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ASSESSMENT OF ENFORCEMENT MECHANISM FOR PORK TRACEABILITY SYSTEM IN KOREA USING MIXED STRATEGY NASH EQUILIBRIUM

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Keywords
Pork Traceability, Labeling, Mixed Strategy Nash Equilibrium, Game Theory

Abstract

The National Agricultural Products Quality Management Service (NAQS) of Korea initiated enforcing the food traceability system since 1994. However, the effectiveness of NAQS' enforcement has been in dispute. To provide a framework for valid assessment of NAQS' enforcement mechanism, the Mixed Strategy Nash Equilibrium, is used. Also, to cover the long range of seller's and NAQS' strategies, a distribution-based model is developed, along with a mean-based model. The analysis is done for pork labeling because pork is the sensitive food item for traceability and labeling. Also, the analysis is limited to year 2009 due to data availability.

The results from the mean-based model suggest that NAQS needed to increase the raid probability for pork significantly from the current 0.1% to 16% in 2009. The cheating probability for pork labeling is calculated as 1.5% in 2009. However, it was found that the data on fines and revenues by cheating are highly skewed. This made implications from the mean-based model unreliable.

Through the sensitivity analysis, it was found that the court needs to increase the amount of fine and the most frequently observed Mixed Strategy Nash Equilibrium would be for the seller to cheat with probability of 1.3% and for NAQS to raid with probability of 0.1%, which was quite close to the actual raid probability of NAQS in 2009.

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Ⅰ. Introduction

National Agricultural Products Quality Management Service (NAQS) of Korea initiated enforcing the traceability system since 1994. As a result, the ratio of proper labeling has been increasing from 62.2% in 1994 to 97.6% in 2009. To improve the ratio, NAQS has been raiding business entities in food industry. For the period of 1995~2010, the number of raids (NR) has increased from 226,120 to 391,116 and the number of raid squads (NS) has also increased from 22,886 to 111,628 as shown in Table 1.

Table 1. Summary of NAQS' Enforcement Efforts and Result of Traceability System

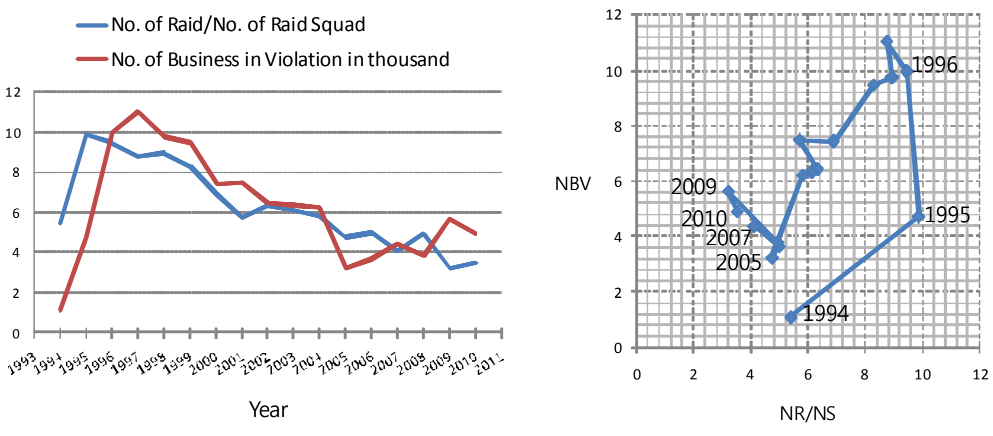
Year	No. of Raid Squad (NS)	No. of Raided Business Entity (NR)	No. of Business Entity in Violation (NBV)	Details of Violation				
				False labeling			No labeling	
				Charged	Under Investigation	subtotal	Fine	Amount (10,000KRW)
1994	15,678	84,701	1,099	55		55	1,044	6,558
1995	22,886	226,120	4,724	238		238	4,486	16,549
1996	30,882	292,230	9,951	277		277	9,674	79,768
1997	39,781	349,002	11,017	619		619	10,398	87,369
1998	33,065	295,750	9,732	785	124	909	8,823	73,528
1999	36,063	299,023	9,455	1,585	693	2,278	7,177	84,558
2000	37,537	258,769	7,430	212	2,565	2,777	4,653	57,619
2001	37,274	212,457	7,478	200	3,604	3,804	3,674	46,850
2002	31,258	197,964	6,427	220	3,502	3,722	2,705	31,305
2003	32,142	196,932	6,327	347	3,408	3,755	2,572	32,768
2004	32,629	189,669	6,201	255	3,322	3,577	2,624	37,251
2005	25,855	122,435	3,231	53	1,698	1,751	1,480	20,000
2006	25,729	128,259	3,634	34	1,868	1,902	1,732	24,800
2007	33,492	136,704	4,374	17	1,706	1,723	2,651	56,500
2008	54,548	268,466	3,803	131	1,923	2,054	1,749	72,457
2009	99,489	318,366	5,635	148	2,663	2,811	2,824	90,280
2010	111,628	391,116	4,894	81	2,991	3,072	1,822	78,963

