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Modeling the Interactions among Green Shipping Policies

Abstract:

Many policies and practical measures have been designed for emission reduction in shipping. Many have studied their contribution to emission reduction and impacts on the shipping industry without considering their interactions. This study analyzes how a change in one policy or measure affect the others using a system pulse model. The results suggest that the factors influencing shipping emissions are inter-dependent, and the developed systematic shipping emission model fluctuates periodically. We find that slow steaming is actually not effective in emission reduction in the long-run as it impacts the implementation of other policies. It poses a high demanding for the adoption of the EEDI (Energy Efficiency Design Index) policy so as to promote the application of advanced technologies in the shipbuilding process. It also suggests that although the implementation of the EEDI policy can promote the adoption of the EEOI (Energy Efficiency Operating Index) policy, the EEOI policy actually relieves the demanding for the EEDI policy.

Keywords: Shipping emission, System pulse modeling, EEDI, EEOI, MBMs (Market-based Measures)

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1. Introduction

The maritime transportation is the most environmentally friendly mode of transportation (IMO 2012) which carries more than 80% of the international trade volume in the world (UNCTAD 2018). However, along with the huge trade volume carried, substantial quantities of emissions are produced from the shipping industry (Sun et al. 2013;Yang et al. 2013;Psaraftis and Kontovas 2013). According to the 2009 GHG (Green House Gas) study (IMO 2014), emissions of carbon dioxide (CO_2) from the shipping accounts for 3.1% of the global CO2 emissions. It is estimated that the shipping emissions would increase by 50-250% by 2050 if there is no effective measures implemented (IMO 2014). Therefore, the IMO (International Maritime Organization) set a goal of reducing the GHG emission by 20-50% by 2050 (IMO 2014).

Actually, the IMO has issued a number of regulations to limit the shipping emissions, such as the technical, operational, and market-based policies. There are many studies discussed the technical (Ančićn and Šestan 2015;Tzannatos and Stournaras 2014;Ekanem Attah and Bucknall 2015) and operational policies (Acomi and Acomi 2014;Lu et al. 2015;Sun et al. 2013) in restraining emissions. Meanwhile, lots of studies investigated the feasibility of implementing the market-based polices (Wang, Fu, and Luo 2015;Lee, Chang, and Lee 2013;Shi 2016;Heitmann and Khalilian 2011). In addition to these, plethora of studies have analyzed the role of slow steaming in emission abatement (Woo and Moon 2013;Ferrari, Parola, and Tei 2015;Doudnikoff and Lacoste 2014) and discussed the optimal ship speed for different types of ships or routes under different green shipping scenarios (Fagerholt et al. 2015;Du et al. 2019). However, these emission abatement measures are analyzed separately instead of systematically and most of them are from microeconomic perspectives. From the macroeconomic level, a systematic analysis is significant as there are mountains of strategies in emission abatement in the shipping industry and most of them are inter-correlated. For example, the implement of the EEOI (Energy Efficiency Operating Index) policy may impact the adoption of the EEDI (Energy Efficiency Design Index) policy, since a strict requirement of EEDI policy can help advance the shipbuilding technology in emission control which will further be helpful in satisfying the EEOI regulations.

Therefore, this study tries to investigate the shipping emission abatement polices and measures in a system model in which various policies and measures are correlated with each other. When there is a change in a certain policy or measure, the impact will transmit to other polices and measures. Hence, we can analyze the evolvement of the system by imposing a pulse to certain polices or measures and observe the its actual effects on other polices. This systematic analysis of the green shipping industry could provide insightful ideas to the practice as it points out the dynamic effects of the policies on other polices and measures. It provides a new type of tool in evaluating policies as it could help simulate the evolvement of the system in consideration and identify the actual effects.

The remains of this study are arranged as follows. Section 2 presents the green shipping policies that are mostly discussed in the shipping industry. Section 3 explains the interactions among different green shipping policies to build the systematic model. Section 4 illustrates the systematic model of the pulse process. Section 5 discusses the dynamics of the pulse process. Section 6 concludes the study.

2. The Green Shipping Policies

The international shipping transportation usually covers multiple jurisdictions, therefore the IMO has to be responsible for regulations on the prevention of shipping pollutant (Fagerholt et al. 2015). Currently, the IMO has issued three types of green shipping policies to regulate emissions from shipping, i.e., the technical, operational and the Market-based measures (MBMs).

From the technical point of view, the new ship EEDI has been introduced by the IMO, which is designed to measure the shipping emissions generated by unite freight volume in designing a new ship (IMO 2009b, 2012). For the incumbent ships, the Ship Energy Efficiency Management Plan (SEEMP) has been proposed to restrict emissions (IMO 2009a), in which the EEOI is introduced to reflect ships' energy efficiency level. In addition to the operation and technical measures, various MBMs have also been introduced such as the emissions trading scheme and the carbon tax proposal (Wang, Fu, and Luo 2015;Lee, Chang, and Lee 2013). It aims to motivate industrial organizations to use up-to-date practical measures to reduce emissions (European_Commission 2013;IMO 2014).

In addition to above three types of policies in emission reduction, speed is also a key factor in the shipping transportation (Psaraftis and Kontovas 2013). In general, the speed of ships is generally slower than other transportation modes and it usually lasts 1-2 months for long-distance trips. Therefore high speed is significant during boom periods as it increases transportation volumes and revenues by faster delivery (Psaraftis and Kontovas 2013). The fuel consumption from ships can be significantly reduced with a lower shipping speed (Stopford 2009) as it is a cubic function of the speed. In line with the plethora of studies analyzing the role of slow steaming (Woo and Moon 2013;Ferrari, Parola, and Tei 2015;Doudnikoff and Lacoste 2014) and optimized ship speed (Fagerholt et al. 2015;Du et al. 2019) in emission abatement under different green shipping scenarios, the Third IMO GHG Study (IMO 2014) reported that slow steaming has been widely adopted during 2007–2012. It is estimated that the average speed reduction in at-sea speed was 12% (IMO 2014).

From the practical perspective, an important reason for operators considering speed reduction is the increasing of the fuel price, especially under the current market and environmental considerations (Psaraftis and Kontovas 2013). Figure 1 illustrates the trends of the bunker price from 1973 to May, 2018 for 180st, 380cst, Gas Oil, Marine Diesel Oil (MDO) and Marine Gas Oil (MGO) from different locations. The bunker price has witnessed a remarkable increase from the early 2000s and the price during 2010 to 2013 is almost six times higher than ten years ago. Currently, although there is a sharp decrease in 2014, it is still three times higher than that in1990s. As discussed by Stopford (2009) and Ferrari, Parola, and Tei (2015), the fuel cost accounts for the largest proportion of a ship's operating costs. In addition, the impact of speed on fuel consumption is nonlinear, i.e., a ship with a faster speed emits much more than that with a slower speed. Therefore, the bunker price is actually a very important factor impacting shipping emissions.

