International Journal of Economics and Finance; Vol. 9, No. 6; 2017
ISSN 1916-971X E-ISSN 1916-9728
Published by Canadian Center of Science and Education

The Evolution of Citizen Participation and Regulatory Success

Ken-Ichi Akao[1] & Geumsoo Kim[2]

[1] School of Social Science, Waseda University, Tokyo, Japan

[2] Department of Global Commerce, Hoseo University, Chonan, Korea

Correspondence : Geumsoo Kim, Department of Global Commerce, Hoseo University, Chonan City, Chungnam, the Republic of Korea. Tel: 82-41-560-8337. E-mail: gsgim@hoseo.edu

Received: April 5, 2017 Accepted: May 9, 2017 Online Published: May 25, 2017

doi:10.5539/ijef.v9n6p179 URL: https://doi.org/10.5539/ijef.v9n6p179

Abstract

In an evolutionary game setting we have shown that either perfect compliance or perfect non-compliance with a regulation can evolve as an asymptotically stable state. However, this depends critically on the size of a defector's additional payoff when there is no private monitoring to a cooperator's payoff, relative to his expected fine from an enforcer's monitoring. As an enforcer's willingness to monitor voluntarily gets affected by their relative share of the population to the defectors', the society could be stuck in the neighborhood of the initial state if many defectors already exist and a little larger than enforcers, even though the regulatory agency has a strong policy in its enforcement.

Keywords: citizen participation, evolutionary game, monitoring, regulation, social capital

1. Introduction

Laws and regulatory rules can be interpreted as social contracts made by people in a society in order to govern themselves. The central government and various regulatory agencies implement these laws and rules. However, the regulatory hand is sometimes too short to implement them at a satisfactory level given a limited enforcement budget. The regulatory agency then calls the citizens' attention to the spirit of the law and invites them to participate in monitoring any violation and work to protect it. One example is the so-called report-reward system for the illegal dumping of waste under the unit pricing system in the Republic of Korea. People have an incentive to discharge waste illegally when it comes to take a cost to dispose legally, i.e., to discharge wastes by a non-zero priced bag (Kim et. al., 2008). Government officials have monitored illegal dumping and burning, but it's been too limited to enforce it properly. After the implementation of the unit pricing five years ago, citizens were invited to work with governmental agency to monitor together for the possibility of a prize.

The willingness to accept to comply, and to enforce voluntarily against any illegal practices of a rule comprise the critical factors for the success of a regulation. However, assuming only a rational egoist, the standard economic model does not allow for these voluntary behaviors. Numerous observations and empirical evidences exist demonstrating the practice of voluntary sacrificial or altruistic behaviors. (Ostrom, 1990, 2000) Sometimes people who cooperate in a public goods situation punish free-riders, even if the punishment is costly to the cooperators (Ostrom, Walker, & Gardner, 1992; Fehr & Gaechter, 2000). These voluntary behaviors are commonly attributed to a social capital. According to the so-called second generation of social capital researchers, social capital is defined as trustworthiness among members in a society, networks and institutions. The present stock of social capital is the result of past investments in terms of time and money, and provides various benefits with the people in a present interaction in a social dilemma situation (Ahn & Ostrom, 2008). In this context, the citizens' voluntary compliance of a regulatory rule and voluntary monitoring of violation of the rule come from the present stock of a social capital.

This paper deals with governance among the regulatory agency and regulated citizens, i.e., a collaboration of the regulatory agency's public enforcement with citizens' private voluntary enforcement. This paper examines what parameter values make successful governance possible, specially focusing on social capital. In contrast to the traditional enforcement literature, we assume that there are three types of citizens with a deterministic behavior pattern, i.e., they do not take any optimizing behavior, but just act as their genetic traits command. However, each of the citizen type has an evolutionary pressure on its population share from its relative payoff to the population average. In the same evolutionary framework, Sethi and Somanathan (1996) analyze the pure private enforcement by showing under what conditions the common-resources users can cooperate to restrain their extraction efforts efficiently, and also how easily cooperation breaks down and gets in stuck in a completely non-cooperative situation (Note 1). In contrast, our focus is on the collaboration of public and private enforcement. Stranlund (1995) has a similar motivation in the sense that he compares a government assistance program for voluntary recycling with an alternative regulatory system with a public enforcement. However, he assumes that the citizen gets a utility from his or her voluntary behavior and carries an optimization.