The ratio of NR/NS has been decreasing from 10 to 3, implying relatively more and more manpower has been deployed. As a result, the number of violating business entities (NBV) has generally decreased as presented in Figure 1. Also, the figure implies that it took two years (1994-1995) for NAQS to stabilize its system and deviation from normal effectiveness occurred in the recent years of 2009 and 2010.

However, since 2005, NBV seems to have increased, which signals that the incentive for business entities to cheat might have augmented. Therefore, a closer and systematic look to assess why this tendency is forming becomes necessary. Especially, the current outbreaks of foot-and-mouth disease in Korea and the recent effectuation of Korea-EU FTA will lead to decreased domestic production of pork and increased imported pork. This situation is volatile for sellers to cheat on labeling imported pork as domestically produced pork. Therefore, in this paper, the effectiveness of NAQS' traceability system is assessed, focusing on pork.

To assess the system effectiveness, explicit consideration of seller's and controlling agency's incentives is needed. Simple manipulation of raid data as in Song (2009) will not help much to provide meaningful implication. Therefore, a game theoretic approach has been taken.

Figure 1. Change of NR/NS and Number of Business in Violation



Ⅱ. Literature Review

Application of the game theory to regulatory process in general is appeared in many game theory literature such as Osborne(2004), Tirole(1988) and Maskin and Tirole(1988). However, there is a limited body of game theoretic literature on food traceability/labeling. A game theoretic approach to food labeling first appeared in McCluskey(2000), where she introduced a basic game theoretic structure of organic food labeling. However, she failed to apply the model to a real case. Cho(2004) also developed a game model of food labeling for safety with application to US meat and poultry industry.

In Korea, the first game theoretic approach to food industry labeling appeared in Song(2008), where he formulated an organic food labeling game and measured the information asymmetry using Shannon's information entropy (Shannon, 1948). The most recent game theoretic approach to Korean food labeling is done by Song(2010), where he investigated the Korean beef labeling system and dealt with enforcement issues using the Bayesian dynamic game model with 12 players. However, all these studies failed to provide a meaningful policy implication/assessment for the implementing agency, namely the NAQS, even though they might have been successful in formulating a game model and measuring the information asymmetry in labeling. To provide the NAQS a plausible policy implication, the Mixed Strategy Nash Equilibrium model(Nash, 1950) is used in this study.

Ⅲ. Model

The Nash Equilibrium(Nash, 1950) is 'the' solution concept in the field of game theory, which generated numerous offspring and cousins in solution concepts afterwards. The problem of this generalized solution concept is that there can be a unique equilibrium, multiple equilibria or no equilibrium at all in pure strategy games(Dixit and Skeath, 2004). However, Nash(1950) proved there always exist equilibria in mixed strategy games. A mixed strategy is a probability distribution of strategy(Gibbons, 1992). The formal definition is as follows.

3.1. Definition

In the normal-form game $G = \{S_1, ..., S_n; u_1, ..., u_n\}$, suppose $S_i = \{s_{i1}, ..., s_{iK}\}$. Then a mixed strategy for player i is a probability distribution $p_i = \{p_{i1}, ..., p_{iK}\}$, where $0 \le p_{ik} \le 1$ for $k = 1, ..., K$ and $p_{i1} + \cdots + p_{iK} = 1$. G stands for the game, S_i for set of strategies of player i, u_i for the payoff to i, s_{ik} for i's k^{th} strategy, and p_{ik} for the probability for i's to take k^{th} strategy (s_{ik}).

In the context of the labeling game for pork, the above definition is demonstrated in the following game table.

