A GAME THEORETICAL MODEL FOR PREVENTION OF MEAT CONTAMINATION AT A MEAT PACKING HOUSE

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A GAME THEORETICAL MODEL FOR PREVENTION OF MEAT CONTAMINATION AT A MEAT PACKING HOUSE

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Thesis

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ABSTRACT

This study aims to develop a theoretical procedure to deal with the strategic decisions taken by a meat packing firm to prevent meat contamination. The analysis is based on a game theoretical model with two players, the firm and the government (regulator). The model assumes that a firm can choose to implement extra controls apart from the usual mandated controls expected of them. At the same time, the government can also implement extra controls beyond those it has mandated for the firm, if the cost of prevention is cheaper for both the firm and the government than cleanup. After modeling the problem and determining the possible cases and equilibria of the game, we use these to elaborate inferences about possible actions of the firm and the government. The results indicate that both the firm and the regulator will control if the cost of cleanup is high or the cost of extra control is low. We also realize that if the level of effectiveness of control is high enough, neither the firm nor the government will be willing to implement extra control.

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CHAPTER I

INTRODUCTION

“There is no magic bullet to prevent” meat contamination, the USDA acknowledges [1]. This statement appeared in the New York Times after the 20th meat recall of 2007. Less than a year later, the USDA announced the largest meat recall in America’s history (at the time of this writing): 143 million pounds of beef [2]. Meanwhile, the beef industry estimates to spend a minimum of 350 million dollars every year toward meat contamination prevention [1].

But this problem has not just evolved. In 1906, Upton Sinclair, a renowned journalist at that time, drew the attention of America to how horrible the conditions inside American meat packing houses were in his novel “The Jungle”. As a consequence, The Federal Meat Inspections Act was passed later that year [3]. Since then, several laws and committees have been made including the Talmadge-Aiken Act of 1962 (7 U.S.C.450) and the 2008 farm bill (P.L. 110-246), signed into law in June 2008 [4] to help steer the affairs of the industry, but to date, due to the nature of the industry, contaminated meat periodically finds its way into the market.

Meat is a consumer product that comes with a government seal of approval on the package in the United States. The government has entrusted the US Department of Agriculture (USDA) to regulate all meat produced in the country. The USDA is therefore, by its standards, to inspect all meat produced before it comes to the consumer. The meat production firms, on the other hand, know what is expected of them and always try to meet the standards of the USDA. Yet the problem of contamination seems to be persistent with over 50 recalls in year 2010 [5].

With the quest to reduce meat contamination, the USDA introduced a new meat inspection program called the Hazard Analysis and Critical Control Point (HACCP) in 1996 [6]. The HACCP allows most of the inspection task to be carried by the firms themselves rather than the USDA [7]. The USDA spends most of its time inspecting the paper work, rather than the products [3]. The HACCP is scientifically driven [3], which allows acid spray and other chemicals to be applied to carcasses before microbial testing. In [3], the authors argue that since the firm will be applying these chemicals to the carcass, it does not pay the needed attention to the fecal and other hygienic handling of the meat. Instead the firm seeks to increase its rate of production to make more profit. Further, there is the likelihood of environmental (river) pollution [8], when these chemicals are eventually washed from the meat.

As has been mentioned above, though the USDA makes inspections on behalf of the government it relies heavily on the firms to execute its duties. Each stage of the meat production requires the right tools, technology and workforce to be used to help prevent meat contamination, or reduce its chances to the barest minimum. According to the United states Bureau of Labour Statistics, little formal education is required for workers in this industry. A high school diploma is not always required, but preferred

[9]. This means the workers of this industry rely on training and experience. What has not been studied is the level of training needed for workers in this industry. This and other factors makes the reliance of the USDA on the firm for the major part of the inspection work a very questionable practice.

Our basic motivation for this research is that, though the firm has been applying the needed controls and the USDA has been inspecting the products of the firms by their standard of control, periodic meat contamination and recalls require extra and updated control measures. In this paper we focus on finding the Nash equilibrium for the firm and government, by assuming that the firm and the government make decisions on controls based on their profit level. With this we are able to relate the effectiveness level of controls for the firm for prevention of contamination, cost of enacting extra control and the expected cost of cleanup in an event of contamination to profits of the firm and the government. Using this relationship, we were able to determine how different responsibility levels of cleanup cost will affect players profits, which will also have a direct consequence on their decisions towards controls.

A 2x2 matrix game is developed in such a way that the regulator has the option to spend extra resources on preventive measures beyond the mandated control level which it has demanded from the firm. The firm also has the option to enact extra controls beyond what is expected of it. For example, the firm may use the highest technology when the need arises. Payoff expressions are developed for both the firm and the regulator with several parameters, such as the effectiveness level of control, the tax rate and the proportion of total cost assumed by the regulator in case there is a contamination event.

The application of game theory to food contamination is relatively new, with very few published articles in this area. In the meat packing industry, there has not been a single paper published as of the time of this writing. We therefore built our model from scratch, though [10] was helpful and we present our results in similar format to [11]. Clearly, the higher the cost of cleanup, the more the regulator and the firm will be willing to enact extra controls, since they do not want to incur huge costs in case of an event. We also realize that, the cheaper the control, the more the firm and the regulator will be willing to control. We shall draw inferences about the possible behavior of the firm, when the government (regulator) assumes different levels of proportions of the cost of cleanup in case there is a contamination event.

We wish to state that though our results look promising, we did not test our results against real data to confirm our findings. We also indicated the mixed strategies that appeared in some specific cases but did not solve them. These are being left for future work.

For the rest of this paper, we proceed by constructing the game model in its basic form in chapter II. In chapter III, we solve the model to get the main results. We will look at some specific cases of our model and analyze the results in chapter IV. Finally in chapter V, we summarize, conclude and give our recommendations for a possible extension of this work in the future.

CHAPTER II

MODEL FORMULATION

In this model, there are two main players: the meat packing firm, which shall simply be referred to as the firm and the USDA, which shall be referred to as the regulator or government. In the model, Q is the total output a firm produces and sells, and therefore Q_{max} is the maximum production the firm can produce to make the maximum profit P_{Fmax}.

We assume the profit function P_F is a linear function which depends on the quantity Q produced and sold by the firm. This also means a further assumption has been made indicating that we are operating in a perfect competitive market and that the price of the meat will remain constant no matter the level of Q. This assumption also implies that the cost and revenue function of the firm must be linear [12]. We are also assuming that the firm operates at Q_{max} and reaches P_{Fmax}, which is beyond its break even-point. It must be stated that these assumptions were made to make the model algebraically simpler.

In addition to the mandated controls, the firm has the option to spend additional resources on controls such as new technology, training of staff members and extra supervision. We shall denote this additional cost of control as C_F. This cost is also assumed to be linear in Q, that is, it depends on the production level of the firm.

Similarly, the regulator has the option to enact extra controls and we shall denote this cost to the regulator by C_R.

With no additional controls, we assume that meat contamination events occur independently with constant probability. That is, we take the probability of a no contamination event for unit production as a constant γ. We use Δ to denote the total cleanup cost in the event of contamination. The cleanup cost refers to both direct and indirect costs incurred by both the firm and the government, as a result of a release of contaminated meat into the market. The portion of this cost assumed by the regulator in the case of an event is denoted by Δ_R, and that of the firm is Δ_F. We define $0 < \alpha < 1$ as the proportion of total clean up cost taken by the government in the event of meat contamination. Hence $\Delta_R = \alpha\Delta$ and $\Delta_F = (1 - \alpha)\Delta$.

One important parameter measure is δ, which is the level of effectiveness of control. This measure can be determined in several ways, one of which can be how frequently a firm initiates a recall. The lower the frequency, the higher the δ. Another name for δ is a firm's reliability level. We shall denote the taxation rate as τ and so the firm gets to keep a fraction $1 - \tau$ of the taxable profit, while the government gets a τ fraction of the taxable profit.

2.1 Relating the various functions to the probability of an event and the cost of cleanup of such an event.

We first look at our probability function,

$$p = 1 - \gamma^Q, \quad 0 < \gamma < 1 \tag{2.1}$$

which is the propensity of contaminated meat entering the market if no extra controls are applied. We observe that as $\gamma \to 0$, then $p \to 1$ and as $\gamma \to 1$, then $p \to 0$. This means that, the smaller the γ, the higher the chances that there will be contamination, and vice versa. We can quantify γ with the education and experience level of the workers in the meat factory.

We also observe that as $Q \to \infty$, then $p \to 1$ and as $Q \to 0$, then $p \to 0$. This correlates with an increasing propensity for meat contamination with an increase in the production level. This also means our model associates all contamination to production.