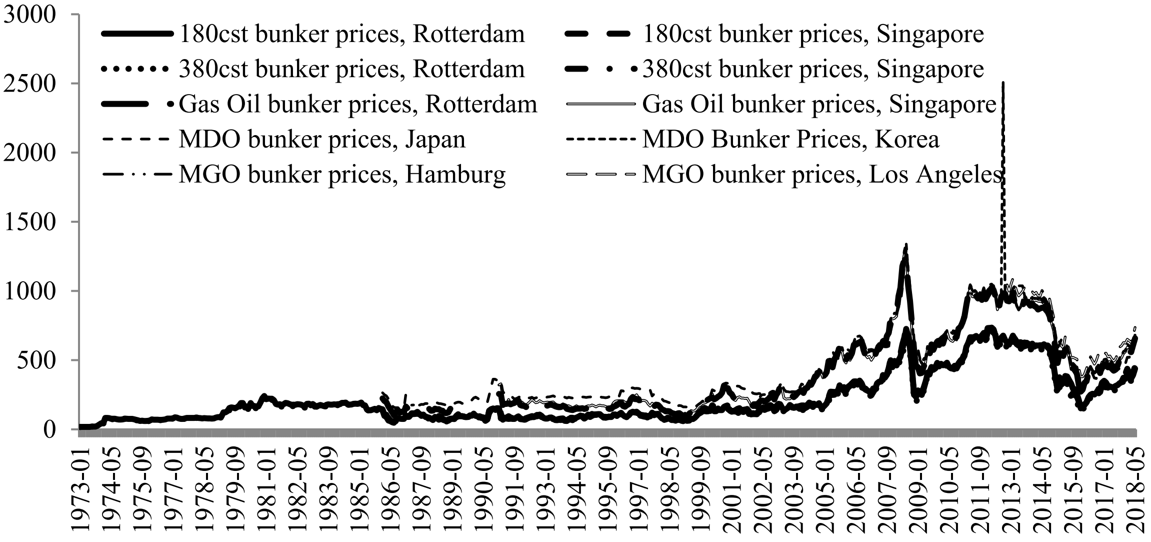

Figure 1. Trend in fuel prices (US$/tonne)
Source: Clarksons Shipping Intelligence Network (Clarksons 2018).

A new progress in the green shipping market is the issue of the Global Sulphur Cap 2020 regulation (IMO 2018) On 26 October, 2018. It requires a lower sulphur content of 0.5% in the fuel instead of the current 3.5% from 1 January, 2020 globally. Although there are few studies have been carried at present, it is obvious that this sulphur cap 2020 will definitely impact the fuel price and shipping emissions when it comes into force.

3. Interactions among Green Shipping Policies

To investigate the structural inter-correlations among various emission abatement policies and measures, the effect between two pairs of policies are specified in Figure 2, which is used as the input to the systematic model. It is worth noting that this study just focuses on the seven key measures discussed above to illustrate the interaction mechanisms among the green shipping regulations. It can be extended by considering various other factors along with different research goals and scopes.

As the focus of the systematic model is to reduce emissions from the shipping industry, we denote V_1 as the shipping emission volume and put it in the middle of the system diagram. Since shipping emission is seriously concerned by the public, we include the environmental quality as variable V_2. It is obvious that V_1 impacts V_2 negatively, i.e., if the shipping emission volume increases, the environmental quality will decrease. So, there is a "-" sign on the line from V_1 to V_2, i.e., V_1V_2=-1.

As mentioned above, speed is an important factor in maritime transportation (Psaraftis and Kontovas 2013). A ship with slow steaming can significantly reduce emissions than those with higher speeds. Many shipping companies have chosen to slow down their shipping speed instead of laying up some of the vessels. According to the Third IMO GHG Study, the average speed reduction relative to design speed was 12% during 2007 to 2012 (IMO 2014). In Figure 2, the slow steaming measure is denoted as V_3. It is obvious that the current emission situation has led to various international regulations on emission control. Therefore, a positive relation is proposed between shipping emission and slow steaming (IMO 2010, 2014). So, V_1V_3 is positive.

Although slow steaming can help reduce emissions for individual ships or voyages (Woo and Moon 2013;Fagerholt et al. 2015;Corbett, Wang, and Winebrake 2009), it recently suffered various criticisms for its ineffectiveness in emission reduction from a macroeconomic perspective (Doudnikoff and Lacoste 2014). The Third IMO GHG Study analyzed that "A reduction in speed and the associated reduction in fuel consumption do not relate to an equivalent percentage increase in efficiency, because a greater number of ships (or more days at sea) are required to do the same amount of transport work" (IMO 2014). because of these controversial discussions on the effectiveness of slow steaming on emission reduction, the model in Figure 2 does not include the impact of V_3 on V_1 or V_2.

Currently, the most discussed polices in shipping emission restriction are the EEOI and EEDI, which are denoted as V_4 and V_5 separately. As they are designed to reduce emissions, the paths of V_4V_1 and V_5V_1 are both negative. Meanwhile, they also connect with other factors. However, Different with all the other effects between any two variables in the model, the signs of V_3V_4 and V_4V_5 are actually not sure. Currently, no studies or practical facts have discussed these correlations. Therefore, we propose the following two propositions:

Proposition 1: the slow steaming activity can facilitate the implementation of the EEOI policy, i.e., V_3V_4 is positive.

Proposition 2: the adoption of the EEDI policy leads to a condition improvement for the implementation of the EEOI policy, so V_4V_5 is positive.

As bunker consumption is one of the most important parts in operating a vessel, bunker price is also considered in this model, which is denoted as V_6. It is naturally derived that a higher bunker price will lead to a reduction in fuel consumption and result in the decrease of shipping emissions according to economics theory. So, V_6V_1 is negative. Similarly, from economics perspective, the higher the bunker price, the lower the ship speed as ship speed cubically impacts bunker consumption (Stopford 2009). Therefore, V_6V_3 is positive. In addition, it is naturally derived that the increase of the bunker price will positively motivate the enforcement of the EEDI and EEOI policies as a high bunker price will bring pressure to improve fuel efficiency. Therefore, V_6V_4 and V_6V_5 are both positive.

On 26 October, 2018, the IMO made a new amendment to support consistent implementation of the 0.5% limit on sulphur in ships fuel oil (IMO 2018), which is designed to benefit for the environment and human health and will be enforced from 1 January, 2020 (IMO 2018). Denote V_7 as the sulphure cap 2020 policy, it is obvious that it will help decrease the shipping emission after it is implemented, therefore, V_7V_1 is negative. Meanwhile, the adoption of the sulphur cap 2020 will definitely increase the bunker price as low sulphur content bunker oil requires capital investments in refinery modifications (Chu Van et al. 2019). So, V_7V_6 is positive.

Finally, although there is no consensus on how to carry out the MBMs policy yet, many researchers agreed on the significance of MBMs on emission abatement (Wang, Fu, and Luo 2015;Lee, Chang, and Lee 2013;Shi 2016;Heitmann and Khalilian 2011). So, V_8V_1 is negative. It is also discussed that a MBM is necessary to supplement the technical and operational policies to achieve effective emission reduction (Shi 2016). Therefore, we propose the deterioration of the environmental quality demands for the implement of the MBMs policy (V_2V_8 is negative), i.e., the continuous deteriorating of the environment will urge various institutions and governments to compromise on the adoption of the most suitable MBMs to help reduce shipping emissions.

Figure 2 is an illustration of the structural connections between various policies and measures, which is used as the input to the pulse analysis in next section.