Table 2. The Pork Labeling Game

Player/ Strategies		NAQS		
		Raid	Don't Raid	q-mix
Seller	Cheat	a, b	c, d	$qa + (1-q)c$, $qb + (1-q)d$
	Don't Cheat	0, f	0, 0	0, qf
	p-mix	pa, $pb + (1-p)f$	pc, pd	$\pi_S = p[qa + (1-q)c]$, $\pi_{NAQS} = p[qb + (1-q)d] + (1-p)qf$

There are two players, the Seller and NAQS with two pure strategies of {Cheat, Don't Cheat} for the Seller and {Raid, Don't Raid} for NAQS respectively. In addition to these two strategies, each player has a mixed strategy of {p=probability of choosing Cheat, (1-p)=probability of choosing Don't Cheat} and {q=probability of choosing Raid, (1-q)=probability of choosing Don't Raid}. The payoffs according to the combinations of players' strategies are represented as {a,b,c,d,f}. Also, the Seller's payoff is assumed to be zero when the Seller chooses 'Don't Cheat' and NAQS chooses 'Raid,' because the Seller isn't better off when it chooses 'Don't Cheat.' But playing 'Raid' incurs costs to NAQS so that NAQS loses in the amount of f. When the Seller chooses 'Don't Cheat' and NAQS chooses 'Don't Raid,' nothing happens so the payoffs are zero for both. The expected payoffs are also represented in the 3rd payoff rows and columns. For example, when NAQS chooses 'Raid' and the Seller chooses the mixed strategy of p-mix, the expected payoff for the Seller is calculated as follows.

$pa + (1 - p)0 = pa$.

When both players play mixed strategies of *p*-mix and *q*-mix, the payoffs are as follows.

$$\begin{aligned} \pi_S &= p\left[qa + (1-q)c\right] + (1-p)\cdot 0 = p\left[qa + (1-q)c\right] \\ \pi_{NAQS} &= p\left[qb + (1-q)d\right] + (1-p)qf \end{aligned} \tag{1}$$

Then, assuming each player maximizes its payoff by choosing its mixed strategy, the best mixed strategy is gained by differentiating the own payoff functions by its strategy and setting the differential equal to zero.

$$\begin{aligned} &\frac{\partial \pi_S}{\partial p} = qa + (1-q)c = 0 \Rightarrow q = \frac{-c}{a-c} \\ &\frac{\partial \pi_G}{\partial q} = pb - pd + (1-p)f = 0 \Rightarrow p = \frac{-f}{b-d-f} \end{aligned} \tag{2}$$

In addition, it is assumed that the following holds
$b = -a + f, d = -c$,

because, *b*(> 0), the NAQS' payoff when the Seller cheats and NAQS raids, consists of the fine ($a < 0$) paid by the cheating player to NAQS(the government) less the cost of the raid ($f < 0$). Lastly, when the Seller cheats and NAQS doesn't raid, the loss ($d < 0$) of the cheated NAQS which represents consumers' interests is the opposite of the Seller's gain ($c > 0$). Therefore, equation (2) can be simplified to equation (3) as follows.

$$\begin{aligned} p &= \frac{-f}{b-d-f} = \frac{-f}{-a+f+c-f} = \frac{-f}{-a+c} \\ q &= \frac{-c}{a-c} = \frac{-1}{\frac{a}{c}-1} \end{aligned} \tag{3}$$

Equation (3) implies that if *a* increases (the fine gets smaller because $a < 0$), the probability for the seller to cheat, *p*, increases, which is intuitively correct. If the absolute value of f increases(f decreases or the raid cost increases), the numerator gets bigger, implying that the cheating probability of the Seller increases. That is, if NAQS becomes less cost-effective in raiding, the Seller will cheat more frequently. Lastly, if c increases(the payoff to the Seller when succeeding in cheating increases), the denominator gets bigger and the cheating probability p gets *smaller*(cheat less frequently). This implication may sound counter-intuitive because one may think that if one can make more money by cheating, one should cheat more often. However, on the other hand, if one expects a certain(or constant) level of payoff from cheating, one will decrease the probability to cheat when the payoff from cheating itself increases. The same reasoning applies to q. If a increases(the fine gets smaller), the absolute value of the denominator gets smaller and q gets bigger. If c gets bigger, q gets bigger(if the Seller gets more by cheating, NAQS should raid more often). All these implications can be confirmed formally as follows.

