Coordination Problem and Coordination among Groups: Effect of Group Size on Business Culture

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***Abstract*—In coordination games, we have multiplicity of equilibria. This multiplicity makes it possible to explain the coexistence of contradictory cultures in a society. Based on this, I construct a coordination game that can explain Japanese cultures, punctuality and unpunctuality. However, the games, if the group size is large, the multiplicity of equilibria disappears. Consequently, we find out that each agent in the group is always unpunctual. So, when considering groups with large size, we have a unique Nash equilibrium and observe only one culture in which each agent is unpunctual. I show that some division of the group can change the structure of games, resulting in multiplicity of equilibria. Therefore, each agent is likely to be punctual. From this viewpoint, I emphasize the information structure in groups and present an interpretation of Just-in-Time system of Toyota.**

***Index Terms*—coordination problem, multiplicity of equilibria, division of groups, coordination among groups, just-in-time system**

I. Introduction

Toyota production system is worldly famous and is sometimes called 'Just-in-Time' system. In this system, Toyota, a Japanese Automobile Company, tries to maximize profit by eliminating all waste including waste time. In order to eliminate waste time, each agent has to be strictly punctual. In fact, each worker is under strong pressure of time. Kamata ([1]), Japanese journalist who had experience to work at Toyota factory, wrote that

"The first shift ends at 2:15pm. Already, the man on the next shift is standing beside me, waiting for me to finish. As soon as I put my hammer down on the belt, he picks it up and begins precisely where I left off. A baton pass, and neatly done, too."

Just-in-Time system is not so peculiar examples in Japan. Someone says that one of the reasons behind Japan's economic growth has been the awareness of being punctual among Japanese.

In contrast, many Western people who visited Japan in the second half of 19th century observed that Japanese seemed to be not punctual. Ernest Satow (1843-1929), a British diplomatic attaché who observed Japanese society before and after the Meiji Restoration (1868), wrote that 'neither clocks nor punctuality were common.' Several decades later, Katharine Sansom, the wife of Geroge Sansom, a notable British historian, noted that 'you must slow down your tempo in Japan.' (See [2].)

From these, it can be safely said that Japanese society has punctuality-culture (now) and unpunctuality-culture (past). In this paper, I logically explain the coexistence of contradictory cultures using coordination games. Specifically, I prove that there are two Nash equilibria in coordination games with weakest-link. In one equilibrium, each agent chooses not to be punctual and we observe unpunctuality culture. On the other hand, each agent chooses to be punctual in the other equilibrium and we observe punctuality culture.

Moreover, I analyze the effect of group size on equilibria of the games. This analysis shows that the group size has a negative effect in the coordination games with weakest-link and accident. This says that a punctuality equilibrium does not exist in large groups.

Last, I consider groups with large size. Because of the group size, there is a unique Nash equilibrium where each agent chooses not to be punctual. Therefore, we cannot observe punctuality culture in the group. Then I show that some division of the group can change the structure of the games. I prove that there are two Nash Equilibria in the games after the division of the group. Based on the results of this analysis, some interpretations of Just-in-Time production of Toyota are presented.

II. Coordination Problemm and Business Culture

Why is someone punctual and why is another one unpunctual? If there is no interaction between agents and each agent tries to maximize his or her net benefit, we can easily formulate this problem. Let B be the benefit from being punctual and C be the cost to be punctual. If $B - C > 0$, then the agents should be punctual; if $B - C < 0$, then the agents should be unpunctual.

This formulization, however, cannot explain an agent who is punctual in his or her office but not in his or her house or one who is punctual among his or her friends but not among strangers.

In this section, I try to explain such behavior focusing on the interaction between agents. Here, the interaction means the external effects of punctuality. This is as follows. Assume that all the agents in a group are punctual. Then all the agents in the group can start their meeting on time and make decision efficiently. Next,

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consider workers in a factory. If all the workers are punctual, parts supply in the factory can be smooth. On contrast, assume that someone is unpunctual. Then the agents in the group cannot start the meeting on time, and in the factory, parts supply will stop, even if the other agents are punctual.

In order to represent such effects, we define the external effect as follows. Denote by a_i the agent i's action. If the agent i is punctual, then $a_i = 1$, and if the agent i is unpunctual, then $a_i = 0$. We define the external effect by $E \cdot min\{a_1, a_2, \cdots, a_n\}$ where E is positive constant. This implies that the external effect realizes only if each agent is punctual. This has the same property as weakest link property defined in [3].