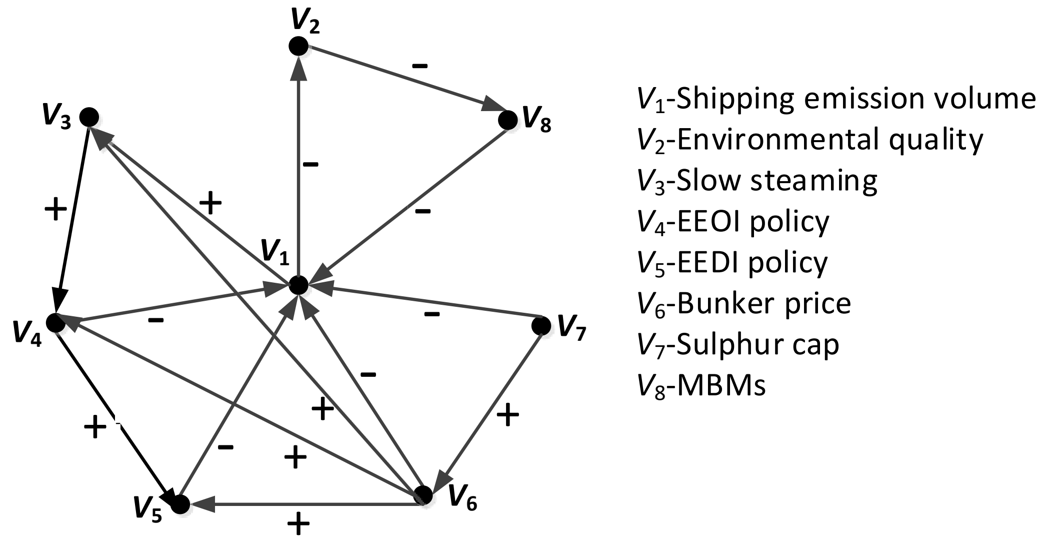

Figure 2: Structural connections of measures impacting shipping emissions.

4. Impulse Analysis of the System and Discussion

To analyze the inter-correlations between variables, we denote matrix A==(a_{ij}) as:

$$a_{ij} = \begin{Bmatrix} 1, & if\ V_iV_j\ is\ positive \\ -1, & if\ V_iV_j\ is\ negative \\ 0, & if\ V_iV_j\ is\ zero \end{Bmatrix} \tag{1}$$

Then, Figure 2 can be represented by the matrix in Equation (2). Actually, it will be more significant if we can calculate the actual effect of each variable on other variables. For example, V_1V_3=0.1 suggests a 10% (or 1 unit) decrease of the ship speed if the emission increase 1% (or 1 unit). However, the effect values are relatively difficult to obtain currently. So, we just focus on the directional adjacency matrix, A, in this study.

$$A = \begin{bmatrix} 0 & -1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{2}$$

4.1 The Pulse Process

To investigate the effect of a sudden change of a variable on the evolvement of the system, $V_i(t)$ is denoted as the value of variable V_i at time t, and $P_i(t)$ is denoted as the change of V_i at time period t, which is called a **pulse**. It is obvious that,

$$V_i(t+1) = V_i(t) + P_i(t+1),\ i = 1,2,\dots,8,\ \ t = 0,1,2,\dots \tag{3}$$

$$P_j(t+1) = \sum_{i=1}^{8} A_{ij} P_i(t)\,,\ j = 1,2,\dots,8,\ \ t = 0,1,2,\dots \tag{4}$$

Denote $V(t)=(V_1(t),V_2(t),\dots,V_n(t))$ and $P(\mathrm{t})=(P_1(t),P_2(t),\dots,P_n(t))$, then Equation (3) and (4) can be illustrated as,

$$V(t+1) = V(t) + P(t) \tag{5}$$

$$P(t+1) = P(t)A,\ t = 0,1,2,\dots \tag{6}$$

Without loss of generality, we suppose

$$V(0)=P(0). \tag{7}$$

If we impose a pulse at the initial time, the values of $P(t)$ and $V(t)$ at any t can be calculated using Equation (5) to (7). This system evolvement caused by imposing one or more pulses at the beginning is called a **Pulse Process**. It is called **Simple Pulse Process** if there is only one pulse, i.e., only one variable whose initial P value is 1 or -1.

4.2 Stability of the Pulse Process

As discussed in Jiang, Xie, and Ye (2013), when there is a pulse at t=0 (a variable is changed to 1 or -1), if all the values of the variables in the system do not change infinitely at any time, the process is denoted as stable. More precisely, for all the i (variables) at any time t, if $|P(t)|$ is finite, it is called **Pulse Stable,** and if $|V(t)|$ is finite, it is called **Value Stable**.

According to Equation (5) and (6), it is obvious that the stability (pulse stable or value stable) of the system is determined by the eigenvalue (λ) of matrix A. Lucas (1996) has proposed the following theorems to ensure the stability of the pulse process.

Theorem 1: the necessary condition for the pulse process to be pulse stable is $|\lambda| \leq 1$.

Theorem 2: the sufficient condition for the pulse process to be pulse stable is $|\lambda| \leq 1$ and the characteristic roots are all single roots.

Theorem 3: the sufficient and necessary condition for the pulse process to be value stable is that the process is pulse stable and $|\lambda| \neq 1$.

According to Theorem 1 to 3, the stability of the systematic model in Figure 2 can be checked by calculating the eigenvalue of matrix A. The characteristic polynomial for matrix A can be derived as:

$$f(\lambda) = \lambda^4\left(\lambda^4 + 2\lambda + 1\right) \tag{8}$$

Since $f(-1)$=0, this systematic model is not value stable according to Theorem 3. To illustrate the evolvement of this unstable system, Figure 3 draws the values of each variable from time period 0 to 50 when there is a sudden change in the EEOI policy, i.e., $P(0)$=(0 0 0 1 0 0 0 0). The value of $P(1)$ can be calculated using Equation (6), and then

V(1) can be calculated using Equation (5). Using these recursive equations, all the values of each variable at any time can be calculated and which are drawn in Figure 3.

The horizontal axis of Figure 3 represents the time period and the vertical axis is the value of each variable. As the values of each variable will change infinitely with time, the system model is not stable, i.e., when there is a change in a variable (here we propose a stricter regulation on the EEOI policy), all the variables will increase or decrease infinitely to a very large number. This obviously cannot represent the reality, i.e., no practical policy can play such a continuous role on the movement of the system.

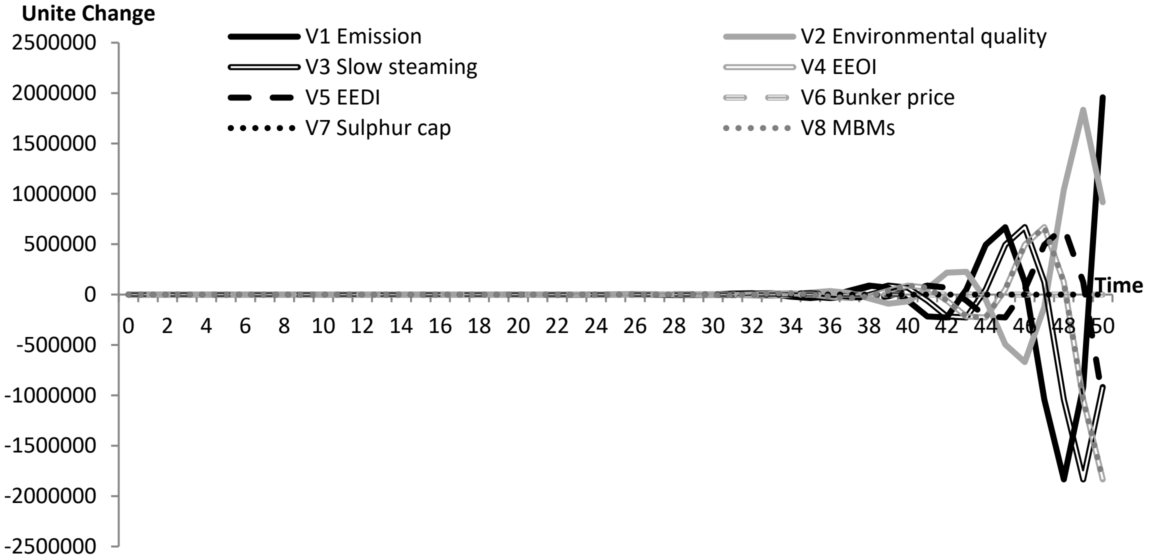

Figure 3: Unstable system evolvement with a pulse in V_4 (EEOI).