$$\frac{\partial p}{\partial a} = \frac{\partial p}{\partial(-a+c)} \cdot \frac{\partial(-a+c)}{\partial a} = -f \cdot (-1) \cdot (-a+c)^{-2} \cdot (-1) = -f(-a+c)^{-2} > 0$$

$$\frac{\partial p}{\partial c} = \frac{\partial p}{\partial(-a+c)} \cdot \frac{\partial(-a+c)}{\partial c} = -f \cdot (-1) \cdot (-a+c)^{-2} = f(-a+c)^{-2} < 0$$

$$\frac{\partial p}{\partial f} = \frac{-1}{-a+c} < 0$$

$$\frac{\partial q}{\partial a} = \frac{\partial q}{\partial(a-c)} \cdot \frac{\partial(a-c)}{\partial a} = \frac{\partial\left[-c(a-c)^{-1}\right]}{\partial(a-c)} \cdot 1 = c(a-c)^{-2} > 0$$

$$\frac{\partial q}{\partial c} = (-1) \cdot (a-c)^{-1} + (-c) \cdot \left[(-1)(a-c)^{-2}(-1)\right] = \frac{-a}{(a-c)^{2}} > 0$$

Ⅳ. Result

4.1. Mean-based Model

Only a partial data for 2010 raids by NAQS can be acquired, missing data on fines for the on-going cases. Therefore, 2009 data is the most current data but it still misses fine data because many cases were still under investigation and fines were not finalized as of the date the data was acquired (3-21-11). Therefore, the violation cases that are still under investigation are excluded in the analysis.

Table 3. 2009 Game of False Labeling for Pork (Payoff Unit=KRW 10,000)

Player/ Strategies		NAQS		
		Raid	Don't Raid	q-mix
Seller	Cheat	-187.28, 183.88	35.82, -35.82	$-223.1q+35.82$, $219.7q-35.82$
	Don't Cheat	0, -3.4	0, 0	0, $-3.4q$
	p-mix	$-187.28p$, $187.28p-3.4$	$35.82p$, $-35.82p$	

The average fine assigned for false labeling was KRW 1,872,800. The average raid cost/raid was KRW 34,000, which was calculated by dividing the total traceability system enforcement budget with the number of raids. The average gains from successful cheating was calculated from the average revenue times 0.05, assuming 5% of gain from revenue in violation.[1]

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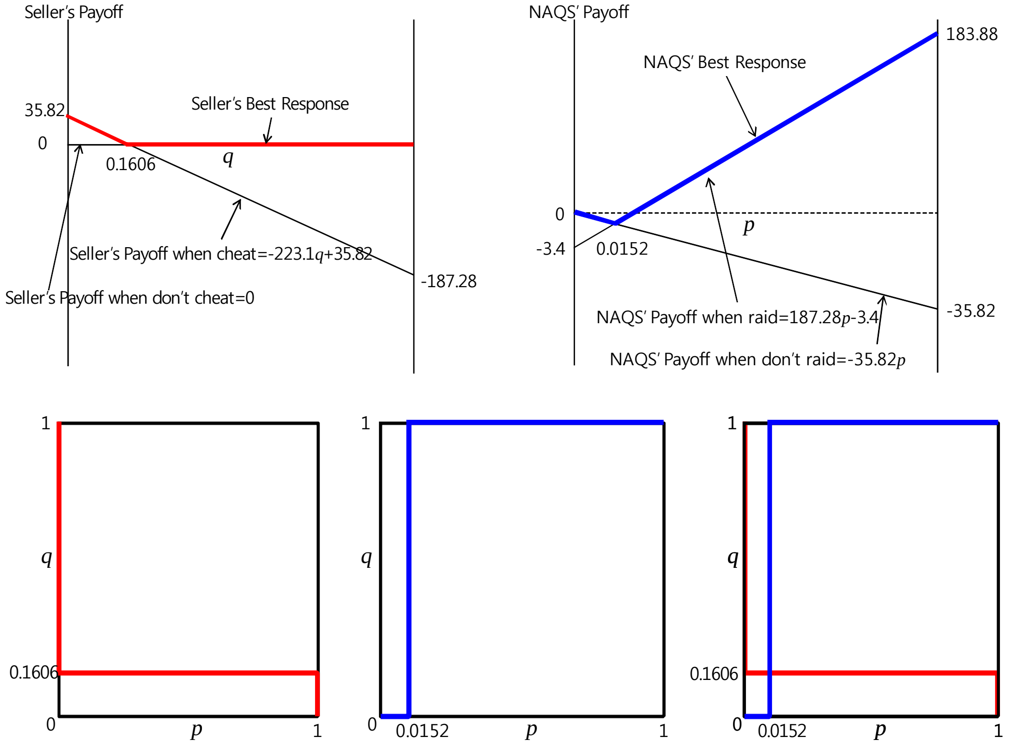
[1] In relation to the measure of illegal profit from violation(c in Table 2), the only available data was the total value of imported agricultural products in the marketing place when raided. The prosecutor could assume that the raided marketing entity intended to sell the entire imported products in the shop at the moment of raid as domestic products. In this case, the illegal profit earned from violation can be measured as the price difference between the domestic and the imported. Because the model in this paper is a static game, we need to measure the profit of the entity *at the moment of raid*. However, the presumed total value of imported agricultural products in violation is a stock. This poses questions: is a kitchen knife which is possessed by an ex-con a weapon or a tool for food preparation?; can we prove his/her criminal intent?; and can we specify the moment of criminal action as in *the Minority Report*. The answers depend on circumstances. Therefore, a simple existence of imported food in the storage can’t specify the severeness of the criminal intent of the prosecuted. Therefore, the court will assess the criminal intent, which is based on many factors including the total value of imported agricultural products found in stock, and will sentence the fine. In fact, the correlation coefficient between the total value and the fine is only 13.74 for pork. In short, the exact profit is private information. Therefore, in this study, it is assumed that the marketing margin of suspected product is 10% for over 20 marketing types, of which will be sold with 50% chance as domestic products. In the future study, a more rigorous approach should be taken to measure the illegal profit from violation.