The paper proceeds in the following order. In Section 2 we provide a basic model for an evolutionary game. In Section 3 we characterize the long-run steady states and their stability. Section 4 highlights the role of social capital and analyzes its effect on the final equilibrium. Finally Section 5 makes some concluding remarks.

2. The Model

There are N citizens which are normalized to 1, assuming there are three types of citizens, namely cooperators, defectors and enforcers, indexed by 1, 2, and 3, respectively. Denoting the population (and population share) of the citizen i by s_i, we have $\sum s_i = 1$. A cooperator always complies with the rule, while a defector always violates the rule (Note 2). An enforcer always complies with the rule and additionally monitors the defectors' violations and reports it to the regulatory agency. The regulatory agency also monitors the defectors' violations, receives the citizen enforcers' reports, and compensates them with a reward. However, the official monitoring activity, and the size of the fine and reward are all given exogenously outside of the analysis. Each of the citizen players is genetically programmed to behave in a deterministic pattern as an organism does in the natural world. Each individual player does not optimize anything in our setting.

In each period, the players are assumed to be randomly matched and carry out one unit of either legal or illegal transaction for a benefit B_i. We assume that $B_1 = B_3 = B^L$, $B_2 = B^H$, and $B^L \leq B^H$. A cost c^p is incurred by complying with the rule. So the payoff for a cooperator is as follows.

$$\pi_1 = B^L - c^p \tag{1}$$

The defectors are faced with both governmental and citizen monitoring activities that are all assumed to be statistically independent of each other. The government official's and one enforcer's monitoring probability get denoted by g and r, respectively. A defector is then faced with the total monitoring probability of $g + s_3 r$. Once caught, a defector needs to pay a fine c^I. So the payoff for a defector is as follows.

$$\pi_2 = B^H - (g + rs_3)c^I \tag{2}$$

Neither the government official nor an enforcer can monitor all of the defectors due to either a limited enforcement budget or a limited willingness. We just assume that the aggregate monitoring probability imposed on a defector is strictly less than 1.

Assumption 1: $g + rs_3 < 1$

A voluntary monitoring and report is assumed to cost an enforcer c^R per incidence of an illegal practice monitored and the reporting enforcer is compensated by a prize z. Thus the payoff for an enforcer is as follows.

$$\pi_3 = B^L - c^p - r(c^R - z)s_2 \tag{3}$$

An enforcer's monitoring activity depends on both the governmental monitoring activity, the prize and the social capital, which will be explained later more in detail. Notice from (1) and (3) that depending on the relative size of monitoring and reporting cost, and the prize, one type out of cooperators and enforcers is strictly dominated by the other (Note 3). The interesting case would be that monitoring and reporting cost is always not less than the prize, so that cooperators always dominate enforcers.

Even though the behavior pattern of the players does not change, the population shares can, depending on their relative payoffs to the population average. In other words, if the payoff of one type of players is above the average, the corresponding population increases just as the more adaptive species produces more offspring in the natural world. This is usually expressed by a replicator dynamics. So, we have the following system of differential equations:

$$\dot{s_i} = s_i(\pi_i - \overline{\pi}) \tag{4}$$

where i=1,2,3 and $\overline{\pi}$ is the average payoff. This dynamic system describes how the players (or strategies) interact to reach at steady states. Here the average payoff is in fact the population-share weighted-average, i.e., $\overline{\pi} = \sum s_i \pi_i$ and the sum of population shares is equal to 1. Using these facts, the average payoff can be rearranged as follows.