4.3 Adjustment of the Pulse Process

To convert an unstable process to a stable one so that it satisfies Theorem 1-3, the values in matrix *A* must be adjusted. Although there is no general conclusion to help transform an adjacent matrix system to a stable pulse process, there are some methods that can be applied to some special matrix systems. Among them, one is called **Advanced Rosette** (Jiang, Xie, and Ye 2013), in which there are bi-directional connections in a diagram and a central vertex exits on all closed circuits just like the diagram in Figure 2. Here, a closed circuit is a path from a vertex to other points along their directional edges without repeating and finally goes back to the starting vertex.

In Figure 2, V_1 is the vertex, V_1V_2, V_2V_8 and V_8V_1 comprises a closed circuit, $V_1V_2V_8V_1$. The number of the directed edges is called the **length** of the closed circuit. So, the length of closed circuit, $V_1V_2V_8V_1$, is 3. If the number of negative directed edges is an odd number, then the **sign** of this closed circuit is -1, otherwise it is +1. Let us denote a_k as the summation of all the k-edges closed circuits. Then, r is the largest number that satisfies $a_r \neq 0$. Therefore, the stability of an advanced rosette diagram can be determined by the value of $\{ a_1, a_2, \ldots, a_r\}$ with the following theorem (Lucas 1996):

Theorem 4: the necessary condition for an advanced rosette diagram system to be pulse stable is

$$a_r = \mp 1 \tag{9}$$

$$a_k = -a_r a_{r-k}, \quad k = 1,2, \ldots, r-1. \tag{10}$$

Theorem 5: the sufficient and necessary condition for an advanced rosette diagram system to be value stable is

$$\sum_{k=1}^{r} a_k \neq 1 \tag{11}$$

Theorem 4 and 5 can be used to find the violations in the system, so that the unstable system can be transformed to a stable one. Seeing from Figure 2, there is no circuit with one- and two- edges paths, so $a_1=0$ and $a_2=0$. There are two 3-edges closed circuits, which are $V_1V_3V_4V_1$ and $V_1V_2\ V_8V_1$. As the signs of these two circuits are both –1, so $a_3=-2$. Similarly, there is one 4-edges closed circuits, which is $V_1V_3\ V_4\ V_5V_1$. Since the sign of this closed path is -1, so a_4=-1. Because a_k=0 for all the k>4, so r=4. We finally get the serial of {a_1, a_2, a_3, a_4} = {0, 0, -2, -1}.

According to Equation (9) and (10), it must satisfy the following equations to be stable:

$$a_1 = -a_4 a_3 \tag{12}$$

$$a_2 = -a_4 a_2 \tag{13}$$

$$a_3 = -a_4 a_1 \tag{14}$$

Obviously, Equation (13) is satisfied. To meet the requirements of Equation (12) and (14), we can only change a_3 to 0. Seeing from Figure 2, the signs along the 3-edges closed circuit of $V_1V_2\ V_8V_1$ cannot be changed. Similarly, the signs of paths V_1V_3 and V_4V_1 are determined according to reality. The only path we can change is V_3V_4. This suggests that **Proposition 1** is rejected. Actually, a negative impact of slowing steaming on the implementation of EEOI is more reasonable, as it will motivate public agencies to consider of the enforcement of EEOI if the ship speed cannot be slow down. Then, a_3 is 0 now. Since the sign of the path from V_3 to V_4 has been changed, the sign of the 4-edges circuit is also change to +1, i.e., a_4=1. The serial of {a_1, a_2, a_3, a_4} is changed to {0, 0, 0, 0, 1} and Equation (12) and (14) are all satisfied.

Above analysis can only ensure this advanced rosette diagram system to be pulse stable. According to Theorem 5, the summation of the a_is should not equal to 1 for the system to be value stable. Seeing from Figure 2, there is only one 4-edges closed circuits, which is $V_1V_3V_4V_5V_1$. The only path that can be changed is V_4V_5 without influencing other variables. Therefore, **Proposition 2** is also rejected. Similar to the change of V_3V_4, the negative effect of EEOI to the EEDI policy indicates the less pressure in adoption of the

EEDI policy if the EEOI policy is successful. By changing the positive sign from V_4V_5 to negative, the serial of a_i changes to {0, 0, 0, -1} and all the Theorems are satisfied now.

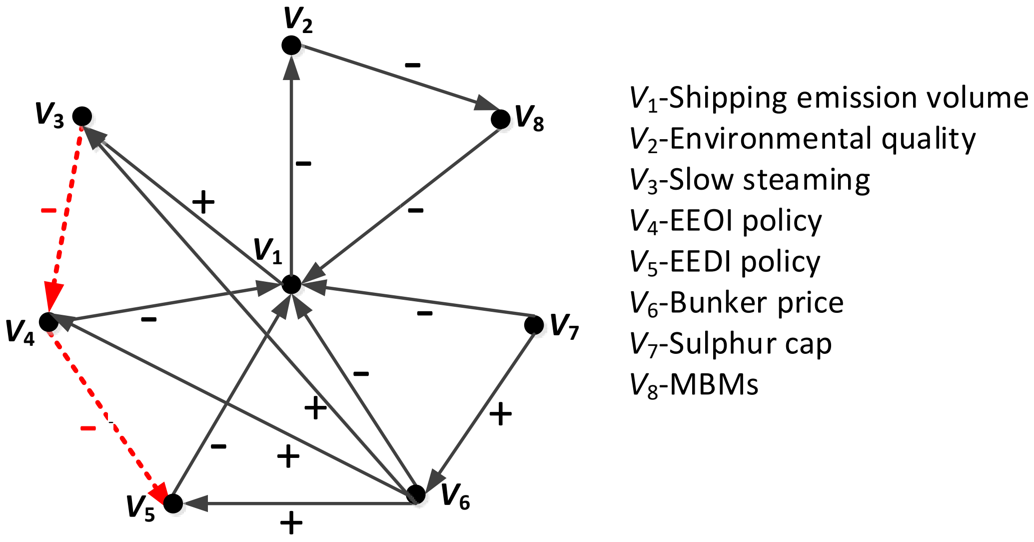

Figure 4: Adjusted structural connections of measures affecting shipping emissions.

According to above Theorems, the shipping emission system illustrated in Figure 4 is a stable pulse process, i.e., under any sudden changes of any variables in the system, the values of all the variables in the following periods are finite.

5. Discussion of the Pulse Process

5.1 Simple pulse processes

To illustrate the evolvement of the variables in the system, we draw the variables at different periods when there is a simple pulse in each of the variable (Figure 5-11). Figure 5 is the pulse process of V_2 (Environmental quality). When the environmental quality deteriorates in time 0 ($P_2(0) = -1$), it will bring some pressure to the implementation of the MBMs policy directly at time 1 ($V_8(1)=1$), which will reduce the shipping emission ($V_1(2)=-1$) in turn. The pulse will then transmit to the adoption of slow steaming at time period 3 ($V_3(3)=-1$). However, the negative value suggests the relieved pressure on the slow steaming practice. According to the systematic model illustrated in Figure 4, the deterioration of the environment brings pressure on the adoption of the MBMs which in turn relieves the requirement of slow steaming practice. The pulse transmits to EEOI ($V_4(4)=1$), and EEDI ($V_5(5)=-1$) at the following time periods gradually. As the values of the variables are inter-determined, the system will fluctuate periodically within [-1,1].

