Nuclear Accident, Liability Rules and a Regulated Monopoly*

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March 29, 2013

Abstract

We study the role of liability rules in the case of nuclear accidents by the Tokyo Electric Power Company (TEPCO), such as the accident after the East Kanto Earthquake in Japan. We re-examine the claim that the absolute or unlimited liability is the best under actual situations. For example, TEPCO is a vertically integrated monopoly power company in the Kanto region. We show that monopolist may produce more than socially optimal level of output and spend too little to prevent an accident with limited liability if cost of accident avoidance is variable cost. When there is under production by the monopoly, then increasing liability will aggravate monopoly distortion and reduce welfare. We show that welfare increases with size of liability when cost of accident avoidance is fixed cost. We also consider possibility of regulatory capture by TEPCO and implications.

1 Introduction

The Great East Kanto Earthquake brought serious tolls on residents in the Northeast region of Japan. Moreover, the miss-management of nuclear radiators in Fukushima caused additional hazards on its resi-

*We are grateful to Ralph Winter for his valuable advice as well participants of Western Economic Association International 10th Biennial Pacific Rim Conference. This paper is part of the academic project on Economic Analysis of Intergenerational Issues: Searching for Further Development, funded by the Grant-in-Aid for Specially Promoted Research from Japan's Ministry of Education, Culture, Sports, Science and Technology (grant number 2200000)1

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dents and neighbors. It also worsened the prospect of Japanese energy sources. Some of these radioactive costs might have been unavoidable, but some others might have been prevented under a better incentive scheme.

This paper explores what economics can contribute to liability rules concerning nuclear accidents. Following the lead of Guido Calabresi (1970), we will discuss the way to find the cheapest cost avoider in this case.

There are two questions to be asked about the effects of liability rules. (a) After the accident has occurred, who should bear the burdens? What kind of liability rules can be fair to involved parties? (b) In order to prevent accidents effectively as well as economically, what kind of liability rules are desirable? Question (a) is an 'equity' question usually asked in a 'ex-post' manner. Japanese civil law lawyers have concentrated themselves on this question without seriously considering efficiency aspects of liability rules. For them the study of incentive mechanism was the subject only in criminal law and not in civil law. Therefore, the study of interaction between law and economics was not a significant topic. This situation is gradually changing.

The economic approach to law, or a field "Law and Economics," concentrates on Question (b)the second question. Here the question is posed in the "ex-ante" form rather than "ex-post" form. We will follow this line of approach here.

In his pioneering *The Cost of Accidents*, Guido Calabresi (1972) asked straightly this efficiency question. As the Coase Theorem (1960) indicates that in absence of transactions and negotiation costs the liability rule does not change the efficiency in the outcome. Furthermore, Demsetz (1972) has proved that, when the market intervenes between the parties involved in the damage case, then there is a case where neither efficiency nor equity is affected by the liability rule. Calabresi argued that, in spite of the validity of the Coase theorem, negotiation costs are substantial in most occasions. Therefore, to minimize the cost of accidents for the society, we have to place the burden of liability on the cheapest cost avoider.[1]

We consider the incentive effect of liability rules as significant, but we have to be careful about the degree by which people are affected by liability rules and civil court procedures work, explicitly or

[1]By coincidence, Hamada learned about *The Cost of Accidents* and the field of law and economics from a superb theoretician, Peter Diamond at MIT in 1970s.

potentially, to deter the accident.

The Great East Kanto Earthquake attacked the Japanese island really unexpectedly. Therefore, most damages seem to have been unavoidable, and the roles of incentives may seem to be minimal. In the cases involving nuclear radioactive damages, however, we notice many instances that economic and other incentives erred against the direction of minimizing the cost of accident. We need to find here the cheapest cost avoider.

There are several parties involved in the legal and economic scene in the damage problem we are considering. Residents who suffer from radioactive nuisance from the TEPCO accidents, industry producers and traders suffering from real or mistaken (*fuhyo higai*) rumors from this accident, the electric company that could not prevent the accident in the premise, the METI and the *Genshiryoku Hoan-in* that was supposed to supervise the devices for safety, and finally the Japanese government that has promoted the development of nuclear energy plants by probably exaggerating the safety of nuclear electric plants. Who is the cheapest cost avoider, or are the cheapest cost avoiders? Other parties than victims should be made liable in this case. Victims could hardly avoid the incidence of the accident and therefore should be excluded from the list. Many analytical questions in economic analysis follow.

"Can there be more than a cheapest avoider?" As shown by J. Brown (1973) and Hamada (1977), multiple agents can minimize the cost of accidents by coordinating their actions if their actions interacts in causing damages. TEPCO is the typical candidate for the cheapest avoider, but other agents such as government may not be completely free of being a candidate.

In a usual market economy, liability costs <u>should be shifted</u> to electricity prices. In the case of TEPCO, it has a monopoly power in a wide area of Kanto and we suspect that it should not be allowed to determine its monopoly price. Under the monopolistic competition, Demsetz's (1972) result that liability rules do not matter because market will shift the cost of burdens (Hamada (1976)). The question is: "What kind of pricing is desirable for a monopoly company that is liable for damages from its operation?" Moreover, the public utility company may have a decreasing cost structure. Thus this reminds us of the Averch and Johnson (1962), Baumol and Klevorick (1970) type of analysis of the regulation of public utility firms.

