Safety and Health of Contract Workers in Japan's Nuclear Utility Industry

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Abstract

We present 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. The models imply that hiring contract workers enables nuclear utilities to implement lower standards of occupational safety and health than those imposed by regulations, and reduce costs by circumventing responsibilities legally imposed on employers. Using measurements of nuclear plant workers' exposure to radiation, we show that occupational safety and health conditions differ among plants governed by the identical regulations.

Keywords: Contract worker, Asymmetric information, Safety and health education, Risk management, Human error.

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1. Introduction

One of Japan's most serious 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 an important and critical one and serious issue. This paper 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—employees of contracting firms who are located as per the specifications of the host plant—is increasing since these workers are similar to the temporary agency workers, although the 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 being examined, because these differences have compromised safety on industrial sites. 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 killing 23 people and injuring 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), the project members, reported results of the 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 U.S., host plants may direct and supervise contract workers,[2] and responsibility for accidents is affixed on the basis of whether the host plant is regarded as the co-employer. Wells et al. (1991) summarized three motives for hiring contractors: reducing compensation costs; the need for workforce flexibility, and the need for 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—i.e., 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 have found that the type of employment contract has little influence if factors such as job descriptions and working conditions are controlled (Amuedo-Dorantes, 2002; Guadalupe, 2003; Hernanz and Toharia, 2006). Although these studies focus on whether the accident or occupational injury rate depends on the type of employment contract, their results suggest that both

[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]Although practiced in the U.S., these activities are prohibited in Japan.

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

Table 1. Number of Reactors Run by Nine Principal Utility Companies in 2010

Tokyo	Chubu	Kansai	Chugoku	Hokuriku	Tohoku	Shikoku	Kyushu	Hokkaido	Total
17	3	11	2	2	4	3	6	3	51

Source: Japan Nuclear Energy Safety Organization, Operational Status of Nuclear Facilities in Japan 2011

accidents and the occupational injury are affected by safety training.

We present a theoretical explanation for differences in safety levels between contract workers and employees, using Japan's nuclear power industry as an example. In nuclear power plants (nuclear plants hereafter), contractors are hired mainly to perform periodic inspections. Each reactor facility must be inspected within 13 months of its previous inspection. Inspection data for the seven nuclear plants at the Kashiwazaki-Kariwa Nuclear Power Station (Tokyo Electric Power Company) from 1998 to 2004 indicate that periodic inspections take 198 days on average.[4] There are customarily multiple reactor facilities in one plant, and therefore the percentage of contract workers is constantly high. There were 43 nuclear reactors in 1994 and 51 reactors in 2010 at 15 nuclear plants. Table 1 shows the number of reactors that Japan's nine principal utility companies operated in 2010.

The number of employees at each nuclear plant is recorded annually in the White Papers on Nuclear Safety of the Nuclear Safety Commission and the Operational Status of Nuclear Facilities in Japan of 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

[4]The table of periodic inspection is available at `http://www.tepco.co.jp/nu/kk-np/data\_lib/index-j.html` (accessed on November 26, 2011).

types of workers, the effects can be great. 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% of employees were exposed to radiation exceeding 5 mSv (millisievert)[5] and 0.02%, were exposed to radiation exceeding 10 mSv. Among contract workers, 4.6% had exposure exceeding 5 mSv and 1.44% 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 their use could disadvantage surety of appropriate occupational safety and health and increase its costs. We also show that radiation exposure is a reliable indicator of occupational safety conditions in nuclear plants. 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. Section 4 provides an empirical study that examines hypotheses about occupational safety and health. Section 5 concludes the paper.

[5]The occupational exposure limit for radiation is 100 mSv over a period of five years and 50 mSv annually. After the nuclear accident at Fukushima on March 11, 2011, the annual exposure figure (50 mSv annually) was temporarily inapplicable to those working in the Fukushima Daiichi nuclear power station until April 30, 2012.