$$\overline{\pi} = (B^L - c^p) + s_2(B^H - B^L + c^p - gc^I) - rs_2s_3(c^I + c^R - z) \tag{5}$$

Then, the system of differential equations (4) can be reduced to the following two-dimensional system.

$$\dot{s_2} = -s_2[(B^L - c^p - B^H + gc^I) + s_2(B^H - B^L + c^p - gc^I) + rc^Is_3 - rs_2s_3(c^I + c^R - z)] \tag{6}$$
$$\dot{s_3} = -s_3[s_2\left(B^H - B^L + c^p - gc^I + r(c^R - z)\right) - rs_2s_3(c^I + c^R - z)]$$

3. Equilibrium and Stability

We start with the long-run consequences of the evolutionary process. Denoting $(B^H - gc^I) - (B^L - c^p)$ by **A**, we can rewrite (6) more compactly as follows in (6)'.

$$\dot{s_2} = -s_2[-A + s_2A + rc^Is_3 - rs_2s_3(c^I + c^R - z)] \tag{6'}$$
$$\dot{s_3} = -s_3[s_2\left(A + r(c^R - z)\right) - rs_2s_3(c^I + c^R - z)]$$

Here **A** can be interpreted as the payoff's difference between a cooperator and a defector without the citizens' private monitoring. We can reasonably assume that defectors strictly dominate cooperators without the enforcers' participation $(\text{i.e.}, A > 0)$, but begin to be strictly dominated by cooperators as enforcers start to participate in monitoring. Notice that the expected fine from enforcers' private monitoring a defector is faced with is rc^Is_3. These can be summarized as follows:

Assumption 2: There exists a level of an enforcer's monitoring probability $\underline{r}$ such that $0 < \underline{r} < 1$ and for $r > \underline{r}$, $A - rc^Is_3 < 0 < A$.

Assumption 2 implies that government enforcement policy measures alone are not so strong that A becomes negative (i.e., defectors get dominated by cooperators), and that the citizens' participation, together with the given government measures, can make a defector unprofitable. We will make one more assumption that the governmental prize is constrained by fines collected. Of course this does not necessarily have to be true, but this is usually what they do in practice. Additionally we need this assumption because this makes problems more interesting.

Assumption 3: $c^I - z \geq 0$. Notice that this implies $c^I + c^R - z > 0$.

Before providing a formal result, we present several observations first. Firstly, note that the coexistence of only cooperators and defectors is not plausible because in the absence of enforcers the cooperators are always strictly dominated by the defectors. Secondly, as the defectors die out for whatever reasons, the payoffs of cooperators and enforcers become the same. Thirdly, the relative size of reporting cost, prize and expected fine determines the relative payoff of the three players. Taking these observations into account we can summarize the possible steady states of the system (6)' as follows in Proposition 1.

Proposition 1: Consider the projection of the simplex $\Delta = \{(s_1, s_2, s_3) : \sum s_i = 1\}$ to s_2, s_3 plane (refer to Figure 1 below). Then, (a) the vertex $s_2 = 1$ and each point of the edge $s_2 = 0$ are steady states. With $s_2s_3 \neq 0$, $r > \underline{r}$, (b) if $c^R - z > 0$ each point of the edge $s_2 + s_3 = 1$ is a steady state and (c) if $c^R - z = 0$, each point of the line segment $s_3 = \frac{A}{rc^I}$ is a steady state.

Proof : (a) is immediate from just observing (6)'. For (b) and (c) remove A from the following equations.

$$0 = -s_2[-A + s_2A + rc^Is_3 - rs_2s_3(c^I + c^R - z)]$$
$$0 = -s_3[s_2\left(A + r(c^R - z)\right) - rs_2s_3(c^I + c^R - z)]$$

Then, we have $r(c^R - z)(1 - s_2 - s_3) = 0$

This implies that if $c^R - z > 0$, $s_2 + s_3 = 1$. On the other hand, with $c^R - z = 0$, we have $s_3 = A/(rc^I)$ from the above set of equations.

