M L = \frac{1 + \frac{1}{2} \frac{D_{vG}(x', y', b', y', \omega')}{1 + \frac{1}{2} \frac{D_{v}(x', y', b', y', \omega')}{}\times\frac{D_{G}(x', y', b', y', \omega')}{}\times\frac{D_{I}(x', y', b', y', \omega')}}{}}{1 + \frac{1}{2} \frac{D_{vG}(x', y', b', y', \omega')}{1 + \frac{1}{2} \frac{D_{v}(x', y', b', y', \omega')}{}\times\frac{D_{G}(x', y', b', y', \omega')}{}\times\frac{D_{I}(x', y', b', y', \omega')}}{}}
\]

\[
= G P C_{i}^{+1} \times S E C_{i}^{+1} \times T C_{i}^{+1}
\] (5)

The GML index was decomposed under the conditions of the hydrolysis based on constant returns to scale (CRS): pure technical efficiency change (PEC), scale efficiency change (SEC), and technological change (TC), which respectively embody the technological progress of the region with respect to scale, economy of scale, and technology preference change (Greene, 1981).

2.3. Variable selection and processes

The innovation process involves creating new knowledge with different resources, such as scientific and technological personnel, equipment, and capital. From the classic production function, it is known that the input and output indexes can be considered based on two aspects: manpower and capital (Xu et al., 2009; Furman and Hayes, 2004). Given the diversity of the input and output of scientific and technological innovation and the availability of data, and in order to make the land as comparable as possible to land and sea, we extended past results (Xu, 2013; Wang, 2015; Guan and Gao, 2009) and increased the physical input, including the number of number of scientific research institutions and research projects. The number of scientific theses published and the number of patent applications accepted are used as output indexes. Scientific theses refer to papers published in national professional academic journals and key university journals, as well as papers published abroad. The number of patent applications accepted refers to the number of job patent applications submitted by the unit in the current year that were accepted. The evaluation index system for the science and technology innovation efficiency in China’s coastal areas under land–sea coordination is shown in Table 1.

It should be noted that because the impact of research and development activities on knowledge is not limited to a short period, the stock of capital investments should be converted into corresponding values (Griliches and Lichtenberg, 1998). In this paper, such funding is calculated using the perpetual inventory method by:

\[
RD_{i} = \left(1 - \delta\right) \times RD_{i-1} + I_{i},
\] (6)

where \(RD_{i}\) and \(RD_{i-1}\) are the i-th region in year \(t \) and in \((t-1)\) years of the research and development (R&D) capital stock, respectively; \(I_{i}\) is the i-th region of the actual research funding; and \(\delta\) represents the depreciation rate of R & D capital. Based on Wu (2006) and the depreciation rate of \(\delta = 10\%\) in this paper, the base period (i.e., 2006) \(RD_{0}\) capital stock equation is:

\[
RD_{0} = \frac{I_{0}}{g + \delta},
\] (7)

where \(I_{0}\) is the i-th region in the base period of the actual research funding, and \(g\) is the actual research funding investment of the average annual growth rate.

2.4. Data sources

The marine economic zone in mainland China is mainly composed of the Bohai Sea, Yangtze River Delta, Pearl River Delta, and Beibu Gulf economic zones. According to the China Marine Statistical Yearbook, this paper selected 11 provinces and cities along the coast of Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi, and Hainan (with the exception of Hong Kong, Macao, and Taiwan) as the research targets. The data used are mainly from the China Marine Statistical Yearbook (2007–2016), China Statistical Yearbook on Science and Technology (2007–2016), China Statistical Yearbook (2007–2016), and the statistical yearbooks of coastal provinces and cities. Owing to the limitations of marine economic statistics, the industries supported by marine science and technology mainly include marine industries as defined in the China Marine Statistical Yearbook, including marine fisheries and other marine industries such as mining, oil and gas, salt, chemical, biological medicine, power, sea water use, shipbuilding, engineering construction, transportation, and coastal tourism.

3. Results

3.1. Efficiency evaluation of coastal scientific and technological innovations and development

3.1.1. General characteristics

The GML index was used to measure the total factor productivity growth index of 11 coastal provinces and cities and the scientific and technological innovation when making coordinated plans for land and sea areas in China’s coastal areas from 2006 to 2015. The comparison of the results is shown in Table 2.