To facilitate understanding how the best strategies are calculated, the following figures can help.

Figure 2. The Traceability Enforcement Game



In Figure 2, the Seller's expected payoff when s/he cheats is represented as a line with negative slope on the top-left figure. The Seller's payoff when s/he doesn't cheat is represented as the horizontal line. Because the Seller chooses a strategy to maximize her/his payoff, s/he will choose 'Cheat' if the probability for NAQS to raid (q) is less than 0.1606 and chooses 'Don't Cheat' if q is greater than 0.1606. In other words, the Seller will choose the upper envelop of the two lines. Likewise, NAQS will choose the upper envelop of the two lines on the top-right figure. Thus, NAQS will not raid if the cheating probability (p) is lower than 0.0152 and will raid if p is higher than 0.0152. If p is exactly equal to 0.0152, NAQS will be indifferent to 'Raid' or 'Don't Raid.' The 2 bottom-left graphs represent the best response functions to each other's mixed strategies. The last bottom graph represents the mixed strategy

Nash equilibrium: it is the best response for the Seller to cheat with probability of 1.52%, and simultaneously, it is best for NAQS to raid with 16.06% of probability.

4.2. Sensitivity Analysis and Distribution-based Model

Due to rigidity of national budget, NAQS can't increase the number of raids with enough flexibility in response to the Seller's strategy, even though NAQS introduced the 'honorary raid squad,' which consists of volunteers of citizens. The alternative to increasing the number of raids (or raid probability) is to levy a heavier fine. The change in cheating probability (*p*) according to different levels of fines is shown in Table 4.

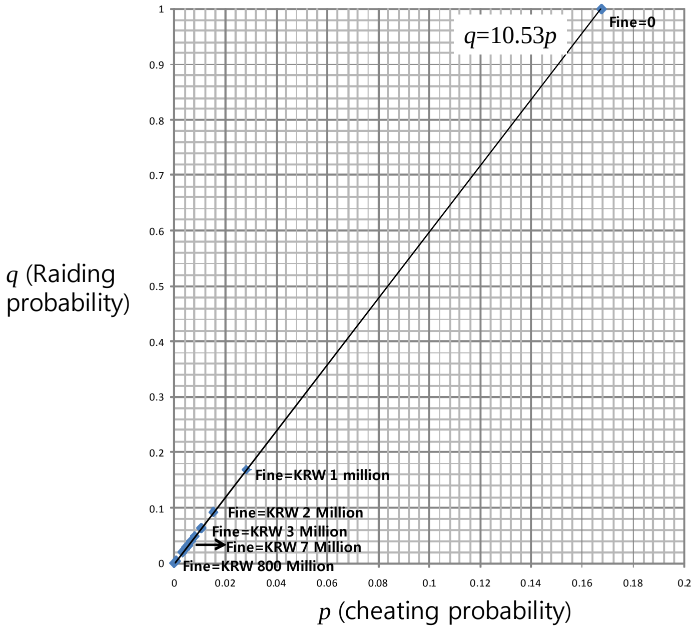
Table 4. Sensitivity Analysis on the Fine