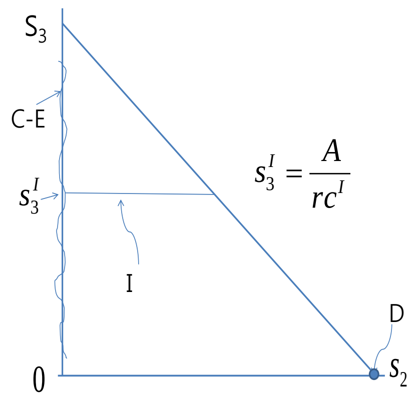

Figure 1. Population simplex and critical points

There are three different types of critical point as depicted in Figure 1. The first type $(s_2 = 1)$ is that only defectors survive. We call this D-equilibrium. At D everybody violates the rule. So a perfect non-compliance is resulted. The second type $(s_2 = 0)$ is that only cooperators and enforcers survive. So the payoffs become the same. We call this C-E equilibrium. The third type $(s_1 > 0, s_2 > 0, s_3 > 0)$ needs a little longer explanation. It is called I-equilibrium because the critical point is in the interior of the simplex. At I all the three players survive. How can this happen? With $c^R - z = 0$, $s_3 = A/(rc^I)$, which we denote by s_3^I in figure 1. That the players' payoffs are the same implies, referring to (1)-(3), that the net benefit difference equals the expected fine a defector is faced with (i.e., $(B^H - (B^L - c^p)) = (g + s_3)c^I$). Now we need to check the stability for each of the steady states.

Proposition 2: (a) D equilibrium is asymptotically stable. (b) C-E equilibrium is asymptotically stable if $s_3 > s_3^I$ and unstable if $s_3 < s_3^I$. (c) I equilibrium is unstable.

Proof: (a) Substitute the condition $s_2 = 1$ into the Jacobian for (6)' and we have

$$J = \begin{pmatrix} -A & -r(2c^I - c^R + z \\ 0 & -(A + r(c^R - z)) \end{pmatrix} = \begin{pmatrix} \lambda_1 & -r(2c^I - c^R + z) \\ 0 & \lambda_2 \end{pmatrix}$$

The matrix is upper-triangular and the two eigen values λ_1, λ_2 are negative.

(b) Consider a point (ϵ, s_3) where ϵ is a small positive number. $\dot{s_2}$ of vector field at this point is given by

$$\dot{s_2} \approx s_2(A - rc^I s_3) > (<) 0 \text{ if } s_3 < (>) s_3^I, \text{respectively}$$

(c) The result follows from the system of differential equations with $c^R - z = 0$.

$$\dot{s_2} = s_2(1 - s_2)(A - rc^I s_3)$$

$$\dot{s_3} = -s_2 s_3 (A - rc^I s_3)$$

Once a a critical point is displaced from the line $s_3 = A/(rc^I)$, s_2 and s_3 keep increasing or decreasing.

We have checked so far the critical points and their stability. Once displaced from these critical points the state should change as the time passes. What path the state would move along depends on several factors. First of all, the proximity to critical points is important. If defectors are sufficiently many already, i.e., the state is in the vicinity of D equilibrium, a perfect non-compliance would soon prevail. The case that enforcers are sufficiently many already can be understood likewise. A perfect compliance would result soon in this case. Secondly the line of $s_3 = s_3^I$ is important. To remind, this line represents the points that the payoffs of a defector and a cooperator incorporating enforcers' monitoring activity become the same. Thus, for example, if the initial state is above s_3^I, defectors are dominated by cooperators and eventually defectors will be completely wiped out, i.e., the system will rest at a point on the edge $s_2 = 0$. In contrast, if the initial state is below s_3^I, defectors dominate cooperators, then cooperators and enforcers begin to die out and eventually defectors will prevail, i.e., the system will rest at D equilibrium. Thirdly, depending on the relative size of reporting cost and prize to an enforcer, the path would be totally different. The reason is because this affects the relative size of the players' payoffs. We are going to look at two different cases below more in detail.