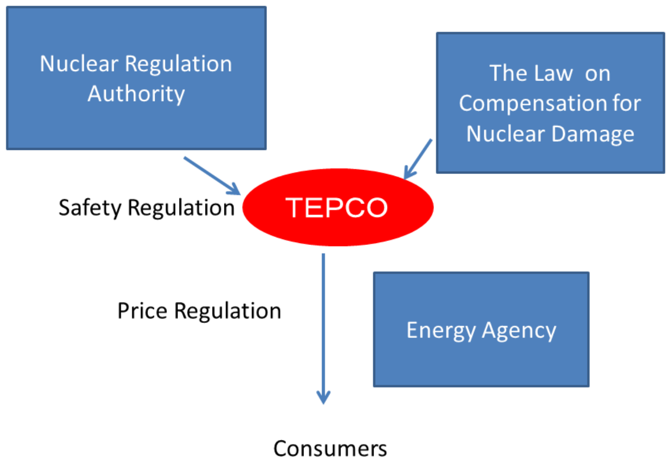

Figure 1: Nuclear Power Generation and Electricity Market

In this paper, we examine the optimal liability rule for TEPCO regarding running of nuclear power plants. We show that when cost of accident avoidance is variable cost, monopoly output may be too high compared to the social optimum under limited liability. Furthermore, increasing liability will not improve welfare in this case. Monopoly under production and optimality of strict liability is restored when cost of accident avoidance is fixed.

2 Background

Tokyo Electric Company (TEPCO) is one of the nine regional electricity companies in Japan. They own generators, the transmission grid and is the only retailer in each region. Tokyo Electric owns three nuclear power plants (including two in Fukushima), 16 thermal power plants , and two hydro power plants. They also have geothermal and solar facilities. Many of the plants are not in areas where TEPCO retails electricity. All three nuclear power plants are outside of TEPCO service area.

The relationship between TEPCO and regulators are summarized in Figure 1. The Energy Agency (part of Ministry of Economy, Trade and Industry) regulates the prices. Nuclear power plants are regulated by Nuclear Regulation Authority in Ministry of the Environment.[2] Nuclear accident compensation is administered by Ministry of Education, Culture, Sport, Science and Technology.[3]

In summary, we characterize TEPCO is an operator that produces electricity and is also a regulated monopolist in the retail market.

The nuclear accident liability legal and compensation frameworks are summarized in Figures 2 and **??**. Japan has ratified the various nuclear accident compensation protocols of the International Atomic Energy Commission. TEPCO has strict unlimited liability and all liability is concentrated to TEPCO, meaning suppliers of TEPC, including the company that built the power plant, are not liable. As with the IAEC protocols, because damages from nuclear accidents can be far beyond what a private company can pay, in reality it is limited liability. The incentive effect this has on TEPCO is standard law and economics and the adverse effects in Japan has been highlighted by Ramseyer (2012). We discuss this issue in concluding remarks.

3 Unregulated Monoplist

We start with the most simple situation with an operator (TEPCO), victims and consumers. Since the nuclear power plant is not in Tokyo, consumers and victims are not the same. Consumers are represented by inverse demand function, $P(q)$, where q is quantity of electricity consumption. The operator generates electricity with cost $C(x, c)$ where c is the actual cost of electricity generation, and x is the cost of avoiding an accident. Accident occurs with probability $\rho(x)$, where $\rho(x)$ is a decreasing and covex function. (See Figure model.) If there is an accident, victims incur harm (pecuniary) of $h(q)$, where $h(q)$ is an increasing and concave (?) function of output. We also assume $|P'(q)| > |h''(q)|$. This guarantees second order conditions are satisfied.[4]

[2] Japan Atomic Energy Commission in the Cabinet Office is responsible for overall atomic energy policy. This would include not only working powerplants but atomic technology development.

[3] The former Science and Technology Agency was merged into Ministry of Education.

[4] If h is convex, this is unnecessary.