Table 2 shows the scientific and technological innovation efficiency of China’s coastal areas from 2006 to 2015: First, the total productivity growth index of scientific and technological innovation efficiency for the vast majority of the coastal areas was generally larger than 1 and at the frontier of efficiency; second, based on the average efficiency in coastal areas, the GML efficiency values of mixed land and sea regions (1.0771) were higher than that on land (1.0585) and sea (1.0483). The comprehensive consideration of the scientific and technological innovation on land and sea is more efficient. Resources, capital, and technology are needed for the development of science and technology innovation, which will constrain innovation efficiency maximization; third, based on the standard deviation of efficiency (Fig. 1), the standard deviation of mixed land and sea regions was lower than that of land areas and that of the ocean; meanwhile, the standard deviation from 2006 to 2015 showed a gradually decreasing trend. The differences among the regional technological innovation efficiency values gradually narrowed, which indicates that coordinated plans for land and sea regions help enhance the regional scientific and
technological innovation efficiency, and that regional communication helps improve the efficiency of the overall science and technology innovation, narrowing the gap between regions; fourth, the regions with a developed marine economy do not show high scientific and technological resources, and mixed land and sea areas were stable. First, based on the GML index, the efficiency in mixed regions was always higher than that in land and sea areas, which further illustrates that coordinated plans for land and sea areas with scientific and technological resources are more efficient. Second, the technical efficiency change was similar to the GML index change, which first showed a sine or cosine function and then generally stabilized. In conclusion, the improvement of the scientific GML index mainly depends on the technological progress (hereinafter confirmed). A similar conclusion was drawn when Yue and Liu (2006) and Jin (2007) studied regional productivity with total factors. Third, the financial crisis from 2008 to 2009 had a negative impact on the GML index and technological change efficiency, and both reached a low point. The crisis did not affect the scale efficiency, which was steady. However, the technical efficiency reached a peak; the pure technical efficiency reflects an output ability given the input resources. In such a case, both the enterprises and research institutions will become more efficient, and resources will be used more reasonably; the staff would work hard in fear of unemployment caused by the crisis, causing an output efficiency increase during the crisis period (Tang, 2013; Wei et al., 2015).

### 3.1.2. Time differentiation characteristics

Fig. 1 shows the science and technology innovation efficiency and time decomposition trend from 2006 to 2015 under land–sea coordination in China’s coastal provinces and cities. In general, apart from individual years, the changes in the science and technology innovation efficiency in coastal areas and decomposition of the land, sea, and mixed land and sea regions were stable. First, based on the GML index, the efficiency in mixed regions was always higher than that in land and sea areas, which further illustrates that coordinated plans for land and sea areas with scientific and technological resources are more efficient. Second, the technical efficiency change was similar to the GML index change, which first showed a sine or cosine function and then generally stabilized. In conclusion, the improvement of the scientific GML index mainly depends on the technological progress (hereinafter confirmed). A similar conclusion was drawn when Yue and Liu (2006) and Jin (2007) studied regional productivity with total factors. Third, the financial crisis from 2008 to 2009 had a negative impact on the GML index and technological change efficiency, and both reached a low point. The crisis did not affect the scale efficiency, which was steady. However, the technical efficiency reached a peak; the pure technical efficiency reflects an output ability given the input resources. In such a case, both the enterprises and research institutions will become more efficient, and resources will be used more reasonably; the staff would work hard in fear of unemployment caused by the crisis, causing an output efficiency increase during the crisis period (Tang, 2013; Wei et al., 2015).

### 3.1.3. Global–Malmquist–Luenberger index decomposition

The evaluation results for the science and technology innovation efficiency in mixed land and sea regions in coastal areas from 2006 to 2015 show (limited by space, please request additional results) that the average GML index grew by 7.71% compared with the previous year. The average annual growth of the technological change was 6.18%; the main source of GML exponential growth and annual pure technical efficiency change and scale efficiency were 3% and 3.50%, respectively, secondary to the power of growth.