In order to guess the general pattern we get the nullclines of $\dot{s_2} = 0$ and $\dot{s_3} = 0$ from (6)' as in (7) and (8). Notice that the nullcline $\dot{s_2} = 0$ is a rectangular hyperbola with s_3' as its horizontal asymptote, while the one for $\dot{s_3} = 0$ is a horizontal line in s_2, s_3 plane.

$$s_3 = \frac{-A}{r(c^I + c^R - z)}\left[1 + \frac{c^R - z}{c^I - s_2(c^I + c^R - z)}\right] \quad \text{for} \quad \dot{s_2} = 0 \tag{7}$$

$$s_3 = \frac{A + r(c^R - z)}{r(c^I + c^R - z)} \quad \text{for} \quad \dot{s_3} = 0 \tag{8}$$

Figure 2 is the phase diagram for the case when $c^R - z > 0$. Notice that s_3^I is located in between the nullcline $\dot{s_3} = 0$ and the asymptote s_3'. These three lines divide the simplex into four different regions. When enforcers are sufficiently many and defectors are sufficiently few, enforcers begin to expand even though an enforcer is dominated by a cooperator (think about the replicator dynamics, (4)) and defectors begin to shrink. Now suppose enforcers are not that many, but still a defector is dominated by a cooperator. Then cooperators begin to expand, and defectors and enforcers begin to shrink. In either case defectors will be completely wiped out, and cooperators and enforcers will survive. The system will rest at C-E equilibrium. We have explained the case when the system starts from below s_3^I, in which case D equilibrium will prevail in the end. The tricky part is the region between $\dot{s_2} = 0$ and s_3^I.

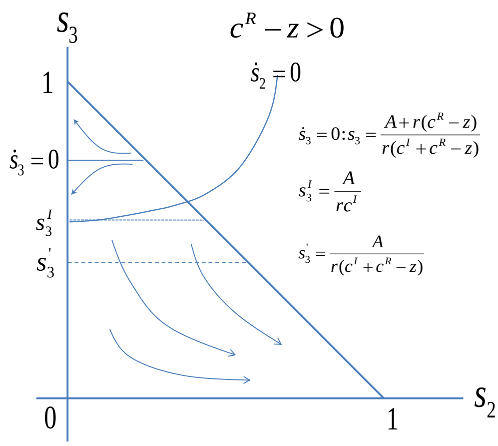

Figure 2. Phase diagram when $c^R - z > 0$

Now it's time to think the case that enforcers are exactly compensated (i.e., $c^R - z = 0$). In this case, the trajectories become linear. To see this, we reproduce the dynamic system (6)' when $c^R - z = 0$ as follows.

$$\dot{s_2} = s_2(1 - s_2)(A - rc^I s_3)$$
$$\dot{s_3} = -s_2 s_3(A - rc^I s_3)$$

Then, the slope of the vector field at (s_2, s_3) is given by

$$\frac{ds_3}{ds_2} = \frac{-s_3}{1 - s_2}$$

From this we have $s_3 = C(1 - s_2)$ where C stands for a constant to be determined by an initial value. This means that the trajectories are linear when $c^R - z = 0$ as depicted in Figure 3. The reason for linearity can be found in the fact that the payoffs of a cooperator and an enforcer have become the same and thus the replicator dynamics (4) became a linear relation. In this case, if cooperators, defectors and enforcers were on the line $s_3^I = A/(rc^I)$ initially, it would stay there. However, once perturbed there, the system would never return, but keep getting away along a linear trajectory either towards the asymptotically stable D equilibrium or an asymptotically stable C-E equilibrium.