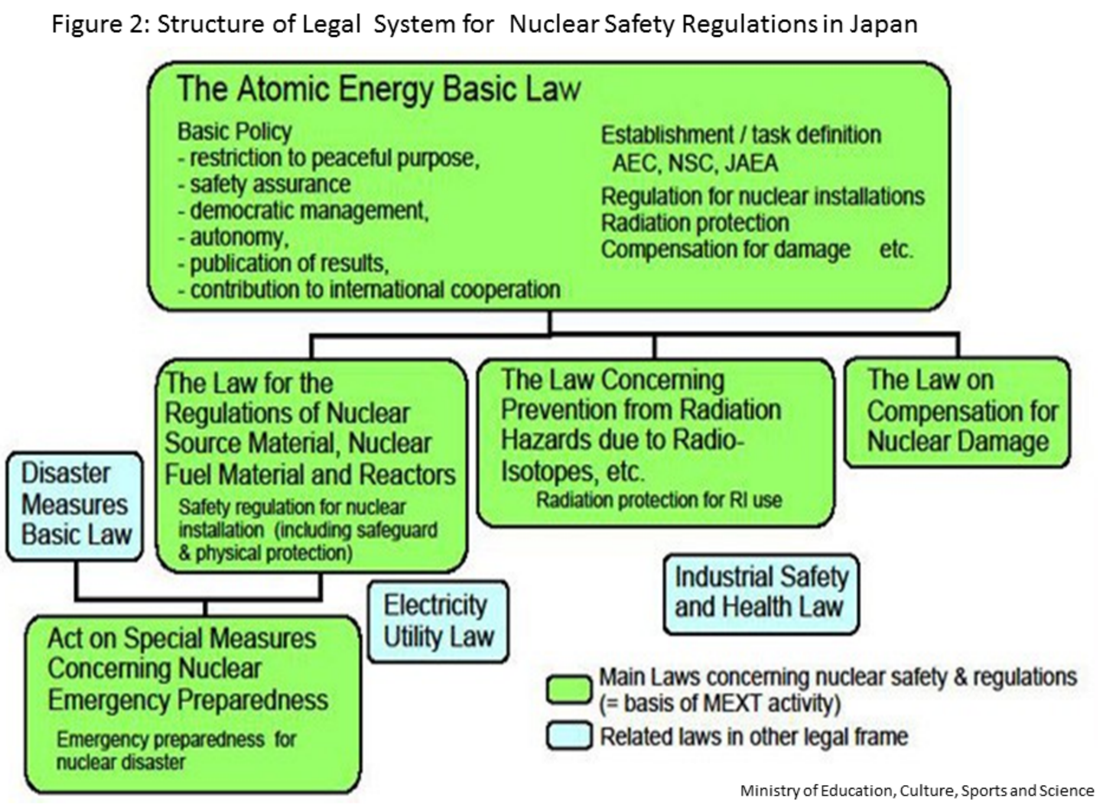

Figure 2: Structure of Legal System for Nuclear Safety Regulations in Japan

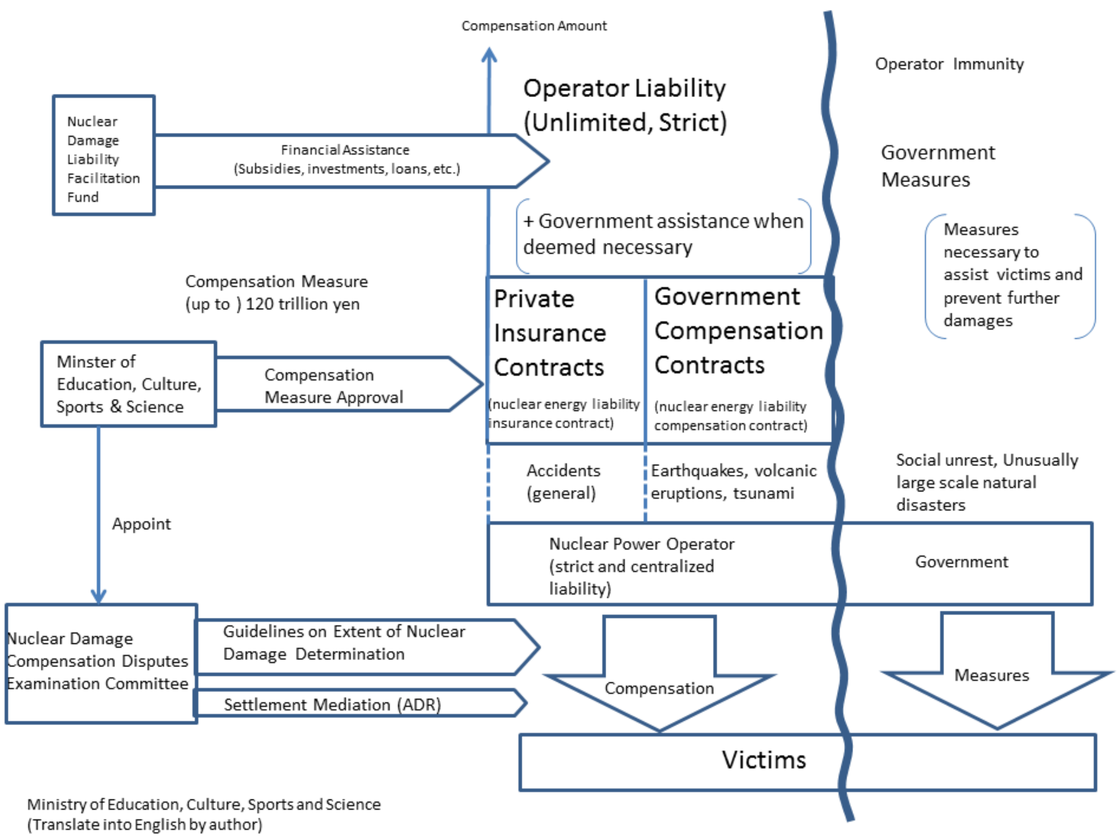

Figure 3: Compensation Framework

The operator'r profit is

$$\pi(q,x) = R(q) - T(q,x) - \rho(x)L, \tag{1}$$

where $R(q)$ is total revenue, $T(q,x)$ is total production cost, and L is amount of liability should an accident happen. . Social welfare function is,

$$W(q,x) = \pi(q,x) + CS(q) + \rho(x)L - \rho(x)h(q), \tag{2}$$

where consumer surplus is

$$CS(q) = \int_0^q P(\zeta) - P(q)d\zeta.$$

We consider two cases regarding cost of accident avoidance and cost of electricity generation:

- **Fixed cost**: $T(q,x) = cq - x$
- **Marginal cost**: $T(q,x) = (c+x)q$.

