Potential Impacts of Maritime Risk on Maritime Traffic Flows and Regional Economies: Case Study at the Straits of Malacca and Singapore

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Abstract: This paper analyzes the vulnerability of the Straits of Malacca and Singapore (SoMS) to maritime risks. The impacts of the risk events on international cargo flows, transshipment at major ports, and domestic economies are simulated with an international cargo traffic simulation model and a spatial general equilibrium model. Both container cargos and dry/liquid cargos are covered. Three cases are analyzed: sea-lane blockade at the SoMS, stop of the service at Singapore Port, and increase of loading/unloading time at all ports in the world. Results show that the risks which occur at the SoMS impact on the economies in the whole Asia; container carriers may change transshipment ports—from littoral ports to other East Asian ports—if the risk events were to actually occur; and the economic impacts of the risk events depend on the cases and the countries. Finally, the implication to the maritime security policy is discussed.

Keywords: Straits of Malacca and Singapore, Maritime risk, International cargo flow, Economic impact, Container cargo, Bulk cargo

1. INTRODUCTION

Currently, over one-third of the world's maritime cargo is transported to and from Asian countries. This fact reflects the rapid growth of economies in the southeast Asian (SEA) region, which include Brunei, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam, as well as the constant growth of economies in the east Asian (EA) region, including China, Japan, South Korea, and Taiwan. Many ports—such as Busan, Hong Kong, Shanghai, and Singapore—have been invested with handling the increased maritime cargo in the SEA and EA regions; they also complement each other in the international hub-and-spoke maritime cargo network. As the importance of the maritime cargo network in these regions increases, the sustainability of the maritime cargo network has also gradually come to be regarded as one of the area's most critical issues. Particularly, it is widely agreed among maritime cargo experts that the Straits of Malacca and Singapore (SoMS) is one of the most essential links in the international maritime network. The SoMS is the shortest sea lane to connect the Pacific Ocean and the Indian Ocean; it is the route where most of the vessels connecting these oceans pass. However, it is widely known that the sea lane in the SoMS is vulnerable to a variety of risk factors. If the SoMS were blocked at such points, the resulting impacts could be considerably serious.

This paper analyzes the vulnerability of the SoMS to the risk of the sea lane in this marine area. The impact of risk on cargo flows will be evaluated with respect to container cargos and bulk cargos. It also focuses on not only the direct impacts of the risks on the regional maritime cargo flows but also the impacts on regional economies. These impacts will be examined in light of the following three pieces of data: the volume of transshipment container cargo at the ports, the transportation costs associated with container cargo from one port to another, and the domestic economies in the countries in the SEA and EA regions.

The impacts and/or scenarios of the vulnerability to the risk in maritime transportation have been discussed by many researchers (for example, International Risk Governance Council, 2011; Raymond, 2006; Rimmer and Lee, 2007; Bergin and Bateman, 2005). One of the risk sources is piracy (Bowden and Basnet, 2011; Toriumi and Watanabe, 2012). A number of researches have analyzed quantitative impact of piracy. Bendall (2010) estimates the expected impacts of piracy on the maritime cost including transportation cost and insurance premiums under the assumption that a Very Large Crude Carrier and a container vessel are forced to reroute as a results of piracy. Fu et al (2010) formulate a simple economic model where container liners choose a route from two route options between Europe and Asia under the assumption of Cournot competition among multiple firms, incorporating the potential increase of transportation cost caused by piracy. Another major risk sources may be natural disasters. More studies pertaining to catastrophic risk managements have been done from the year 2000 mainly because of the widespread awareness of serious risk events including Hurricane Katrina and East Japan Great Earthquake. Some studies report the impacts of natural disasters on maritime transportation such as Wang et al. (2013). The methodologies for understanding the risk and impact of natural disasters on shipping network have been also proposed. For example, Tan and Lam (2013) proposes a Petri Net approach for modeling the maritime catastrophe. Further risks including planning horizon risks (Autry and Griffiths, 2008) and financial risks (Ducret et al, 2010) have been also discussed recently. However, to our knowledge, unfortunately the impacts of vulnerability along a maritime network on regional economies have been rarely discussed in the previous studies. Although Fu et al (2010) analyze the economic welfare loss caused by the increase of expected cost caused by piracy, they do not analyze the changes of international trading patterns among regions nor those of domestic industrial structures. Particularly if a risk event would cause long-term changes in the level of international maritime transportation service, it could lead to significant negative impacts on the economic activities in multiple industries of widespread regions in the international supply chain in addition to the shipping industry.

One of the originalities of this paper is that the maritime risk is evaluated with the integrated simulation models including the traffic flow analysis of container cargos and bulk cargos as well as the economic impact analysis. This paper extends Ogawa et al. (2010) by incorporating the impact analysis of bulk cargos and by improving the economic impact analysis. Particularly Ogawa et al. (2010) did not show the results of macro-economic impact analysis while this paper explicitly presents them. The integrated analysis could contribute to the realistic discussions on the risk prevention/mitigation policy.

The paper is organized as follows: first section provides research background information and the goals of this study. Next section outlines this study's methodology, including the international cargo flow simulation model used. Seven scenarios will be developed and three risk cases are formulated on the basis of scenarios. Then, the impacts of the risk events will be analyzed through the use of the international cargo flow simulation model and the spatial general equilibrium model in the three risk cases. Finally, the findings of the case analysis are summarized and further research issues are discussed.

2. METHOD

2.1 Simulation Model

Cargo flows are simulated in a baseline case and in risk cases, to evaluate the potential impacts of risks at the SoMS. The baseline case assumes economic development without a catastrophic risk event at the SoMS until 2020, whereas the risk cases assume that catastrophic risk events have occurred at the SoMS as of the year 2020.

The risk events are expected to impact not only maritime transportation directly but also economic activities in related regions indirectly. To evaluate those impacts consistently, it is necessary to simulate the risk situations with a package of empirical models that enable us to analyze the changes in transportation network flows and those in macroscopic economic indexes in a systematic way. The impact analysis on the maritime transportation should cover both container traffic and bulk traffic because both of them heavily rely on the level of service at the SoMS in the SEA and the EA while the impact analysis on the macroscopic economies should cover both domestic economic activities in each country and international trade between countries. Then, three models are used for the cargo flow simulation. The first is the standard Global Trade Analysis Project (GTAP) model (Hertel, 1997). This model is a spatial computable general equilibrium model by which changes in economic activities as a result of changes in the level of transportation service can be estimated. It covers multiple sectors in multiple regions, with the assumptions of perfect competition and constant returns to scale. The second model is the Model for International Cargo Simulation (MICS), proposed by Shibasaki et al. (2005). This model simulates cargo flows by incorporating market competition among shipping companies and the preferences of container shippers (i.e., route and carrier choices), based on Nash equilibrium. The cargo transportation demand between regions is assigned to the network. The transportation network covers both land and sea transportation. As the flows in the network depend on link performance, the change in transportation time and/or cost as a result of the SoMS blockage will influence the traffic flows of the corresponding links in the network. Increased transportation costs will be also calculated by the simulation. The detail of MICS is presented in Appendix 1. The third model is the Model for International Bulk cargo Simulation (MIBS), newly introduced in this paper. This model simulates the flows of bulk cargo including the dry bulk and the liquid bulk. On the basis of the distribution of current goods transported through the SoMS, it is assumed that the dry bulk is composed of coal, iron ore, grains, and minor bulks while the liquid bulk is the oil only. The model assumes that the bulk ships directly sail from an origin to a destination through the lowest-transportation-cost route without any transshipment. The transportation costs are composed of ship costs and the running costs. The detail of the MIBS is presented in Appendix 2.