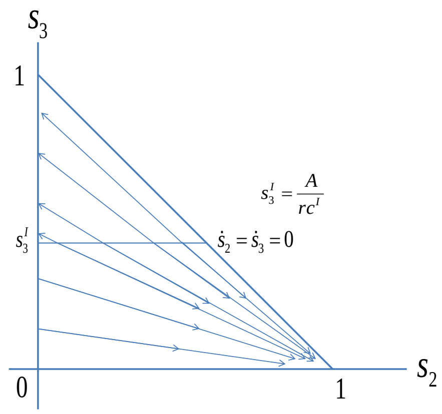

Figure 3. Phase diagram when $c^R - z = 0$

We have analyzed the phase diagrams so far for as many as possible cases. All the cases, however, end up with either a perfect compliance or a perfect non-compliance, which is unrealistic. In the next section we are going to deal with a more realistic case. However, the model provides us with a good policy implication. For an example, let's think about a plausible policy scenario. Suppose that the regulatory agency has introduced a report-reward system to give prizes to reporting citizens and reduce its monitoring frequency minding of its limited enforcement budget. Reducing official monitoring activity g, other things equal, pushes up s_3^I to have the set of asymptotically stable C-E equilibrium shrink. However, at the same time the prize has been introduced, which should induce enforcers to get more involved in private monitoring. In addition enforcers might increase their monitoring frequency just because official monitoring activity has been decreased. These facts press down s_3^I. If the net effect is to have lowered s_3^I, then we can say that the report-reward system is cost-effective.

As we have seen, citizen participation (note 4) is critical. Citizen participation depends on the social capital as is defined in the introduction, as well as regulatory policy variables. An interesting fact is that social capital depends on citizen participation. Torgler, Frey and Wilson (2009) argues in their analysis of a littering behavior that an individual is more likely to comply with the rule the more often he or she sees others complying. Thus if we want to analyze the effect of social capital, we need to endogenize the social capital in a more extended system, which we are going to deal with in the next section.

4. Social Capital and Citizen Participation

In our model social capital is reflected in the monitoring probability r an enforcer exerts. We assume that r increases (decreases) as social capital deepens (attenuates). Also we assume that r interacts with population shares s_i with the following requirements. Firstly, once any one type of player has occupied the whole population, r stops changing. Secondly, as defectors (enforcers) increase, r decreases (increases), respectively, but at a decreasing rate. Thus the initial value matters. Thirdly, the relative share of defectors and enforcers matters. For instance, if the defectors' share is bigger than the one for enforcers, r decreases, and vice versa. In mathematical notation we can express as follows.

$$\dot{r} = -r(1 - s_2)(1 - s_3)(s_2 + s_3)(s_2 - s_3) \tag{9}$$

Now we are able to analyze the interaction between the population shares s_i and private monitoring probability r more systematically in an extended dynamic system of (6)' and (9). For simplicity, we focus on the case that enforcers are exactly compensated, i.e., $c^R - z = 0$. Then the dynamic system can be reduced to the following.

$$\begin{gathered} \dot{s_2} = s_2(1 - s_2)(A - rc^I s_3) \\ \dot{s_3} = -s_2 s_3(A - rc^I s_3) \\ \dot{r} = -r(1 - s_2)(1 - s_3)(s_2 + s_3)(s_2 - s_3) \end{gathered} \tag{10}$$

Let's take an example to look at how the system works. Suppose that the population share of both defectors and enforcers is in above s_3^I in the simplex and at the same time enforcers' is bigger than defectors'. In other words the initial state is in region I in Figure 4. Since defectors are dominated by cooperators, defectors begin to die out. More specifically, defectors decrease (and cooperators increase) along a linear trajectory, eventually resting at some C-E equilibrium. Now r also increases as defectors get scarce. Thus, $s_3^I = A/rc^I$ shifts down, the set of C-E equilibrium being expanded. So the equilibrium is more safely attained. More interesting case is that defectors' share is bigger than enforcers'. (i.e., region Ⅳ in Figure 4) In this case defectors decrease, but r also decrease because enforcers are relatively few. So, $s_3^I = A/rc^I$ shifts up and might catch up the movement towards some C-E equilibrium along a linear trajectory. The relative speed of the movement along a linear trajectory and the change in r is important. If the movement along a trajectory escapes from s_3^I's catch-up, it will be getting in region Ⅰ and now r will be increasing, and the system will attain an equilibrium at C-E safely.