Fig. 3 shows the science and technology innovation efficiency and decomposition in mixed land and sea regions in coastal areas. Fig. 3 is divided into four parts based on the GML change index and mean decomposition efficiency. Based on the coastal province distribution, the coordinate plane mainly includes the following: First, the dynamic science and technology efficiency in coastal areas is affected by the technical change efficiency. Fig. 2a shows that most of the provinces and cities are evenly distributed in four quadrants the efficiency is at the leading edge. The science and technology efficiency in traditional highly developed economic regions might not have high GML and
technical efficiency values. Taking Guangdong in the first quadrant I as an example, the GML index and technical efficiency values were lower than the geometric mean values and lagged behind most of the regions, while the science and technology efficiency might be relatively higher in poorer areas. In traditional highly developed economic regions, the funds, personnel, and technology investments needed for science and technology innovation tend to be saturated; the output returns are diminishing. In relatively undeveloped areas, science and technology innovation is in the stage of scale-increasing returns. The GML index would grow with technological progress, such as in Hebei. Second, regions with low-scale efficiency do not necessarily have lower GML values. Fig. 2b reveals that most regions are in quadrants I and II, the scale efficiency of which was lower than average values. Several of the GML values were lower than average but at frontier of efficiency. Areas with a lower scale efficiency than average, such as Hebei, Zhejiang, and Tianjin, have high GML values, which indicates that the scale efficiency is not the main factor of technological innovation efficiency growth in most regions. The expansion of pure science and technology might not introduce much output efficiency with respect to science and technology innovation; the reasonable scale level is the right choice. Third, the pure technical efficiency change is synchronized with GML value changes, except for individual regions. Fig. 2c shows that other regions are located in quadrants I and III, apart from Fujian, with high pure technical efficiencies and high GML values. However, regions with pure technical efficiencies lower than the geometry average have low GML values. Fujian, with high pure technical efficiency values, is expected to enter quadrant III with its emphasis on marine science and technology innovation and expected supplementation of resources for science and technology. Fourth, the science and technology innovation efficiency in coastal areas is greatly influenced by the pure technical efficiency; an
influence by the scale efficiency is not notable. Fig. 2d shows that other areas are in quadrants I and IV, except for Liaoning and Hainan, with low scale efficiency values; the technical efficiency varies among areas. This shows that the science and technology innovation efficiency in coastal areas is greatly influenced by the pure technical efficiency and rarely influenced by the scale efficiency. Strengthening regional cooperation and reducing technical barriers could reduce the technical differences between regions and enhance the overall level of science and technology innovation efficiency.

In conclusion, the GML index of the science and technology innovation efficiency in coastal areas is affected by the technological change; scale efficiency change is not the main cause of regional differences, and pure technical efficiency change follows the regional GML index change and has notable effects on regional differences.

3.2. Regional differences in scientific and technological innovation efficiency

3.2.1. Analyzing regional differences among scientific and technological innovation levels

Based on the science and technology innovation efficiency from 2006 to 2015, the total factor production growth efficiency of land, sea, and mixed land and sea regions in coastal provinces and cities was classified into three categories: efficiency drive on land (EDL), efficiency drive of marine areas (EDM), and efficiency drive of mixed land and sea regions (EDL and EDM). Efficiency drive on land refers to the comprehensive GML value on land, which is larger than that of mixed land and sea areas, or the comprehensive GML value on land that is larger than that of the sea. This indicates that the development of science and technology innovation efficiency on land is higher than that of the sea and mixed land and sea regions. The efficiency drive of marine areas refers to the comprehensive GML value of the ocean that is larger than that of mixed land and sea regions or the comprehensive GML value of the ocean that is larger than that of land. The development of science and technology innovation efficiency in the ocean is larger than that on land and in mixed land and sea regions. The efficiency of mixed areas refers to the comprehensive GML value of mixed land and sea regions, which is larger than that of land, or the comprehensive GML value of mixed land and sea regions that is larger than that of the ocean. This means that the development of science and technology innovation efficiency of mixed land and sea regions is larger than that on land or sea. The specific classification is shown in Fig. 4.