3.1 Cost of avoidance is fixed cost

The operator's profit defined by (1) with $T(q,x) = cq - x$ is,

$$\pi(q,x) = P(q)q - cq - \rho(x)L - x. \tag{3}$$

Socially optimal output (q^*) and care (x^*) maximizes social welfare function (2),

$$W(q,x) = \int_0^q P(\zeta)d\zeta - cq - x - \rho(x)h(q).$$

Output and care should satisfy the following first-order conditions,

$$\frac{\partial}{\partial q}W(q,x) = P(q) - c - \rho(x)h'(q) = 0 \tag{4}$$

$$\frac{\partial}{\partial x}W(q,x) = -1 - \rho'(x)h(q) = 0. \tag{5}$$

Condition (4) is marginal cost pricing, where marginal cost includes marginal expected harm, given x. Condition (5) is the same as the condition for care that minimizes total social cost, $C(q, x) + \rho(x)h(q)$, given q. Let us denote solution to (4) by $q^W(x)$, stressing the fact that there is an optimal q for each level of x. Similarly, we denote the solution of (5) by $x^W(q)$. The socially optimal output and care satisfy, $x^* = x^W(q^*)$ and $q^* = q^W(x^*)$.

We now turn to operator's choice of care with liability $L \leq h(q)$ for all q (we assume there is harm even if there is no electricity being produced, $h(0) > 0$) when accident occurs. The operator maximizes (3). The operator's choices q^M, x^M satisfy the following first-order conditions,

$$\frac{\partial}{\partial q}\pi(q, x) = R'(q) - c = 0 \tag{6}$$

$$\frac{\partial}{\partial x}\pi(q, x) = -1 - \rho'(x)L = 0. \tag{7}$$

(6) is the usual monopoly pricing condition. Thus q^M is monopoly output. Comparing (5) and (7), it is obvious that $x^M \leq x^*$ since $\rho''(x) > 0$. Level of care will be too low compared to the social optimum as long as $L \leq h(q^*)$ since $\rho(x)$ is convex.

Proposition 1. *The operator will choose monopoly output, q^M and care is too low, $x^M \leq x^*$.*

The operator will choose the socially optimal level of care, $x^M = x^*$ when $L = h(q^*)$. However, output will still be determined by (6), so there will be underproduction of electricity. Note that q^* is not the competitive output with marginal cost c. The social marginal cost is higher, $c + \rho(x^*)h'(q)$. So it can be $x^M > x^*$ with overproduction.

However, we can make the following statement for increasing liability,

Proposition 2. *When cost of accident avoidance is fixed, then welfare will increase when liability is increased. That is , $\frac{dW(q^M, x^M)}{dL} > 0$.*

Greater liability will increase care but leave quantity unaffected.

Proof. We examine the effect of increasing liability on welfare,

$$\frac{dW(q,x)}{dL} = \frac{\partial W}{\partial q}\frac{dq}{dL} + \frac{\partial W}{\partial x}\frac{dx}{dL}. \tag{8}$$

We evaluate this at (q^M, x^M). First-order condition (4) evaluated at (q^M, x^M) is ambiguous even if we knew the relative size of x^M and x^* because the marginal costs are different from monopolist's. However, we know $\frac{dq^M}{dL} = 0$. Thus the first term of (8) is zero. First-order condition (5) evaluated at x^M is positive since $L < h(q^M)$. $\frac{dx}{dL}$ is positive from (7). $\square$

When the operator is held to strict liability such that $L = h(q)$ for any q. Profit is,

$$\pi(q,x) = R(q) - x - cq - \rho(x)h(q).$$

Then we can make the following statement,

Proposition 3. *When cost of accident avoidance is fixed, then the monopolist will under produce and invest in too little care level compared to the social optimal with strict liability in the stable equilibrium. That is, $q^m < q^*$ and $x^m < x^*$, where (q^m, x^m) is monopolist's choice with strict liability.*

Proof. The first-order conditions that define operator's optimal choice (q^m, x^m) are,

$$\frac{\partial}{\partial q}\pi(q,x) = R'(q) - c - \rho(x)h'(q) = 0 \tag{9}$$

$$\frac{\partial}{\partial x}\pi(q,x) = -1 - \rho'(x)h(q) = 0. \tag{10}$$

Totally differentiating (10), we get

$$\frac{dx}{dq}\Big|_{\frac{\partial \pi}{\partial x}=0} = -\frac{\rho'(x)h'(q)}{\rho''(x)h(q)} > 0. \tag{11}$$