In the same manner we can analyze the case that the population share of both defectors and enforcers is in below s_3^I in the simplex. (region Ⅱ and Ⅲ in Figure 4). Suppose the initial state is in region Ⅱ in Figure 4. Then cooperators begin to die out and defectors begin to increase. At the same time r increases because defectors are relatively few. So the line s_3^I shifts down and might catch up the movement along a trajectory towards D-equilibrium. If the movement along a trajectory escapes from s_3^I's catch-up, it will be getting in region Ⅲ and then r will be decreasing, and the system will rest at D equilibrium safely.

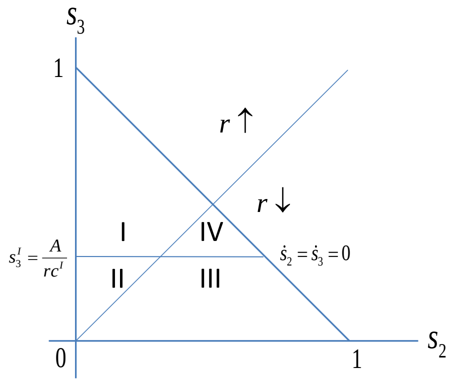

Figure 4. Phase diagram for s_2, s_3 and r when $c^R - z = 0$

What if the movement along a linear trajectory is caught up? The answer is that the system is going to stay there, but it is unstable, which will be explained in Proposition 3. We called this interior equilibrium in the previous section. Notice that the interior equilibrium in the extended system is located along the line segment of $s_2 = s_3$ facing region Ⅱ and Ⅳ.

Proposition 3: If enforcers are exactly compensated by a prize, there is a set of interior steady state $(s_2^*, s_3^*, r^*) = (\frac{C}{1+C}, \frac{C}{1+C}, \frac{A(1+C)}{c^I C})$ for some values of C and the interior equilibrium is unstable.

Proof : Since the slope of the vector field is invariant to r, the population share always satisfies $s_3 = C(1 - s_2)$ for some value of C where C is the constant determined by an initial value. Thus, given C, we can reduce the dynamic system (10) to the following two dimensional system (11).

$$\dot{r} = -r(1 - s_2)[1 - C(1 - s_2)][s_2^2 - (C(1 - s_2))^2]$$
$$\dot{s_2} = s_2(1 - s_2)[A - rc^I C(1 - s_2)] \tag{11}$$

The interior steady state satisfies the condition that $s_2 = s_3$ and $s_3 = A/rc^I$. Using the fact that $s_3 = C(1 - s_2)$, we have the result. The Jacobian of (11) evaluated at the interior equilibrium is as follows.

$$J = \begin{pmatrix} 0 & -r^*(1 - s_2^*)(1 - s_3^*)(s_2^* + s_3^*)(1 + C) \\ -s_2^*(1 - s_2^*)c^I C & s_2^*(1 - s_2^*)r^* c^I C \end{pmatrix}$$

Since the trace of J is positive and the determinant of J is negative, the equilibrium is unstable.

Proposition 3 has an interesting policy implication. Even though the regulatory hand is so short that the line s_3^I could not be lowered below the present state of a society, the society might not move into a perfect non-compliance if enforcers are already many and bigger than defectors. Then r will be increasing and the line s_3^I might be able to catch up the movement towards perfect non-compliance. On the other hand, even though the regulatory agency could move up the line s_3^I above the present state of a society, the society might be stuck in the neighborhood of the present state if defectors are already many and relatively bigger than enforcers. Then r

will be decreasing and the line s_3^I might be able to catch up the movement towards perfect compliance.

