東京大学 工学系研究科 総合研究機構
イノベーション政策研究センター

IPRC Discussion Paper Series No.09

松本 章邦
東京大学大学院工学系研究科 助教
原 尚幸
新潟大学経済学部経済学科 准教授
縄田 和満
東京大学大学院工学系研究科 教授

Safety and Health of Contract Workers in Japan’s Nuclear Utility Industry: Can we Maintain Safety Standards at Nuclear Power Plants?

August 2013

Innovation Policy Research Center,
The University of Tokyo, Japan
http://ipr-ctr.t.u-tokyo.ac.jp/

Safety and Health of Contract Workers in Japan's Nuclear Utility Industry: Can we Maintain Safety Standards at Nuclear Power Plants?

Akikuni Matsumoto[†] Hisayuki Hara[‡] Kazumitsu Nawata[†]

Aug 2013

Abstract

As many small contracting firms are used to maintain nuclear power plants in Japan, the major question is whether safety standards can be upheld under this situation. This study presents a theoretical explanation for the intuitive proposition that the occupational safety conditions of on-site contract workers (employees of contracting firms) and employees (employees of host companies) are likely to differ. We derive ordinary imperfect information models from a review of regulations governing Japan's nuclear utility industry. These models imply that hiring contract workers enables nuclear utilities to implement lower standards of occupational safety and health than those imposed by regulations and to reduce costs by circumventing responsibilities legally imposed on employers. Using measurements of nuclear plant workers' exposure to radiation, we show that this hypothesis is supported for Japan's nuclear power generation industry. (*JEL* D21, J23)

[†]Department of Technology Management for Innovation, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

[‡]Faculty of Economics, Niigata University, 8050 Ikarashi 2-no-cho, Nishi-ku, Niigata 950-2181, Japan

We would like to thank Professor Kohei Daido and Professor Erin Scott. We would like to thank seminar participants at Kinki University, Waseda University, Hokkaido University, the University of York, Hitotsubashi University, and the University of Tokyo. for valuable comments on earlier drafts of the article. This work was supported by the University of Tokyo GCOE program "Nuclear Education and Research Initiative" (GoNERI) of the Ministry of Education, Culture, Sports, Science and Technology-Japan and by the Grant-in-Aid for Scientific Researches by the Japan Society of Science and Research (Grant Number 25380264). The basic idea has been pointed out at the program of "International Symposium commemorating the First Anniversary of the Foundation of GoNERI" on Oct 9, 2008 (`http://ajw.asahi.com/article/0311disaster/fukushima/AJ201207260074`).

1. Introduction

One of Japan's worst accidents occurred at the Fukushima Daiichi nuclear power station after the earthquake and tsunami on March 11, 2011. Japan's nuclear utility industry had believed that the station could safely withstand natural disasters, but soon after the accident, the issue of whether nuclear plants are prepared for future risks became a critical and much-debated issue. Hence, this study examines the relationship between occupational risks and types of employment at Japan's nuclear power plants.

Replacement of permanent employees with contingent workers has proliferated throughout all major industries in developed countries. The importance of on-site contract workers—the contracting firms' employees who are located as per the specifications of the host plant—is increasing since these workers are similar to temporary agency workers, although the former category includes many permanent employees. With demand for on-site contract workers increasing, differences in working conditions between these workers and the host firm's employees are under scrutiny because these differences have compromised safety on industrial sites. In the United States, safety and health education and training (hereafter, safety training) of contract workers attracted attention after the 1989 explosion at a Phillips Petroleum chemical plant in Pasadena, Texas that killed 23 people and injured 300. Because the plant engaged contract workers, the safety conditions of workplaces reliant on contract workers became a major issue. The U.S. Occupational Safety and Health Administration (OSHA) hired the John Gray Institute to collect data about safety issues in the U.S. petrochemical industry. Wells et al. (1991), as project members, reported results of this investigation. Their report involved a survey of plant managers, employees, and contract workers, and nine plant-level case studies.[1]

Wells et al. (1991) found that contract workers and employees differed in education, age, ability to speak and understand spoken English, and other attributes. In the United States, host plants may direct and supervise contract workers,[2] and responsibility for accidents is affixed based on whether the host plant is regarded as the co-employer. Wells et al. (1991) summarized three motives for hiring contractors: reducing compensation costs, ensuring workforce flexibility, and providing workers with specialized skills. They also mentioned avoiding co-employment as another controversial motive.[3] Rebitzer (1995) conducted an in-depth analysis of the same data and found that host plants have an incentive to pass responsibility for safety training and supervision of contract workers to contracting firms—that is, firms that provide contract workers—because by doing so, they escape the potential liabilities from becoming co-employers. On the basis of probit analyses of accident rates, he also found that host plants offered more effective safety training and supervision for both contract workers and employees than contracting firms. Few studies of factors contributing to accidents and occupational injuries discriminate between contract workers and employees, but studies about the effects of employment terms do exist. Most such studies have found that the type of employment contract has little influence if factors such as job descriptions and working conditions are controlled for (Amuedo-Dorantes, 2002; Guadalupe, 2003; Hernanz and Toharia, 2006). Although these studies focus on whether accidents or the occupational injury rate depends on the type of employment contract, their results suggest that accidents and occupational injury are both affected by safety

[1] Kochan et al. (1992) provide a summary of the report. Data from surveys of plant managers and case studies were not available from OSHA.

[2] Such activities are prohibited in Japan.

[3] They also pointed out that the use of contract workers results in union avoidance.

Table 1. Summary data on commercial nuclear power plants in Japan (2010)

Operator	Station	BWR	PWR
Japan Atomic Power	Tokai Daini	1	0
	Tsuruga	1	1
Hokkaido	Tomari	0	3
Tohoku	Onagawa	3	0
	Higashidori	1	0
Tokyo	Fukushima Daiichi	6	0
	Fukushima Daini	4	0
	Kashiwazaki-Kariwa	7	0
Chubu	Hamaoka	3	0
Hokuriku	Shiga	2	0
Kansai	Mihama	0	3
	Takahama	0	4
	Oi	0	4
Chugoku	Shimane	2	0
Shikoku	Ikata	0	3
Kyushu	Genkai	0	4
	Sendai	0	2
	Total	30	24

BWR: Boiling water reactor
PWR: Pressurized water reactor
Source: Japan Nuclear Energy Safety Organization, Operational Status of Nuclear Facilities in Japan (2011 edition)

training.

We present a theoretical explanation for differences in safety levels between contract workers and employees, using data on Japan's nuclear power industry. Table 1 shows summary data on the 54 commercial nuclear power plants (nuclear plants, hereafter) in Japan as of March 2010. In nuclear plants, contractors are hired mainly to perform periodic inspections. Each reactor facility must be inspected within 13 months of its previous inspection. Inspection data from 1998 to 2004 for the seven plants at the Kashiwazaki-Kariwa Nuclear Power Station (owned and run by Tokyo Electric Power Company (TEPCO)) indicate that periodic inspections take 198 days on average.[4]

[4] The table of periodic inspections is available at `http://www.tepco.co.jp/nu/kk-np/data_lib/index13-j.html` (accessed on June 17, 2013).

Typically, multiple reactor facilities exist in one plant, and therefore, the percentage of contract workers is constantly high.