2.2 Simulation Process

The simulation process is divided into three stages: origin–destination (O-D) cargo flow estimation, traffic assignment, and economic impact analysis. The simulation process is depicted in Figure 1. The first stage estimates twenty-foot-equivalent-unit (TEU)-based O-D cargo flows between regions in 2020, using the GTAP model. This stage involves two steps: the estimation of monetary-based O-D flows, and the conversion of monetary-based O-D flows into TEU-based O-D flows. First, the monetary-based O-D flows in 2020 are estimated with the GTAP model. For the estimation, changes in the following factors within each region are forecasted: population, skilled labor, unskilled labor, capital, natural resources, and total

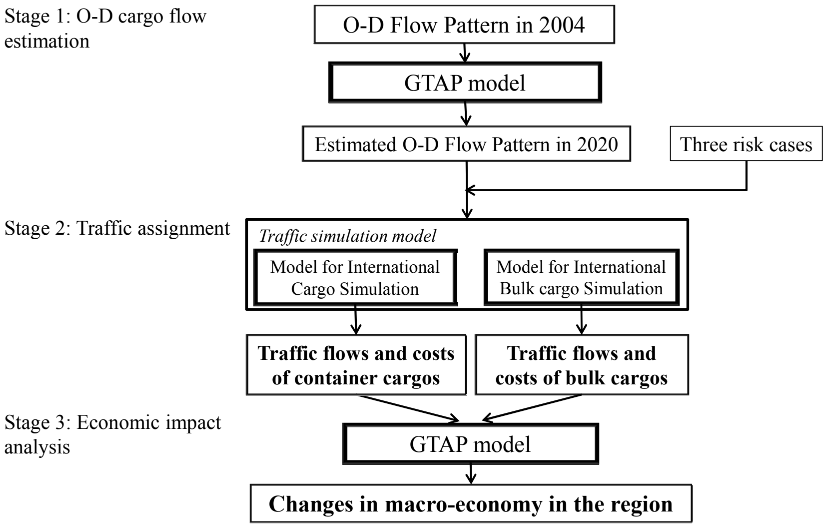

Figure 1 Process of simulating the impacts on international maritime flow patterns and the impacts on regional economies

factor productivity. Then, the international economy in 2020 is estimated by four sequential simulations (Shibasaki et al., 2010). The first simulation estimates changes from 2001 to 2005 by inputting changes in the above factors into the GTAP model, along with 2001 data. The second simulation estimates changes from 2005 to 2010 by inputting changes in the above factors into the GTAP model, along with the 2005 data estimated by the first simulation. The third simulation estimates changes from 2010 to 2015 by inputting changes in the above factors into the GTAP model, along with the 2010 data estimated by the first simulation. Finally, the fourth simulation estimates changes from 2015 to 2020 by inputting changes in the above factors into the GTAP model, along with 2015 data estimated by the second simulation. Note that the first and second simulations do not use the observed data in 2005 and 2010 although they are available. This is first because our analysis intends to show the feasibility of forecasting the future situations using the simulation processes with the limited data and second because we highlight the consistency of model output. Next, the monetary-based O-D flows are converted into TEU-based O-D flows; to do so, the coefficients—including the share of land transportation, share of sea transportation, ratio of value to weight in each transportation mode, containerization rate, and ratio of weight to TEU in sea transportation—are estimated for each commodity and each O-D pair.

The second stage assigns the O-D flows to the transportation network. The network covers sea, road, and rail transportation for container cargo flows while only sea transportation network is considered for bulk cargo flows. The volume of container cargo in each link is estimated by the MICS while the volume of bulk cargo in each route is estimated by the MIBS. This study focuses on not the domestic trade, but the international trade. As for the MICS, the network covers sea, road, and rail transportation. The model covers 182 zones in the world, including 167 zones in SEA/EA and 15 zones elsewhere. The MICS also covers the worldwide transportation network, including 92 ports. It focuses particularly on the sea network of SEA/EA, including 17 ports in Japan, 16 ports in China, 14 ports in Indonesia, 12 ports in Malaysia, nine ports in the Philippines, five ports in Vietnam, four ports in the Indian Ocean Area, three ports in the Bay of Bengal, three ports in Chinese Taiwan, three ports in South Korea, two ports in Russia, and two ports in Thailand. As for the MIBS, for the analytical simplicity, the East, South, and Southeast Asia are divided into 24 regions in which most of the countries with the coastline in this area are allocated to the different regions. Exceptionally Malaysia and Indonesia are divided into three regions since they may be impacted significantly due to its vicinity of the SoMS. Malaysia is divided into the following three regions: the eastern side of the Peninsular Malaysia, the western side of the Peninsular Malaysia, and the northern side of the Borneo Island whereas Indonesia is divided into the following three regions: Sumatra Island, Jawa Island, and the eastern side of Indonesia. Other countries are aggregated, and are divided into 9 regions. It is also assumed that each region has only one representative port. Note that the capacity of ports in our analysis may be different from that of the real ones because the ports in our analysis are representing multiple ports in the region. The capacity of port is defined by commodities. The capacity with regard to bulk carriers is classified into seven classes, and the capacity with regard to tankers is classified into five classes by dead weight tonnage (DWT).

The third stage estimates the economic impacts of risk events in terms of domestic demand, foreign demand, and real gross domestic product (GDP) in each country. The changes in transportation cost output from the MICS and MIBS are input into the GTAP model again. The transportation cost is estimated as follows. First, it is assumed that the container-based transportation cost does not vary among commodities but vary by O-D pair. This is because the MICS can estimate the transportation cost of a unit container, but not that by commodity. Then, the container-based transportation cost of a given O-D pair is estimated by multiplying the transportation cost of a unit container of the O-D pair with the load-factor of container of the O-D pair. Second, the bulk-based transportation cost by commodity for a given O-D pair is estimated by the transportation cost of the O-D pair by commodity output from the MIBS is multiplied with the bulk rate of the O-D pair by commodity or the tanker rate of the O-D pair. The bulk rate is defined as the share of the cargo volume carried by bulk carrier out of the total non-container cargo by commodity while the tanker rate is defined as the share of the volume carried by tanker out of the total oil volume. It is assumed that the bulk rate and the tanker rate are constant among the different cases.

3. RISK SCENARIOS IN THE SoMS

3.1 Approach

For the case analysis, risk scenarios were developed to analyze the expected damages incurred near the SoMS. A number of studies have reported the potential risks in the SEA, including those of the Japan Association of Maritime Safety (2006, 2007, 2008, 2009), the Research Institute of Peace and Security (2007, 2008, 2009), Takeda (2006), Allison (2006), and Ursano *et al.* (2006). To develop the scenarios, three separate elements are examined, each of which is based on the literature: the risk actor, the risk source, and the main target of attack. These elements are summarized in Figure 2.

First, the risk actor is the trigger of events that induce risk, either intentionally or unintentionally. There are four categories of risk actors: terrorists, vicious individuals, delinquency, and natural occurrences. “Terrorists” are members of a group or organization that takes part in violent actions in order to achieve political aims or to force a government to act. “Vicious individuals” are people who are driven not by any political aim but by the personal intention to “make their mark.” “Delinquency” refers to unintentional fault or human error. Finally, “natural occurrence” refers to natural phenomena that cause disasters.

Next, the risk sources in maritime transportation are categorized into a six-fold typology: tiny nuclear bombs, high explosives, computer viruses/hacking, biochemical weapons, hazardous freight, and natural sources. First, it is possible that terrorists or another criminal organization could obtain a tiny nuclear bomb from a nuclear-capable nation; if they were to position a bomb inside container cargo and initiate it at a certain port, they could

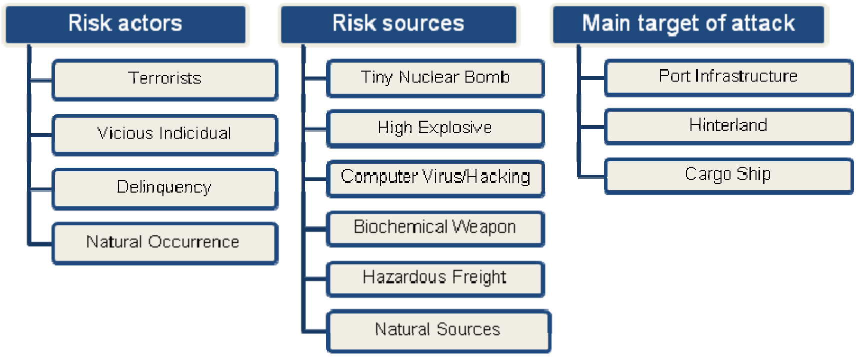

Figure 2. Scenario development framework

completely destroy the port's functionality. Second, it is also possible that terrorists or another criminal organization could obtain a high explosive; again, if they were to position such a bomb inside container cargo and initiate it at a certain port, it could obliterate that port. Third, computer viruses and hacking may create vicious disruptions on ports' system servers. In major ports, most embark/disembark information is controlled electronically, so if one were to falsify or scramble that information, it could disrupt maritime traffic. Fourth, biochemical weapons comprising viruses or bacteria may cause outbreaks of infectious disease among humans; this may paralyze the functionality of a port, among other things. Fifth, noxious substances can inflict damage or otherwise prove hazardous to humans or the environment; these so-called hazardous noxious substances include xylene, benzene, and other industrial chemicals. Finally, natural sources include the typhoons, earthquakes, tsunamis, and malignant viruses.