Here, if $a_i = 1$ for any i, the agent i's net benefit is $B + E - C$ (both of the private benefit and the external effect realize); if $a_j = 0$ for some j, the agent i's net benefit is $B - C$ or 0 for any i (the external effect vanishes and only private benefit realizes or there is no benefit). The following is the pay-off matrix for the two-agent case (Table I).

TABLE I. PAY-OFF MATRIX OF G^1

		agent 2: being punctual	agent 2: being unpunctual
agent 1	being punctual	$B + E - C$, $B + E - C$	$B - C$, 0
	being unpunctual	0, $B - C$	0, 0

We name this game G^1 and assume that each agent takes only pure strategies. Then, as proved in [4], we have the following proposition.

Proposition 1. (1) Suppose that $B - C > 0$ holds. Then, there is a unique Nash equilibrium in G^1 and $a_i = 1$ holds for any i in the equilibrium. (2) Suppose that $B + E - C < 0$ holds. Then, there is a unique Nash equilibrium in G^1 and $a_i = 0$ holds for any i in the equilibrium. (3) Suppose that $B - C \leq 0$ and $B + E - C \geq 0$ hold. Then, there are two Nash equilibria in G^1. In one equilibrium, $a_i = 1$ holds for any i, and in the other equilibrium, $a_i = 0$ holds for any i.

In (3) of Proposition 1, we have the multiplicity of equilibria. In this case, we can say that if the punctuality equilibrium realizes, then we observe the culture of punctuality; if the unpunctuality equilibrium realizes, then we observe the culture of unpunctuality. So, in Japan, the latter equilibrium realized in the past and then the former one emerged at a certain time in history.

Multiplicity of equilibria creates a new question: Which equilibrium is desirable? When there are two equilibria, the Nash equilibrium where each agent is punctual is Pareto superior to the Nash equilibrium where each agent is unpunctual, since $B + E - C > 0$ holds. So if the latter equilibrium realizes, we have a coordination failure. In this sense, Japanese faced coordination failure problems in the past.

Next, I add another factor into the coordination game. Let an agent choose to be punctual. But, for example, if he or she has a wrong watch, he or she is unpunctual as a result. If he or she is in a traffic jam, he or she is also unpunctual. So, in the real world, each agent's intention to be punctual does not always lead to his or her behavior that he or she is punctual. Let p be the probability that an agent has a correct watch and does not face accidents like a traffic jam. Then, if each agent chooses to be punctual, the external effect realizes with the probability p^n. In other words, even if each agent chooses to be punctual, the external effect vanishes with the probability $1 - p^n$.

Then the pay-off changes as follows. If $a_i = 1$ for any i, the agent i's net benefit is $pB + p^n E - C$; if $a_j = 0$ for some j, the agent i's net benefit is $pB - C$ or 0 for any i. The following is the pay-off matrix for the two-agent case (Table II).

TABLE II. PAY-OFF MATRIX OF G^p

		agent 2: punctual	agent 2: unpunctual
agent 1	punctual	$pB + p^2E - C$, $pB + p^2E - C$	$pB - C$, 0
	unpunctual	0, $pB - C$	0, 0

We name this game G^p. Assuming that each agent takes only pure strategies, as proved in [5], we have the following results.

Proposition 2. (1) Suppose that $pB - C > 0$ holds. Then, there is a unique Nash equilibrium in G^p and $a_i = 1$ holds for any i in the equilibrium. (2) Suppose that $pB + p^n E - C < 0$ holds. Then, there is a unique Nash equilibrium in G^p and $a_i = 0$ holds for any i in the equilibrium. (3) Suppose that $pB - C \leq 0$ and $pB + p^n E - C \geq 0$ hold. Then, there are two Nash equilibria in G^p. In one equilibrium, $a_i = 1$ holds for any i, and in the other equilibrium, $a_i = 0$ holds for any i.

Let $B + E - C \geq 0$ hold. Even in this case, small p makes $pB + p^n E - C$ to be negative. Then, the game G^p has a unique Nash equilibrium, the unpunctuality equilibrium. But we have the punctuality equilibrium in G^1 in the case where $B + E - C \geq 0$. So, the possibility of having wrong watches or facing accidents changes the property of equilibria.