Let us denote the relationship between q and x that satisfy (9) by $q = q^M(x)$ and the relationship for the social optimal defined by (4) by $q = q^W(x)$. For a given x, marginal cost is $\rho(x)h'(q)$ for both monopolist and social planner. Since $R'(q) < P(q)$, it follows that $q^M(x) < q^W(x)$ for all x. They are also increasing functions,

$$\frac{dq^M}{dx} = \frac{dq}{dx}|_{\frac{\partial \pi}{\partial q}=0} = \frac{\rho h'}{R'' - \rho h''} > \frac{dq^W}{dx} = \frac{dq}{dx}|_{\frac{\partial W}{\partial q}=0} = \frac{\rho h'}{P'' - \rho h''} > 0.$$

First-order conditions (5) and (10) are identical and also define a increasing function,

$$\frac{dq}{dx}|_{\frac{\partial W}{\partial x}=0} = \frac{dx}{dq}|_{\frac{\partial \pi}{\partial x}=0} = -\frac{\rho'' h}{\rho' h'} > 0.$$

The stable equilibria requires,

$$|\frac{dq^W}{dx}| < |\frac{dq}{dx}|_{\frac{\partial W}{\partial x}=0}|.$$

That is, $q = q^W(x)$ is flatter than $q = q(x)|_{\frac{\partial W}{\partial x}=0}$. In this case, the $(q - x)$ space. intersection of $q = q^M(x)$ with (10) is below that of $q = q^W(x)$. That is , (q^m, x^m) is south-west of (q^*, x^*) Together with (11), we have $x^* > x^m$ and $q^* > q^m$. □

Stability will be guaranteed for instance if ρ'' is not too large. Monopolist reduces cost by reducing output and takes less care because marginal return from taking care is not very large. If the return is large (ρ'' is very large), then monopolist can reduce cost by taking greater care, and expand output. Monopolist will over produce and choose level of care greater than the socially optimal.

3.2 When cost of avoidance is varaible cost

The operator's profit defined by (1) with $T(q, x) = (c + x)q$ is,

$$\pi(q, x) = P(q)q - (c + x)q - \rho(x)L. \tag{12}$$

Social welfare function (2) becomes,

$$W(q, x) = \int_0^q P(\zeta)d\zeta - (c + x)q - \rho(x)h(q).$$

Socially optimal output and care should satisfy the following first-order conditions,

$$\frac{\partial}{\partial q}W(q,x) = P(q) - (c+x) - \rho(x)h'(q) = 0 \tag{13}$$

$$\frac{\partial}{\partial x}W(q,x) = -q - \rho'(x)h(q) = 0. \tag{14}$$

Condition (13) is marginal cost pricing, where marginal cost includes marginal expected harm, given x. Condition (14) is the same as the condition for care that minimizes total social cost, $T(q,x) + \rho(x)h(q)$, given q. Let us denote solution to (13) by $q^W(x)$, stressing the fact that there is an optimal q for each level of x. Similarly, we denote the solution of (14) by $x^W(q)$. Unlike the when the cost of avoidance was fixed, $q^W(\cdot)$ and $x^W(\cdot)$ may not be decreasing functions. This is because

$$\frac{\partial^2 W}{\partial x \partial q} = 1 + \rho'(x)h'(x),$$

can be positive or negative. That is, the only interaction between output and avoidance cost was through expected damage when avoidance cost was independent of output. When avoidance cost is variable cost, marginal welfare also depends on change in marginal cost, $\frac{\partial^2(c+x)q}{\partial x \partial q} > 0$. Since marginal cost increases with x while marginal expected damage decreases with x, the total effect is ambiguous. ‘

We now turn to operator's choice of care with liability $L \leq h(q)$ for all q. The operator maximizes (12).

$$\frac{\partial}{\partial q}\pi(q,x) = R'(q) - (c+x) = 0 \tag{15}$$

$$\frac{\partial}{\partial x}\pi(q,x) = -q - \rho'(x)L = 0. \tag{16}$$

(15) is the usual monopoly pricing condition. We denote by $q^M(x)$ solution to (15) and $x^M(q)$ the solution to (16). Then operator's optimal choices, q^M and x^M satisfy $q^M = q^M(x^M)$ and $x^M = x^M(q^M)$. (Unlike the case of fixed avoidance cost, q^M is not "monopoly output" when marginal cost is c.) The following statement is immediate from the first-order conditions,

Lemma 1. *When avoidance cost is variable, $T(q,x) = (c+x)q$, then the operator's output is decreasing*