Finally, the main targets of attack are the locations in which risk is incurred. They are categorized into port infrastructure, hinterland, and the cargo ship areas. The port infrastructure includes the access/egress sea lane, berths, the container yard, handling machines and facilities, and the port management office. The hinterland refers to the area surrounding the port, including urban areas (e.g., industrial, residential, and commercial areas). Cargo ships, of course, are the vessels or ships that transport goods.

3.2 Risk Scenarios

Theoretically, there are 72 different ways in which one can combine these three elements. However, some combinations—such as one comprising "vicious individual," "natural sources," and "cargo ship"—are either nonsensical or impossible; after eliminating such combinations, seven scenarios were created, as shown in Table 1. Note that the typical natural disaster including earthquake and tsunami is not included in the scenarios. This is because this paper highlights unfamiliar risk events rather than the classical/popular risk events.

Table 1. Scenarios of maritime risk in SoMS

No.	Risk actors	Risk source	Main target of attack
1	Terrorists	Tiny nuclear bomb/ high explosive	Port/hinterland
2			Cargo ship
3		Biochemical weapon	Hinterland
4	Natural occurrence	Natural sources	
5	Delinquency	Hazardous freight	Cargo ship
6	Terrorists		Hinterland
7	Vicious individual	Computer virus/hacking	Port (control server)

We then described each scenario in terms of a story, to explain the risk process thereof; this included the risk source, risk actors, main target of attack, and risk results. Although the severity of impacts may vary—even with the same risk sources, risk actors, and main target of attack—the most serious case was assumed in each scenario. We followed expert advice in describing these scenarios. These seven scenarios are described below, in greater detail.

Scenario 1: A small nuclear weapon explodes unexpectedly at a major port
Terrorists have obtained a small nuclear weapon at some country. They transported from there to another country via container cargo. The container cargo containing the nuclear weapon suddenly exploded when it was loaded at a major port. All the buildings near the explosion point were destroyed, and all nearby streets were enveloped in flames and radiation. The incident eventually triggered an increase in insurance costs for cargo, and all traffic was detoured to another sea lane until the radioactive contamination subsided.

Scenario 2: Terrorists attack a cargo vessel with high-explosive weapons
Terrorists obtained small, high-explosive weapons. They embarked each weapon in container cargo and transferred them worldwide from a port. The terrorists detonated them by remote control, one after another. The physical damage inflicted by each explosion would have been small, but shippers may then consider it enormously risky to voyage, severely curtailing traffic. Some of the port control authorities may also decide to inspect all cargo that arrives at or departs from there, resulting in greatly increased shipping costs.

Scenario 3: Terrorists attack a major port and its hinterland with a biochemical weapon
Terrorists obtained a smallpox virus. They succeeded in mass-producing it and spreading it aerially near a major port. Because the disease had been considered virtually eradicated—and hence no one had been inoculated—most of the local citizens near the port became infected. The port authorities may decide to inspect all cargo that arrives at or departs from there, resulting in greatly increased shipping costs.

Scenario 4: Natural occurrence of pandemic
A new and highly toxic virus was found in some cities. The mortality rate of infected patients was considerably high. Governments in other countries immediately prohibited the embarkation to and disembarkation from there. However, the virus had already proliferated to other countries and is already exerting an overwhelming influence. The port authorities may decide to inspect all cargo that arrives at or departs from there, resulting in greatly increased shipping costs.

Scenario 5: Collision between a cargo ship and a crude-oil tanker
A massive forest fire occurred on the areas near the sea lane. Due to the heavy smoke-haze, visibility on the sea lane became seriously obstructed. One mid-class cargo ship incorrectly broke into the sea lane, colliding with a crude-oil tanker. The location of the collision was at the narrowest part of the strait. Spilled crude oil covered the width of the sea lane and interfered with the voyage of other cargo ships. It took three months to clean up the crude oil on the sea lane, and during that time, all ships passing through this area were detoured to the other sea lanes.

Scenario 6: Terrorists attack the hinterland with a crude oil tanker
Terrorists hijacked a crude-oil tanker near a major port. They were able to sail the tanker and

attack other crude tankers on the seashore of industrial zone near the port. A massive explosion occurred, spilling crude oil that covered the sea surface of a nearby area. The port was closed for a few days, due to damage inflicted by the explosion and the massive crude-oil spill. Even after the port's functionality was restored, shipping costs remained high because of increased insurance prices.

Scenario 7: Computer-hacking of the port authority's system server
A vicious individual skilled at computer programming was eager to show off his or her computer skills. He or she decided to hack the system server of a major port, which controls all information pertaining to stowage plans and shipping schedules, and scramble all the data therein. The port authority did not notice the computer-hacking prior to receiving many reports of distribution where the wrong container cargo had been received from all over the world. It took one month to completely recover the system. During recovery, the cargo-handling capacity of the port sharply diminished. Even after the port's function was restored, shipping costs remained high because of increased insurance prices.

4. ANALYSIS OF RISKY CASES AT THE SOMS

4.1 Definitions of Cases

The expected damages from the risk events vary with their risk factor. As this paper focuses on the impact of damage on the traffic patterns as well as the regional economy, the impacts of the following three factors will be considered in the simulation analysis: sailing cost, including the sailing time; sailing route; and the ports' service levels. Then, the scenarios will be recategorized into risk cases, based on the impacts on sailing cost and sailing route. Scenarios 1, 3, 4, 5, and 7 assume that the ships sailing through the SoMS detour to other sea lanes—such as the Sunda or Lombok Strait—while Scenarios 2 and 6 assume that the transportation cost of sailing the devastated sea lane increases drastically. Finally, the three cases are considered in our analysis.

First, in the case of "sea lane blockade at the SoMS" (Case 1), it is assumed that vessels cannot pass through the Singapore Straits for a year. The blockade point is assumed to be Raffles lighthouse, which is the west side of the Singapore Port and next to the separation of the sea lanes. Any vessel passing through the SoMS must detour to the Lombok Strait or the Sunda Strait. As the depth of the Sunda Strait is less than that of the SoMS, the vessels whose draft is over 18 meters cannot pass through the Sunda Strait. The tanker whose draft is over 18 meters is categorized into the type of Very Large Crude Oil Carrier (VLCC) whereas the bulk carrier whose draft is over 18 meters is categorized into the Capesize or Very Large Ore Carrier (VLOC). As the draft of container ships is assumed to be less than 14 meters, it is assumed that all container ships can pass through the Sunda Strait in our simulation. The sea routes including the alternative ones are illustrated in Figure 3.

Next, in this case of "stop of the service at Singapore Port" (Case 2), it is assumed that vessels cannot enter the Singapore port for a year. In this case, all the container cargos transshipped at the Singapore Port must be transshipped at other ports while all the cargos to/from Singapore must be transported by land transportation. To deal with the land transportation of bulk cargos, the land transportation network is newly added to the MIBS in this case. The land transportation network covers only the road network for analytical simplicity although there is the rail network. The bulk-based transportation cost by the road transportation is estimated on the basis of the data shown by Shibasaki (2011). It should be

Figure 3. Alternative routes in Case 1: "sea lane blockade at the SoMS"

noted that the vessels passing through the SoMS without stopping at the Singapore Port do not need to change their routes in Case 2.

Finally, Case 3 is an additional one. In this case of "increase of loading/unloading time at all ports in the world" (Case 3), it is assumed that the loading and unloading time at all ports over the world will be longer than those in the baseline case for a year. This reflects the expected situation where the security level of inspection or monitoring of the cargos will be reinforced at any port when the some potential risks are identified and/or forecasted by all port operators. For analytical simplicity, the loading/unloading time in Case 3 is assumed to be five time longer than those in the baseline case. The five time longer loading/unloading time is assumed on the basis of expert's advice, but it should be discussed more in details. This is one of further research issues.