Table 3 shows significant differences among the science and technology innovation efficiencies in China's coastal areas in 2006. Provinces with relatively strong land economies with marine science and technology efficiency advantages reflect the implementation of development strategy adjustments in the various provinces and cities based on “coordinated plans for land and sea” in the process of “focusing on land and ignoring ocean” to “mutual importance of land and sea.” Seven provinces and cities realized coordinated plans for land and sea in 2015, both in traditional economically developed areas and regions with relatively undeveloped economies. The classification based on the detailed analysis of science and technology innovation and development efficiency in coastal provinces and cities in 2015 is as follows:

(1) Efficiency of land

The science and technology innovation efficiency in Hebei and Liaoning transformed from marine efficiency drive in 2006 to efficiency drive on land in 2015, reflecting the change in science and technology innovation of the two provinces in recent years. The land technological innovation efficiency of the two provinces is superior to the marine science and technology innovation efficiency. The main features are: 1) With respect to government investment in science and technology, the land investment in science and technology in the coastal area is far higher than that of marine science and technology. The research funds and personnel engaged in scientific activities on land in Liaoning accounted for 12.61% and 12.01% of activities in the coastal areas, respectively. These rankings were far higher than those of marine scientific and technological investment in the coastal areas; 2) with respect to the science and technology output levels, the output efficiency on land was higher than the sea output efficiency, although published scientific papers and patent authorizations were not dominant in the two provinces. The sea patent authorizations in Liaoning accounted for 19.84% of patents in the coastal areas, which is expected to shift the efficiency of mixed land and sea regions; 3) with respect to the comprehensive strength of science and technology, the science and technology innovation efficiency levels in the two provinces are relatively low. Although Liaoning is the only province on the coast of the old northeastern industrial base, traditional industries were given priority with respect to economic development. Both the science and technology achievements and innovation efficiency conversion of the land economy and marine economy are low. Hebei is limited by its geographical location and resources for science and technology, and thus science and technology innovation does not show high efficiency levels.

Fig. 4. Classification of the science and technology innovation efficiency of China's coastal provincial and cities from 2006 to 2015.
In the future, the land and marine science and technology resources of the two provinces will be coordinated, and increases in the investments in science and technology innovation increase will strengthen regional cooperation to enhance the technology innovation.

(2) Marine efficiency

The marine science and technology innovation efficiency in Jiangsu and Zhejiang is marine-driven and superior to land science and technology innovation efficiency and economic investments because such provinces tend to be saturated. The investments in science and technology are higher in these areas. The promotion of the marine economy is one way to understand the sea as a whole; the main features are: 1) Government investment in science and technology: Marine scientific and technological investments in the two provinces are smaller than land science and technology investments; however, the growth rate of marine scientific and technological investments is higher than that of land science and technology investments. The number of marine science and technology projects in the two provinces increased notably in recent years. Among them, Jiangsu accounts for up to 20.89% of the coastal areas; the marine science and technology input levels significantly improved; 2) Science and technology output: The marine science and technology output is lower than that of land; however, the marine science and technology output efficiency in the two provinces is higher than that of land. The ocean production efficiency steadily improves; the gap between land and sea is narrowing; 3) Comprehensive science and technology strength: Jiangsu has a high comprehensive science and technology strength in the coastal areas; both the science and technology input and output are among the top three, in addition to the high number of scientific research institutions. The comprehensive science and technology strength of Zhejiang is relatively small, mainly owing to the small number of research institutions and scientific papers; the patents account for 18.03% of the coastal areas. The high conversion rate of science and technology achievements greatly promotes the development of science and technology innovation in the industry.

(3) Efficiency of mixed land and sea areas

The land and marine science and technology innovation efficiency developed in a more balanced way in the Pan-Pearl River Delta region; Guangdong, Fujian, Guangxi, Hainan, Shandong, Shanghai, and Tianjin are characterized by the efficiency of mixed land and sea areas. The efficiency of mixed land and sea area includes both traditional economically developed areas and areas with relatively undeveloped economies, indicating that the strength of the economy is not the only determinant of the science and technology innovation efficiency. The economy in Shanghai and Guangdong is relatively developed, and the land and marine science and technology innovation efficiency is relatively balanced. The main features are: 1) Government investment in science and technology: The science and technology innovation investments in the two areas, both in scale and effectiveness, are leading in the coastal region. The policies, science and technology innovation funding, environment, and other factors are ahead of other regions, which greatly promotes the development of science and technology innovation in industry; 2) Science and technology output: The output of science and technology innovation efficiency in mixed land and sea areas is higher than the efficiency of land and sea. The science and technology papers published in Shanghai account for 13.41% of the coastal region; the number of patent authorizations in Guangdong accounts for 19.76% of the coastal areas. The effective integration of science and technology resources promotes the growth of the output efficiency of science and technology; 3) Comprehensive strength of science and technology: The two areas attract a large number of elements needed for science and technology innovation owing to the good innovation environment and regional conditions; terrestrial and marine scientific and technological innovation activity is robust. The new highly developed high-technology industries greatly promote science and technology innovation and the development of science and technology industries, ranking high with respect to the comprehensive strength of science and technology in coastal areas.