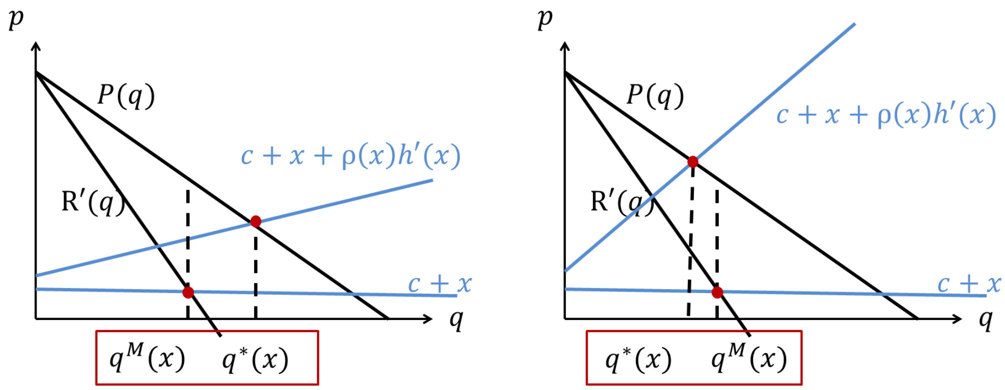

Figure 4: Monopoly Under and Over Prodction

in liability, and level of care is increasing in liability. That is,

$$\frac{dq^M}{dL} < 0, \qquad \frac{dx^M}{dL} > 0.$$

No we compare the monopoly choices to the social optimum. As was the case of fixed avoidance cost, $x^M(q) \leq x^W(q)$, for same level of output, there is suboptimal level of care by a monopolist from equations (14) and (16). However comparison of outputs even for the same of care, from (6) and (15) is not straightforward. Although there is distortion from market power, $R'(q) < P(q)$, monopolist ignores the marginal cost of expected damages, $\rho(x)h(q)$ because liability L does not depend on output. Thus for the same level of care, it is not clear if monopolist will over ($q^M(x) > q^W(x)$) or under ($q^M(x) < q^W(x)$) produce. (See Figures 4.) We can summarize the proceeding observation as follows.

Proposition 4. *When avoidance cost is variable, $T(q,x) = (c+x)q$, then monopoly operator will over produce and take too little care ($q^M > q^*$, $x^M < x^*$), under produce and take too much care ($q^M < q^*$, $x^M > x^*$), or both under produce and take little care ($q^M < q^*$, $x^M < x^*$) .*

We saw in Lemma 1 that monopoly choice of output is effected by the level of liability. Together with Proposition 4, evaluation of equation (8) becomes ambiguous. Most interestingly, increasing liability may decrease welfare. This is in sharp contrast to Proposition 2.

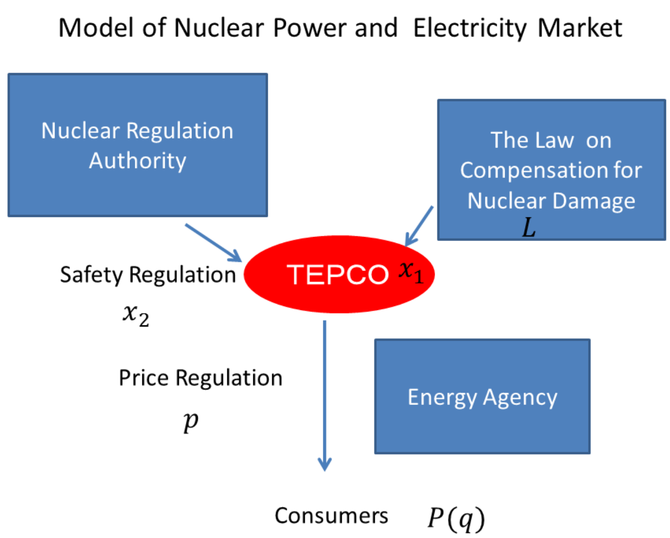

Figure 5: Model of Nuclear Power and Electricity Market

Proposition 5. *If there is under production and too much care by monopoly operator ($q^M < q^*$, $x^M > x^*$), then increasing liability will reduce welfare,*

$$\frac{dW(q^M, x^M)}{dL} < 0.$$

4 Safety Regulation

We strict the analysis to fixed avoidance cost, $T(q, x) = cq - x$ but expand so that there are two channels of safety measures, x_1 and x_2. x_1 is level of care not observable by the regulator and x_2 is verifiable, such as wall thickness (Figure 5). It is possible to regulate x_2 directly but not x_1. Now probability of accident is $\rho(x_1, x_2)$ where $\rho_i(x_1, x_2) = \partial\rho(x_1, x_2)/\partial x_i < 0$, $\rho_{ii}(x_1, x_2) = \partial^2\rho(x_1, x_2)/\partial x_i^2 > 0$, and $\rho_{ij}(x_1, x_2) = \partial^2\rho(x_1, x_2)/\partial x_i \partial x_j > 0$. The last implies that greater care leads to less reduction in risk as level of regulated safety is increased (Trebilock and Winter, 1997).