It should be noted that the above three cases assume the irregular situations continue for a year. One of the reasons for it is that our models can deal with annual-based data only. The other reason is that the expected impacts caused in each case might be too small if the service would be recovered immediately. In this sense, the one-year cases assume the worst scenarios in terms of risk period.

4.2 Results of Case Analyses

The estimated average cost of import to major countries; estimated annual volumes of transshipments in major ports; estimated private consumption, government expenditure, and business investment in the major countries of the EA and the SEA regions in the three cases; and estimated export and import in the major countries of the EA and the SEA regions in the three cases are summarized in Figures 4 to 12 respectively.

First, Figures 4 and 5 show that, in Case 1, the average import cost of container to Singapore increases by 4.7%, which is largest among countries while that of bulk cargo to Singapore increases by 13.4 %, which is also largest among them. The average import cost of bulk cargo to the littoral countries of the SoMS including Thailand also significantly increases. This is because the cargos transported from the west side of Singapore Strait to Singapore or to the littoral countries of the SoMS should be detoured and this increases the average transportation cost to there. Second, in Case 1, the change rate of average import cost of bulk cargo is higher than that of container cargo to all countries except India. This is because the

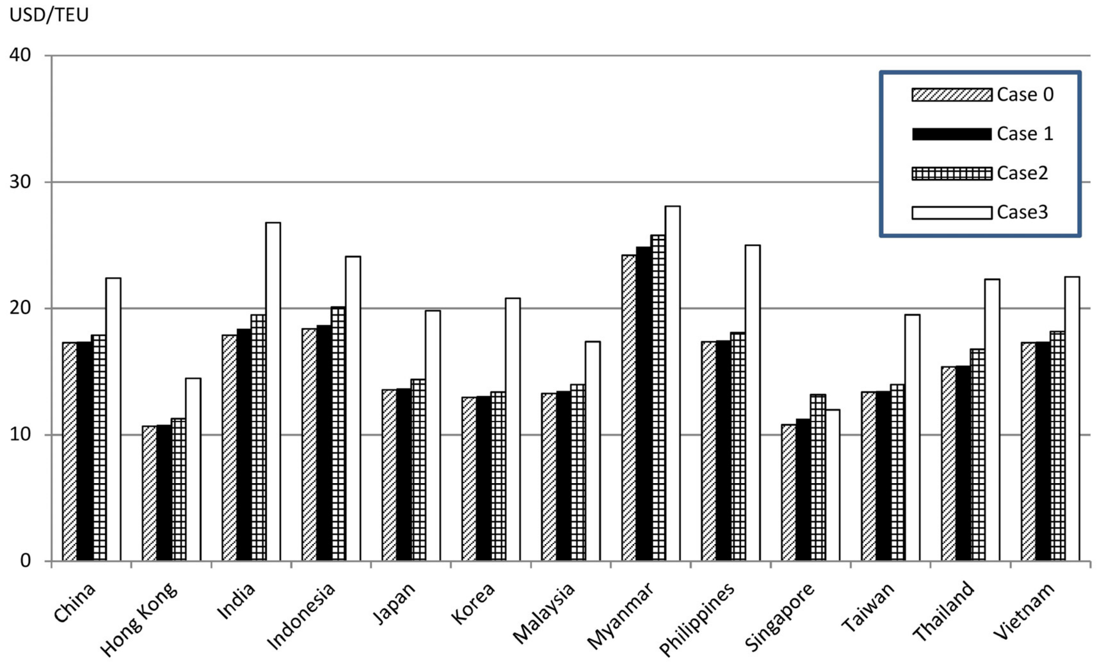

Figure 4. Estimated Average Cost of Container Imports to Countries in EA and SEA in the Three Cases

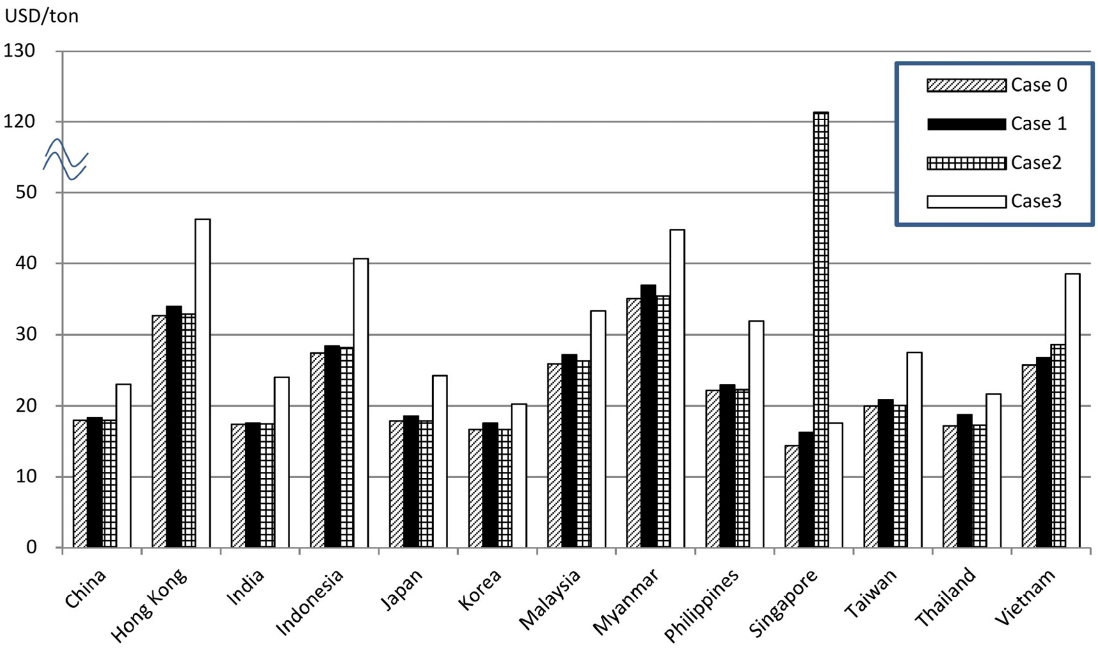

Figure 5. Estimated Average Cost of Bulk Cargo Imports to Countries in EA and SEA in the Three Cases

bulk cargos are imported more from the west side of Singapore Strait than from the EA region. Third, in Case 2, the average import cost of bulk cargo to Singapore increases by 742.0 % while that of container cargo to Singapore increases by 21.6 %. They reflect the transportation cost of the alternative routes including other ports and land transportation to import the cargos to Singapore. The result suggests that the cost of land transportation of bulk cargo is much higher than that of container cargo. Fourth, in Case 3, the import cost increases significantly in all countries of the EA and the SEA regions. This simply reflects the increase of transportation cost in all ports all over the world. Fifth, in Case 3, the increase rate of average import cost of container cargos to Singapore is the lowest among the countries. This reflects the fact that the loading/unloading time at Singapore Port is currently much shorter than others due to its high efficiency of port operation. The same increase rate of loading/unloading time at all ports leads to smaller increase of loading/unloading time at Singapore Port than that at other ports. Consequently the service level at Singapore Port becomes relatively better than that at other ports although the service level at all ports becomes worse.