Let us define the profit function of the firm as

$$P_F(Q) = a_1 Q - a_0, \qquad a_0 \geq 0 \quad a_1 > 0. \tag{2.2}$$

Here a_0 is the total estimated cost incurred by the firm to pack meat and a_1 is the marginal increase in sales. Hence $a_1 Q$ is the total revenue.

If the firm decides to apply extra control, the cost it incurs for that extra control is given as

$$C_F(Q) = b_1 Q + b_0. \tag{2.3}$$

Here, b_0 is the fixed cost the firm incurs, no matter the level of extra control it decides to apply and b_1 is the marginal increase in cost with respect to the level of production Q.

Similarly, if the regulator decides to apply extra controls, the cost it incurs for that extra control is

$$C_R(Q) = d_1 Q + d_0. \tag{2.4}$$

Here d_0 is the fixed cost the regulator incurs no matter the level of extra control it decides to apply, and d_1 is the marginal increase in cost with respect to the level of production Q. We note that this cost is also assumed to be linear.

In a case of contamination, the total cost of cleanup has been estimated as Δ. The cost to the regulator is $\alpha\Delta$, and that to the firm is $(1-\alpha)\Delta$. Therefore

$$\Delta = \Delta_F + \Delta_R. \tag{2.5}$$

Notice that the expected cleanup cost of a contamination event is $p\Delta$, and the expected cleanup cost to the firm and the regulator in an event of contamination are $p\Delta_F$ and $p\Delta_R$, respectively.

If a firm decides not to apply extra controls, then it has taken a higher risk of paying cleanup costs in the future. Therefore the payoff for a firm which does not apply extra controls will be estimated as the total taxable profit minus the estimated cost of cleanup in a case of an event. Hence, the firm's payoff is

$$(1-\tau)P_F(Q) - p\Delta_F. \tag{2.6}$$

But if a firm decides to apply extra controls, then part of the profit has already been spent on extra controls and the effectiveness level δ of the firm will increase correspondingly. Therefore, its payoff will be

$$(1-\tau)(P_F(Q) - C_F(Q)) - (1-\delta)p\Delta_F. \tag{2.7}$$

Similarly, when the regulator decides to control, there will be a reduction in contamination which will increase the firm's effectiveness level δ. This will reduce the chances of an event. Taking account of this fact will introduce another $(1-\delta)$ factor in the model and therefore in a case where both the firm and the regulator are controlling, the payoff to the firm will be

$$(1-\tau)(P_F(Q) - C_F(Q)) - (1-\delta)^2 p\Delta_F. \tag{2.8}$$

The situation described above results in a game between the regulator (USDA) and the meat packing firm. The solution to the game indicates the behavior of the firm and the regulator at various levels of δ. Table 2.1 illustrates the payoffs for the firm and the regulator. The values y and x represent the probabilities of the firm and the regulator to respectively enact extra controls.

Now we choose a Q_{max} such that at this level of production, the firm can

Table 2.1: The Regulator, Meat Packing Firm payoff matrix

	Regulator Control (x)	**Regulator No Control (1 - x)**
Firm controls (y)	$(1-\tau)\,(P_F(Q)-C_F(Q))$ $-(1-\delta)^2 p\Delta_F$, $\tau(P_F(Q)-C_F(Q))-C_R(Q)$ $-(1-\delta)^2 p\Delta_R$	$(1-\tau)(P_F(Q)-C_F(Q))$ $-(1-\delta)p\Delta_F$, $\tau(P_F(Q)-C_F(Q))$ $-(1-\delta)p\Delta_R$
Firm does not control (1 - y)	$(1-\tau)P_F(Q)-(1-\delta)P\Delta_F$, $\tau P_F(Q)-C_R(Q)-(1-\delta)p\Delta_R$	$(1-\tau)P_F(Q)-p\Delta_F$, $\tau P_F(Q)-p\Delta_R$

maximize profit. This will give us the matrix 2.2 with the following payoffs:

$$\begin{aligned}
\Pi_I &= (1-\tau)(a_1Q_{max}-a_0)-(1-\gamma^{Q_{max}})\Delta_F-(1-\tau)(b_1Q_{max}+b_0) \\
&+ [1-(1-\delta)^2](1-\gamma^{Q_{max}})\Delta_F \qquad (2.9)
\end{aligned}$$

$$\begin{aligned}
\Pi_{II} &= (1-\tau)(a_1Q_{max}-a_0)-(1-\gamma^{Q_{max}})\Delta_F-(1-\tau)(b_1Q_{max}+b_0) \\
&+ [1-(1-\delta)](1-\gamma^{Q_{max}})\Delta_F \qquad (2.10)
\end{aligned}$$

$$\begin{aligned}
\Pi_{III} &= \tau(a_1Q_{max}-a_0-b_1Q_{max}-b_0)-(d_1Q_{max}+d_0) \\
&- (1-\delta)^2(1-\gamma^{Q_{max}})\Delta_R \qquad (2.11)
\end{aligned}$$

$$\Pi_{IV} = \tau(a_1Q_{max}-a_0-b_1Q_{max}-b_0)-(1-\delta)(1-\gamma^{Q_{max}})\Delta_R \qquad (2.12)$$

$$\Pi_V = (1-\tau)(a_1Q_{max}-a_0)-(1-\gamma^{Q_{max}})\Delta_F+\delta(1-\gamma^{Q_{max}})\Delta_F \qquad (2.13)$$

$$\Pi_{VI} = (1-\tau)(a_1Q_{max}-a_0)-(1-\gamma^{Q_{max}})\Delta_F \qquad (2.14)$$

$$\Pi_{VII} = \tau(a_1Q_{max}-a_0)-(d_1Q_{max}+d_0)-(1-\delta)(1-\gamma^{Q_{max}})\Delta_R \qquad (2.15)$$

$$\Pi_{VIII} = \tau(a_1Q_{max}-a_0)-(1-\gamma^{Q_{max}})\Delta_R \qquad (2.16)$$

2.2 The simplified matrix

We observe that all entries in the payoff matrix (2.2) contain the terms $(1-\tau)(a_1Q_{max}-a_0)-(1-\gamma^{Q_{max}})\Delta_F$ for the firm and $\tau(a_1Q_{max}-a_0)-(1-\gamma^{Q_{max}})\Delta_R$ for the regulator. Subtracting the common terms simplifies the payoff matrix, as shown in Table 2.3.

Table 2.2: The maximized payoff matrix

	Regulator Control (x)	**Regulator No Control (1 - x)**
Firm controls (y)	Π_I Π_{III}	Π_{II} Π_{IV}
Firm does not control (1 - y)	Π_V Π_{VII}	Π_{VI} Π_{VIII}

Table 2.3: The simplified maximized payoff matrix

	Regulator Control (x)	**Regulator No Control (1-x)**
Firm controls (y)	$-(b_1Q_{max} + b_0)(1-\tau)+$ $(2\delta - \delta^2)(1-\gamma^{Q_{max}})\Delta_F,$ $-\tau(b_1Q_{max} + b_0) - (d_1Q_{max} + d_0)$ $+(2\delta - \delta^2)(1-\gamma^{Q_{max}})\Delta_R$	$-(b_1Q_{max} + b_0)(1-\tau)+$ $\delta(1-\gamma^{Q_{max}})\Delta_F,$ $-\tau(b_1Q_{max} + b_0)+$ $\delta(1-\gamma^{Q_{max}})\Delta_R$
Firm does not control (1-y)	$\delta(1-\gamma^{Q_{max}})\Delta_F,$ $-(d_1Q_{max} + d_0) + \delta(1-\gamma^{Q_{max}})\Delta_R$	0, 0

CHAPTER III

SOLUTION TO THE MODEL

We start the solution of the model with the assumption that

$$(1-\tau)(a_1 Q_{max} - a_0) - (1-\gamma^{Q_{max}})\Delta_F > 0. \tag{3.1}$$

This assumption means the firm makes profit whether or not it adds extra controls, otherwise the firm will not produce. More specifically, the estimated cost of control should not be more than the profit of the firm. By contrast, the regulator's payoff can be negative, since it is supported by the government and the latter may choose to invest for the safety and the satisfaction of the people.

Consider Table 3.1 with four different regions: (I), (II), (III)and (IV). Region (I) represents the case where both the regulator and the firm controls. Region (IV) is the region where no one controls. Region (II) is the region where only the firm controls. And region (III) is the region where the regulator only controls. We now Compare Table 2.2 to Table 3.1, and observe the following:

There is a Nash equilibrium at (I) when $\Pi_I > \Pi_V$ and $\Pi_{III} > \Pi_{IV}$.