NAQS				seller				p	q
Raid		Don't Raid		Cheat		Don't Cheat			
a	b	c	d	e	f	g	h		
-80796.4	80792.991	35.82	-35.82	0	-3.4	0	0	0.0000	0.0004
-10000	9996.6	35.82	-35.82	0	-3.4	0	0	0.0003	0.0036
-5000	4996.6	35.82	-35.82	0	-3.4	0	0	0.0007	0.0071
-1000	996.6	35.82	-35.82	0	-3.4	0	0	0.0033	0.0346
-900	896.6	35.82	-35.82	0	-3.4	0	0	0.0036	0.0383
-800	796.6	35.82	-35.82	0	-3.4	0	0	0.0041	0.0429
-700	696.6	35.82	-35.82	0	-3.4	0	0	0.0046	0.0487
-600	596.6	35.82	-35.82	0	-3.4	0	0	0.0053	0.0563
-500	496.6	35.82	-35.82	0	-3.4	0	0	0.0063	0.0669
-400	396.6	35.82	-35.82	0	-3.4	0	0	0.0078	0.0822
-300	296.6	35.82	-35.82	0	-3.4	0	0	0.0101	0.1067
-200	196.6	35.82	-35.82	0	-3.4	0	0	0.0144	0.1519
-100	96.6	35.82	-35.82	0	-3.4	0	0	0.0250	0.2637
0	-3.4	35.82	-35.82	0	-3.4	0	0	0.0949	1.0000

Table 4 shows that if the court increases the fine to KRW800,000,000 compared to the current average of KRW1,870,000 (about 430 times), virtually no Seller would cheat and NAQS only needs to raid 4 business entities out of 10,000. However, this may be against legal fairness, compared to fines for similar frauds. Then the question is, what is the achievable level of raid?

There were 568,737 business entities that sold pork and NAQS raided 227,139 times in 2009. Therefore, about 49% of the whole business entities have been raided in 2009. However, a business entity can cheat all year round, not once a year. Therefore, each one of 568,737 entities had a chance of cheating for 365 days a year. This means the total possible cases of cheating is 207,589,005 (=568,737x365). Therefore, NAQS' raid probability in 2009 was actually 0.1% (=277,139/207,589,005). This means the fine should be increased to more than KRW 100,000,000. If the court is willing to double the fine to KRW 4,000,000 compared to the current level, only 1 % of the Seller is expected to cheat and NAQS only needs to increase the raid probability to 8%. However, 8% seems to be still too much work for NAQS to execute. All these arguments are illustrated in Figure 3. Figure 3 shows that a simple levying fine of KRW 1 million to cheating will dramatically decrease the cheating probability. However, the effect of levying fines will wear off fast. Over the fine of KRW 3 million, NAQS will not be able to significantly control the cheating behavior of the Seller. Therefore, as a rule of thumb, the fine can be increased to KRW 4 million on average but not more than that, even though some courts levied fines up to KRW 7 million in 2009.