The science and technology innovation and development in Shandong, Tianjin, and Fujian are relatively coordinated, and are grouped according to the efficiency of complex areas on land or sea. The main features are: 1) Government investment in science and technology: The number of scientific research and technology personnel is higher in Tianjin and Shandong; their marine science and technology investment accounts for more than 30% of the coastal areas. Shandong hosts nearly 50% of the nation's marine talent, effectively guaranteeing the human capital required for science and technology innovation; 2) Science and technology output: The number of scientific papers ranks high; the output efficiency of sea and land is relatively balanced, and the science and technology achievement conversion rate is high; 3) Comprehensive strength of science and technology: The strength is on par with that of middle coastal areas. With the continuous development of marine resources, terrestrial and marine communities communicate more frequently. The information and technology resources are fully utilized, and the marine science and technology efficiency improved significantly. The science and technology level of the land and sea areas was gradually coordinated.

Because of the small economy, the development of Guangxi and Hainan is relatively rudimentary; however, the land and marine science and technology innovation efficiency has always been coordinated, and is grouped according to the efficiency of mixed land and sea areas. The main features are: 1) Government investment in science and technology: Limited by science and technology resources (such as scientific research institutes and scientific research in colleges and universities), science and technology investments are relatively low; all indexes rank low among the coastal areas. However, the proportion of science and technology investments in the two areas is strongly growing, which is expected to improve this ranking; 2) Science and technology output: The output efficiency of science and technology innovations is high, and the science and technology development is increasing; low input could lead to higher output; 3) Comprehensive science and technology strength: The comprehensive science and technology strength is relatively rudimentary; both land and sea science and technology are limited by resources, and development is relatively slow. However, the development of science and technology innovation would introduce new opportunities based on economic advantages and the release of government’s policy dividend.

3.2.2. Reasons for differences among science and technology innovation levels

Based on the analysis, there are notable differences in the science and technology innovation efficiency owing to land–sea coordination in
China's coastal areas. The main reasons are:

(1) Level of economic development: The level of economic development is often accompanied by the accumulation of production factors. The relatively small development of the marine economy limits the accumulation of marine science and technology innovation funds and investments but also restricts the construction of marine science and technology innovation systems and steady progress in marine research (NDRC, 2015). The marine economy lags behind; the lack of marine industry leads to insufficient industry development and support of marine science and technology innovation, and thus gaps between sea and land science and technology and the regional development of science and technology.

(2) Differences in industrial structure: The industrial structure has an important influence on the development of science and technology innovation (Zweimüller and Brunner, 2005; Ge et al., 2013). For the second industry, mainly the manufacturing industry, the cycle of industrial upgrading is generally longer; the improvement of technical levels requires long-term accumulation. The science and technology innovation of the third industry, mainly the service industry, was relatively active with higher innovative rates. Land and marine economies should mainly rely on the second and third industries, narrowing the differences in sea and land economic industrial structure and adjusting the industrial structure of the sea and land science and technology innovation efficiency.

(3) Science and technology personnel structure: Intelligence is the key to research and development in science and technology, and personnel structure optimization increases the investment in a high level of intelligence. The sharing of knowledge and strengthening of an external intelligence network improve the technical progress and technical application ability, and the efficiency of technological innovation. However, China lacks a science and technology innovation system and disciplined leaders; conversely, the distribution of regional scientific and technological personnel is very unbalanced, particularly in Guangxi and Hainan, which have relatively undeveloped economies, which is one of the reasons for the influence of science and technology innovation.