The number of employees at each nuclear plant is recorded annually in the Operational Status of Nuclear Facilities in Japan by the Japan Nuclear Energy Safety Organization. In 2010, utilities employed 9,210 workers who were potentially exposed to radiation (radiation workers hereafter) in nuclear plants, whereas eight times that number (74,279) were contract workers at those facilities. If occupational safety levels differ for the two types of workers, the effects can be significant. We examined radiation exposure for all workers as a proxy for occupational safety and found it to be much higher among contract workers: 0.58 percent of employees were exposed to radiation exceeding 5 mSv (millisievert)[5] and 0.02 percent were exposed to radiation exceeding 10 mSv. Among contract workers, 4.6 percent had suffered exposure exceeding 5 mSv and 1.44 percent received more than 10 mSv. In 2002, Junichiro Koizumi, the prime minister of Japan, admitted that three fatal cases of occupational injury and illness (occupational injury hereafter) in nuclear plants had been certified as resulting from radiation-related diseases.[6] Job titles suggest all three fatalities were contract workers.

This study shows that Japan's nuclear utilities prefer to hire contract workers, although this practice could hamper adherence to appropriate occupational safety and health standards and increase its costs. The remainder of this paper is organized as follows. Section 2 presents a brief history and the current components of regulations relating to contract workers and Japan's nuclear utility industry. Section 3 shows that regulations lead to several implications in conventional imperfect information models.

[5] Public Notice No. 810 of 1976, the Ministry of Health, Labour and Welfare stipulates that when a radiation worker has leukemia, his radiation dose, in principle, must not be less than 0.5 mSv per year to be designated as an occupational injury.

[6] The response to question no. 3 posed by the House of Representatives in 2002.

Section 4 provides an empirical study that examines hypotheses about occupational safety and health. Section 5 concludes the paper.

2. Contract Workers and Regulation of Japan's Nuclear Utility Industry

This section describes the present situation and history of Japanese regulations relating to contract workers and the nuclear utility industry based on Sugeno (1992), Hamaguchi (2004), and Anayama (2005).

2.1. Regulations Relating to Contract Workers

Hiring on-site contract workers is considered a normal activity, and therefore, no formal laws directly regulate their employment, although conditions are placed on their use. Since employing on-site contract workers is similar to employing temporary agency workers, their contracts are indirectly regulated under the Employment Security Act and Worker Dispatching Act.[7] The Employment Security Act was enacted in 1947 under the influence of the International Labor Organization (ILO) convention and recommendations C034 and R042 of 1933, and until 1985, it prohibited commercial employment agencies and labor supply agencies other than free employment agencies managed by labor unions. This law was intended to eliminate "bosses" who acted as labor supply agencies and human traffickers; it protected workers against human rights' infringements. The term "labor supply" formerly referred to employing people who worked under the direction of others according to a supply contract. Thus, the temporary agency was regarded as an example of the labor supply agency. This regulation is based

[7] The Act for Securing the Proper Operation of Worker Dispatching Undertakings and Improved Working Conditions for Dispatched Workers is commonly known as the Worker Dispatching Act. We use the latter term in this paper.

on the consideration that forced labor and intermediary exploitation can exist if the host can directly control the working conditions of contract workers.

Immediately after the Employment Security Act took effect, exceptions were made to its enforcement. Ministerial ordinances were instituted for industries deemed unable to operate because of the law and in which infringements on human rights were not a concern.[8] For example, the occupations of nurse and midwife were such exceptions. Enacted in 1985, the Worker Dispatching Act was originally a prohibition-based law that permitted dispatching of workers only for explicitly identified types of jobs.[9] Worker dispatching was drastically deregulated between 1994 and 2003, and with few exceptions, it remains unregulated. The Employment Security Act was amended in 1985. Under the present law, labor supply refers to "having workers work under the direction and orders of another person based upon a supply contract, and does not include that which falls under worker dispatch provided in Article 2, item 1 of [the Worker Dispatching Act]" (Article 4, paragraph 6 of the Employment Security Act).[10] That is, the law has been changed to acknowledge the contractual relationship among the suppliers, host, and workers since the relationship is not considered to lead to infringements of workers' rights. Currently, such a relationship is called a temporary agency or worker dispatching business. Most European labor markets were also deregulated around these years.[11]

Shirai (2007) compared several surveys of Japanese manufacturing and found that the use of contract workers expanded rapidly in the 1990s alongside deregulation of

[8] A ministerial ordinance is an order issued by the relevant ministry under the relevant law.

[9] Hamaguchi (2004) argued that the regulations imposed on employment agencies were not concerned with protecting human rights, but rather, with protecting the employees of the host plant.

[10] We referred to the following website for translated statements of Japanese Laws: `http://www.japaneselawtranslation.go.jp`.

[11] The OECD Indicator of Employment Protection of 1985–2008. In 1997, the ILO adopted convention C181 and recommendation R188 to recognize employment agencies and temporary agencies as legitimate bodies of the labor market.

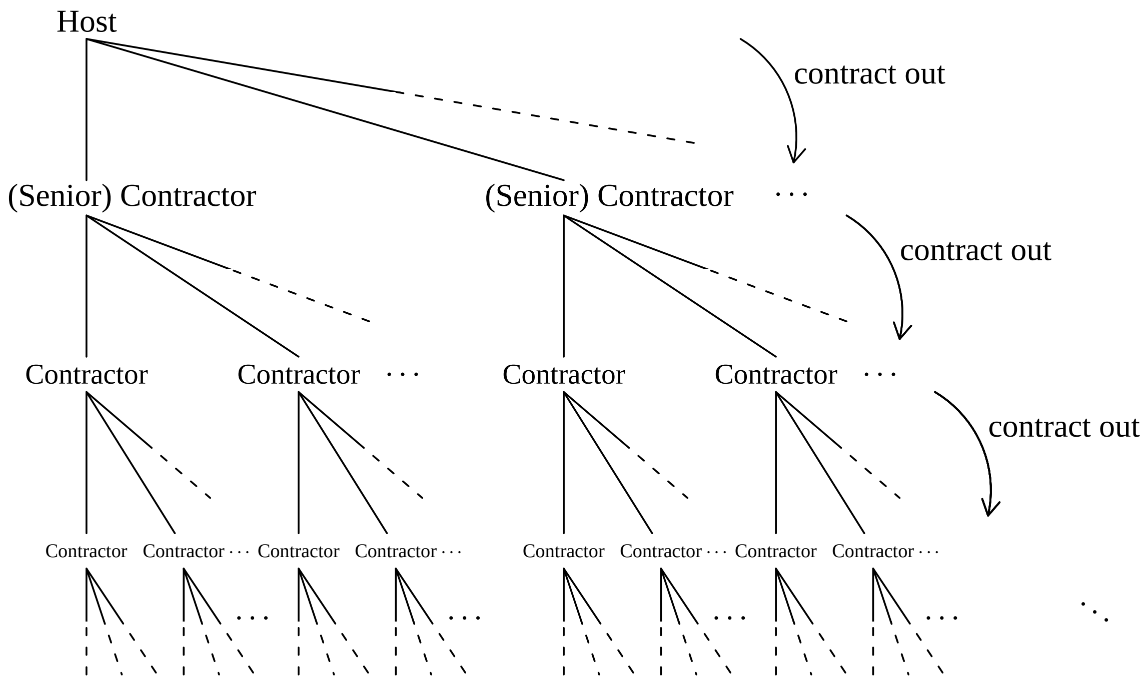

Figure 1. Hierarchical use of contractors

the worker dispatching business. On-site contracting firms and temporary agencies are similar in that both supply labor to other industries as a business. On-site contract work was and is common in the construction industry. In 1970, the Safety and Health Subcommittee of the Ministry of Labour was established to address safety and health problems among contract workers. Its 1971 report pointed out that the then current methods of correcting problems among small- and medium-sized firms and on-site contracting firms were inadequate (Hamaguchi, 2004, p. 236). Although it was widely known that the use of on-site contract workers could generate issues of occupational safety and health management by making contract work hierarchical, regulations primarily targeted direct employment contracts (Figure 1).[12] The Industrial Safety and Health Act was enacted in 1972 on the basis of this report, according to

[12]On the basis of data supplied by TEPCO, Shimizu (2002) revealed that TEPCO recognized as many as five strata of contractors from the top contractors in the Fukushima Daiichi nuclear power station as of December 1, 2001.