There is also a Nash equilibrium at (II) when $\Pi_{II} > \Pi_{VI}$ and $\Pi_{IV} > \Pi_{VIII}$.

Another Nash equilibrium occurs at (III) when $\Pi_V > \Pi_I$ and $\Pi_{VII} > \Pi_{VIII}$.

Region (IV) is also a Nash Equilibrium when $\Pi_{VI} > \Pi_{II}$ and $\Pi_{VIII} > \Pi_{VII}$.

Table 3.1: A Table for the representation of results.

	Regulator Control (x)	**Regulator No Control (1 - x)**
Firm controls (y)	I	II
Firm does not control (1 - y)	III	IV

These equilibria will be very useful for the analysis of our solution later on in this paper.

From the simplified maximized payoff matrix, let us consider the case where the regulator controls, then the firm will only control if

$$-(b_1 Q_{max} + b_0)(1 - \tau) + (2\delta - \delta^2)(1 - \gamma^{Q_{max}})\Delta_F > \delta(1 - \gamma^{Q_{max}})\Delta_F, \tag{3.2}$$

which simplifies to

$$-(b_1 Q_{max} + b_0)(1 - \tau) + (\delta - \delta^2)(1 - \gamma^{Q_{max}})\Delta_F > 0. \tag{3.3}$$

Hence

$$\delta - \delta^2 > \frac{(b_1 Q_{max} + b_0)(1 - \tau)}{p_{max}\Delta_F}. \tag{3.4}$$

Let

$$F = \frac{(b_1 Q_{max} + b_0)(1 - \tau)}{p_{max}\Delta_F}, \tag{3.5}$$

and note that F decreases when the cost to the firm for extra control is small or when the expected cost to the firm in case of an event is high. Then equation (3.4) becomes,

$$\delta - \delta^2 > F. \tag{3.6}$$

In the case where the regulator decides not to control, the firm will only control if

$$-(b_1 Q_{max} + b_0)(1 - \tau) + \delta(1 - \gamma^{Q_{max}})\Delta_F > 0. \tag{3.7}$$

Rearranging yields

$$\delta > \frac{(b_1 Q_{max} + b_0)(1 - \tau)}{p_{max}\Delta_F}. \tag{3.8}$$

Therefore,

$$\delta > F. \tag{3.9}$$

By a similar argument, if the firm decides not to control, then the regulator controls only when

$$\delta > \frac{d_1 Q_{max} + d_0}{p_{max}\Delta_R}. \tag{3.10}$$

If we let the right hand side of equation (3.10) be denoted by R, then we have

$$\delta > R. \tag{3.11}$$

We remind ourselves that R depends on the cost of extra control and the expected cost of cleanup to the regulator in an event of contamination. But if the firm decides to control, then the regulator controls only when

$$-(d_1 Q_{max} + d_0) + (2\delta - \delta^2)(1 - \gamma^{Q_{max}})\Delta_R > \delta(1 - \gamma^{Q_{max}})\Delta_R. \tag{3.12}$$

This simplifies to

$$\delta - \delta^2 > R. \tag{3.13}$$

The results obtained above as a result of the simplified matrix in Table 2.3 are presented in Figure 3.1.

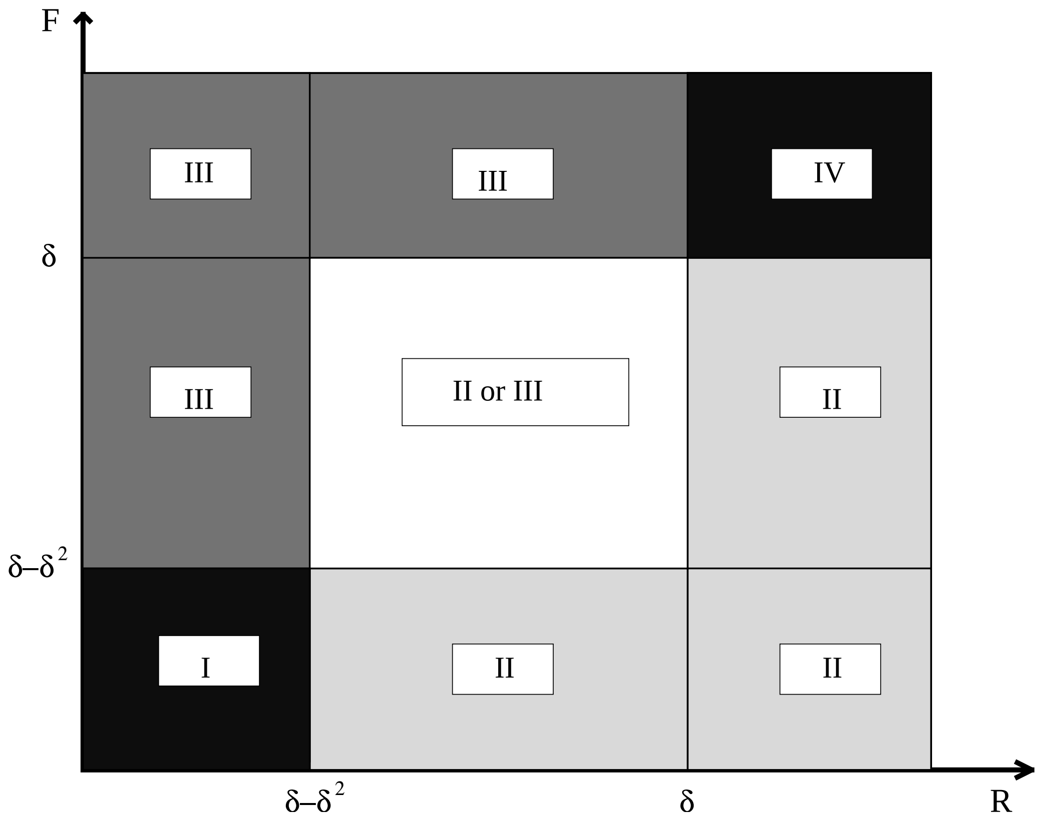

Figure 3.1: A chart showing the results of the simplified payoff matrix in Table 2.3.

Discussion of the main results.

From equations (3.6),(3.9),(3.11) and (3.13), it is clear that both the firm and the regulator's decisions depend on how F and R respectively relate to the effectiveness level δ of the firm. We acknowledge the fact that there are nine different sections on the chart, but it has been clearly labelled into four main regions and a fifth region which is a combination of two of the four main regions. Labeled regions (I),(II), (III) and (IV), but not (II or III) all have a single Nash Equilibrium, a pure strategy.

In region (I), both the firm and the regulator will always control. This is because within this region, $F \leq \delta - \delta^2$ as well as $R \leq \delta - \delta^2$. Since within this region both R and F are relatively small, its economic interpretation is either the expected cost of cleanup by both the firm and the regulator is too high and therefore is not worth the risk of not applying extra control, or the cost of control is cheap, so both the firm and the regulator can afford the extra cost that will be incurred to enact extra control. Henceforth, any region on a chart that will be labeled (I) will represent a region where both the regulator and the firm will always be controlling.

In region (II), only the firm will control. This is because the following conditions apply: either $\delta - \delta^2 < R$ and $F \leq \delta - \delta^2$, or $R > \delta$ and $\delta - \delta^2 < F < \delta$. The reasoning behind the decision of the firm to control is either it sees the level of effectiveness δ to be relatively low or it is not ready to take the risk of the high cost of cleanup in case of a contamination event. We shall refer to any region where only the firm controls as (II).

In region (III) only the regulator controls. This region requires either $F > \delta - \delta^2$ and $R \leq \delta - \delta^2$, or $F > \delta$ and $\delta - \delta^2 < R < \delta$. The reasons for the control by the regulator is either it sees the level of effectiveness δ of the firm to be relatively low or it is not ready to take the risk of the high cost of cleanup in case of a contamination event. We shall denote any region that will be controlled only by the regulator from now to the end of this research as region (III).

Region (IV) is the region which is created by the case $R > \delta$ and $F > \delta$. Here, neither the firm or the regulator will control. This is partly due to the fact that the effectiveness level δ is low and/or the cost of control is relatively high. Such a region will be denoted as region (IV).

Finally, we want to look at the region labelled (II or III). There are two pure Nash equilibria in this region. If the regulator chooses not to control, then the firm will control. Also, if the regulator decides to control, the firm will not control. Therefore in this region, either the regulator or the firm may control but not both. All regions with this property will be denoted as (II or III) throughout this literature.