Figures 6 and 7 show that, in Case 1, the volume of tranship container cargos handled at TJ Pelepas, Port Klang, Singapore, and Berawan decrease by 23.7%, 23.7%, 20.5%, and 58.4% respectively whereas those handled at Busan, Shanghai, and Kaoshung increase by

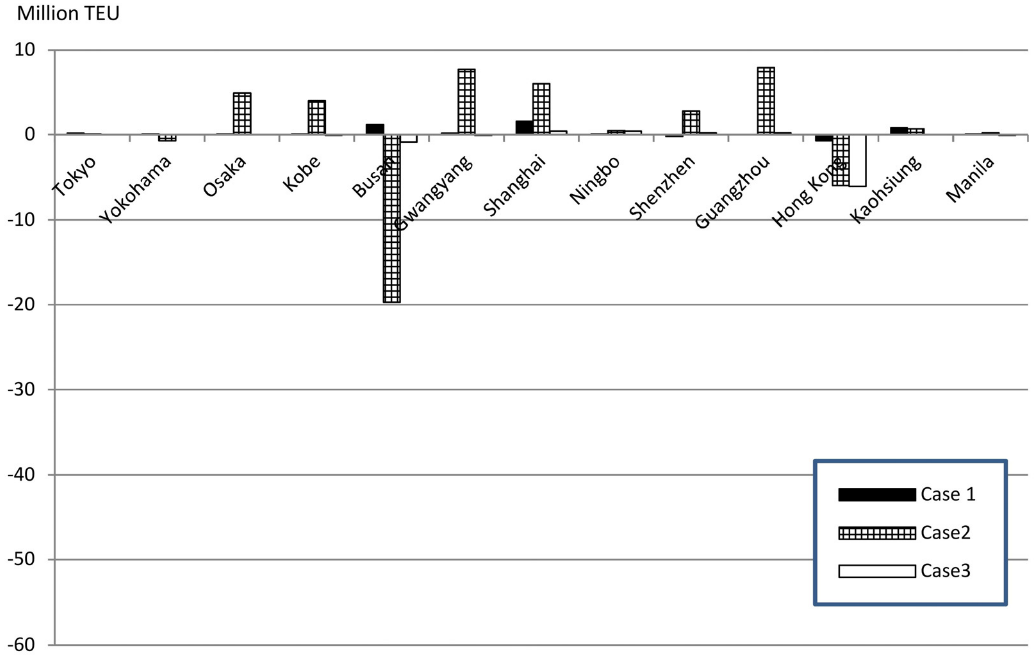

Figure 6. Estimated Volumes of Transship Cargos in Major Ports at EA and SEA regions in the Three Cases

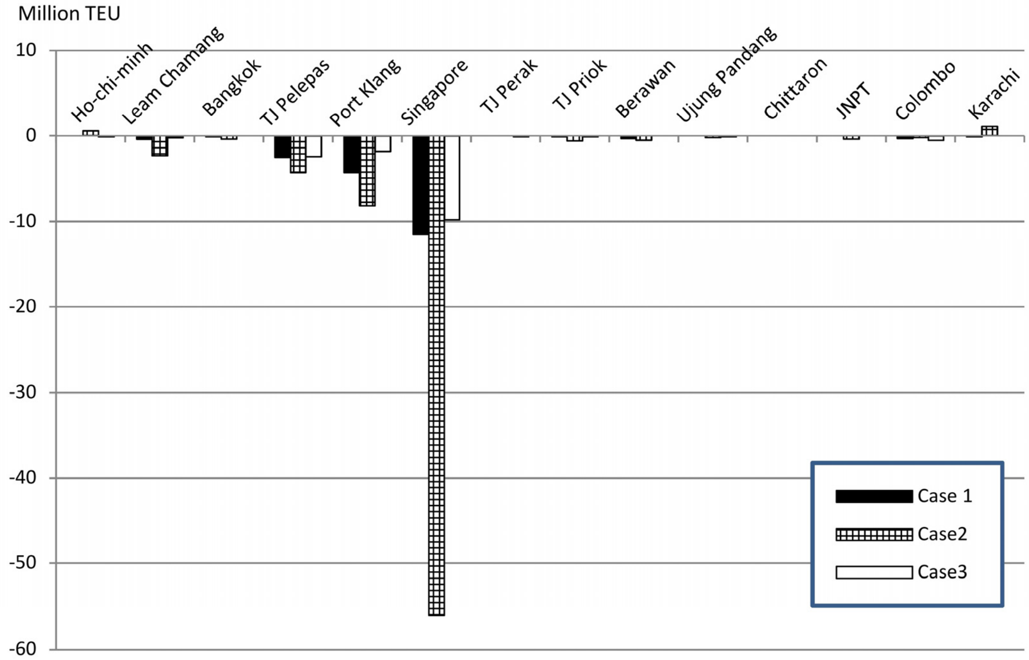

Figure 7. Estimated Volumes of Transship Cargos in Major Ports at EA and SEA regions in the Three Cases

6.6%, 24.8%, and 4.7% respectively. These mean that the volume of transship container cargos at the littoral ports of the SoMS decrease drastically while those at East Asia increase. This may be because the carriers change their transshipment ports from the littoral ports of the SoMS to other ports in Korea, Taiwan, and China. The results also show that although the volume of transship container cargos handled at Singapore decrease drastically, it is still more than any other ports in Asia. This means that Singapore still plays the important role of hub in Asia in spite of the blockade of the SoMS. In Case 2, the volumes of transship container cargos handled at the ports in Thailand, Malaysia, Singapore, and Indonesia decrease significantly whereas those handled at Osaka, Kobe, Gwangyang, Shanghai, and Guangzhou increase significantly. This may be because the carriers change their transshipment ports from ports in the SEA region to the other ports in the EA region. Interestingly the volumes of transship container cargos in Busan decreases by 62.3% whereas that in Gwangyang increase by 7.7%. This could mean that the main port in Korea may change when the vessels cannot enter the Singapore port. In Case 3, most of the ports decreases the volume of transship container cargos. For example, Busan, Hong Kong, Port Klang, and Singapore lose their volumes of transship container cargos by 0.1%, 31.3%, 9.9%, and 17.5%, respectively. This means that carriers hesitate to transship cargos because longer time is required in transshipment. On the contrary, many ports in China increase the volume of transship cargos. This may be because the container carriers change their transshipment ports into the ports in China since the handling cost of container cargos is cheaper than that at other ports.

Figures 8, 9, and 10 show that, in Case 1, the decreasing rate of business investment is higher than those of private consumption and government expenditure in all countries. This means that the increase of transportation cost gives significantly the negative impacts on the business investment on their facilities and inventory while that gives less significantly the negative impacts on the domestic consumption. Next, the results show that, in Case 2, the private consumption, the government expenditure, and the business investment in Singapore decrease by 0.61%, 0.38%, and 1.15%, respectively. This means that the stop of the service at Singapore Port significantly damages the domestic demand in Singapore. The results also show that, in Case 2, the business investment in India, Japan, Korea, and Taiwan increases by 0.01%, 0.03%, 0.02%, and 0.02%, respectively. This reflects that the transportation cost of bulk cargo to those countries does not increase significantly. Note that Figures 4 and 5 show the average import costs of bulk cargo to India, Japan, Korea, and Taiwan slightly increase in Case 2. As the transportation cost of bulk cargo to the above four countries increase less significantly than other countries, the business in the four countries becomes more attractive than that in other countries. This may promote the business investment in the four countries under the international competition. The results also show that, in Case 3, the increase of loading/unloading time at all ports significantly damages the domestic demand in most countries.

Finally, Figures 11 and 12 shows that, in Case 1, both the export and the import decrease to/from the littoral countries of the SoMS. This is because the transportation cost increase significantly in such countries. Next, in Case 1, the change rates of export in Japan, Korea, Philippines, and Thailand are 0.06%, 0.03%, 0.04%, and 0.09% respectively while those of import in the four countries are -0.08%, -0.05%, -0.02%, and -0.18% respectively. The exports from those countries increase mainly because the transportation costs from the western side of the SoMS to the EA (mainly China) and/or North/South America regions increase due to the blockade whereas that from the eastern side of the SoMS to the EA and/or North/South America regions are not damaged. This leads to the increase of exports from Japan, Korea, Philippines, and Thailand whereas the decrease of exports from the countries located at the west of the SoMS. Both the export and import increase to/from Hong Kong.