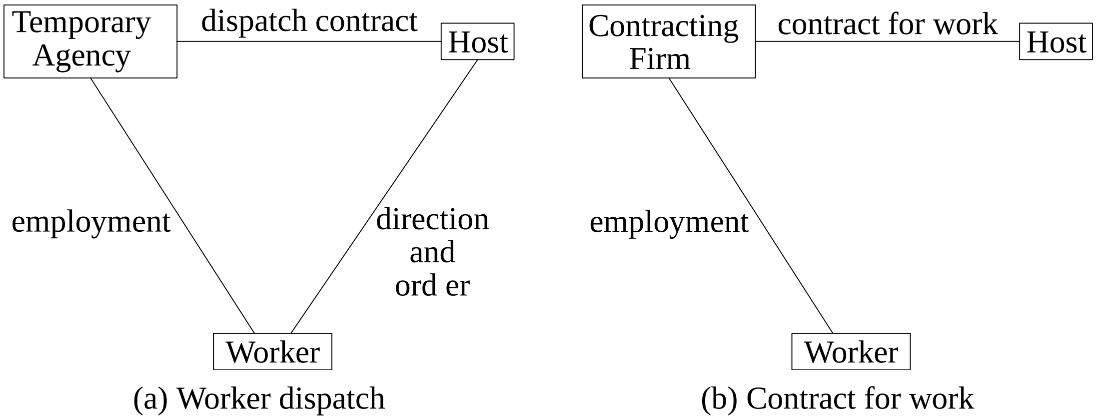

Figure 2. Relationships in worker dispatch and contract for work

which the senior contractor in the hierarchy is responsible for the safety and health of all contract workers, including those in lower tiers of the hierarchy. Therefore, host plants are not responsible for the safety and health of contract workers. In contrast, the Worker Dispatching Act makes the host plant as well as the temporary agency responsible for the safety and health of temporary agency workers (Article 45 of the Worker Dispatching Act).

In Public Notice No. 37 of 1986, the Ministry of Health, Labour and Welfare distinguished between worker dispatching and on-site contract work.[13] Figure 2 shows the relationship of each type[14]. Temporary agency businesses employ workers and the host directs and orders these workers, unlike in contract work. In other words, in the latter case, contract workers are not under the direct control of the host plant. However, distinguishing a temporary agency business from a contract-for-work situation is seldom easy. The Prefectural Labour Office investigates whether the relationship among suppliers, hosts, and workers is that of contract-for-work and makes recommendations, if necessary. If contract specifications are extremely lax, then substitutable workers must

[13]The public notice is an instruction issued by the relevant ministry under the relevant law and order.
[14]Available at `http://www.mhlw.go.jp/bunya/koyou/dl/tekisei.pdf` (accessed July 8, 2013) (in Japanese).

regard themselves as self-employed persons engaged in contract work with their actual employers. If contract specifications are extremely strict, firms must hire engineers even to repair a water pipe.

Previous studies on transaction costs usually focused on the benefits of integration (e.g., Klein et al. (1978), Williamson (1971), Grossman and Hart (1986)). However, the benefits of outsourcing are focused on in the contract-for-work context. Generally, three incentives induce firms to hire contract workers (see, e.g., Abraham and Taylor (1996)):

(1) The employees' wage rate is higher than that of external workers.[15] This fact is explained by the efficiency wage hypothesis that firms pay employees above-market wages to control employees' efficiency.

(2) The cost of adjusting labor inputs is less for contract workers than for employees. Generally, firms incur costs for increasing or reducing their own workforce. Japanese employers must satisfy restrictive conditions to justify reducing the number of employees.[16] However, host firms can simply reduce the number of contract workers as part of cost reductions. It also makes it easy for contracting firms to justify reducing the number of their employees when they face financial difficulties caused by a decrease in demand.

(3) A firm can enjoy economies of scale by outsourcing relatively minor jobs that require some specialization. Since a nuclear plant requires special equipment such as its reactor, outsourcing the tasks of inspection and maintenance to manufacturers may be preferable. By contrast, the scale of these activities in a nuclear plant is large because they are constantly undertaken. Outsourcing may

[15] Garen (2006) also discusses fringe benefits.

[16] Employers need to satisfy rigid conditions for dismissal based on legal precedents, particularly if the dismissal is owing to economic circumstances. For details, see Sugeno (1992, pp. 407–410).

offer relatively few benefits, and hiring employees for such jobs may be preferable.

In addition to these motivations, Shirai (2007) and Wells et al. (1991) pointed out that firms can circumvent an employer's legally specified responsibilities by hiring contractors. In a worker dispatching situation, the host assumes some employer responsibilities—for example, occupational safety training. In addition, in principle, the Worker Dispatching Act prohibits hosts from engaging worker dispatching services continuously for more than three years (Article 40-2, paragraph 3; and Article 40-5). No such restriction pertains to contract workers, and contracting firms bear all obligations to assure that contract workers obey relevant laws. This fact is inseparable from regulation that prohibits host firms from directing contract workers. Theoretically, the host plant is indifferent between hiring employees and contract workers, since in the latter case, contractor fees include the cost of the employer's legal obligation. However, every year, many firms illegally avoid paying social insurance for their employees[17] and it seems likely that firms can reduce the cost of their legal obligations by hiring contract workers. This type of cost reduction severely damages occupational safety conditions because contract workers are not under the host plant's direction and supervision. Utilities that own nuclear plants must provide operational safety programs that meet government regulations. These programs must include compliance training. However, utilities are not exempt from the prohibition on directing and supervising contract workers, even for safety purposes.

2.2. Laws Regulating Japan's Nuclear Utility Industry

Japan's nuclear utility industry is regulated under the Electricity Business Act and the Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors.

[17] Social insurance in Japan generally includes five compulsory types of insurance: occupational injury, employment, health, welfare pension, and nursing care.

In general, the former stipulates conditions about facilities and equipment and the latter regulates management of compliance and safety training to enhance public safety by preventing radiation-related hazards. An important ministerial ordinance under the latter law—the Rule for the Installation, Operation, etc. of Commercial Nuclear Power Reactors—requires nuclear plant operators or utility companies to provide operational safety programs (Article 7 and Article 16) and report accidents and irregularities (Article 19-17). Article 7-5 of this ordinance also requires utilities to assess their activities, incorporate lessons from the experiences of other utilities in their own practices, and undergo inspections to assure that they comply with regulations. These requirements increase risk management costs. If violations of safety protocols occur, utilities may be ordered to suspend reactor operations (Article 33 of the Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors and Article 98 of the Industrial Safety and Health Act). Note that the term “risk of an accident” in this study includes the risk of receiving this order. Utilities conduct safety training for employees to comply with these regulations.