Figure 3. The Relationship among p, q and Fine

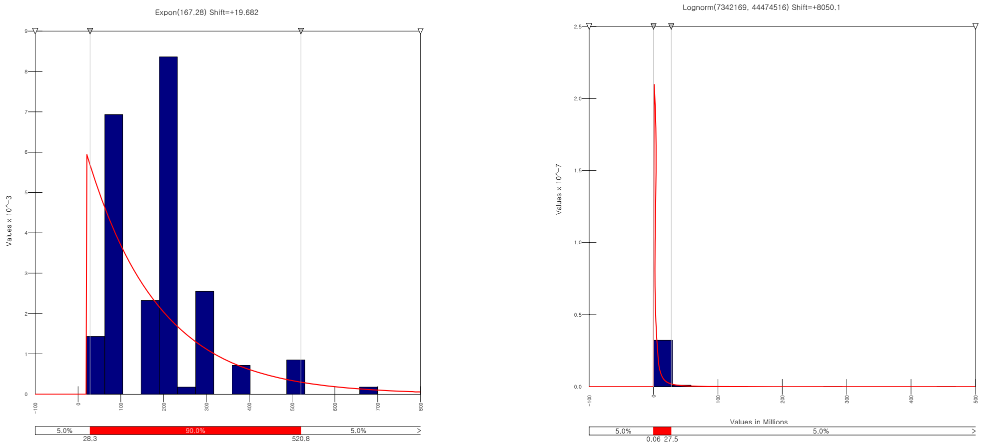


Lastly, to investigate the impact of changes in the fine (a) and the payoff when cheating but not raided (c), the mean-based model has been converted to a distribution-based model. To estimate the distributions of a and c, @Risk and Best-Fit of Palisade are used. Among many distributions estimated using Best-Fit, the best functional form for distribution of *a* was found to be an exponential, ranked by χ^2 statistics.[2] The best distributional functional form for *c* was found to be log-normal. The estimated distributions are as follows.

$$\text{For } a,\quad f(x)=\frac{e^{-x/167.28}}{167.28}+19.682 .$$

$$\text{For } c,\quad f(x)=\frac{1}{x\sqrt{2\pi}\cdot 44474516}e^{-\frac{1}{2}\left[\frac{\ln x-7342169}{44474516}\right]^2}$$

Figure 4. Estimation of Distributions for a and c



Estimated Distribution of *a* : exponential Estimated Distribution of *c* : log-normal

The simulated results for *p* and *q* are shown in Figure 5 and 6.

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[2] $\chi^2=\sum_{i=1}^{K}\frac{(N_i-E_i)^2}{E_i}$

where K= the number of bins, N_i=the observed number of samples in the *i*th bin, E_i=the expected number of samples in the *i*th bin. χ^2 is most frequently used to rank the goodness of fit and can be used for discrete and continuous data. The problem with ranking fitness of good for a distribution using χ^2 is that the decision on the number of bins is arbitrary.

Figure 5. Density and Cumulative Functions for Cheating Probability (p)

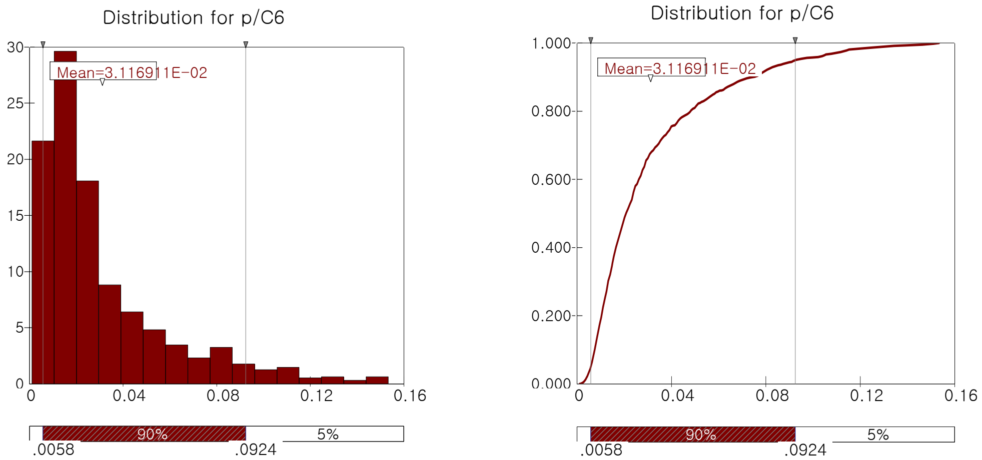
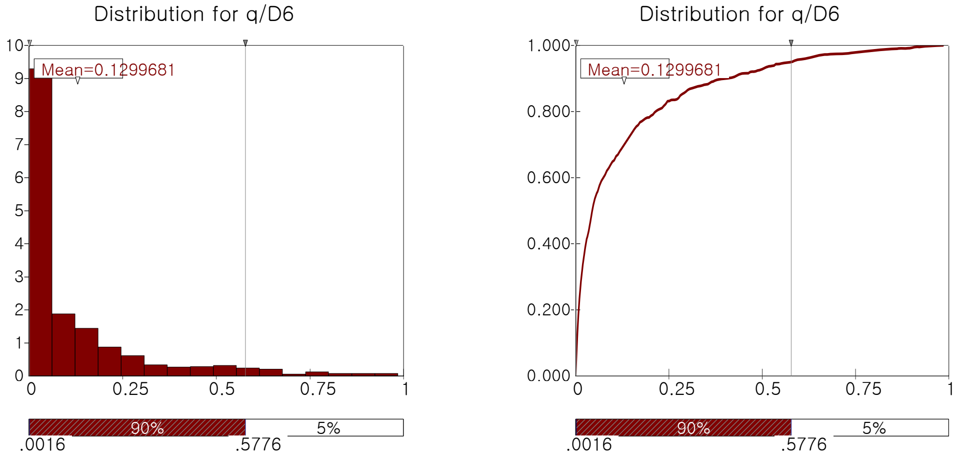
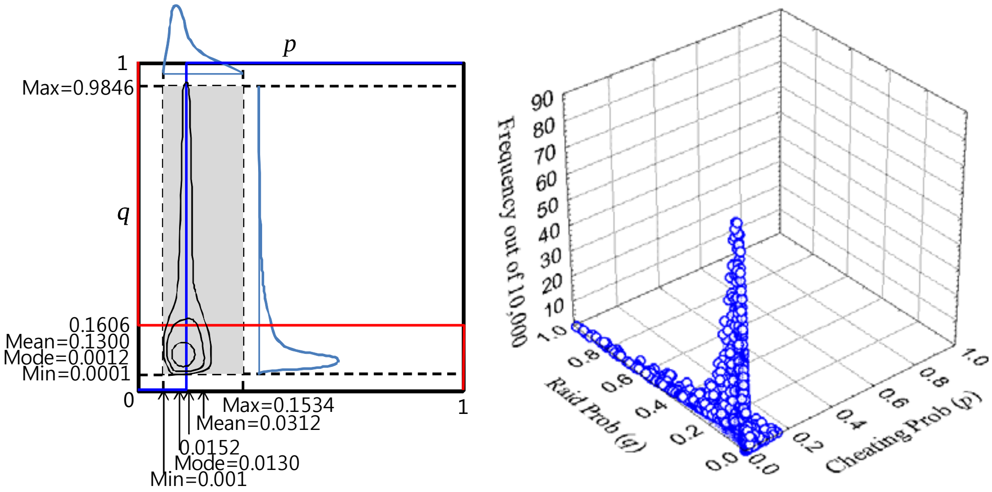