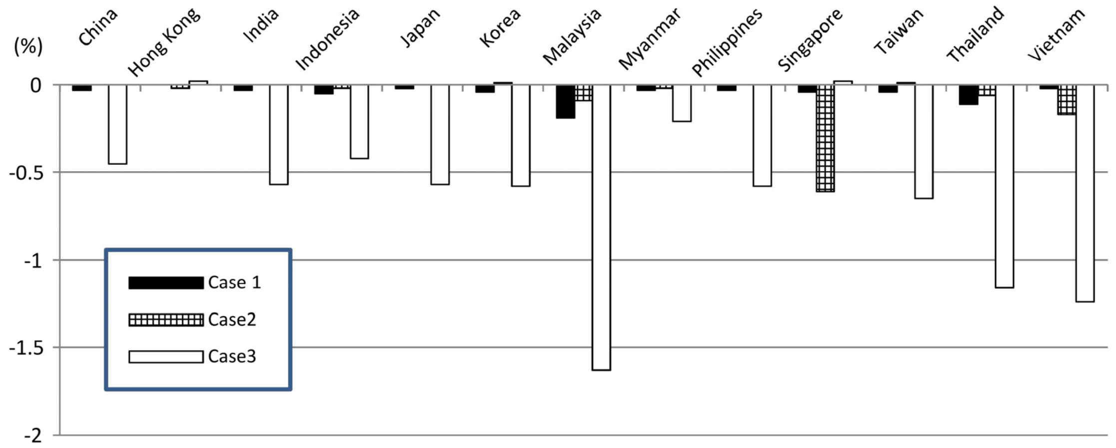

Figure 8. Estimated Private Consumption in the Major Countries of EA and SEA in the Three Cases

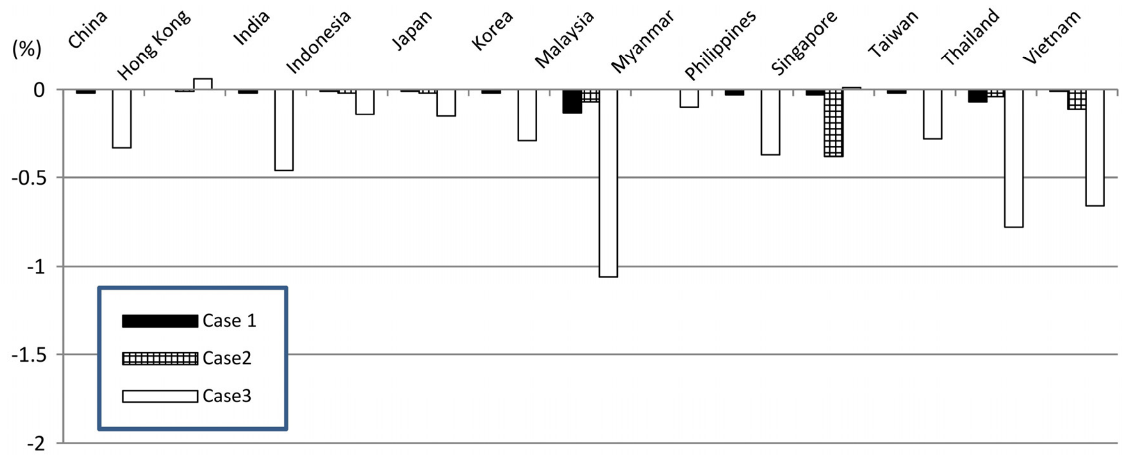

Figure 9. Estimated Government Expenditure in the Major Countries of EA and SEA in the Three Cases

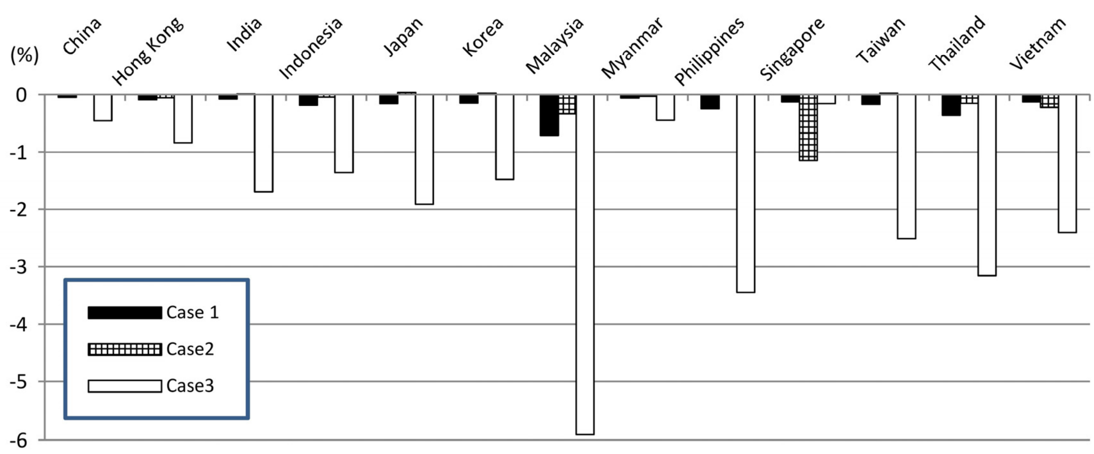

Figure 10. Estimated Business Investment in the Major Countries of EA and SEA in the Three Cases

The results also show that, in Case 2, the export/import of Singapore significantly decreases. They also show that the export/import in Japan, Korea, and Taiwan does not change or slightly increase in Case 2. One of the possible reasons is that the container carriers change their transshipment ports from ports in the SEA region to the ports in the EA region as shown in Figures 6 and 7. The results show that, in Case 3, many countries decrease their import/export significantly.

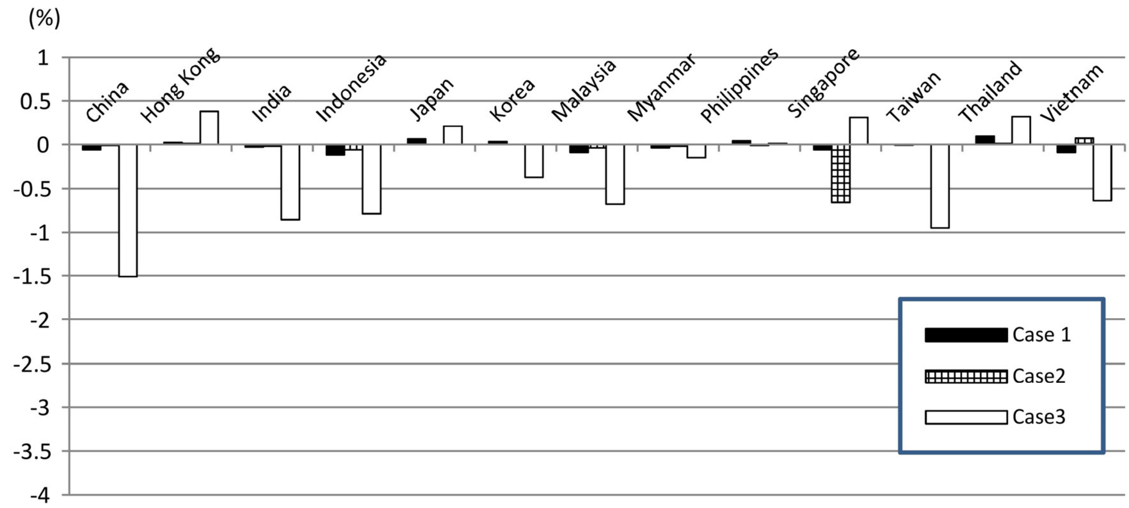

Figure 11. Estimated Export in the Major Countries of the EA and the SEA in the Three Cases

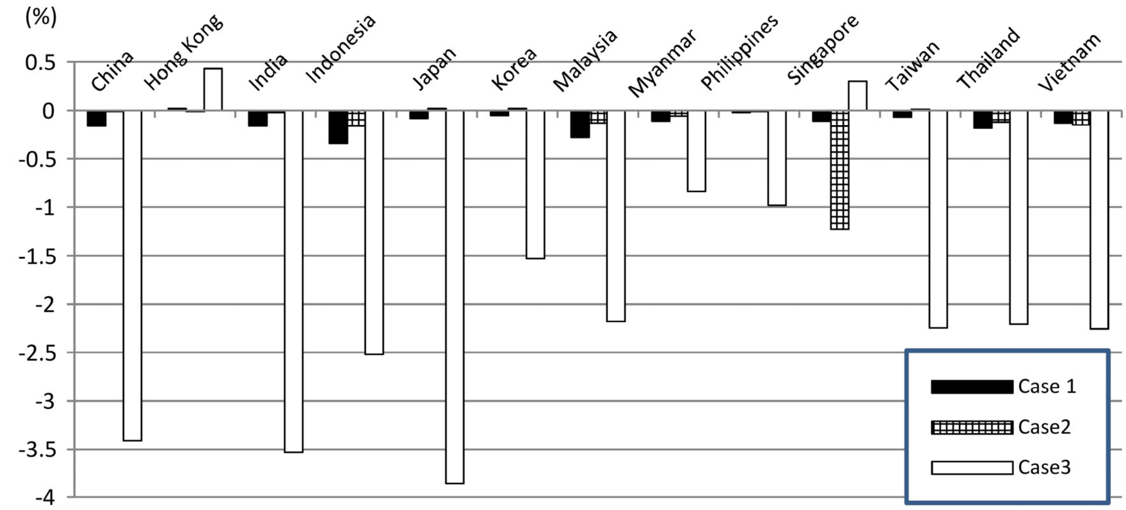

Figure 12. Estimated Import in the Major Countries of the EA and the SEA in the Three Cases