Uezu et al. (2007) determined that occupational injury rates that include injuries to contract workers are higher than rates that count only injuries to employees. According to the Ministry of Health, Labour and Welfare (2005), the smaller the firm, the smaller the fraction of workers not offered safety training during orientation. In addition, the report on the accident at the Mihama Nuclear Power Station (operated by Kansai Electric Power Company) on August 9, 2004 pointed out that employees should have established the thickness of the pipe in the secondary loop to assure safety. This suggests the utility recognized that employees were preferable for jobs requiring extensive safety training, although no empirical evaluation has established whether gaps in safety training explain differences between employees and contract workers.

In case of a severe nuclear accident, the utility is solely assigned liability. The Act on Compensation for Nuclear Damage assigns operators of nuclear facilities sole and strict liability for compensating for nuclear damage caused by factors other than disasters, upheavals, and similar incidents (Article 3). The law intends to protect accident victims and promote business by reducing contractors' risks. It also specifies that contractors are not liable for unintentional nuclear damage caused by reactor operation (Article 4 and Article 5). In short, contractors are perfectly protected by limited liability and the utility can only use a threat that the contract will be terminated if an accident takes place. Auditing is not available in this case, because direct supervision of contract workers by the host is not permitted.[18] This fact seems to make the information rent higher than required to offset the technical advantage of the contractor if it exists.

3. Model Featuring Imperfect Contractor Information

Let us consider a model in which a utility hires contracting firms for jobs that pose a risk of accidents. Assuming the utility wants to restrict the probability of accidents and has imperfect information about the contracting firms' safety training, we derive several implications from models of adverse selection (Rothschild and Stiglitz, 1976) and moral hazard (Laffont and Martimort, 2002).

3.1. Motivation of Utility Companies to Hire Contractors

We consider five assumptions:

(1) The utility's revenue decreases if an accident occurs.

(2) The probability of accident decreases as workers' safety training increases.

[18]Article 16 of the Act on Compensation for Nuclear Damage also provides that the government can subsidize the part of the compensation that exceeds the stipulated amount.

(3) The safety training cost is positive.

(4) The utility decides whether to hire contractors by comparing the maximum expected profits.

(5) The utility cannot observe the safety training of contract workers.

It is reasonably assumed that the probability of an accident rises as the degree of workers' safety training decreases because training to prevent occupational injuries is related to training for preventing severe accidents. If workers are insufficiently trained about operational risks, they are more likely to adopt shortcuts to reduce their work burden. For instance, a critical accident in 1999 at the uranium processing plant at Tokai-mura, Japan involved two workers who were killed because they violated operating procedures for their convenience.

It is difficult to know whether the relationship between utilities and contracting firms is more accurately defined as adverse selection or moral hazard. However, in models involving asymmetric information, the principal must pay an information rent to the agent to control accident risks. The present value of the total expected profit of the utility that does not hire contractors is written as

$$\Pi^N = R - P^N(C)L - C \tag{1}$$

where the superscript N indicates "with no contractor," R is the revenue, p is the accident probability, L is the loss from an accident, and C is the cost of safety training. The first order condition is written as

$$\frac{d}{dC}P^N(C) = -\frac{1}{L}. \tag{2}$$

The present value of the total expected profit of the utility that hires contractors and that of the contractor are written as

$$\Pi^C = R - P^C(F)L - F \quad \text{and} \tag{3}$$

$$\pi = (1 - p(c))F - c \tag{4}$$

where superscript C indicates "with contractors," F is the present value of the total contractor fee transferred from the utility to the contractors, P^C and p are the accident probabilities, and c is the safety training cost. Although the specification seems to assume that the utility hires only one contractor, we can assume such a situation for every contractor. From the first order condition of the contractor, c^*, the contractor's optimal safety training, becomes a function of F. Functions p and P^N have the same shape if the utility and the contractor have the same technology on the safety training, and $c^*(F) = F$ if the contractor does not shirk. Specifically, if both hold, the sum of the utility's optimal contractor fees meets $F^* = C^*$. That is, the utility is indifferent between hiring and not hiring contractors. The difference between p and P_i indicates the contractor's technical advantage in the safety training field, and $\frac{dc^*}{dF} < 1$ indicates that the contractor does not use the entire fee on the safety training. Whether the utility uses the contractor can be derived from the balance of these two factors. This is a normal explanation of using contractors, and there is no safety problem. However, another mechanism that makes the utility use contractors likely exists.

We introduce the notion of "minor incident" to explain why Japanese nuclear utilities engage many contracting firms. The term "minor incident" includes detection of violations of regulations concerning occupational safety, additional operations owing to small difficulties, occurrence of an occupational injury,[19] and damage to the firm's

[19] On May 31, 2011, Ritsuo Hosokawa, the Minister of Health, Labour and Welfare, admitted that there were ten nuclear plant workers whose leukemia had been designated as an occupational injury in the

reputation by those incidents. When a minor incident occurs, penalties to the utility that does not engage the contractor can be larger than those for a utility that does, because the utility's reputation is damaged more than the contractor's reputation by minor incidents.[20] Damage to a utility's reputation raises its financial costs, particularly for operators of nuclear plants engaged in other businesses such as constructing nuclear plants. Under these conditions, a utility's expected loss can be smaller by hiring contract workers. The expected profit of the utility that does not hire the contractor is written as

$$\Pi^N = R - P_M^N L_M^N - C \tag{5}$$

where subscript M is the minor incident. The first order condition is written as

$$P_M^{N\prime} = -\frac{1}{L_M^N}. \tag{6}$$

The expected profits of the utility and contractor are written as

$$\Pi^C = R - P_M^C L_M^C - F \quad \text{and} \tag{7}$$

$$\pi = (1 - p_M)F - c \tag{8}$$

where superscript M indicates the minor incident. We assume that $L_M^N > L_M^C$, $P_M^{N\prime} < 0$, and $P_M^{N\prime\prime} > 0$. Again, we can write P_M^C as a function of F from the contractor's first order condition. Thus, the utility's first order condition is written as

$$P_M^{N\prime} = -\frac{1}{L_M^C}, \tag{9}$$

when the safety training technology is common and the contractor does not shirk. Since $P_M^{N\prime\prime} > 0$ and $-\frac{1}{L_M^C} < -\frac{1}{L_M^N}$, we get $F^* < C^*$, that is, $\Pi^C(F^*) > \Pi^N(C^*)$. If the utility can claim damages for a minor incident from the contractor, it is more profitable for the

Tohoku Region Pacific Coast Earthquake Reconstruction Special Board of the House of Representatives.

[20] Wells et al. (1991), in their case studies, stated that some plant managers mentioned reputation as a motivation for their use of contractors.

utility to hire contractors than hire employees. In this case, even if the technology is common to the utility and the contractor and the contractor does not shirk, the utility chooses to use the contractor.

Let us consider a case where risks of severe accident and minor incident both exist. The expected profit of the utility that does not hire the contractor is written as

$$\Pi^N = R - P_S^N L_S - P_M^N L_M^N - C \tag{10}$$

where P_S is the probability of a severe accident, L_S is the loss from a severe accident, P_M is the probability of a minor incident, and L_M is the loss from a minor incident. We assume that $P_S^N < P_M^N$ and $L_S > L_M$. The probability that nothing happens is $(1 - P_S - P_M)$. The first order condition is

$$-P_S^{N\prime} L_S - P_M^{N\prime} L_M^N - 1 = 0. \tag{11}$$

The expected profits of the utility and contractor are written as

$$\Pi^C = R - P_S^C L_S - P_M^C L_M^C - F \quad \text{and} \tag{12}$$

$$\pi = (1 - p_S - p_M)F - c \tag{13}$$

where $L_M^N > L_M^C$. Again, we can write P_S^C and P_M^C as functions of F from the contractor's first order condition. The utility's first order condition is written as

$$-P_S^{C\prime} L_S - P_M^{C\prime} L_M^C - 1 = 0. \tag{14}$$

If the safety training technology is common and the contractor does not shirk, (11) and (14) only differ in L_M^N and L_M^C. Therefore, we obtain $\Pi^C(F^*) > \Pi^N(C^*)$.