It worth noting that the bunker price V_6 and the sulphur cap policy V_7 are not impacted in this scenario ($V_6(t)=0$ and $V_7(t)=0$ at all periods). Finally, all the variables will fluctuate between -1 and 1 periodically.

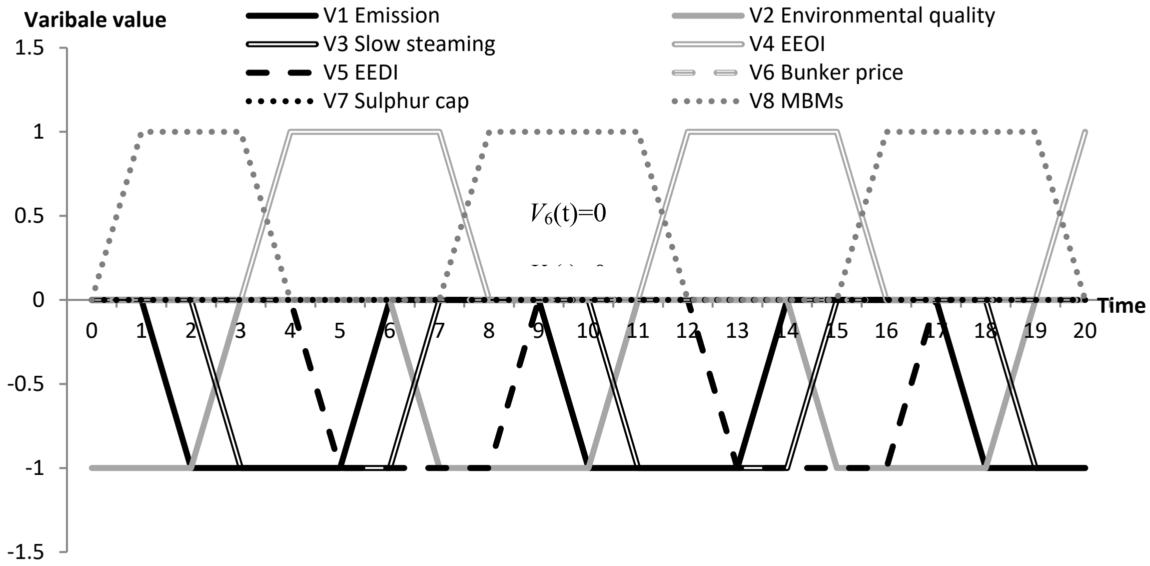

Figure 5: System evolvement with a pulse in V_2 (Environmental quality).

When there is a pulse in V_3 (slow steaming), the system will move significantly as illustrated in Figure 6. As analyzed above, the active slow steaming practice may relieve the pressure on imposing the EEOI policy ($V_4(1)=-1$) and it in turn impacts the implement of the EEDI ($V_5(2)=1$) policy. It then deteriorates the environmental quality ($V_2(3)=-1$). In the following periods, the pressure on the EEOI policy is further relieved ($V_4(4)=-2$), and the pressures on the EEDI is increased ($V_5(5)=2$). It is worth to mention that, the shipping emission is increased in period 2, and then reduced to 0 an -1. It then fluctuates between -1 and 1. This suggests the ineffectiveness of slowing steaming in emission reduction.

Although different methods have been employed, this study gets the similar result with Doudnikoff and Lacoste (2014), where the authors found that the total emissions are increased through slowing down within SECA and speeding up outside SECA for shipping companies to maintain a fixed service frequency.

Seeing from Figure 5, the effect of slowing steaming on other policies will then further increase the pressure on the adoption of slow steaming at time period 3 ($V_3(3)=2$). This also suggests the ineffectiveness of slow steaming in reducing emissions in the shipping industry. This explains the popularized slow steaming practice in the shipping industry (IMO 2014). However, this result suggests that it is actually not effective in reducing emissions. Therefore, it points out a higher demanding for the adoption of the EEDI policy, which could be more effective in emission reduction in the long-run as the demanding of the EEDI policy is increasing ($V_5(2)=1$ and $V_5(5)=2$).

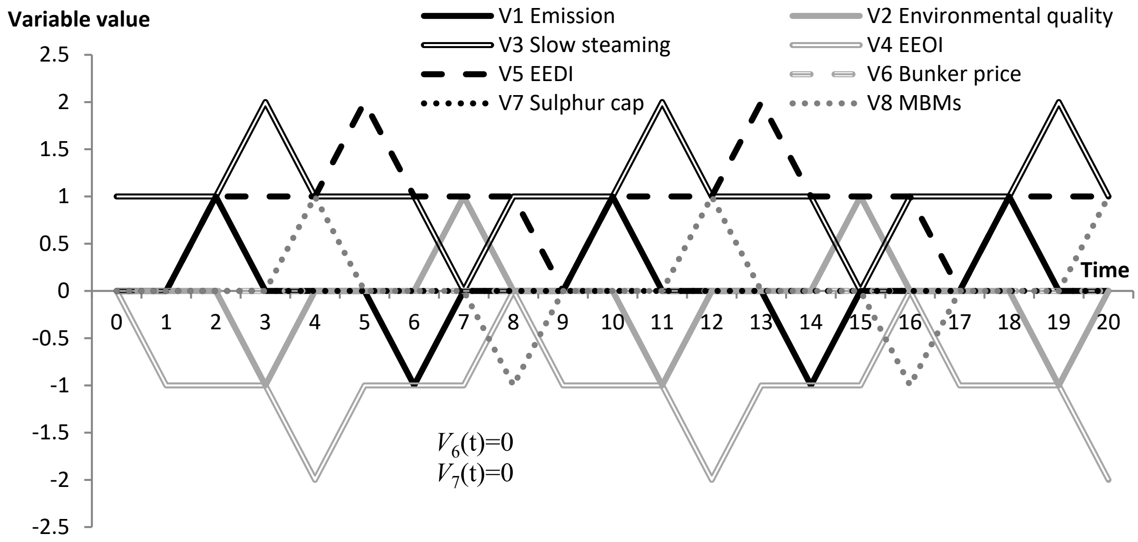

Figure 6: System evolvement with a pulse in V_3 (Slow steaming).

The dynamics of the system variables with a pulse in the EEOI (V_4) policy are illustrated in Figure 7. Similar to the slow steaming pulse process, the emission reduction is also fluctuated between -1 and 1. It also indicates the ineffectiveness of the EEOI policy if it is implemented alone.

The implementation of the EEOI policy will relieve the demanding of the EEDI policy as discussed previous as the values of V_5 are negative (V_5(t)=-2, -1 and 0). Similarly, it also decreases the pressure on the adoption of the slow steaming practice at some periods as the value of V_3 at time period 2 is -1.