5. DISCUSSION

First, the case analysis shows that the risks which occur at the SoMS impact the economies in the whole Asia. From an economic point of view, not only littoral countries but also other user countries receive the negative impacts caused by the increase of transportation costs. From the freight traffic point of view, since the carriers change their transshipment ports from the littoral ports of the SoMS to other ports in the EA region in case the risks occurred. This may imply that the risks at the SoMS should be discussed not only among the neighbor countries of the SoMS, but by all countries in Asia. However, it should be noted that the negative impacts on the major users of the SoMS, such as Japan, Korea, China, and India, are less than those in other countries. This is probably because the share of cargos to/from those countries passing through the SoMS is smaller than that of neighbor countries. This may mean that it is hard for them to have motivation to support the maritime safety at the SoMS.

Second, the results of the case analysis also show the change of the transportation cost of each region may depend on the pairs of the origin and the destination. In addition to that, the change also depends on the risk cases. The degree of the increased costs of container cargos is smaller than that of bulk cargos in Case 1 while that of container cargo is much larger than that of bulk cargos in Case 2. This may mean that the role of hub port is significantly important for container cargos. The carrier's choices of container ship size and/or on the carrier's choice of transshipment port have large impacts on the decision of the change of transportation cost.

Third, the results show that the change in the domestic demand does not always change the same way as the change of transportation costs. Note that the domestic demand is defined to be the sum of private consumption, government expenditure, and business investment. The reduction of business investment could decrease the domestic demand significantly. The results show that Malaysia, Thailand, and Vietnam receive more negative impacts than other regions. Additionally the results show that the increase of the transportation costs tends to expand the foreign demand due to the reduction of import. Note that the foreign demand is equal to the import plus the export. The results in Case1 and Case3 show that all countries in Asia increase the foreign demand.

Fourth, the results show the growth of the real GDP does not necessary indicate the positive meaning. In Singapore and Hong Kong, the foreign demand tends to change more significantly than the domestic demand because their export/import is greater than that in other regions. Consequently the real GDP can grow even if the transportation costs increase in Singapore and Hong Kong.

Finally, the results of Case1 and 2 show that the carriers tend to substitute the ports in the EA region for the littoral ports if risks occur. However, the total volume of the transshipment cargos in Singapore is the largest in Asia, and it still works as the hub port in Asia even under the risk events at the SoMS as shown in Case1 and Case3. Case2 shows that no port would work as the hub port. This means the transportation system of hub-and-spoke would fail to work in case of the stop of service at the Singapore Port.

6. CONCLUSIONS

This paper analyzed the impacts of risk events on the international cargo flows and on the regional economies in the EA and SEA regions. The analysis covers the three cases: sea lane blockade at the SoMS, stop of the service at Singapore Port, and increase of loading/unloading time at all ports in the world. The results show that the risks at the SoMS impacted on the economies in the whole Asia; the change of the transportation cost of each region may depend on the pairs of the origin and the destination; the carriers tend to substitute the ports in East Asia for ports in littoral ports if risks occur; the increase of the transportation costs tends to expand the foreign demand caused by the reduction of the amount of import; and the change in the domestic demand does not always change the same way as the change of transportation costs.

Future research issues are summarized. First, the accuracy of the simulation model should be improved. Although the case analysis used the simulation model developed by Shibasaki *et al.* (2005) in a straightforward manner, it still has some technical issues that should be explored. For example, because the model does not account well for a carrier's choice of adjacent ports in some regions, the estimated volume of container cargo handled at an individual port may not be sufficiently accurate. Although this paper discusses simulation results in terms of aggregated cargo volumes in some regions, future research could examine simulation results in greater detail by making use of estimated cargo volumes at individual ports. Next, the GTAP model uses the conventional approach with the assumptions of perfect competition, constant returns and iceberg transport cost. However, this approach has been criticized by many researchers including new economic geography theorists such as Krugman (1990). Relaxing these assumptions could change the results, especially at sector level, dramatically. Finally, future research could address political interactions among countries in the SEA and the EA *vis-à-vis* the security of international maritime transportation. Future international policies or institutional systems for promoting safer international maritime transportation could be investigated by analyzing the political behavior of the stakeholders.

Appendix 1 Model for International Cargo Simulation (MICS)

The MICS simulates cargo flows by incorporating market competition among shipping companies and the preferences of container shippers concerning route and carrier choices. The model structure is depicted in Figure 13. A number of factors—including OD cargo volume; land transportation network and cost function; lead time at port; level of service at ports, including number of berths and port charges; maritime shipping network and cost functions; and initial values such as maritime shipping flows—are input into the MICS. Meanwhile, the cargo flows in the land transportation network, local cargo handled by ports, cargo demands by carrier groups, cargo flows in the maritime shipping network by ship size and carrier, and transshipment cargo volume by port are output from the MICS. The MICS assumes multi-layered equilibria, including the equilibrium between shipper and carrier, equilibria among carrier groups, and the equilibrium in the profit-maximization behavior of each carrier group. The MICS also includes a shipper submodel and a carrier submodel. In the shipper submodel, an individual shipper chooses the import and export ports and land transportation routes, in addition to carriers, by minimizing the perceived cost. A multinomial logit model is used to choose carriers, while the stochastic network assignment model is used to choose the ports and land transportation routes in the shipper submodel. The demand by route output from the shipper submodel is then input into the carrier submodel. In the carrier submodel, an individual carrier group will maximize its income by choosing the prices, ship size, and transshipment ports under the condition that total cost is minimized. It should be noted that this is equivalent to the profit maximization of the carrier group. The income maximization model assumes that the total income of carrier group is maximized on the basis of the Bertrand equilibrium model under differentiated transportation service whereas the cost minimization model assumes that the total cost in the carrier group is minimized under the condition that the demand by route is given. The carrier group then sets the prices, ship size, and transshipment ports to maximize its profit, under the condition that the carrier choice of shippers is given; the prices, ship size, and transshipment ports output from the carrier submodel are then input into the shipper submodel.

The volumes of container cargo handled at local ports estimated with the MICS using 2008 data versus the observed volumes in 2008 is shown in Figure 14 and the volumes of container cargos transshipped at major ports using 2008 data versus the observed volumes in 2008 is shown in Figure 15. They show that the fitness of the MICS is quite high although some ports have outliers.