At this point, we make one important observation. If the effectiveness level δ, is small, then region (IV) will be relatively larger. This means there will be a larger region which no one will be controlling. Therefore in the next chapter, we shall investigate some conditions that will help reduce this region as much as possible.

CHAPTER IV

BEHAVIOR OF THE MODEL AS THE PROPORTION OF CLEANUP COST VARIES

From previous chapters, the behavior of both the regulator and the firm depends on δ, and on Δ. Also the government assumes the portion α of the cleanup cost and the firm assumes the portion $1 - \alpha$. At this point, we want to investigate how different responsibility levels α will affect the behavior of the players of the game in a contamination event. We first make the following assumptions: The regulator assumes the portion α_1 of the cleanup cost when the firm implements extra controls. And we further assume that α_1=α.

The regulator assumes α_3 when the firm does not apply extra controls but the regulator does. The regulator assumes α_4 when both the firm and the regulator do not apply extra controls. With these assumptions, we get the modified matrix in Table 4.1 with the following payoffs

$$
\begin{aligned}
\Pi_a &= (1-\tau)(a_1 Q_{max} - a_0) - p_{max}(1-\alpha_1)\Delta - (1-\tau)(b_1 Q_{max} + b_0) \\
&+ [1-(1-\delta)^2] p_{max}(1-\alpha_1)\Delta \qquad (4.1) \\
\Pi_b &= (1-\tau)(a_1 Q_{max} - a_0) - p_{max}(1-\alpha_1)\Delta - (1-\tau)(b_1 Q_{max} + b_0) \\
&+ [1-(1-\delta)] p_{max}(1-\alpha_1)\Delta \qquad (4.2) \\
\Pi_c &= \tau(a_1 Q_{max} - a_0 - b_1 Q_{max} - b_0) - (d_1 Q_{max} + d_0) \\
&- (1-\delta)^2 p_{max}\Delta\alpha_1 \qquad (4.3) \\
\Pi_d &= \tau(a_1 Q_{max} - a_0 - b_1 Q_{max} - b_0) - (1-\delta) p_{max}\Delta\alpha_1 \qquad (4.4) \\
\Pi_e &= (1-\tau)(a_1 Q_{max} - a_0) - p_{max}(1-\alpha_3)\Delta \\
&+ [1-(1-\delta)] p_{max}(1-\alpha_3)\Delta \qquad (4.5) \\
\Pi_f &= (1-\tau)(a_1 Q_{max} - a_0) - p_{max}(1-\alpha_4)\Delta \qquad (4.6) \\
\Pi_g &= \tau(a_1 Q_{max} - a_0) - (d_1 Q_{max} + d_0) - (1-\delta) p_{max}\Delta\alpha_3 \qquad (4.7) \\
\Pi_h &= \tau(a_1 Q_{max} - a_0) - p_{max}\Delta\alpha_4. \qquad (4.8)
\end{aligned}
$$

Using the same method of solving for the solution as used in chapter III, we find the firm will only control if

$$
\begin{aligned}
&(1-\tau)(a_1 Q_{max} - a_0) - p_{max}\Delta(1-\alpha_1) - (b_1 Q_{max} + b_0)(1-\tau) \\
&+[1-(1-\delta)^2] p_{max}\Delta(1-\alpha_1) \geq (1-\tau)(a_1 Q_{max} - a_0) \\
&-p_{max}\Delta(1-\alpha_3) + [1-(1-\delta)] p_{max}\Delta(1-\alpha_3). \qquad (4.9)
\end{aligned}
$$

Table 4.1: The modified payoff matrix

	regulator Control (x)	**regulator No Control (1 - x)**
Firm controls (y)	Π_a Π_c	Π_b Π_d
Firm does not control (1 - y)	Π_e Π_g	Π_f Π_h

This implies

$$-p_{max}\Delta(1-\alpha_1)-(b_1Q_{max}+b_0)(1-\tau)+p_{max}\Delta[1-(1-\delta)^2](1-\alpha_1)$$
$$\geq -p_{max}\Delta(1-\alpha_3)+p_{max}\Delta[1-(1-\delta)](1-\alpha_3), \quad (4.10)$$

and so

$$(2\delta-\delta^2)(1-\alpha_1)+(\alpha_1-\alpha_3)-\delta(1-\alpha_3) \geq \frac{(b_1Q_{max}+b_0)(1-\tau)}{p_{max}\Delta}. \quad (4.11)$$

We denote the right hand side of equation (4.11) as

$$F_N = \frac{(b_1Q_{max}+b_0)(1-\tau)}{p_{max}\Delta}. \quad (4.12)$$

Also the firm will control if

$$-p_{max}\Delta(1-\alpha_1) - (b_1 Q_{max} + b_0)(1-\tau) + \delta p_{max}\Delta(1-\alpha_1)$$
$$\geq -p_{max}\Delta(1-\alpha_4), \tag{4.13}$$

$$(\alpha_1 - \alpha_4) + \delta(1-\alpha_1) \geq \frac{(b_1 Q_{max} + b_0)(1-\tau)}{p_{max}\Delta} = F_N. \tag{4.14}$$

Now we look at the regulator's case. The regulator will control if

$$-(d_1 Q_{max} + d_0) - (1-\delta)p_{max}\Delta(\alpha_3) \geq -p_{max}\Delta(\alpha_4), \tag{4.15}$$

$$\alpha_4 - (1-\delta)\alpha_3 \geq \frac{(d_1 Q_{max} + d_0)}{p_{max}\Delta}. \tag{4.16}$$

We let

$$R_N = \frac{(d_1 Q_{max} + d_0)}{p_{max}\Delta}. \tag{4.17}$$

Now the regulator also controls if

$$(1-\delta)\alpha_1 - (1 - 2\delta + \delta^2)\alpha_1 \geq \frac{(d_1 Q_{max} + d_0)}{p_{max}\Delta}, \tag{4.18}$$

$$(\delta - \delta^2)\alpha_1 \geq R_N. \tag{4.19}$$

We observe here that

$$F = \frac{F_N}{(1-\alpha)}, \tag{4.20}$$

and

$$R = \frac{R_N}{\alpha}. \tag{4.21}$$

From equations (4.20) and (4.21), we can relate the results of any conditions that will be investigated to the results of the main model discussed in chapter 3.

Some specific cases.

Case 1: We assume that $0 < \alpha_3 = \alpha_1 = \alpha_4$.

Clearly, this is the case that was discussed in chapter 3.

Case 2: We assume that $0 < \alpha_4 < \alpha_1 = \alpha_3 = \alpha$, which means the regulator picks up a smaller portion of the cleanup cost when no one controls. In this case when the regulator controls, the firm will only control if

$$(2\delta - \delta^2)(1 - \alpha_1) + (\alpha_1 - \alpha_3) - \delta(1 - \alpha_3) \geq F_N. \tag{4.22}$$

Dividing through equation (4.22) by $(1 - \alpha)$ we find

$$(2\delta - \delta^2)\frac{(1 - \alpha_1)}{1 - \alpha} + \frac{(\alpha_1 - \alpha_3)}{1 - \alpha} - \frac{\delta(1 - \alpha_3)}{1 - \alpha} \geq \frac{F_N}{1 - \alpha}. \tag{4.23}$$

Therefore

$$(2\delta - \delta^2) - \delta \geq F. \tag{4.24}$$

This simplifies to equation (3.6). That is $\delta - \delta^2 \geq F$. In this case, when the regulator controls, the firm will control. But if the regulator is not controlling, then the firm will only control if

$$\frac{(\alpha_1 - \alpha_4)}{1 - \alpha} + \delta\frac{(1 - \alpha_1)}{1 - \alpha} \geq \frac{F_N}{1 - \alpha}, \tag{4.25}$$

$$\frac{(\alpha_1 - \alpha_4)}{1 - \alpha} + \delta \geq F. \tag{4.26}$$

We now want to look at the behavior of the regulator. If the firm controls, then the regulator will control if

$$\frac{(\delta - \delta^2)\alpha_1}{\alpha} \geq \frac{R_N}{\alpha}. \tag{4.27}$$

By our assumptions, equation (4.27) will be identical to equation (3.13). This is the pure strategy that when the firm is controlling, the regulator will also control at the level of effectiveness δ.