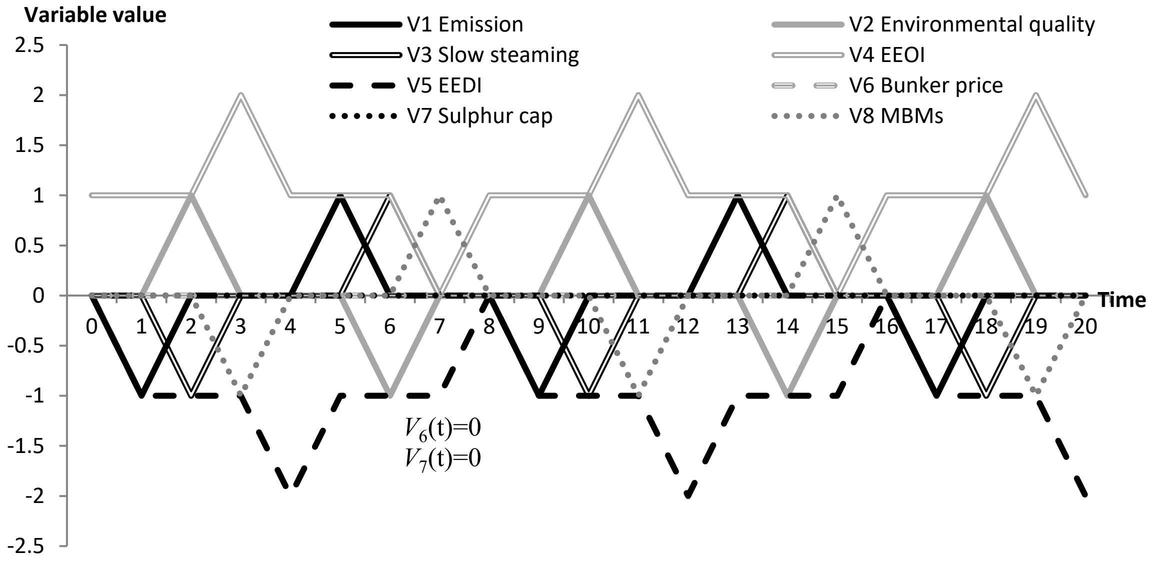

Figure 7: System evolvement with a pulse in V_4 (EEOI).

Figure 8 illustrates the dynamics of the system when there is a pulse in the EEDI policy. It will decrease the emission level (V_1(t=[1,4])=-1) and improve the environmental quality (V_2(t=[2,5])=1) at most of the periods. However, the improved shipbuilding technology motivated by the imposed EEDI policy will relax the demand for slow steaming. This is indicated by the lowered relatively stable level of the slow steaming variable (V_3(t=[2,5])=-1). Similar to this, the improvement in shipbuilding will improve the operation of the ship and smooth the adoption of the EEOI policy as the values of the EEOI variable at most time periods are positive (V_4(t=[3,6])=1).

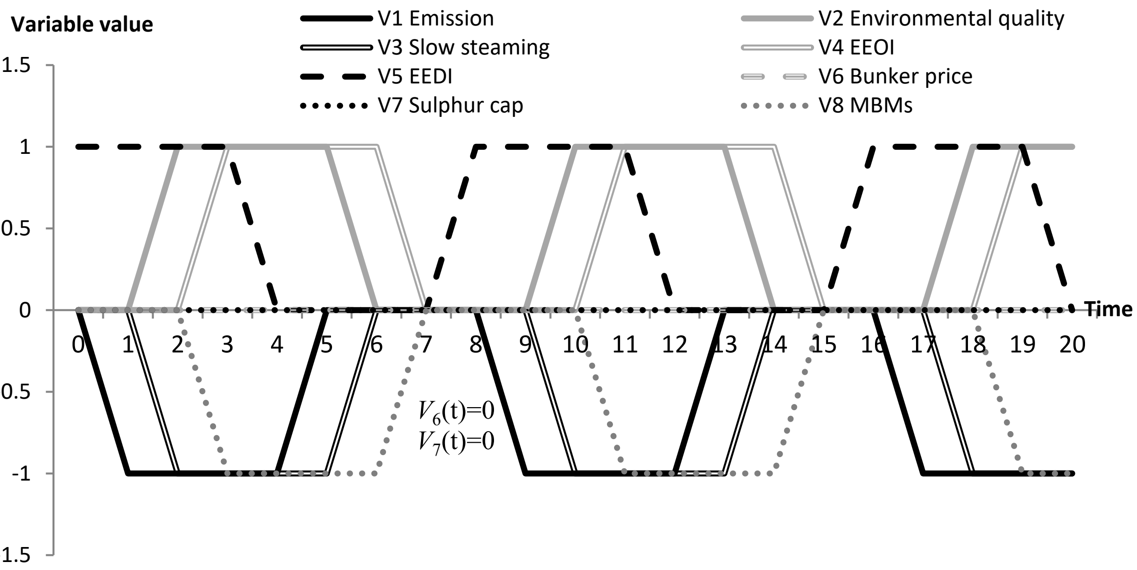

Figure 8: System evolvement with a pulse in V_5 (EEDI).

When there is a pulse in V_6 (bunker price), the dynamics of the system is more significant (the largest values are bigger), which is drew in Figure 9. It keeps decreasing the shipping emissions in the first two periods. After that it gradually returns to its original level ($V_1(8)=0$). The fluctuation of the environmental quality is the same.

It generally motivates the adoption of the EEOI policy (the values of EEOI are positive) and reduces the ships' choices of the slow steaming practice (the values of Slow steaming are negative). Its impacts on the EEDI policy is also changing from positive to negative, but there are more positive effects within a cycle. This suggests the pressure for the shipbuilding industry in technology development to satisfy emission regulations in dealing with the high bunker price.

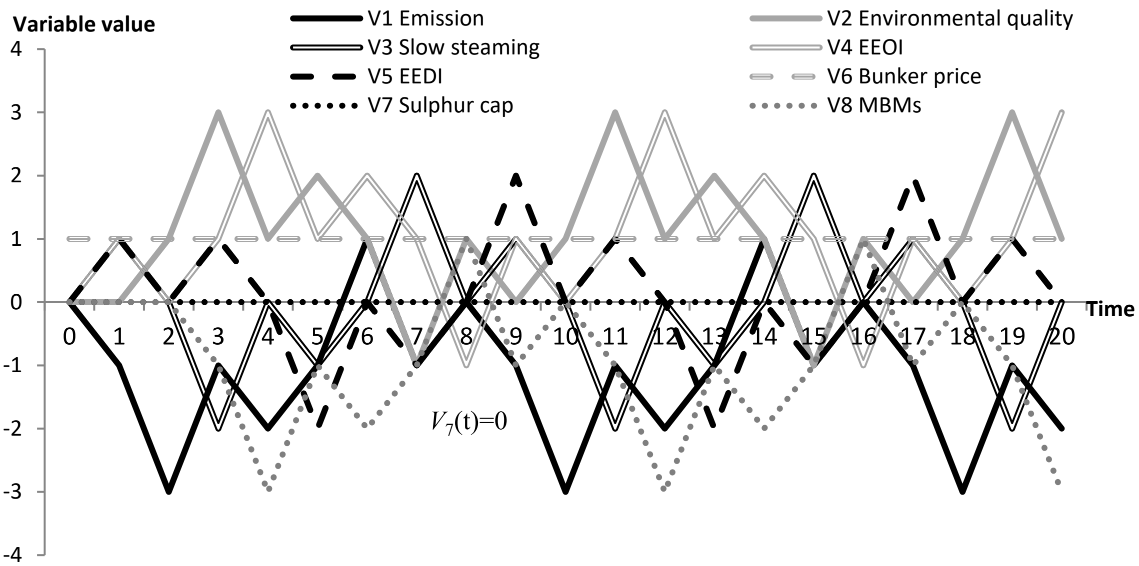

Figure 9: System evolvement with a pulse in V_6 (Bunker price).