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

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 on the basis of 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 the use of such workers. 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 infringements of their human rights. The term "labor supply" formerly referred to employing people who worked under the direction of others according to a supply contract. Thus, temporary agencies were regarded as example of "labor supply" agencies. This regulation is based on the consideration that forced labor and intermediary exploitation can exist if the host can directly control the working conditions

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

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] Enacted in 1985, the Worker Dispatching Act originally was 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, item 6 of the Employment Security Act).[10] That is, the law has been changed to acknowledge the contractual relationship among 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 the worker dispatching business. On-site contract work had been and is common in the

[8] The ministerial ordinance is an order issued by the relevant ministry under the relevant laws.

[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 web site 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.

construction industry. On-site contracting firms and temporary agencies are similar in that both supply labor to other industries as a business. In 1970, the Safety and Health Subcommittee of the Ministry of Labor was established to address safety and health problems among contract workers. Its 1971 report pointed out that 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, regulation primarily targeted direct employment contracts.[12] The Industrial Safety and Health Act was enacted in 1972 on the basis of this report, according to 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 temporary agency as well as the host plant responsible for the safety and health of temporary agency workers.

In Public Notice No. 37 of 1986, the Ministry of Health, Labor and Welfare distinguished between worker dispatching and on-site contract work.[13] Temporary agency businesses employ the workers that the host directs and orders. In contract work, the supplier employs the worker, and the host does not direct or order that workers; in other words, 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 Labor Office investigates whether the relationship

[12] Shimizu (2002) revealed, on the basis of data supplied by Tokyo Electric Power Company (TEPCO), 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.

[13] The public notice is an instruction issued by the relevant ministry under the relevant law and order.

among suppliers, hosts, and workers is a contract-for-work one, and if necessary makes recommendations. If contract specifications are extremely lax, then substitutable workers must 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.

Abraham and Taylor (1996) noted three incentives for firms to hire contract workers:

(1) The wage rate of employees is higher than that for external workers.[14] 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 workforce or working hours. Japanese employers must satisfy restrictive conditions to justify reducing the number of employees.[15] However, host firms can explain a reduction in the number of contract workers simply as cost reduction. In addition, contracting firms can 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. On the other hand, the scale of these activities in a nuclear plant is large because they are constantly required. Outsourcing may

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

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

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

Shirai (2007) 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, the Worker Dispatching Act in principle prohibits hosts from engaging worker dispatching services continuously for more than three years. 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 hiring employees or contract workers, since in the latter case contractor fees include the cost of the employer's legal obligation. However, many firms every year illegally avoid paying social insurance for their employees,[16] 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. 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. In general, the former law stipulates conditions about facilities and equipments, and the

[16]The social insurance in Japan generally includes five compulsory types of insurance: occupational injury, employment, health, welfare pension, and nursing care insurances.

latter regulates management of compliance and safety training to enhance public safety by preventing radiation-related hazards. Article 7 of 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 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. Laws concerning radiation require utilities to provide operational safety programs and report accidents and irregularities. Regulatory laws specify matters that must be addressed within operational safety programs. If violations of safety protocols occur, utilities may be ordered to suspend reactor operations. The term “risk of an accident” in this paper 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, Labor 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 (Kansai Electric Power Company) on September 8, 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 are appropriate for jobs requiring extensive safety training, although no empirical evaluation has established whether gaps in safety training explain differences between contract workers and employees.

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

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 serious accidents. If workers are insufficiently trained about the risks of operations, they are more likely to adopt shortcuts to reduce their work burdens. For instance, a critical accident at the uranium processing plant at Tokai-mura, Japan, in 1999, 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. But in models involving asymmetric information, the principal must pay information rent to the agent to control accident risk. In the case of a serious 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. The law intends to protect accident victims and promote business by reducing excessive risk of contractors. It also specifies that contractors are not liable for unintentional nuclear damage caused by the operation of reactors. In short, contractors are perfectly protected by limited liability, and utility companies' profits do not depend on involvement of the contractor with respect to serious accidents.[17]

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 due to small difficulties, and damage to the firm's reputation by incidents. When minor incidents occur, penalties to utilities that do not engage contracting firms can be larger than those for utilities that do, because the utility's reputation is damaged more than the contracting firm's by these minor incidents.[18] Damage to a utility's reputation of safety 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.