III. EFFECT OF GROUP SIZE

In the previous section, I show the multiplicity of equilibria in the coordination game. This multiplicity makes it possible to logically explain the coexistence of the contradictory cultures. In this section, I examine the effect of group size on the structure of the games. So, treating the number of agents, n, as parameter, we rename the games G_n^p. Denote by $NE(G_n^p)$ the set of Nash equilibria of G_n^p.

In order to focus on the multiplicity of equilibria, I assume that $pB - C \leq 0$ for any p. Under this assumption, $NE(G_n^p)$ with $0 < p \leq 1$ is {the unpunctuality equilibrium} or {the unpunctuality equilibrium, the punctuality equilibrium} from

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Propositions 1 and 2. (i.e. We have $NE(G_n^p) = \{(a_1 = 0, \cdots, a_n = 0)\}$ or $NE(G_n^p) = \{(a_1 = 0, \cdots, a_n = 0), (a_1 = 1, \cdots, a_n = 1)\}$.)

If $pB + p^n E - C \geq 0$ holds, then each agent chooses to be punctual in the case where the others do so; otherwise, each agent always chooses to be unpunctual. So, if $pB + p^n E - C \geq 0$ holds, there are two equilibria. On the other hands, if $pB + p^n E - C < 0$ holds, there is one equilibrium in which each agent always chooses to be unpunctual. Since $p < 1$, we have $p^n E > p^{n'} E$ if $n < n'$. This implies that $pB + p^n E - C > pB + p^{n'} E - C$ if $n < n'$. Therefore, as proved in [5], we have the following result.

Proposition 3. (1) We have $NE(G_n^p) \supset NE(G_{n'}^p)$ for any n and n' such that $n < n'$. (2) If $NE(G_n^p) \supsetneq NE(G_{n'}^p)$, then each agent's strategy in $NE(G_{n'}^p)$ is $a_i = 0$.

This proposition implies that, with possibility of accidents, the group size would have a negative effect on the punctuality equilibrium. That is, even if each agent is punctual and the punctuality equilibrium realizes in the small group, he is unpunctual and the unpunctuality equilibrium emerges in the large group.

IV. Group Division

As shown above, the group size has a negative effect on the punctuality equilibrium. This fact presents another question: Can we realize the punctuality equilibrium by dividing a large group where we have only the unpunctuality equilibrium into some small groups?

Consider a group $N = \{1,2, \cdots, n\}$. The benefit from being punctual, the cost to be punctual and the external effect of being punctual are denoted by B, C and E_N respectively. Here, since the external effect depends on the group character, this dependency is represented by the subscript. Assume that $B + E_N - C \geq 0$ and $pB + p^n E_N - C < 0$ hold. We name this game G_N^p and denote by $NE(G_N^p)$ the set of Nash equilibria of G_N^p. Because $pB + p^n E_N - C < 0$ holds, only the unpunctuality equilibrium realizes in the game G_N^p. (We have $NE(G_N^p) = \{(a_1 = 0, \cdots, a_n = 0)\}$)

Next, consider a division of the group. That is, suppose that the group N is divided into some subgroups: $N_1 = \{1, \cdots, n_1\}$, $N_2 = \{1, \cdots, n_2\}$, …, $N_s = \{1, \cdots, n_s\}$. This means that $N_1 \cup N_2 \cup \cdots \cup N_s = N$ and $N_l \cap N_m = \emptyset$ for any $l \in \{1, \cdots, s\}$ and $m \in \{1, \cdots, s\}$ with $l \neq m$.

In this case, we have to define the external effect in each subgroup. Denote these effects by $(E_{N1}, E_{N2}, \cdots, E_{Ns})$. Since $N_l \subset N$ holds, it is natural that we have $E_{Nl} < E_N$ for any $l \in \{1, \cdots, s\}$ because of economy of scale. Note that even though the external effect in the subgroup N_l is smaller than that in the ground group N, we can have $p^{n_l} E_{Nl} > p^n E_N$ for some $E_l < E_N$ because $p < 1$ and $n_l < n$ hold.