APPENDIX 2 Model for International Bulk cargo Simulation (MIBS)

The MIBS is the model to calculate the route chosen by vessel from a given origin port to a given destination port. It assumes that the bulk carrier or the tanker chooses the lowest-transportation-cost route. The transportation cost is defined as follows:

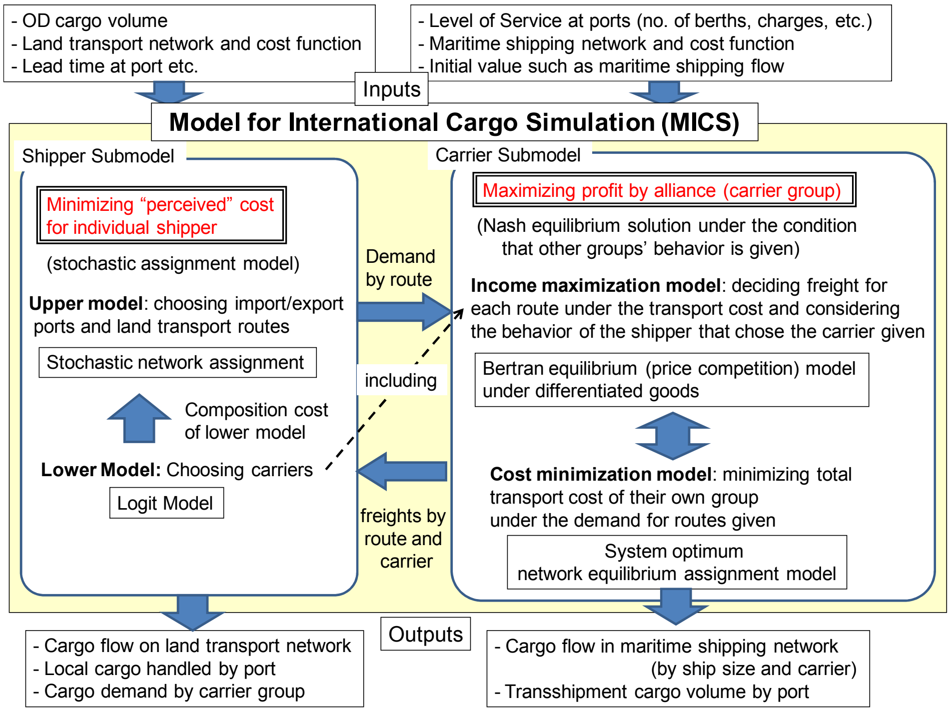

Figure 13. Model for International Cargo Simulation (MICS)

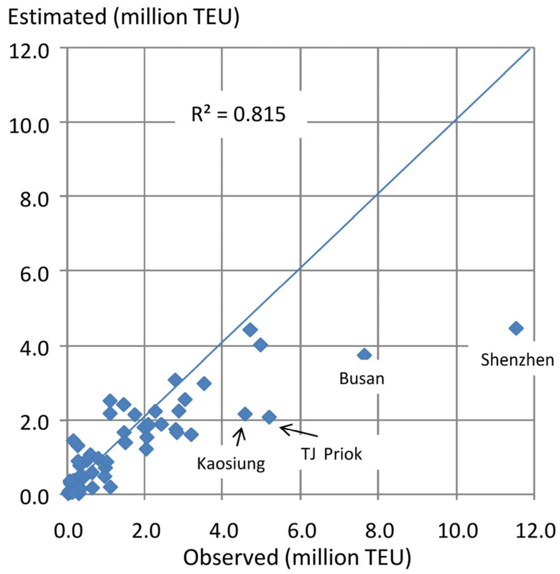

Figure 14. Estimated versus observed container cargo volumes handled at local ports

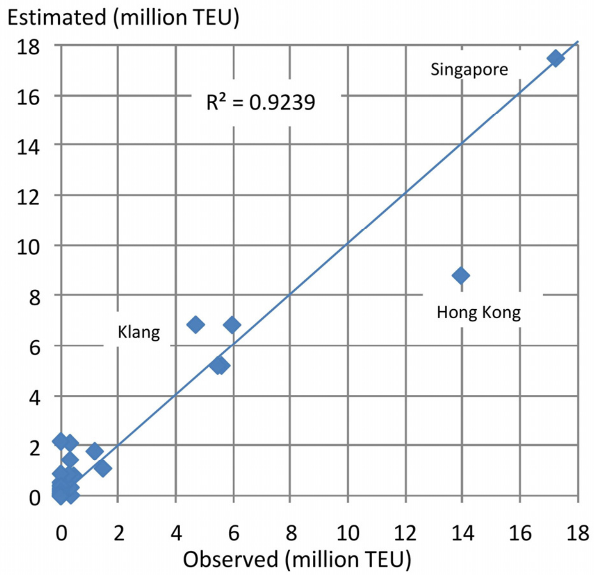

Figure 15. Estimated versus observed container cargo volumes transshipped at major ports

$$TC^j_{rsiy} = \left(CO^j_i + CP^j_i\right)\cdot\left(\frac{2N_{rs}}{v^j_i} + S^j_{riy} + S^j_{siy}\right) + CF^j_{ri} + CF^j_{si} + CPS^j_{riy} + CPS^j_{siy} + CPE^j_{riy} + CPE^j_{siy} + CC^j_{rsiy} + CI^j_{rsiy}$$

where TC^j_{rsiy} is the total transportation cost per voyage in US dollar to transport commodity y from origin port r to destination port s by the ith level of vessel in carrier type j. The carrier type j is a bulk carrier or a tanker. The level of vessel means the size of vessel used for transporting the goods. CO^j_i denotes the operation cost of the ith level of vessel in carrier type j; CP^j_i denotes the capital cost of the ith level of vessel in carrier type j; N_{rs} denotes the distance between port r to port s (nm); v^j_i denotes the sailing speed of the ith level of

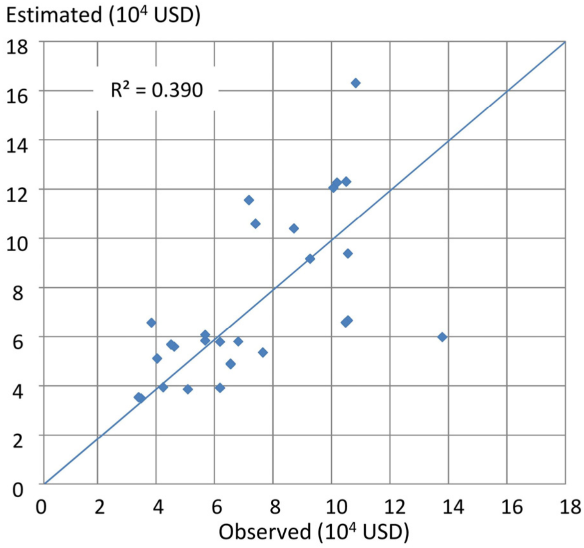

Figure 16. Estimated versus observed container cargo volumes handled at local ports

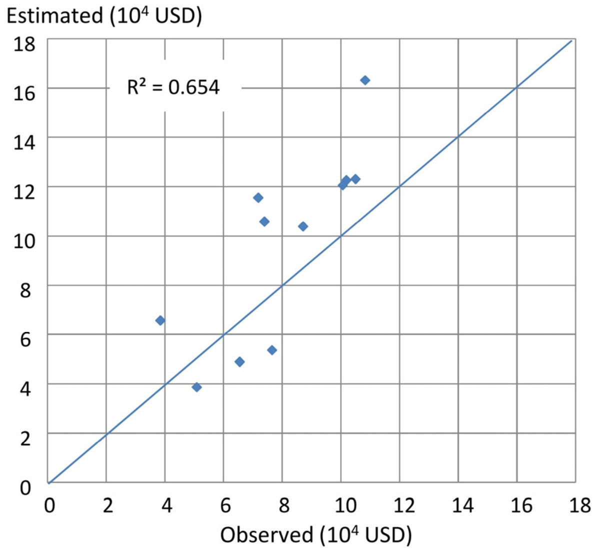

Figure 17. Estimated versus observed container cargo volumes transshipped at major ports

vessel in carrier type j; S^j_{riy} and S^j_{siy} denote the time (day) to load/unload the commodity y at origin port r and destination port s respectively when the ith level of vessel in carrier type j is used; CF^j_{ri} and CF^j_{si} denote the freight cost of the ith level of vessel in carrier type j at origin port r and destination port s respectively; CPS^j_{riy} and CPS^j_{siy} denote the costs of the ith level of vessel in carrier type j carrying commodity y to stop at ports r and s; CPE^j_{riy} and CPE^j_{siy} denote the costs of the ith level of vessel in carrier type j carrying commodity y to enter ports r and s; CC^j_{rsiy} denotes the fuel cost to transport commodity y from origin port r to destination port s by the ith level of vessel in carrier type j; and CI^j_{rsiy} denotes the insurance cost to transport commodity y from origin port r to destination port s by the ith level of vessel in carrier type j. The data of these costs are collected from the interviews with carriers and/or the related literature.

Figure 16 shows the transportation costs of commodities including iron ore, coal, grains estimated with the MIBS using the data in 2008 versus those observed in 2008 while Figure 17 shows the transportation costs of oil estimated with the MIBS using the data in 2008 versus those observed in 2008. They show that the reproductivity of the transportation costs of oil with the MIBS seems good while that of the commodities seems lower. The improvement of the model is one of further research issues.

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