Also when the firm is not controlling, the regulator will only control if

$$\frac{\alpha_4}{\alpha} - \frac{(1-\delta)\alpha_3}{\alpha} \geq \frac{R_N}{\alpha}. \tag{4.28}$$

This simplifies to

$$\frac{\alpha_4}{\alpha} - (1-\delta) \geq R, \tag{4.29}$$

or

$$\delta - (1 - \frac{\alpha_4}{\alpha}) \geq R. \tag{4.30}$$

Clearly $1 - \frac{\alpha_4}{\alpha} \geq 0$. So $\delta - (1 - \frac{\alpha_4}{\alpha}) < \delta$. In addition $\delta - (1 - \frac{\alpha_4}{\alpha}) \geq \delta - \delta^2$ when $1 - \frac{\alpha_4}{\alpha} \leq \delta^2$. This will be true when α is sufficiently large. Hence we consider two subcases.

If $1-\frac{\alpha_4}{\alpha} < \delta^2$, then Figure 4.1 represents the results discussed above. However, the case when $1 - \frac{\alpha_4}{\alpha} > \delta^2$, which is true for small α_4, is represented in Figure 4.2.

We observe in Case 2, the firm will always control more than the regulator. In the subcase case where $1-\frac{\alpha_4}{\alpha} > \delta^2$, we realize that the regulator controls relatively less than when $1 - \frac{\alpha_4}{\alpha} < \delta^2$. Though Case 2 favors the regulator, Figure (4.2) also

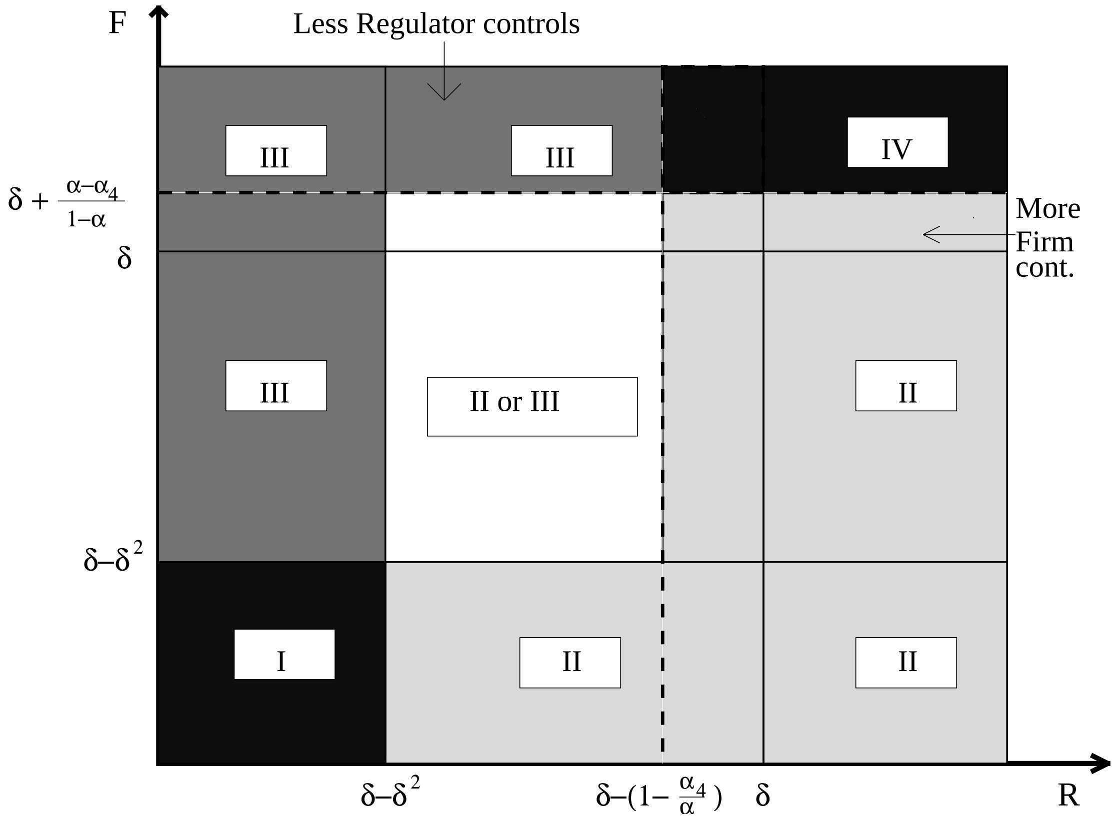

Figure 4.1: A chart displaying the results of Case 2, when $1 - \frac{\alpha_4}{\alpha} < \delta^2$. Here the region where the firm controls is larger.

indicates a large portion labeled (IV), where no one controls. Therefore in the long term, this condition will not favor the consumer. Figure (4.2) also indicates a mixed strategy, which we shall investigate in the future.

In summary when the regulator pays a small portion of the cleanup cost, then the firm must choose to apply more controls.

Case 3: We now examine the case $0 < \alpha_1 = \alpha_3 = \alpha < \alpha_4$. Here the firm pays a smaller portion of the cleanup cost. When the regulator controls, the firm will

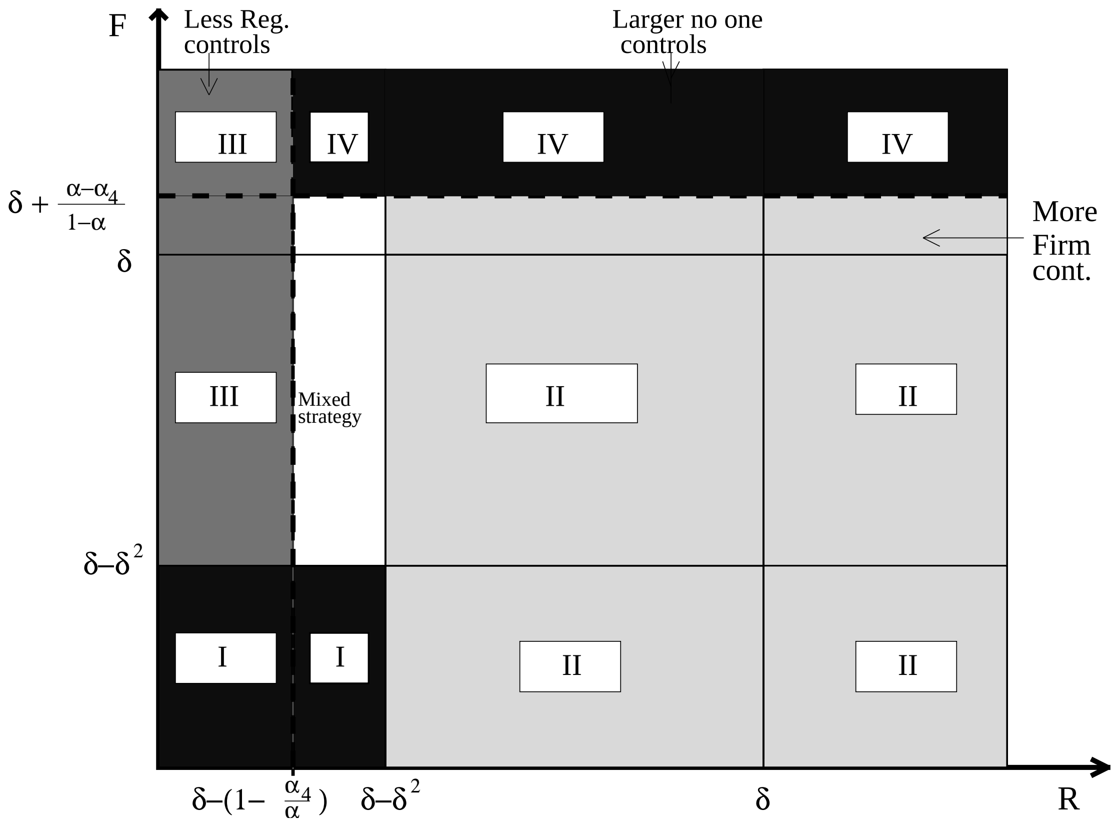

Figure 4.2: A chart displaying the results of Case 2, when $1 - \frac{\alpha_4}{\alpha} > \delta^2$. Here the region where the firm controls is larger than the other case.

control if

$$(2\delta - \delta^2)\frac{(1-\alpha_1)}{1-\alpha} + \frac{(\alpha_1 - \alpha_3)}{1-\alpha} - \frac{\delta(1-\alpha_3)}{1-\alpha} \geq \frac{F_N}{1-\alpha}. \tag{4.31}$$

Here too, equation (4.31) will become identical to equation (3.6) based on the assumptions above. But if the regulator does not control, then the firm will control if

$$\frac{(\alpha_1 - \alpha_4)}{1-\alpha} + \delta\frac{(1-\alpha_1)}{1-\alpha} \geq \frac{F_N}{1-\alpha}, \tag{4.32}$$

and so

$$\frac{(\alpha_1 - \alpha_4)}{1-\alpha} + \delta \geq F. \tag{4.33}$$

Clearly $\frac{(\alpha_1-\alpha_4)}{1-\alpha} < 0$ so that $\frac{(\alpha_1-\alpha_4)}{1-\alpha} + \delta < \delta$. In addition $\frac{(\alpha_1-\alpha_4)}{1-\alpha} + \delta \geq \delta - \delta^2$ provided $\frac{(\alpha_4-\alpha_1)}{1-\alpha} \leq \delta^2$. This will be true for α_1 sufficiently large. Thus similar to Case 2, there will be two subcases for Case 3.