3.2. Problems on Using Contractors in a Regulated Industry

In the relationship between the utility and the contracting firm involving asymmetric information, the former may be unable to offer a contract such that the latter voluntarily chooses an appropriate level of safety training. Verifying training is often too costly since direct supervision by the host is disallowed. Furthermore, the utility may prefer not to offer a contract that leads to appropriate safety training levels if the socially optimal level required by the regulator exceeds what is privately optimal. In this case, the utility offers the contractor fees, which does not reflect the cost of conducting the necessary safety training.

For simplicity, let us consider a case in which a utility does not hire contract workers, employees perform all the work, and only one type of accident is possible. Let T and N be the utility's strategies corresponding to whether it offers safety training, and let A and S represent states with and without an accident, respectively. Expected profits for Strategies T and N are written as

$$\Pi^T = R - P^T L - C, \quad \text{and} \tag{15}$$

$$\Pi^N = R - P^N L, \tag{16}$$

respectively. The utility chooses Strategy T when $\Pi^T \geq \Pi^N$; or, in other terms, $(p^N - p^T)L - C \geq 0$. Strategy N becomes optimal when the effect of safety training, $(p^N - p^T)$, is small; $(p^T < p^N)$; the loss by accident, L, is small; and the cost of safety training, C, is large.

Severe accidents are rare at nuclear plants, but minor difficulties are frequent. Table 2 shows the number of reported incidents at nuclear plants run by Japan's principal utility companies between April 1994 and March 2006. Data are from the website of Japan Nuclear Technology Institute. During this period, 103 incidents stopped reactor operations. On average, there were 0.18 incidents per reactor per year, and reactors were out of operation 371 hours per incident. Of the 103 incidents, seven reportedly originated because of worker error and the others were caused by deterioration such as

Table 2. Incidents Causing Reactor Stoppages between 1994–2005

Year	Number of Incidents	Incidents per Reactor	Stop Interval	Human Error
1994	9	0.21	401	1
1995	8	0.18	279	1
1996	7	0.16	170	0
1997	8	0.17	325	0
1998	10	0.21	577	1
1999	8	0.17	120	2
2000	13	0.28	157	0
2001	6	0.13	816	1
2002	3	0.06	95	0
2003	4	0.08	340	0
2004	12	0.25	345	0
2005	15	0.31	610	1
Total	103	0.18	371	7

Stop interval: (average hours per incident)
Human error: (number of human error-related incidents)
Source: NUCIA, Japan Nuclear Technology Institute

fatigue, corrosion, and their associated consequences. None was attributed to deviations in workers' practices. Periodic inspections stop a reactor for about 198 days per 13 months. Compared to this number, the contracting firm's cost of safety training had likely no major impact on the operations of nuclear plants. Therefore, we may conclude that $(p^T - p^N)$ and L may be ignored in the utility company's decision.

This is also explained as follows. Where the regulator and the utility are respectively the principal and the agent, the former can motivate the latter to assure a level of worker safety training by penalizing it for inadequate safety training. However, informational asymmetry occurs when the utility engages a contracting firm and requires it to train contract workers appropriately. This asymmetry allows the utility to avoid the responsibility and cost of safety training. The number of contracting firms far exceeds the number of utilities—only ten companies have nuclear plants, whereas there are thousands of contracting firms—and it is difficult for the regulator to inspect that many firms, and thus, to verify safety training.

4. Empirical Analysis

From the above discussion, a verifiable question arises about the host firm's main motivation for using contract workers: Do utilities hire contract workers for temporary work requiring special skills on equipment, or do they attempt to avoid the responsibilities of an employer? To answer this question, we seek evidence through two empirical analyses concerning radiation workers in Japan's nuclear power industry.

4.1. Empirical Models and Explanatory Variables

Before testing the main hypothesis, we simply examine factors of the probability of a worker being exposed to radiation greater than 5 mSv. We use the radiation exposure as a proxy variable for occupational safety in nuclear plants. We denote the number of workers at utility i ($i = 1, 2, \ldots, n$) in year t ($t = 1, 2, \ldots, T$) as n_{it}. Let P_{ijt} be the probability of a worker j ($j = 1, 2, \ldots, n_{it}$) being exposed to radiation (> 5mSv). A logit model of the probability of exposure is represented as

$$P_{ijt} = \Lambda(x_{ijt}\beta), \tag{17}$$

for each of n_{it} workers, where x_{ijt} is the vector of explanatory variables, β is the vector of parameters, and Λ is the cumulative distribution function of the logistic distribution (see, e.g., Amemiya, 1985, Chapter 9). For the characteristics of the employers, financial data were used.

The second model examines the type of worker preferred by the utility company. Let r_{it}^{E} be the proportion of employees among all (n_{it}) radiation workers in the company. The ratio of employees to contract workers is written in the form of an odds ratio,

$$\frac{r_{it}^{E}}{1 - r_{it}^{E}}.$$

We ask whether firm size correlates with this variable. The regression is done by the minimum chi-square method (in line with Amemiya, 1985, Chapter 9). Following the discussion in Section 2, we propose two explanations for the firm's use of contract workers. One is that it hires them to enjoy economies of scale if it has a temporary job requiring specialized worker skills. If this is the case, the larger the scale of the host, the larger the ratio of employees to contract workers, since it becomes efficient and inexpensive for the host to do the required work. The other explanation is that the host seeks to avoid employer responsibilities, as it is costlier to hire employees than contract workers, despite the information rent. In this case, a larger host may choose a smaller ratio of employees since a larger host is expected to uphold greater social responsibility and has a greater incentive to avoid embarrassment on failing to do so than smaller firms.

4.2. Data

The numbers for radiation workers are from Japan Nuclear Energy Safety Organization (1983–2009) for the years 1984–2010 (as of March each year). The data are available for the nine principal utilities that operate nuclear plants. The companies are denoted as Tokyo, Chubu, Kansai, Tohoku, Hokuriku, Chugoku, Shikoku, Kyushu, and Hokkaido. (Japan's principal utility companies are named for the regions they serve, as they are, in effect, local monopoly suppliers.) The percentages of contract workers and employees exposed to radiation exceeding 5 mSv were computed from this data. Average values listed for each year appear in Figure 3. The proportion of employees trends upward, while the number of workers per reactor trends downward. The rate of exposed (>