Figure 6. Density and Cumulative Functions for Raid Probability (q)



Finally, the simulated distributions of the best mixed strategies of the Seller and NAQS, along with the contour lines of equilibrium points, are sketched on the left figure of figure 7. On the right of figure 7, a 3-D graph of the shaded area of the left graph is shown. As expected from the contour line of the left, the 3-D distribution is a horn-type with the highest frequency around the two modes. That is, the most frequently observed equilibrium is expected to be around (0.0130, 0.0012). As mentioned before, NAQS' raid probability for pork in 2009 was 0.001(0.1%), which is quite similar to 0.0012. Therefore, NAQS seems to be operating the labeling system at optimal level.

Figure 7. Distribution of Mixed Strategy Nash Equilibria



Ⅴ. Summary and Conclusion

Even though levying fines and raiding are the two methods to control cheating behaviors of the sellers of pork, NAQS can only use raiding to control the system because levying fines is the court's own legal authority. Then the research question is, 'what is the optimal level of enforcement for the pork labeling system?'

To answer the question, the Mixed Strategy Nash Equilibrium is used. The model is applied to the year 2009 case, because the data on fines were only available before 2009. The mean-based Mixed Strategy Nash Equilibrium model suggests that NAQS needed to increase the raid probability for pork significantly from the current 0.1% to 16% in 2009. The cheating probability for pork labeling is calculated as 1.5% in 2009. However, it was found that the data on fines and revenues by cheating are highly skewed. This made the implications from the mean-based model suspicious. Therefore, an analysis using the distribution-based model is done.[3]

Through the sensitivity analysis, it was found that the court needs to increase the amount of fine to promote the labeling system. A plausible recommendation is to double the fine. Also, it was found that the most frequently observed Mixed Strategy Nash Equilibrium would be for the seller to cheat with probability of 1.3% and for NAQS to raid with probability of 0.1%, which is quite close to the actual raid probability of NAQS in 2009. Therefore, it was proposed that NAQS enforced the pork labeling system quite optimally in 2009.

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[3] For a more extensive analysis of distribution-based model by marketing types, please refer to Song (2011) and Lee et al. (2011).

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