We now look at the case when the firm is not controlling, then the regulator will control if

$$\frac{\alpha_4}{\alpha} - \frac{(1-\delta)\alpha_3}{\alpha} \geq \frac{R_N}{\alpha}. \tag{4.34}$$

Hence

$$\frac{\alpha_4}{\alpha} - (1-\delta) \geq R, \tag{4.35}$$

or

$$\delta - (1 - \frac{\alpha_4}{\alpha}) \geq R. \tag{4.36}$$

On the other hand if the firm controls, then the regulator controls for $\delta - \delta^2 \geq R$.

Now we summarize the results of Case 3 in Figures 4.3 and 4.4. For the case $\delta^2 \geq \frac{(\alpha_4-\alpha_1)}{1-\alpha}$, see Figure 4.3. If $\delta^2 \leq \frac{(\alpha_4-\alpha_1)}{1-\alpha}$, then Figure 4.4 represents the results discussed above. We observe that Case 3 forces the regulator to control more often than the firm, because the firm pays less for cleanup. This is particularly true in Figure 4.4. As in Case 2, there is a relatively large region not controlled by both players in Figure 4.4. We also have a mixed strategy under the second subcase of Case 3.

Lastly we consider Case 4: $0 < \alpha_3 = \alpha_4 < \alpha = \alpha_1$. Here the regulator pays less of the cleanup cost if the firm chooses not to control. If the regulator controls,

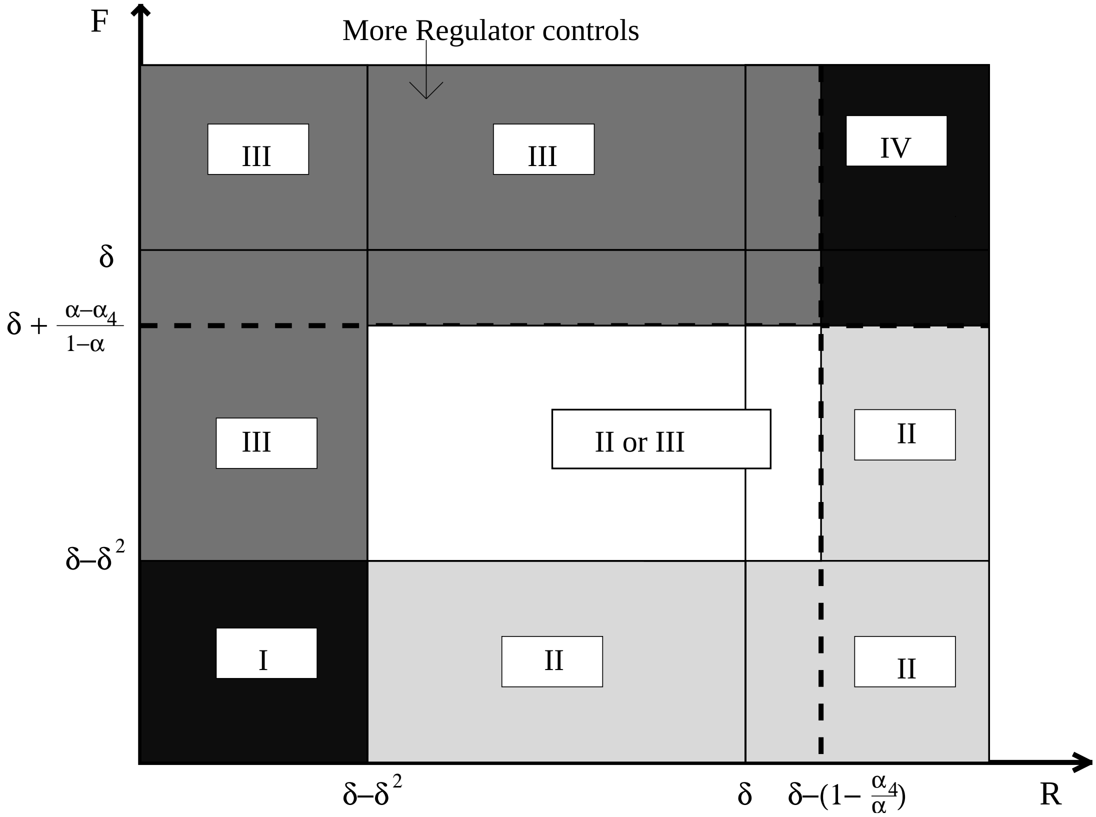

Figure 4.3: A chart displaying the results of Case 3, when $\delta^2 \geq \frac{(\alpha_4-\alpha_1)}{1-\alpha}$.

the firm will control if

$$(2\delta - \delta^2)\frac{(1-\alpha_1)}{1-\alpha} + \frac{(\alpha_1-\alpha_3)}{1-\alpha} - \frac{\delta(1-\alpha_3)}{1-\alpha} \geq \frac{F_N}{1-\alpha}, \tag{4.37}$$

$$(\delta + \delta - \delta^2) + \frac{(\alpha_1-\alpha_3)}{1-\alpha} - \frac{\delta(1-\alpha_3)}{1-\alpha} \geq F, \tag{4.38}$$

$$(\delta - \delta^2) + \frac{\delta(1-\alpha)}{1-\alpha} - \frac{\delta(1-\alpha_3)}{1-\alpha} + \frac{(\alpha-\alpha_3)}{1-\alpha} \geq F. \tag{4.39}$$

Hence

$$\delta - \delta^2 + \frac{(\alpha-\alpha_3)}{1-\alpha}(1-\delta) \geq F. \tag{4.40}$$

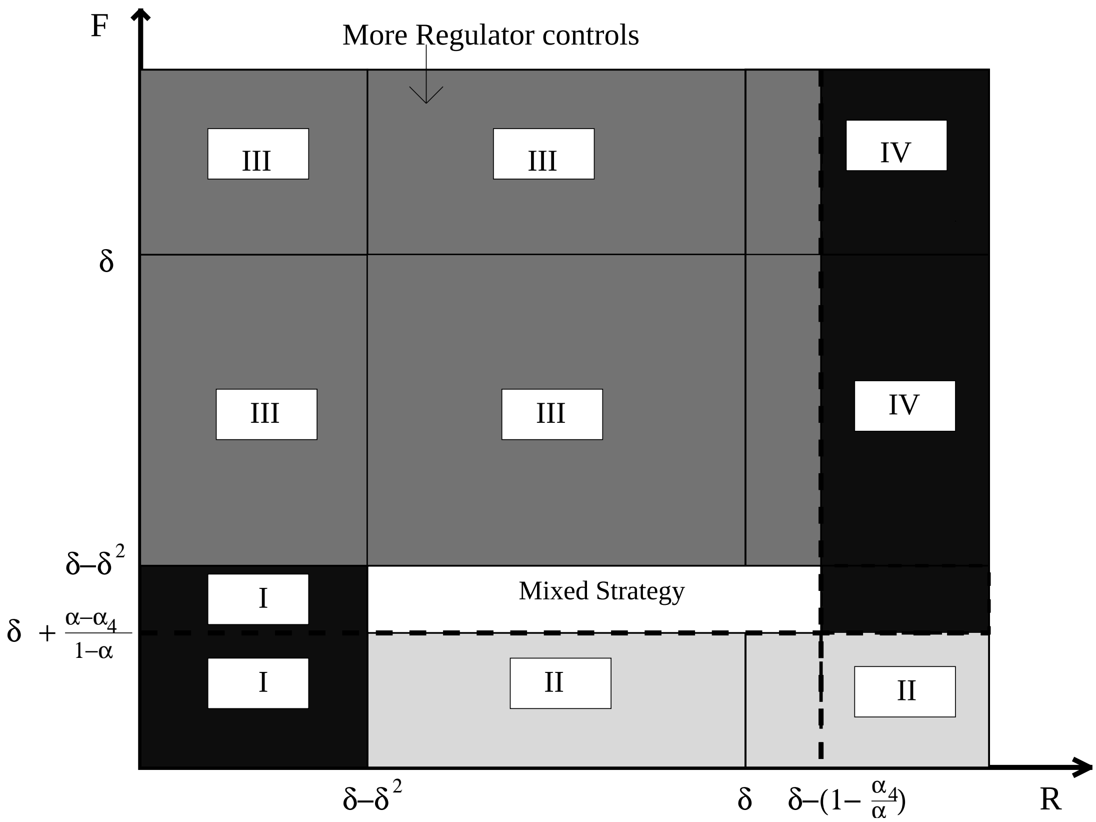

Figure 4.4: A chart displaying the results of Case 3, when $\delta^2 \leq \frac{(\alpha_4 - \alpha_1)}{1-\alpha}$.