5. Conclusion

Assuming that there are three different types of people, each born to be cooperator or defector or enforcer, we have provided with an alternative perspective for the effect of a regulation. Our setting is in contrast to the traditional one in which people is assumed to be just rational egoists. So our framework is useful for analyzing the situation where the traditional enforcement policies are ineffective as in littering, forest fire, hazardous wastes, etc.

In our model there are two kinds of asymptotically stable equilibrium: C-E equilibrium (perfect compliance) and D equilibrium (perfect non-compliance). We have shown that depending on whether the initial state is located either above or below the line s_3^I in the simplex (the points that the payoffs of a defector and a cooperator incorporating enforcers' monitoring activity become the same), the system will evolve into either perfect compliance or perfect non-compliance. However, introducing the role of social capital, we have shown that the system can rest at some point inside the simplex (i.e., a partial compliance or the coexistence of three types of player). This has an interesting policy implication. Even though the regulatory hand is so short, the society might not evolve into a perfect non-compliance if enforcers are already many and bigger than defectors. Likewise, even though the regulatory agency is strong in its enforcement policy, the society might be stuck in the neighborhood of the initial state if defectors are already many and bigger than enforcers.

The regulatory agency's choice is given outside of the model. However, the agency could take a strategic choice. The law of motion in social capital in our model is assumed as simple as we have defined in (9) and it may be related to the agency's choice. For example, as the agency decreases its monitoring activity, enforcers may increase their monitoring frequency. These are all interesting and important issues, but we leave for future research.

Acknowledgements

The authors are grateful for the financial support from Japan Society for the Promotion of Science (2011 JSPS Fellowship Program).

References

Ahn, T., & Ostrom, E. (2008). Social Capital and Collective Action. In D. Castiglione, J. Van Deth, & G. Wolleb (Eds.), *The Handbook of Social Capital* (pp. 70-100). Oxford University Press.

Fehr, E., & Gaechter, S. (2000). Cooperation and Punishment in Public Goods Experiment. *The American Economic Review, 90*, 980-994. https://doi.org/10.1257/aer.90.4.980

Kim, G., Chang, Y., & Kelleher, D. (2008). Unit pricing of municipal solid waste and illegal dumping: An empirical analysis of Korean experience. *Environmental Economics and Policy Studies, 9*, 167-176. https://doi.org/10.1007/BF03353988

Ostrom, E. (1990). *Governing the Commons*. Cambridge University Press. https://doi.org/10.1017/cbo9780511807763

Ostrom, E. (2000). Collective Action and the Evolution of Social Norms. *Journal of Economic Perspective, 14*, 137-158. https://doi.org/10.1257/jep.14.3.137

Ostrom, E., Walker, J., & Gardner, R. (1992). Covenants with and without a Sword: Self-Governance is Possible. *The American Political Science Review, 86*, 404-417. https://doi.org/10.2307/1964229

Sethi, R., & Somanathan, E. (1996). The Evolution of Social Norms in Common Property Resource Use. *The American Economic Review, 86*, 766-788.

Stranlund, J. (1995). Public Mechanisms to Support Compliance to an Environmental Norm. *Journal of Environmental Economics and Management, 28*, 205-222. https://doi.org/10.1006/jeem.1995.1014

Torgler, B., Frey, B., & Wilson, C. (2009). Environmental and Pro-social Norms: Evidence on Littering. *The BE Journal of Economic Analysis and Policy, 9*, Article 18. https://doi.org/10.2202/1935-1682.1929

Notes

Note 1. However, they note that their framework can be extended to the centralized enforcement with a voluntarily contributed enforcement budget.

Note 2. In practice, a defector sometimes may follow the rule for fear of being fined as specified in the traditional enforcement literature. Our setting can be interpreted as three different egos within one person. So the population share of the three players to be determined in our setting can be thought of either as a mixed strategy of a person or the different actions share of the whole society with sufficiently many citizens.

Note 3. Cooperators and enforcers are interpreted here as strategies in the evolutionary game. So we may use such terminology as dominated.

Note 4. In our model this means either the population share of enforcer or the monitoring frequency an enforcer has.