We consider the game consisting of the following subgames: for each $l \in \{1, \cdots, s\}$ and each $i \in N_l$, (1) agent i decides his action $a_i \in \{0,1\}$; (2) agent i's net benefit is $pB + p^{n_l} E_{Nl} - C$ if $a_j = 1$ holds for any $j \in N_l$, agent i's net benefit is $pB - C$ if $a_i = 1$ and $a_j = 0$ hold for some $j \in N_l \backslash \{i\}$, and agent i's net benefit is zero if $a_i = 0$ holds. We name this game G_{N-S}^p and denote by $NE(G_{N-S}^p)$ the set of Nash equilibria of G_{N-S}^p. The following is the pay-off matrix of the subgame in the subgroup N_l for the two-agent case (Table III).

TABLE III. Pay-Off Matrix of the Subgame in N_l

		agent 2	
		punctual	unpunctual
agent 1	punctual	$pB + p^2 E_l - C$, $pB + p^2 E_l - C$	$pB - C$, 0
	unpunctual	0, $pB - C$	0, 0

In this game, the unpunctuality equilibrium always exists. Under some division of the group, however, each agent may be punctual in the Nash equilibrium because $p^{n_l} E_{Nl} > p^n E_N$ can hold. Specifically, if $pB + p^{n_l} E_{Nl} - C > 0$ holds, agent i takes the action $a_i = 1$ when $a_j = 1$ holds for any $j \in N_l \backslash \{i\}$. Therefore, we have the following result.

Proposition 4. If $pB + p^{n_l} E_{Nl} - C \geq 0$ holds for any $l \in \{1, \cdots, s\}$, we have $NE(G_N^p) \subset NE(G_{N-S}^p)$.

The result of Proposition 4 means that $NE(G_{N-S}^p) = \{(a_1 = 0, \cdots, a_n = 0), (a_1 = 1, \cdots, a_n = 1)\}$ if $pB + p^{n_l} E_{Nl} - C \geq 0$ holds for any $l \in \{1, \cdots, s\}$. Therefore, we can have the punctuality equilibrium under the division of the ground group N even though only the unpunctuality equilibrium realizes in the ground group N.

V. Concluding Remarks

Proposition 4 in the previous section proves that some division of a large group into some small groups likely realizes the punctuality culture in the group. This is the main finding in this paper.

The realization of the punctuality equilibrium needs a fairy large external effect E_{Nl} in the subgroups E_{Nl} for any $l \in \{1, \cdots, s\}$ such that E_{Nl} satisfies $(C - pB)/p^{n_l} < E_{Nl} < E_N$. If the subgroups do not have close relationship among them, the punctuality culture of any subgroup has a little spillover effect on other subgroups, resulting in a little benefit for the ground group. This leads to a little external effect for the subgroup itself that realizes the punctuality culture. In other words, coordination among the subgroups is necessary for a large external effect.

What is needed for the coordination among the subgroups? I think that Just-in-Time system provides us with a good example explaining the coordination among the subgroups. Last, I show this point.

Just-in-Time system is commonly labeled as a "kanban" system ([6]). "The most common form of kanban is a rectangular piece of paper in a vinyl envelope. The information listed on the paper includes pick up information, transfer information, and production information. It basically tells a worker how many of which parts to pick up or which parts to assemble" ([7]). The use of kanban assists in linking the different production processes together.

In addition, continuous flow production, combined with a pull system of production control, is at the heart of Just-in-Time system ([8]). "The process basically must be looked at backwards since later processes are picking up material from earlier ones" ([7]). Each subgroup produces only what is necessary to satisfy the demand of the succeeding subgroup. No production takes place until a signal from a succeeding process indicates a need to produce. Parts and materials arrive just in time to be used in production.

I think that these are the information system that allows minute adjustment in delivery time of products. Moreover, this information system makes the coordination among the subgroups easy, resulting in a fairly large external effect in each subgroup. In fact, kanban provides the subgroups with adequate information, enabling the subgroups to decide what and when to produce. In addition, the pull system compels the subgroups to produce only needed products. So, the subgroups spontaneously coordinate their activities.

In this paper, I show that these are necessary for the realization of the punctuality culture in Just-in-Time system.

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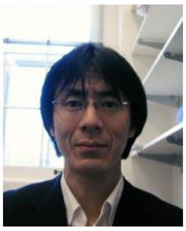

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