Now let

$$-\delta^2 + \frac{(\alpha - \alpha_3)}{1 - \alpha}(1 - \delta) = \beta. \tag{4.41}$$

Then we have

$$\delta + \beta \geq F. \tag{4.42}$$

On the other hand, if the regulator does not control, then the firm controls if

$$\frac{(\alpha_1 - \alpha_4)}{1 - \alpha_1} + \delta \geq F. \tag{4.43}$$

If the firm does not control, then the regulator will control if

$$\delta \frac{\alpha_3}{\alpha} \geq R, \tag{4.44}$$

and if the firm controls, then equation (3.13) is satisfied. This particular case, unlike the previous cases, will be presented in four different charts below.

First, when $\beta < 0$ and $\delta \frac{\alpha_3}{\alpha}$ is between δ and $\delta - \delta^2$, then the results for Case 4 are displayed in Figure 4.5. As expected the firm must choose to control more often than Figure 3.1.

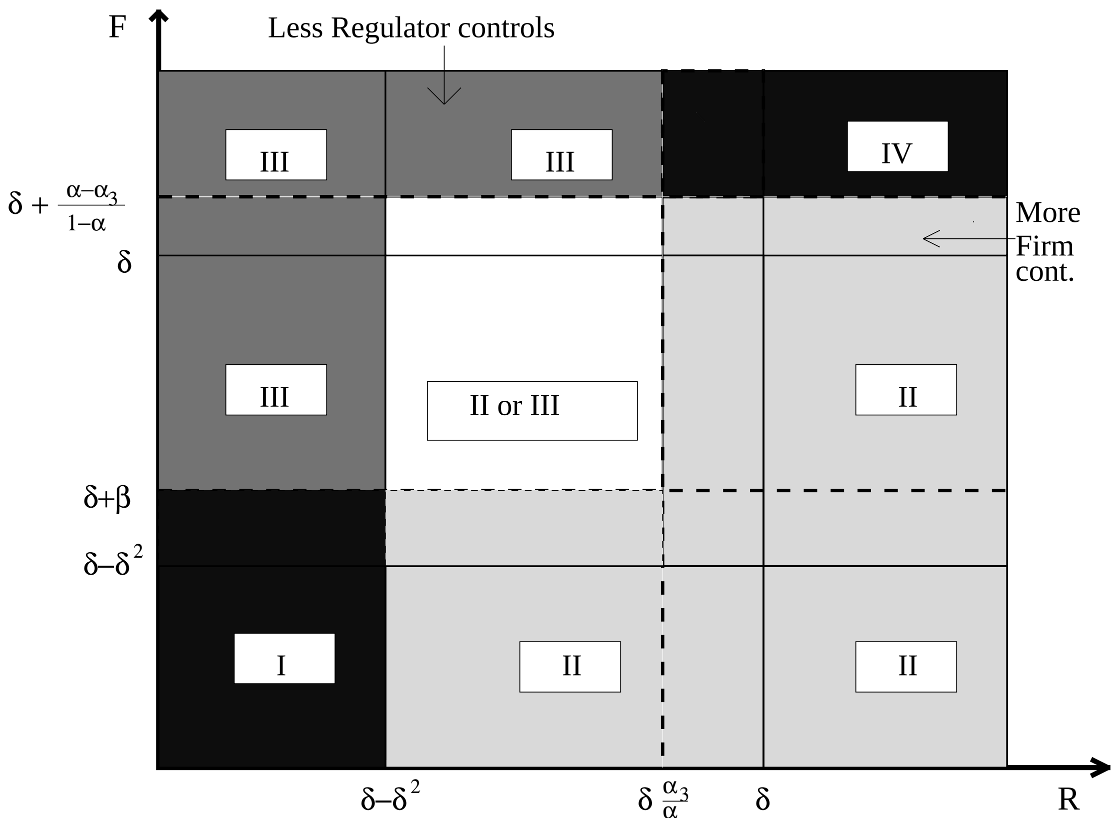

Figure 4.5: A chart displaying the results of Case 4, when $\beta < 0$ and $\delta \frac{\alpha_3}{\alpha}$ is between δ and $\delta - \delta^2$.

For $\beta > 0$ and $\delta\frac{\alpha_3}{\alpha}$ is between δ and $\delta - \delta^2$, the results are displayed in Figure 4.6.

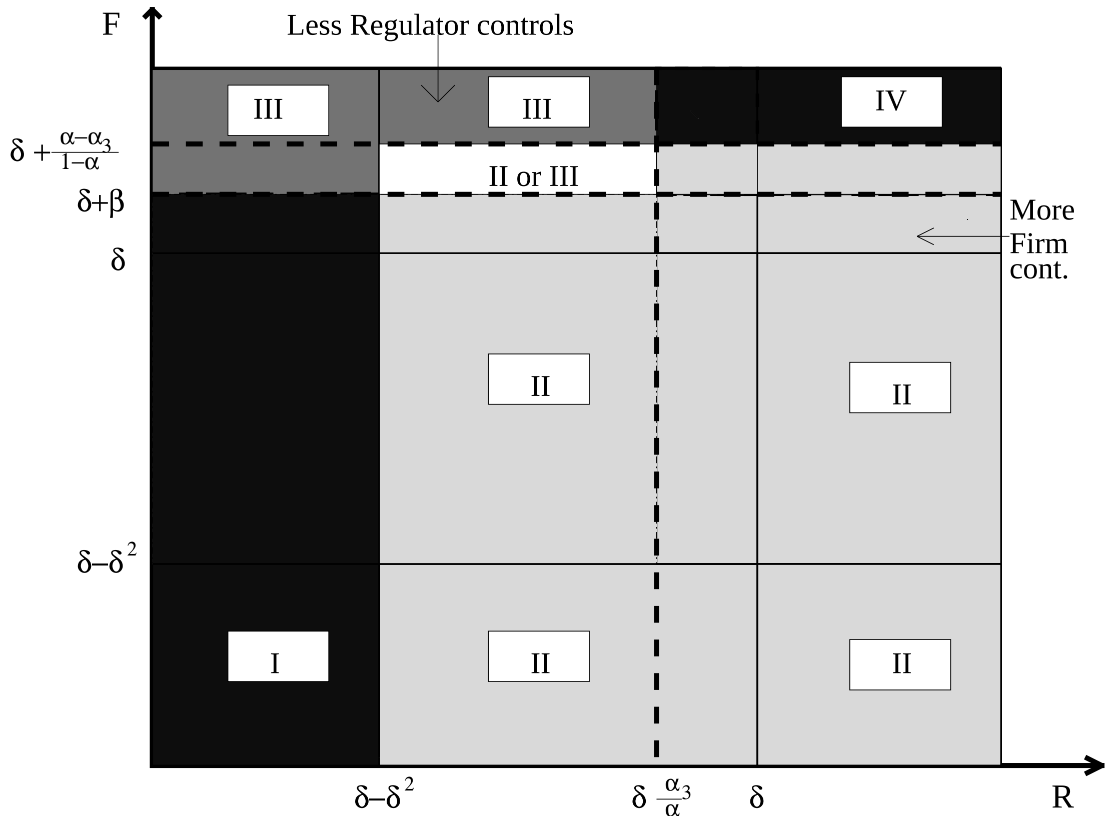

Figure 4.6: A chart displaying the results of Case 4, when $\beta > 0$ and $\delta\frac{\alpha_3}{\alpha}$ is between δ and $\delta - \delta^2$.

Now consider the case when $\beta < 0$ and $\delta\frac{\alpha_3}{\alpha} < \delta - \delta^2$. The result is depicted in Figure 4.7.

The last scenario representing Case 4 will be when $\beta > 0$ and $\delta\frac{\alpha_3}{\alpha} < \delta - \delta^2$ and is depicted in Figure 4.8.