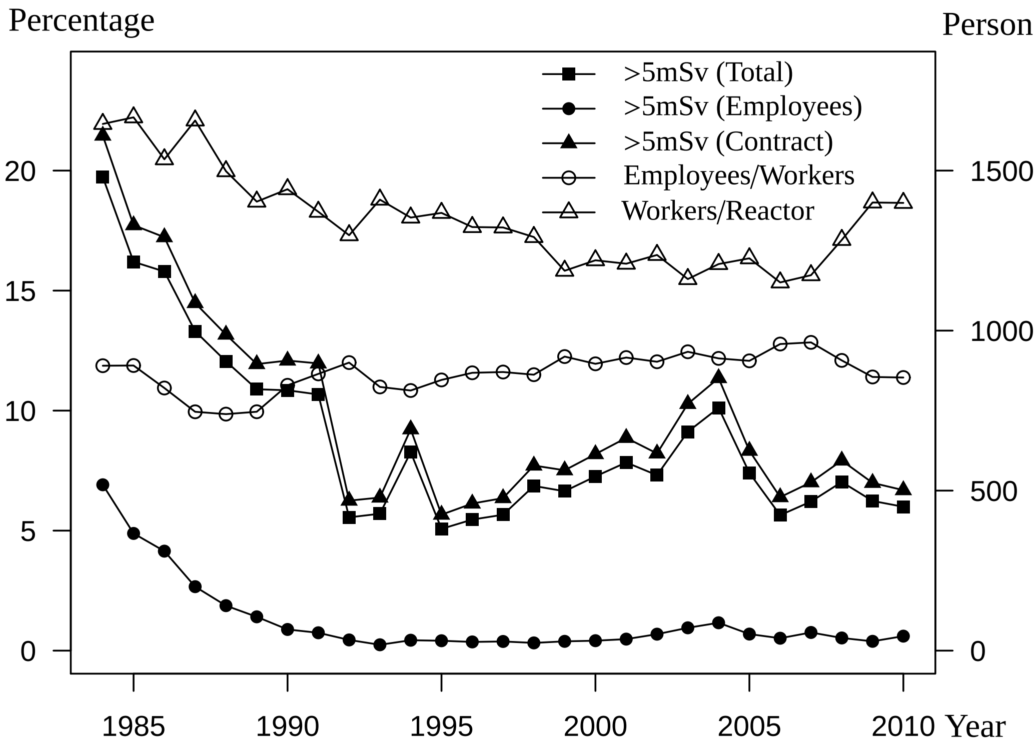

Figure 3. Number of workers per reactor, percentages of employees, percentages of workers exposed to radiation greater than 5 mSv in nuclear plants hiring employees and contract workers (annually). Souce: Japan Nuclear Energy Safety Organization (1983–2009).

5mSv) workers trends downward for employees, contract workers, and all workers until 1994, and then trends slightly upward. It is necessary to distinguish the downward effect of technical progress and the upward effect of plant aging. Financial data were obtained from the annual reports of Japan's nine utilities that operate nuclear plants. The deflator was obtained from the National Accounts for 2009 (the base year is 2001).

The explanatory variables are defined as follows:

$$
\begin{aligned}
\text{F\_SIZE}_i &: \text{Total size of company's businesses} \\
&:= \text{Average of total ordinary revenues}, \\
\text{N\_RATE}_{it} &: \text{Dependence on nuclear power} \\
&:= \text{Nuclear electricity output/Electricity sales volume}, \\
\text{FEE}_{it} &: \text{Contractor fee per capita} \\
&:= (\text{Repair expenses for nuclear branch} \\
&\quad + \text{Outsourcing expenses for nuclear branch}) \\
&\quad /\text{Number of contract workers}, \\
\text{TREND}^{\alpha} &: \text{Time trend } (1984 = 0) \text{ powered by parameter } \alpha, \\
\text{AGE}_{it} &: \text{Degree of reactor aging} \\
&:= \Big(\sum_{\text{reactors}} \text{Accumulated years from beginning of operation}\Big) \\
&\quad /\text{Number of reactors}, \\
\text{CHANGE(Y)}_{it} &:= 1 \text{ if } t \text{ is after year Y},\ 0 \text{ otherwise}, \\
\text{C\_DUMMY}_{ijt} &:= 1 \text{ if the concerned worker is a contract worker},\ 0 \text{ otherwise}.
\end{aligned}
$$

The variables are chosen based on the following considerations:

(1) The size of a power utility company is represented by its ordinary revenue. To exclude temporal fluctuations, we used the average value in the sample period. This variable is not expected to be correlated with P_{ijt} if government regulations require a level of safety management that exceeds the plant's optimal level. Otherwise, it is expected to be negatively correlated owing to the economies of scale. In the second model, this variable is expected to be positively correlated

with $r^E_{it}/(1 - r^E_{it})$ if the utility uses contract workers for temporary jobs requiring some specialization and negatively correlated if it does so to avoid employer responsibilities.

(2) A utility may invest more in safety management at nuclear plants if its power generation depends extensively on nuclear power. Hence, the rate of nuclear power generation is expected to correlate negatively with P_{ijt}.

(3) If training cost is reflected in contractor fees, the per capita fee of contract workers should correlate negatively with P_{ijt}. By contrast, if a premium is paid for a lower level of safety (the compensating wage differentials hypothesis), a positive correlation is expected.

(4) The time trend is expected to correlate negatively with P_{ijt} since technical progress and accumulation of experience and knowledge decrease risk.

(5) The length of time after the plant commences operation is expected to be positively correlated with P_{ijt} since old plants generally tend to have more accidents.

(6) The structural change dummy should correlate with P_{ijt} if the radiation exposure jumped at some point in time. We determined the breaking point Y from $\{1988, \ldots, 2005\}$ by model selection with AIC.

(7) The contract worker dummy should correlate positively with P_{ijt} if contract workers are exposed to greater radiation than employees.

Table 3 summarizes the data. On average, 10–20 percent of workers are utility company employees (the rest are contract workers), and the proportion of exposed workers (>5mSv) among contract workers is nearly 10 times that among employees.

Table 3. Summary of Variables for Nuclear Power Sections of Utility Companies 1984–2010