(4) Industry-university research: The enhancement of science and technology innovation efficiency is not only related to research institutions but also depends on the transformation and application of innovation achievements. That is, there is a need for close cooperation between industry, production, and research, including the construction of a relevant public platform for production and research and the establishment of a suitable “research” industrial security mechanism (Kulatunga et al., 2007; Cummings and Teng, 2003; Puilbin, 2008). The links between the internal innovation systems in China are still very weak; industry-university research cooperation is not sufficient to improve the efficiency of the innovation system. The market mechanism needs to be further developed, the system construction needs to be perfected, and the effective implementation of “industry–university–institute” cooperation needs to be promoted.

(5) Influence of the government: To enhance the science and technology innovation efficiency, market power injection is needed, which further verifies that the “wider market plays a fundamental role in the allocation of resources” assumption is correct. The government plays an important role in promoting the development of science and technology innovation (Treloar et al., 2015). We need to increase the investments in science and technology. However, the market entry needs to be correctly guided, and relevant policies and laws and the regulation system need to be improved to create a good market environment for the development of science and technology innovation.

4. Discussion and conclusions

In this paper, based on the theory of regional mixed technological systems on land and sea and an input-output perspective, the total factor productivity index (GML) was used to measure the development of the science and technology innovation efficiency and analyze the general regional differences under land–sea coordination in China's coastal areas. The following main conclusions can be drawn:

(1) In general, the efficiency of the total factor productivity growth rate of science and technology innovation in most coastal provinces and municipalities is larger than 1 and at the frontier of efficiency from 2006 to 2015. The land and ocean GML index efficiency is higher than that of the land and sea, and the efficiency of technological innovation between the regions gradually narrows. The change in the GML index efficiency of land, sea and land, and sea is consistent with respect to temporal differentiation. The efficiency of the technological change is consistent with that of the GML index, and the financial crisis of 2008–2009 had a notable positive effect on pure technical efficiency. The efficiency of technological change is the main source of GML index growth with respect to specific decomposition efficiency. The change of the scale of the efficiency is not the main reason for the regional differences, but the pure technical efficiency change notably influences the regional difference.

(2) This study shows that during the period from 2006 to 2015, the scale and quality of scientific and technological innovation in the coastal areas has been greatly improved, but regional differences are notable. The land science and technology innovation efficiency in Hebei and Liaoning is better than the marine science and technology innovation efficiency because of the influence of the industrial structure and science and technology resources. The level of efficiency and the science and technology achievement conversion rate are low. The marine science and technology innovation efficiencies in Jiangsu and Zhejiang are better than those of the land. The marine science and technology input and output efficiency is higher. The emerging strategic industry development is rapid, and the gap between land and sea is narrowing. Shandong, Shanghai, Tianjin, and the Pan-Pearl River Delta region have efficiency in the mixed land and sea areas, but regional differences in the comprehensive strength of science and technology innovation. However, the land and marine science and technology resources are mixed well, the input and output efficiency is relatively balanced, and the science and technology achievement conversion rate is higher. The causes for regional differences mainly include: the economic development levels, differences in the industry structure, science and technology personnel structure, and the state of production and influence of the government.

Based on the above-mentioned conclusions, and to further improve the level of science and technology innovation in China’s coastal areas, we provide following suggestions: 1) The cooperation between coastal regions should be strengthened, and administrative regulations should be abated; under such conditions, science and technology factors of production would freely flow, regional differences would dwindle, and the overall level of the GML index would be upgraded; 2) Technical innovation should be advocated, and foreign technology should be introduced; the effect of technical efficiency on scientific and technological innovation should be mobilized; the conversion of science and technology achievements should be stressed; and the relationship between science and technology innovation and industrialization should be coordinated by means of an industry–university–research public service platform; 3) To promote the development of the marine economy and bridge the gap between ocean and land, the marine industrial structure should be upgraded, marine technology and human capital investment should be increased, the level of marine tertiary
industries should be enhanced, and marine emerging technology should be cultivated; 4) The structure of the scientific research system should be further optimized to strengthen basic research and promote the overall development of marine science and technology innovation; 5) The government should clarify its function. The investment in technology industries should be intensified; in addition, measures such as formulating more scientific and technological innovation policies and providing improved scientific and technological financial services should be taken to guide and support innovative activities of enterprises, provide a good policy environment for enterprise innovation, and support real enterprise innovation.

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Appendix A. Supplementary data

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