In all scenarios of Case 4 the firm must control more often than all other cases. This is because the regulator picks up the lowest portion of the cleanup cost

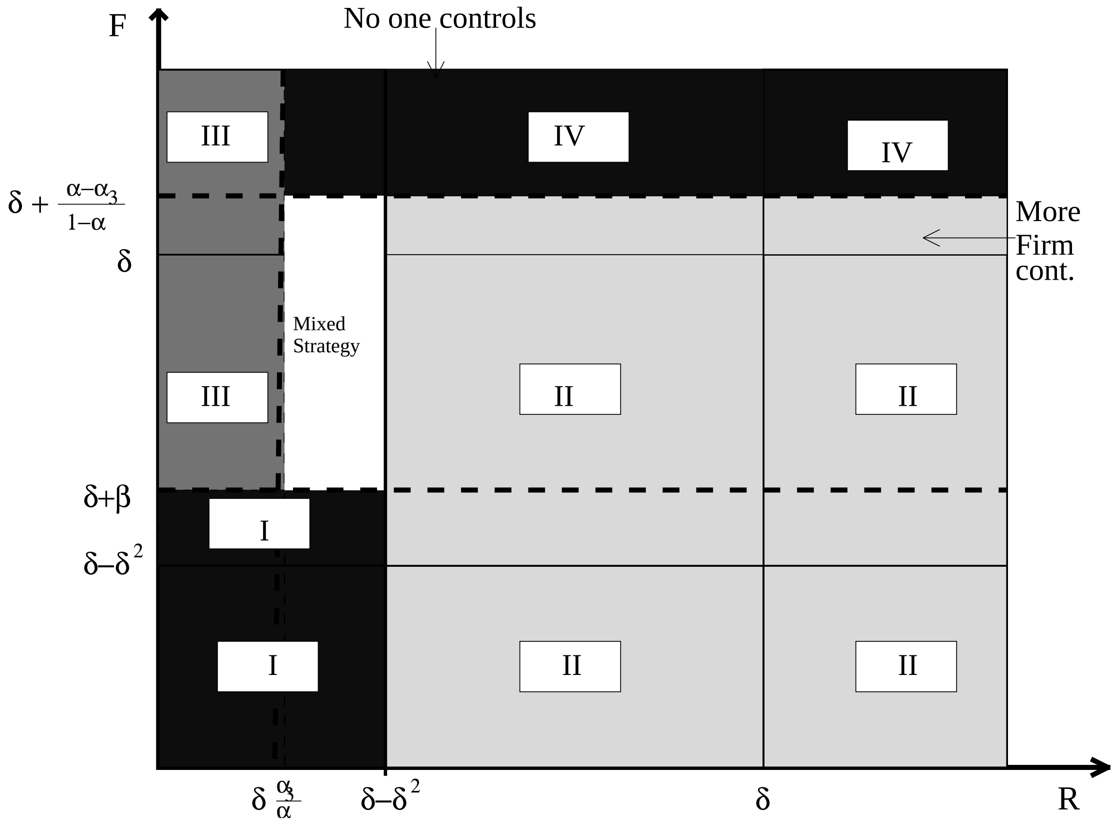

Figure 4.7: A chart displaying the results of Case 4, when $\beta < 0$ and $\delta\frac{\alpha_3}{\alpha} < \delta - \delta^2$.

in Case 4. If the goal of the regulator is to force the firm to take responsibility for the quality of the meat, then Case 4 is the policy to establish.

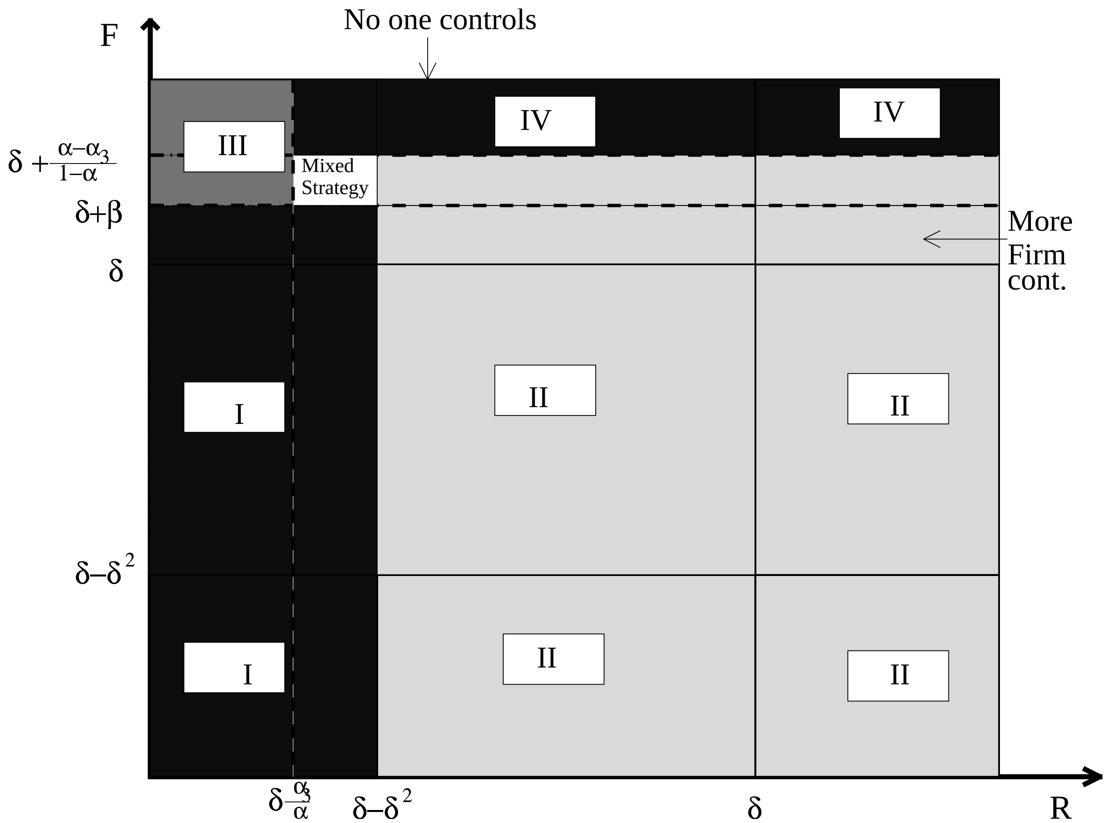

Figure 4.8: A chart displaying the results of Case 4, when $\beta > 0$ and $\delta\frac{\alpha_3}{\alpha} < \delta - \delta^2$.

CHAPTER V

SUMMARY

This paper discusses the use of game theory to establish policy for prevention of meat contamination. The game is played between the firm and the regulator(USDA). For close to a century in the U.S., the USDA did most of the meat inspection work themselves and since the implementation of the HACCP, it is believed that most of the inspection work has been shifted to the firm. But there has not been much significant change in terms of meat recall. In fact, the biggest recall in America's history [2] occured after this switch of responsibilities.

Since each party seems to be certain to play a role in the prevention of contamination, and there are still frequent recalls, this thesis examined how an application of an extra control can prevent or reduce contamination events. Payoffs were chosen to define the profit of the player, his cost of controls and the estimated cost of cleanup should there be an event. Using our model we have been able to establish the behavior of both the regulator and firm towards meat contamination prevention. Our first observation is that both parties will respond to preventive measures based on how much it will cost them should there be an event of contamination. The cheaper the cost of cleanup, the more reluctant both the firm and the regulator are towards controls. We also observe that, the cheaper it is to apply extra controls, the more likely both parties will be willing to control. Based on these findings, we examined various conditions in terms of one's behavior towards prevention and its associated cost to that party in case of an event. It is interesting to see that both parties applied more controls when their share of cleanup responsibilities are higher in case of an event. Since the cost of controls may never be low, we advise the regulator (government) to pay little of the cleanup cost if firms refuse to control well enough and there is a contamination event. This action will cause the firms to apply more controls. We wish to state that firms may end up passing that extra cost of control to consumers, but at least our aim of having quality meat in America will be achieved.

We note that though our results are interesting, the model has some limitations. It is applicable to only a perfect competitive market, because of our choice of profit function. Though we acknowledge the fact that some of the attributes of a perfect competitive market can be met by the meat industry, the firms in the meat industry are relatively large in size. Also we do not have an upper limit for our controls, that is one can keep controlling until all their resources are used. We assumed that the profit is maximized, which in reality may not be the case.

There are many extensions that can be done on this work. This includes solving the mixed cases that evolved under the specific cases that were studied in chapter IV to determine probabilities for the regulator and firm towards controls. We may also go beyond the linear profit function to quadratic and other realistic profit functions which may produce exciting results to investigate. Another extension is to investigate the economic implications of fines to firms and the impact on society.

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