Operator's profit is,

$$\pi(q, x_1) = R(q) - x_1 - x_2 - \rho(x_1, x_2)L,$$

where $L \leq h(q)$ (for all q and $h(0) > 0$) is firm's liability. We now assume that marginal cost of production is negligible. Social welfare is,

$$\begin{aligned} W(q, x_1, x_2) &= R(q) - x_1 - x_2 - \rho(x_1, x_2)h(q) + CS(q) \\ &= -x_1 - x_2 - \rho(x_1, x_2)h(q) + \int_0^q P(\zeta)d\zeta. \end{aligned}$$

Proposition 6. *Increasing liability improves welfare, for any level of regulation, x_2. That is, $\frac{dW(q^L, x_1^L, x_2)}{dL} > 0$ for any x_2, where x_1^L and q^L are operator's choice of care and output, given liability L.*

This implies that benefit of strict unlimited liability is the same as without regulation. This extends Trebilcock and Winter (1997) for a monopolist.

Proof. The operator's first-order conditions are,

$$\frac{\partial \pi}{\partial q} = R'(q) = 0 \tag{17}$$

$$\frac{\partial \pi}{\partial x_1} = -\rho_1(x_1, x_2)L - 1 = 0, \tag{18}$$

From (18), we have

$$\frac{dx_1}{dL}\Big|_{\frac{\partial \pi}{\partial x_1 = 0}} = -\frac{\rho_1}{\rho_{11}} > 0. \tag{19}$$

So firm's choice of x_1 is increasing in L. To see the effect of L on welfare, we differentiate welfare with respect to x_1 and evaluate at operator's choices,

$$\frac{\partial W(q^L, x_1^L, x_2)}{\partial x_1} = -\rho_1(x_1^L, x_2)h(q^L) - 1 > -\rho_1(x_1^L, x_2)L - 1 = 0. \tag{20}$$

The last equality follows from (18) and inequality before that follows from $L < h(q)$. The proposition follows from (19) and (20). $\square$

Thus strictly unlimited liability is desirable even when there is a safety regulator.

With strict liability, we can use the proof for Proposition 3 for a given x_2, replacing $\rho(x)$ with $\rho(x_1, x_2)$. If we define $x_1^m(x_2)$, $q^m(x_2)$ to be operator's choice given x_2, and $x_1^*(x_2)$ and $q^*(x_2)$ to be socially optimal levels for given x_2, then Corollary of Proposition 3 is ,

Corollary 1. *With strict liability, for a given level of safety x_2, monopoly operator will product less and choose lower level of care than the social optimum in the stable equilibrium. That is, $q^m(x_2) < q^*(x_2)$ and $x_1^m(x_2) < x_1^*(x_2)$ for given x_2.*

Socially optimal level of regulated care, x_2^*, satisfies the first-order condition,

$$\frac{\partial W(q^*(x_2, x_1^*(x_2), x_2)}{\partial x_2} = -1 - \rho_2(x_1^*(x_2), x_2)h(q^*(x_2)) = 0. \tag{21}$$

We are interested in the safety standard that the regulator will set when the operators is held to strict liability. Regulator chooses x_2 to maximize welfare, given monopolist choice. If the regulator makes its decision at the same time as the operator, then safety regulator chooses x_2 to satisfy

$$\frac{\partial W(q^m, x_1^m, x_2)}{\partial x_2} = -1 - \rho_2(x_1^m, x_2)h(q^m) = 0 \tag{22}$$

To compare regulator choice with the optimal level of x_2, we evaluate the first-order conditions,

$$\frac{\partial W(q^m, x_1^m, x_2^*)}{\partial x_2} - \frac{\partial W(q^*(x_2), x_1^*, x_2^*)}{\partial x_2} = \rho_2(x_1^m, x_2^*)(h(q^*) - h(q^m)) + h(q^*)(\rho_2(x_1^*, x_2^*) - \rho_2(x_1^m, x_2^*)). \tag{23}$$

Note the second term on the left-hand side is zero from (21). The first term on the right-hand side is negative and the second term is positive. Thus if the effect of monopoly under-production is greater than that of under investment in care, then the regulator will choose safety standard that is more than the social optimal. If the effect of under investment in care is greater, than the regulator 'compensates' by setting x_2 higher than social optimal.

Now suppose the safety regular chooses safety level *before* the monopolist. Then, the regular's first-order condition is,

$$\frac{dW(q(x_2), x_1(x_2), x_2)}{dx_2} = \frac{\partial W}{\partial q}\frac{dg}{dx_2} + \frac{\partial W}{\partial x_1}\frac{dx_1}{dx_2} + \frac{\partial W}{\partial x_2} = 0. \tag{24}$$

We evaluate this at $x_1^m(x_2)$ and $q^m(x_2)$. Recall the first-order conditions regarding x_1 are the same for the social optimum (5) and the monopolist (10). Thus the second term in (24) disappears. Since $R''(q) < P'(q)$, we have $\frac{\partial W(q^m(x_2), x_1^m(x_2), x_2)}{\partial q} < 0$ and by taking the total derivative of first-order conditions,

$$\frac{dq}{dx_2} = \frac{\rho_2 h}{R'' - \rho h''} > 0.$$

The first term is positive. We have demonstrated the following.

Proposition 7. *If the safety regulator is able to commit to a safety standard prior to monopolist's output and safety decision, it will set the safety standard higher than if it were not able to commit.*

5 Price Setting Regulation

We argue price regulation will lead to over reliance on nuclear power generation. We consider the case of "naive regulator" (Baron and Taggart (1980). The regulator takes operator choice K as given and sets price. Therefore the operator will behave strategically when choosing level of K.