The pulse process of the sulphur cap policy is illustrated in Figure 10. It is obvious that the sudden adoption of the sulphur cap policy will increase the bunker price (V_6(t>0)=1).

Its impacts to all the other variables are gradually expanded, and then diminished. In summary, the implement of the sulphur cap policy can help increase the environmental quality, bunker price and the adoption of the EEOI policy, while, it relieves the adoption of the slow steaming practice and the EEDI policy and MBMs as the sulphur cap policy is expected to have a significant role in reducing shipping emissions.

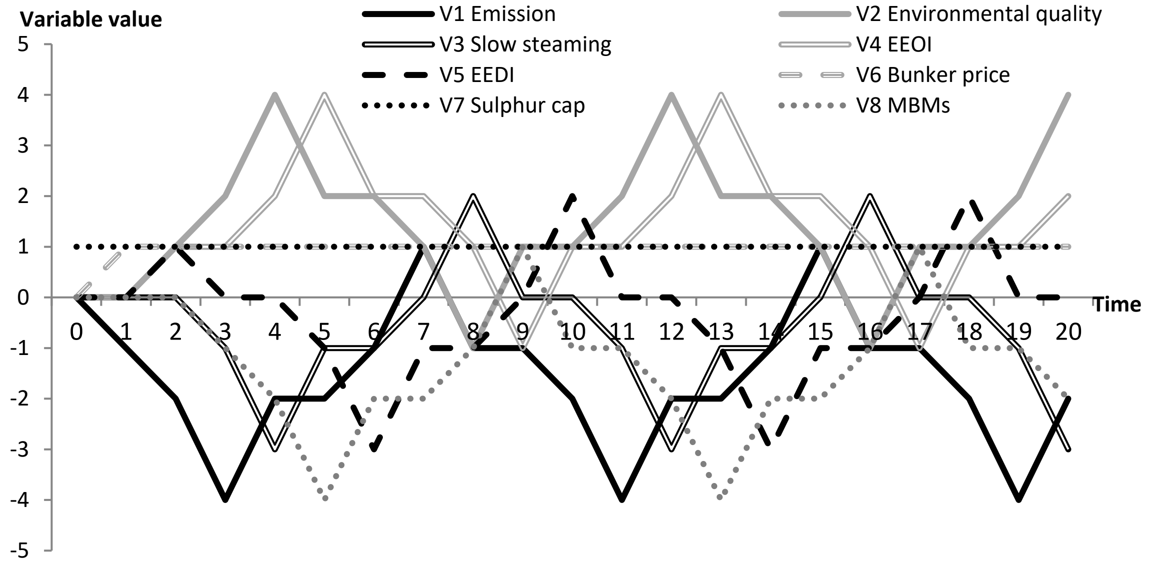

Figure 10: System evolvement with a pulse in V_7 (Sulphur cap).

The effects of an impulse in the MBMs policy are illustrated in Figure 11. First of all, it decreases the shipping emission (V_1(t=[1,4])=-1). Similar with other pulses, the impacts on the EEDI and EEOI policies are opposite. The effect on slow steaming at most of the periods are negative, which suggests the relieved pressure on adopting the slow steaming practice.

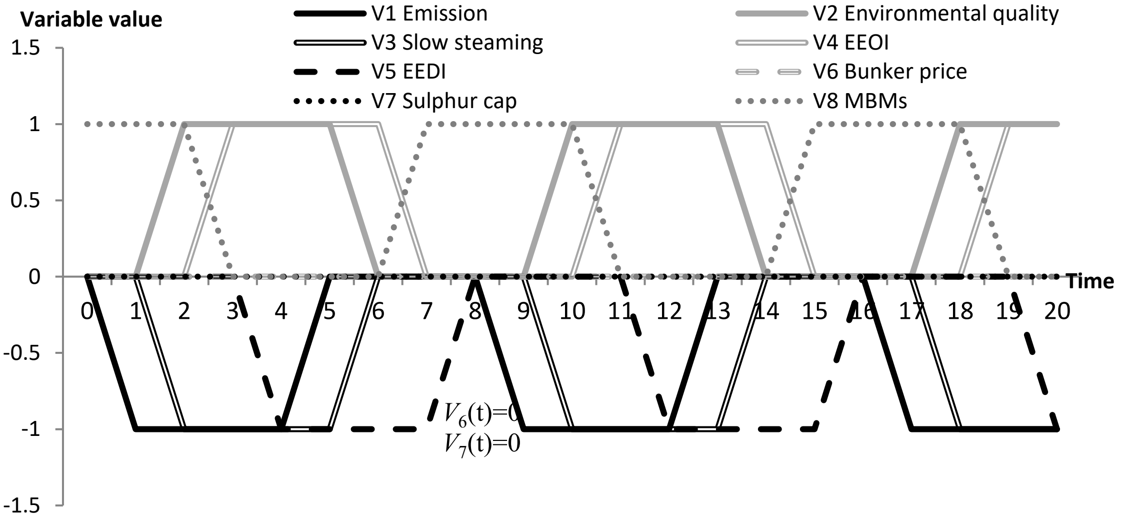

Figure 11: System evolvement with a pulse in V_7 (MBMs).

To summarize, the emissions from each pulse are drawn in Figure 12. It is obvious that all the pulses have positive influence on the decrease of shipping emissions except the slow steaming practice and the EEOI policy (the positive effect can be canceled by the negative effect). The sulphur cap policy and the increase of bunker price have the biggest impact on emission decrease. Since the initial input of the system is the directional impact between variables, not their actual value effects, the values in Figure 12 can only be used to suggest the evolving direction of the variables.

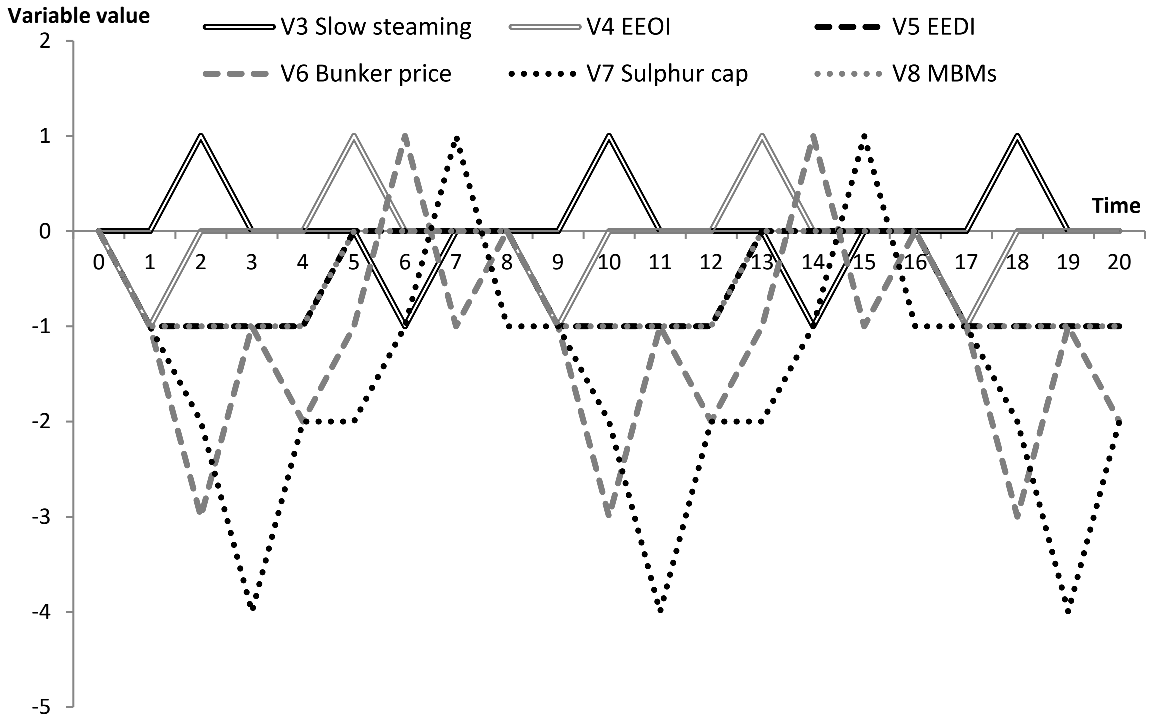

Figure 12: Emission dynamics under various pulses.