Utility Company		Total Radiation Workers	Proportion of Employees (Percent)	Exposed (Employees) (Percent)	Exposed (Contract) (Percent)	Total Revenue (F_SIZE)	Number of Reactors	AGE	N_RATE (Percent)	FEE
Tokyo	Mean	21967	9.6	2.4	11.0	4.72	14.4	14.1	35.3	6.0
	S.D.	3252	1.3	3.3	5.0	0.52	3.1	5.8	8.0	1.6
	Min.	14202	6.9	0.2	5.2	3.72	8.0	6.1	14.5	3.1
	Max.	28163	12.1	14.0	25.9	5.68	17.0	25.1	47.2	9.1
Chubu	Mean	5143	12.6	1.9	11.8	2.00	3.1	13.4	17.2	7.3
	S.D.	616	2.0	2.1	5.7	0.20	0.7	4.2	4.5	2.1
	Min.	4250	9.2	0.0	1.3	1.64	2.0	6.7	8.7	3.4
	Max.	6738	16.2	8.2	22.3	2.36	4.0	19.5	24.2	11.8
Kansai	Mean	11582	12.4	0.6	12.0	2.37	10.3	17.7	45.9	9.9
	S.D.	1281	1.1	0.6	5.4	0.19	1.2	6.8	5.2	1.5
	Min.	9720	10.4	0.0	6.1	2.03	7.0	8.3	36.5	6.5
	Max.	13887	14.6	2.8	24.4	2.61	11.0	29.7	54.6	14.0
Chugoku	Mean	2483	13.7	0.8	7.8	0.96	1.8	17.0	15.5	6.3
	S.D.	455	2.6	2.0	6.5	0.08	0.4	6.3	4.5	2.2
	Min.	1798	10.5	0.0	0.2	0.80	1.0	7.6	8.2	2.8
	Max.	3203	19.3	10.3	26.2	1.12	2.0	28.6	22.7	12.1
Hokuriku	Mean	2167	14.9	0.1	2.3	0.48	1.3	6.8	17.9	5.1
	S.D.	592	6.2	0.2	2.9	0.02	0.5	3.3	8.6	3.1
	Min.	912	10.2	0.0	0.0	0.44	1.0	0.7	0.0	1.6
	Max.	3041	31.9	0.7	11.5	0.52	2.0	11.7	35.6	12.2
Tohoku	Mean	3136	12.9	0.0	1.9	1.39	1.7	8.1	13.2	5.8
	S.D.	1363	2.0	0.0	2.2	0.20	1.6	3.2	6.1	1.8
	Min.	1554	9.5	0.0	0.0	1.05	0.0	0.8	5.7	1.8
	Max.	6685	17.0	0.2	9.3	1.67	4.0	13.3	25.8	10.4
Shikoku	Mean	2514	14.1	0.5	5.7	0.49	2.6	14.3	51.6	9.9
	S.D.	455	2.5	1.0	2.9	0.06	0.5	6.0	7.8	2.1
	Min.	1778	9.0	0.0	1.1	0.39	2.0	4.3	35.9	5.2
	Max.	3379	17.9	3.9	10.7	0.58	3.0	25.3	66.1	13.9
Kyushu	Mean	4984	13.5	0.4	6.5	1.28	5.0	13.0	43.9	10.1
	S.D.	1285	1.6	0.4	2.1	0.14	1.2	5.7	7.6	2.6
	Min.	3161	10.3	0.0	2.7	1.04	2.0	4.4	21.8	3.4
	Max.	7870	16.1	1.9	10.8	1.44	6.0	23.7	54.3	14.0
Hokkaido	Mean	2023	15.9	0.0	1.3	0.52	2.0	9.7	31.3	9.1
	S.D.	440	2.8	0.0	1.3	0.03	0.4	5.7	5.0	2.8
	Min.	1507	11.5	0.0	0.0	0.45	1.0	0.8	21.3	1.9
	Max.	3261	21.0	0.0	4.2	0.58	3.0	18.9	39.4	16.1
Total	Mean	54629	11.6	1.2	9.8	13.86	41.3	14.2	32.0	7.5
	S.D.	8921	0.8	1.6	4.1	1.86	9.3	5.2	4.0	1.4
	Min.	36207	9.9	0.2	5.7	9.81	22.0	6.9	25.4	4.6
	Max.	71353	12.8	6.9	21.5	16.54	51.0	23.5	39.2	9.6

Exposed (Employees): proportion of exposed workers (> 5mSv) among utilities' employees;
Exposed (Contract): proportion of exposed workers (> 5mSv) among contract workers;
Total revenue (N_RATE): index of firm size (¥trillion); AGE: degree of reactor aging;
N_RATE: dependence on nuclear power (percent); FEE: contractor fee (million Yen / person)
Source: Japan Nuclear Energy Safety Organization, Operational Status of Nuclear Facilities in Japan (1983–2009); Cabinet Office, Government of Japan, National Accounts for 2009 (base: 2001)

4.3. Results of Estimation

Results of our estimations appear in Table 4. The two columns correspond to the two models described in this section. The first column (Model 1) is the results of the logit model of exposure probability. The figures are the marginal effects at the average of the utilities' employees after 1997 except two dummy variables CHANGE(1997) and C_DUMMY, which are estimated with C_DUMMY$= 1$ and CHANGE(1997)$= 1$, respectively. We estimated α in the trend term by grid search from $(0, 1]$ maximizing the likelihood. The second column (Model 2) shows the results of the worker type choice model aimed at revealing why utilities use contract workers. Standard errors are in parentheses.

For Model 1, Table 4 reports the marginal effects at the average values of utilities' employees, where three estimates are significant, but all of the coefficients are significant at the 1 percent level. If Model 1 is regarded as a model of occupational safety, the signs of the coefficients of N_RATE, TREND, AGE and C_DUMMY should be negative, negative, positive, and positive, respectively. The estimates show that the signs for all of them are as expected, although the effects of TREND and AGE are not significant at the average values. The marginal effect of N_RATE is −0.0142, indicating that safety is high among utilities that depend heavily on nuclear power generation. Two possibilities explain this result. First, perhaps they excel at safety management since the marginal cost of safety training decreases as the size of nuclear power generation in the utility increases. Second, perhaps they focus on avoiding accidents by attending to worker safety since accidents imperil their profits more extensively as the proportion of nuclear power to all types of power generation increases, that is, when the risk premium for nuclear power generation is increased. The marginal effect of TREND is not significant,

Table 4. Analyses of Radiation Exposure and Worker Type 1984–2010

Model	(1) P(> 5 mSv)	(2) Odds
Constant		-1.74 ***
		(1.46×10^{-2})
F_SIZE	2.01×10^{-3}	-8.82×10^{-2} ***
	(3.00×10^{-3})	(1.89×10^{-3})
N_RATE	-1.42×10^{-2} ***	-2.85×10^{-1} ***
	(5.62×10^{-4})	(2.12×10^{-2})
FEE	9.84×10^{-4}	2.42×10^{-2} ***
	(1.41×10^{-2})	(1.47×10^{-3})
$\text{TREND}^{0.778}$	-3.09×10^{-3}	
	(1.33×10^{-2})	
$\text{TREND}^{0.188}$		-8.74×10^{-2} ***
		(9.86×10^{-4})
AGE	8.34×10^{-4}	-3.45×10^{-3} ***
	(2.35×10^{-2})	(6.19×10^{-4})
CHANGE(1997)	-4.12×10^{-2} *** [a]	
	(2.78×10^{-4})	
CHANGE(1996)		1.16×10^{-1} ***
		(7.00×10^{-3})
C_DUMMY	7.72×10^{-2} *** [b]	
	(1.72×10^{-3})	

First Column: Logit of the exposure probability (marginal effect at average).
Second Column: Odds of the proportion of employees.
***: significant at the 1 percent level.
[a]: Estimated with C_DUMMY= 1.
[b]: Estimated with CHANGE(1996)= 1.
Standard errors are in parentheses.

indicating that there is no evidence that technical progress reduces the probability of radiation exposure. The marginal effect of CHANGE(1997) is −0.0412 and significantly negative. This indicates that the occupational safety in the nuclear plant was improved by some reason at this point of time. The marginal effect of C_DUMMY is 0.0772, a positive value. This indicates that the safety level for contract workers is below that of employees, although conducting new investigations into the relationship between safety training and worker type exceeds the scope of this paper.