Production of electricity $q = f(K, M)$ is achieved by investment in nuclear power, K and other factors of production, M. The operator has private information θ and thus regulator relies on price regulation and sets price p based on observables M and K. Operator's profit is,

$$\pi(p, K, \theta) = pq(p, \theta) - vM(q, K), \tag{25}$$

where v is cost of all other inputs M and $M(q, K)$ is optimal level of M given output q and choice of K. Expected value of the firm is,

$$V = \frac{\int g(\theta)\pi(p, K, \theta)d\theta}{r}, \tag{26}$$

where r is the interest rate and $g(\cdot)$ is the density function of random variable θ.

The regulator sets price, given K, to restrict excess return $V - K$. Equivalently, chooses price to satisfy, $V = sK$ with $s > 1$. So the price must satisfy,

$$p = \frac{rsK + v\int g(\theta)M(q,K)d\theta}{\int g(\theta)q(p,\theta)d\theta}.$$

Now we examine the operator's choice of level of K. It chooses K to maximize $V - K$ subject to $V \leq sK$. The first-order conditions are,

$$\begin{aligned} \frac{\partial V}{\partial K} - 1 - \lambda(\frac{\partial V}{\partial K} - s) = 0, \\ \frac{\partial V}{\partial p}(1-\lambda) = 0, \\ V - sK. \end{aligned} \tag{27}$$

Using (25) and (26) to evaluate of $\frac{\partial V}{\partial K}$, we can rewrite (27) as,

$$-\int g(\theta)\frac{\partial M}{\partial K}d\theta = \frac{r}{v} + \lambda r\frac{1-s}{1-\lambda}.$$

Since $s > 1$ and $0 < \lambda < 1$, this show that price regulation leads excessive K. This is equivalent to the Averch and Johnson result.

Thus we have shown that it is possible to interpret the naive regulator as a form of regulatory capture. However, is it possible to have more sophisticated regulatory regimes in place to avoid over investment in K, unlike the pessimistic view of Ramseyer (2012),

6 Concluding Remarks

From the fact that Japan's government, with help of media, has long disseminated the optimistic information on radioactive safety and guided the public opinion towards nuclear electric generation. Thus, the government should be included as an agent in the pair of the cheapest cost avoiders. However, government officials are seldom put to criminal justice in Japan. Even if government is designated as liable, it is the general public of taxpayers who pay the cost. Thus sanction pressures through court are week. Politicians are tested by election, but this feedback may be too indirect. "Should the government be included as the parties that contribute to compensate victims, or should administrators be under stronger sanctions? If not, Mark Ramseyer's (2012) analysis that there is no excuse for the TEPCO will uphold.

"Can we develop a general theory of a regulation captive?" Stigler (1971) had a brilliant foresight and developed a story of the regulator becoming a captive of powerful regulated company. It looks to fit to no other cases better than to the government-TEPCO case. If we can develop such a theory, for example, repeated game theory, can we propose a solution for preventing it? We leave this for future research.

Japan's government, with help of media, has long disseminated the optimistic information on radioactive safety and guided the public opinion toward the introduction and development of nuclear electric generation. Thus, the government should be included as an agent that affects the cost structure of nuclear accident prevention. In the framework of Brown, it can be a component to be included in the optimal pair of the cheapest cost avoiders.

However, government officials are seldom put to criminal justice in Japan. Even if government is designated as liable, it is the general public of taxpayers who pay the cost. Thus sanction pressures through court are week. Politicians are tested by election, but this feedback may be too indirect. "Should the government be included as the parties that contribute to compensate victims, or should administrators be under stronger sanctions? (for reference: what kind of behavioral changes are observed when civil servants are punished more severely? [5]

More in general, regulators are often captured by regulation capture. A rich firm like the TEPCO can influence the behavior of regulators — by *amakudari* opportunity, entertainments etc. The formation of regulation capture can be modeled as a coalition game and /or repeated game.

1. When they are foaming coalition, what role does the sanction on firms play? What the sanction on regulators play? They must have different effectiveness? Which of the regulator of the regulated

[5] In the United States, Antitrust Criminal Penalty Enhancement and Reform Act of 2004 made jail time a possible penalty for antitrust violation. This law is known to have been effective in increasing successful antitrust prosecution in combination with leniency program (USGAO (2011), Block(1981), Klawiter and Driscoll (2009).

will respond better to sanction. If there is a coalition, which should be chosen as the target of sanctions?

2. Lack of cases where Japanese regulators are punished.

Ramseyer stresses that there is a fundamental paradox in the problem. Unlimited or strict liability on the TEPCO is desirable. However, this solution may conflict with the general principle of limited liability of firms under commercial law, or the basic principle of modern capitalistic society

Lastly, another interesting problem is to analyze by a simple price theory model the effect of *hatssuden-soden bunnri*, i.e., separation of competitive generation of electricity with many firms and a single monopoly firm that takes advantage of the economies of scale in sending electricity to customers.

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