5.2 Multiple pulse processes

Above discussion only contains one pulse or change of one variable each time. If there are multiple changes for different variable at the beginning, we can get a **Multiple Pulse Process**. Suppose there are strict requirements on all the policies or measures from V_3 to V_8 currently (as V_1 the shipping emission volume and V_2 environmental quality are not policies or measures, they are not included in this multiple pulse process analysis). Then, the initial pulse values for V_3 to V_8 are 1, i.e., $P(0)=(0,0,1,1,1,1,1,1)$. The observed multiple pulse processes are reported in Figure 13. The following results can be observed:

1) The systematic shipping emission model is not stable at fixed values as the variables are inter-dependent. It will fluctuate within a fixed band (here it is [-7,7]).
2) The shipping emission can be reduced in a large scale shortly as the value of $V1$ decreases at the beginning, while the environmental quality can be improved accordingly seeing from the positive value of V_2. However, these significant improvements cannot keep working. It changes periodically. This result suggests that when designing a new policy, decision makers should take this fluctuation effect into consideration as this may restrain its setting goal.
3) The value of EEOI (V_4) are positively fluctuates. This suggests that the complicated inter-correlations between policies will lead to a higher requirement on adopting the EEOI policy. Since all the other policies, i.e. slow steaming (V_3), EEDI (V_5), higher bunker price (V_6), sulphur cap (V_7), and MBMs (V_8), are designed to actually reduce emissions from building to operating a vessel, while, the EEOI policy is designed to monitor the operating of ships.

   Currently, the IMO has included a guideline of using EEOI as a helpful tool to monitor the operational efficiency of a ship (IMO 2009a). Only when this policy is more strictly imposed by IMO and all port authorities, such as ships cannot be allowed to access a port with lower EEOIs, the benefits brought by all the other policies or measures (slow steaming, EEDI, bunker price, sulphur cap and MBMs) can be effectively carried on.

4) In the current systematic model, the bunker price (*V_6*) and the sulphur cap policy (*V_7*) are exogenous factors. They may be impacted by the oil production industry or the IMO's governance, not the other policies or measures considered in this study. Their values are stable in the system.

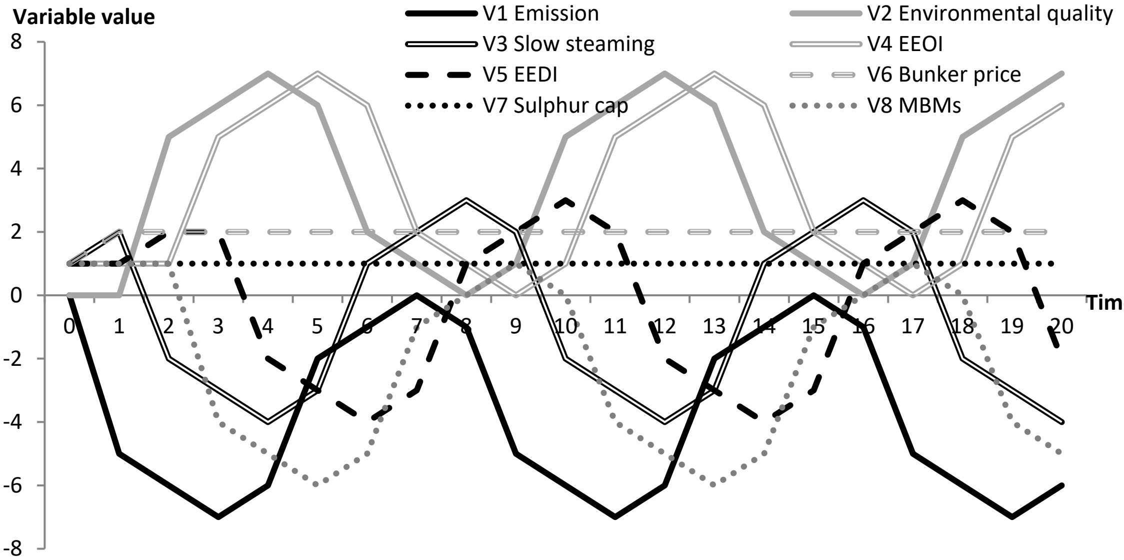

Figure 13: Emission dynamics under multiple pulses.

6. Conclusion

With the rapid growth of the international maritime transportation, the shipping emission has aroused significant attention from international communities, maritime authorities, trade associations and academic scholars recently. Broadly saying, there are two types of policies and measures in the shipping industry. The most important one relates to policies issued by the IMO. For example, the several amendments of MARPOL 73/78/97 (IMO 1997). It was revised again in 2008 with some specified approaches and phases to stringently control shipping emissions in the revised Annex IV (IMO 2008). The IMO also set a goal of reducing the GHG emissions by 20-50% by 2050 (IMO 2014). The other type of policies and measures are those issued by port authorities or related associations. For example, the requirements of using shore power facilities for berthing ships.

Since those policies and measures are interconnected, this study investigates the interactions of the emission abatement policies and measures in a systematic model by considering their structural correlations. By introducing the definition of the pulse process and its stability, it discusses the adjustment of the shipping emission system and the Proposition 1 and 2 are rejected by the model. These suggest that the effects of slow steaming practice on the EEOI policy and the EEOI policy on the EEDI policy are both negative.

The dynamics of the system is then discussed when there is a pulse in each of the variable. The results suggest: 1) the shipping emission model is a dynamic system, in which variables are inter-dependent. The values of the variables fluctuate periodically within a band. 2) the slow steaming practice is actually not effective in emission reduction in the long-run. It poses a positive pressure on adopting the EEDI policy to reduce emissions in the long-run. 3) although the implementation of the EEDI policy can promote the adoption of the EEOI policy, the EEOI policy actually relieves the demanding for the EEDI policy. 4) the effects of the sulphur cap regulation and the bunker price on emission reduction are larger (in direction) than other measures. 5) the current joint implementation of various policies results in a higher demanding for the adoption of the EEOI policy, which can help monitor and ensure the effectiveness of other policies.

The analytical discussion of this study provides some fundamental understanding of the green shipping policies. Different with previous studies, the discussion is from a macroeconomic level in which the polices and measures are analyzed in a system model. Very importantly, the pulse analysis considered in this study can help predict the effects of the polies on emission abatement and other policies. This could help the decision-making process before implementing new polices or measures as it can simulate the effect dynamically and predict its actual role. This study is also subject to several limitations, which may be addressed in future work. First, the current model only contains seven factors. As there are mountains of factors connecting to this topic, future studies could try to extend the model by incorporating other key variables for various objectives. Second, as mentioned in the analysis, it is impossible to obtain the actual effects between the variables currently, so we just consider the directional effects in this study. The real effects can be discussed when the mutual effects data accumulated in the future as more and more data are recorded by various agencies and companies.

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