The result of Model 2 appears in the second column of Table 4. The coefficient of F_SIZE is −0.0882. As mentioned, the negative correlation with $r_{it}^{E}/(1-r_{it}^{E})$ indicates that the utility hires contract workers to avoid employer responsibilities. On considering this fact together with the fact that contract workers receive greater radiation doses than directly hired workers, it is interesting to examine whether utilities are inclined to contract out risky jobs. Even if the difference in the total radiation dose is not due to a difference in safety training but due to a difference in the characteristics of the jobs performed, the model in the previous section points to the logic of using contract workers in the riskier jobs. The coefficient of N_RATE is −0.285. This suggests that the more the utility depends on nuclear power, the more it prefers using contract workers in nuclear plants. If utilities recognized that employees are more suitable than contract workers for jobs requiring extensive safety training, it was not reflected in the configuration of the workforce. The coefficient of FEE is 0.0242, a positive value. This indicates that employees and contract workers are substitutes. The coefficient of TREND is −0.0874, a negative value, indicating that utilities were decreasing the proportion of their employees contrary to the upward trend in Figure 3. The coefficient of AGE is −0.00345, a negative value. This indicates that the utility tends to hire contract workers as the reactors become older. Periodic inspection presumably requires more hands for older reactors. The coefficient of CHANGE(1996) is 0.116, indicating that the utilities increased the ratio of employees to contract workers at this point. Along with the positive coefficient of CHANGE(1997) in Model 1, some event is supposed to have occurred around this point of time, which made the utilities increase the proportion of direct employees and resulted in a decrease of the probability of radiation exposure in the nuclear plant. Two events might have influenced the utilities' workforce configuration in the nuclear plant. One is an earthquake, the Great Hanshin-Awaji earthquake, which occurred on January 7, 1995. The other is an accident that occurred at a fast breeder reactor in Fukui, Japan on December 8, 1995. This accident focused people's attention on the risk of nuclear plants, although the reactor was not operated by a utility company and although the accident is rated at level 1 in the International Nuclear and Radiological Event Scale (INES). This is because it was revealed that Power Reactor and Nuclear Fuel Development Corporation, the operator of the breeder reactor, falsified reports and edited a videotape of the scene of the accident before broadcast.

On the basis of the two models, we obtained two results. First, the probability of radiation exposure in the nuclear plant is low when the degree of the utility's dependence on nuclear power generation is high. Second, the utility hires contractors primarily to avoid employer responsibilities. If we assume that the radiation doses received by radiation workers indicate the lack of occupational safety, it may be effective for the regulator to motivate plant operators to replace contract workers with those they can direct and order. This may be achieved by (1) making the utility smaller, (2) decreasing the dependence on nuclear power, (3) increasing the cost of using contract workers, and (4) imposing penalties for running old nuclear plants.

5. Conclusions

When asymmetry of safety-related information occurs between on-site contractors and the host company, the level of safety training is assumed to be less than the regulator's requirements because it is more difficult for the regulator to verify the actions of many small contractors than to verify that of one utility company. We investigated the laws and regulations governing Japan's nuclear power industry, which hires a sizable number of on-site contract workers and has high safety training costs. We discovered several incentives for hiring contract workers to increase profits, a primary motivation being that hiring contract workers allows the host plant to circumvent legal responsibility for safety training. Thus, to minimize compromising safety conditions, it is essential that companies increase the ratio of employees and temporary agency workers to contract workers as much as possible.

References

[1] **Abraham, Katharine G., and Susan K. Taylor.** 1996. "Firms' Use of Outside Contractors: Theory and Evidence," *Journal of Labor Economics*, 14 (3): 394–424.

[2] **Amuedo-Dorantes, Catalina.** 2002. "Work Safety in the Context of Temporary Employment: The Spanish Experience," *Industrial and Labor Relations Review*, 55 (2): 262–285.

[3] **Amemiya, Takeshi.** 1985. *Advanced Econometrics*. Cambridge: Harvard University Press.

[4] **Anayama, Teizo.** 2005. *Denryoku Sangyo no Keizaigaku (Economics of Electricity Industry)*. Tokyo: NTT Shuppan (in Japanese).

[5] **Cabinet Office, Government of Japan.** 2009. *National Accounts for 2009*. `http://www.esri.cao.go.jp/en/sna/data/kakuhou/files/2009/tables/21fcm3d_jp.xls` (accessed December 13, 2012).

[6] **Garen, John.** 2006. "Use of Employees and Alternative Work Arrangements in the United States: A Law, Economics, and Organizations Perspective," *Labour Economics*, 13: 107–141.

[7] **Grossman, Sanford. J., and Oliver D. Hart.** 1986. "The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration," *Journal of Political Economy*, 94 (4): 691–719.

[8] **Guadalupe, Maria.** 2003. "The Hidden Costs of Fixed Term Contracts: The Impact on Work Accidents," *Labour Economics*, 10: 339–357.

[9] **Hamaguchi, Keiichiro.** 2004. *Rodoho Seisaku* (*Law and Policy on Labor*). Kyoto: Minerva Shobo (in Japanese).

[10] **Hernanz, Virginia, and Luis Toharia.** 2006. "Do Temporary Contracts Increase Work Accidents? A Microeconometric Comparison between Italy and Spain," *Labour*, 20 (3): 475–504.

[11] **Japan Nuclear Energy Safety Organization.** 1984–2010. *Operational Status of Nuclear Facilities in Japan* (in Japanese).

[12] **Klein, Benjamin, Robert Crawford, and Armen A. Alchian.** 1978. "Vertical Integration, Appropriate Rents, and the Competitive Contracting Process," *Journal of Law and Economics*, 21 (2): 297–326.

[13] **Kochan, Thomas A., Michal Smith, Jhon C. Wells, and James B. Rebitzer.** 1992. "Managing the Safety of Contingent Workers: A Study of Contract Workers in the Petrochemical Industry," MIT Sloan School of Management Working Paper 3442-92-BPS.

[14] **Laffont, Jean-Jacques, and David Martimort.** 2002. *The Theory of Incentives: The Principal-Agent Model*. Princeton: Princeton University Press.

[15] **Ministry of Health, Labour and Welfare.** 2005. The Basic Survey on Industrial Safety and Health (in Japanese).

[16] **Japan Nuclear Technology Institute.** *Nuclear Information Archives*. `http://www.nucia.jp` (accessed December 22, 2010).

[17] **OECD**. *OECD Indicators of Employment Protection*. `http://www.oecd.org/employment/protection` (accessed April 26, 2010).

[18] **Rebitzer, James B.** 1995. "Job Safety and Contract Workers in the Petrochemical Industry," *Industrial Relations*, 34 (1): 40–57.

[19] **Rothschild, Michael., and Joseph E. Stiglitz.** 1976. "Equilibrium in Competitive Insurance Markets: An Essay on the Economics of Imperfect Information," *The Quarterly Journal of Economics*, 90 (4): 629–649.

[20] **Shimizu, Shuji.** 2002. "Paburikku Akuseputansu no Seiji Shakairon (2) (On the Public Acceptance of Nuclear Power Facilities (2))," *The Shogaku Ronshu (Journal of Commerce, Economics and Economic History)*, 70 (4): 143–160 (in Japanese).

[21] **Shirai, Kunihiko.** 2007. "Gyomu Ukeoi to Rodo Mondai (Contract Job and Labor Problem)," Nihon Rodo Nenkan (The Labour Year Book of Japan), Ohara Shakai Mondai Kenkyujo, 77 (in Japanese).

[22] **Sugeno, Kazuo.** 1992. *Japanese Labor Law*. Seattle: University of Washington Press.

[23] **Uezu, Yasuhiro, Takeshi Ouchi, Kenji Shirai,and Yoshibumi Terakado.** 2007. "Nihon Genshiryoku Kenkyuu Kaihatsu Kikou ni okeru Roudou Saigai Toukei (The Industrial Accident Statistics in JAEA)," Paper presented at Atomic Energy Society of Japan 2007 Fall Meeting of AESJ, Kitakyushu International Conference Center, Fukuoka, Japan.

[24] **Wells, John C., Thomas A. Kochan, and Michal Smith.** 1991. *Managing Workplace Safety and Health: The Case of Contract Labor in the U.S. Petrochemical Industry*. 3 vols. The John Gray Institute, Lamer University.

[25] **Williamson, Oliver E.** 1971. "The Vertical Integration of Production: Market Failure Consideration," *American Economic Review*, **61** (1), 112–123.