3.2. Problem of 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 in that the latter voluntarily choose 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 level if the socially optimal level required by the regulator exceeds what is privately optimal. In this case, the utility offers the contracting firm fees that are lower than its cost of conducting necessary safety

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

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

training.

For simplicity, let us consider a case in which a utility does not hire contract workers, employees perform all 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 A and S are states with and without an accident, respectively. Expected profits for Strategies T and N are written as

$$\Pi_T = (1 - p_T)R_S + p_T R_A - C, \quad \text{and} \tag{1}$$

$$\Pi_N = (1 - p_N)R_S + p_N R_A, \tag{2}$$

respectively, where p_T and p_N ($p_T < p_N$) are probabilities an accident will occur, R_S and R_A ($R_S > R_A$) are revenues, and C is the cost of safety training. The utility will choose Strategy T when $\Pi_T \geq \Pi_N$; or, in other terms, $(p_N - p_T)(R_S - R_A) - C \geq 0$. Strategy N becomes optimal when the effect of safety training, $(p_N - p_T)$, is small, the loss by accident, $(R_S - R_A)$, is small, and the cost of safety training, C, is large. Serious accidents are rare at nuclear plants, but minor difficulties are frequent. Table 2 shows numbers for reported incidents at nuclear plants run by Japan's principal utility companies between April 1994 and March 2006. Data are from the web site of the Nuclear Information Archives (NUCIA, Japan Nuclear Technology Institute; `http://www.nucia.jp`). 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 fatigue, corrosion, and their associated consequences. None was attributed to deviations in workers' practices. Periodic inspections stop a reactor about 198 days per 13 months.

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

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

Compared to this number, the contracting firm's cost of safety training had no major impact on the operations of nuclear plants. Therefore, we may conclude that $(p_T - p_N)$ and $(R_S - R_A)$ may be ignored in the utility company's decision.

This is also explained as follows. Where the regulator and the utility is the principal and the agent, respectively, the former can motivate the latter to assure a level of worker safety training by penalizing the agent 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 10 companies have nuclear plants, whereas there are thousands of contracting firms—and it is difficult for the regulator to inspect that many, 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. Models

Before testing the main hypothesis, we ascertain whether radiation exposure credibly represents the level of workplace safety. In 2002, it was revealed that Japanese utilities had falsified self-inspection records, and risk management practices at nuclear plants were subsequently revised. Therefore, we assume that the level of safety in nuclear plants improved following this scandal. In the first model, we examine this hypothesis using 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_{it} be the probability of a worker being exposed to radiation ($>$ 5mSv). A logit model of the probability of exposure is represented as

$$P_{it} = \Lambda({x_{it}}'\beta), \tag{3}$$

for each of n_{it} workers, where x_{it} is a vector of the explanatory variables, β is the vector of parameters, and Λ is the cumulative distribution function of the logistic distribution (e.g., Amemiya, 1985, Chapter 9). We expected that P_{it} would decrease after the 2002 falsification scandal, due to improvements in risk management. If this is the case, the assumption is supported that radiation exposure can be a proxy for occupational safety. The structural change can be tested by including a dummy variable for the years following the scandal ($t > 2002$). 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 (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 employers 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 cost of asymmetric information. 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 than smaller firms.

4.2. Data

The numbers for radiation workers are from the White Paper on Nuclear Safety for the fiscal years 1994–1998, 2000, and 2002–2005. 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 fiscal year appear in Figure 1. The proportion of employees trends upward, while the number of workers per reactor trends downward. The rate of exposed (> 5mSv) workers trends upward for employees, contract workers, and all workers until 2003. It is necessary to distinguish the downward effect of technical progress and the upward effect of plant aging. Financial data were obtained from annual reports of Japan's nine utilities that operate nuclear plants.

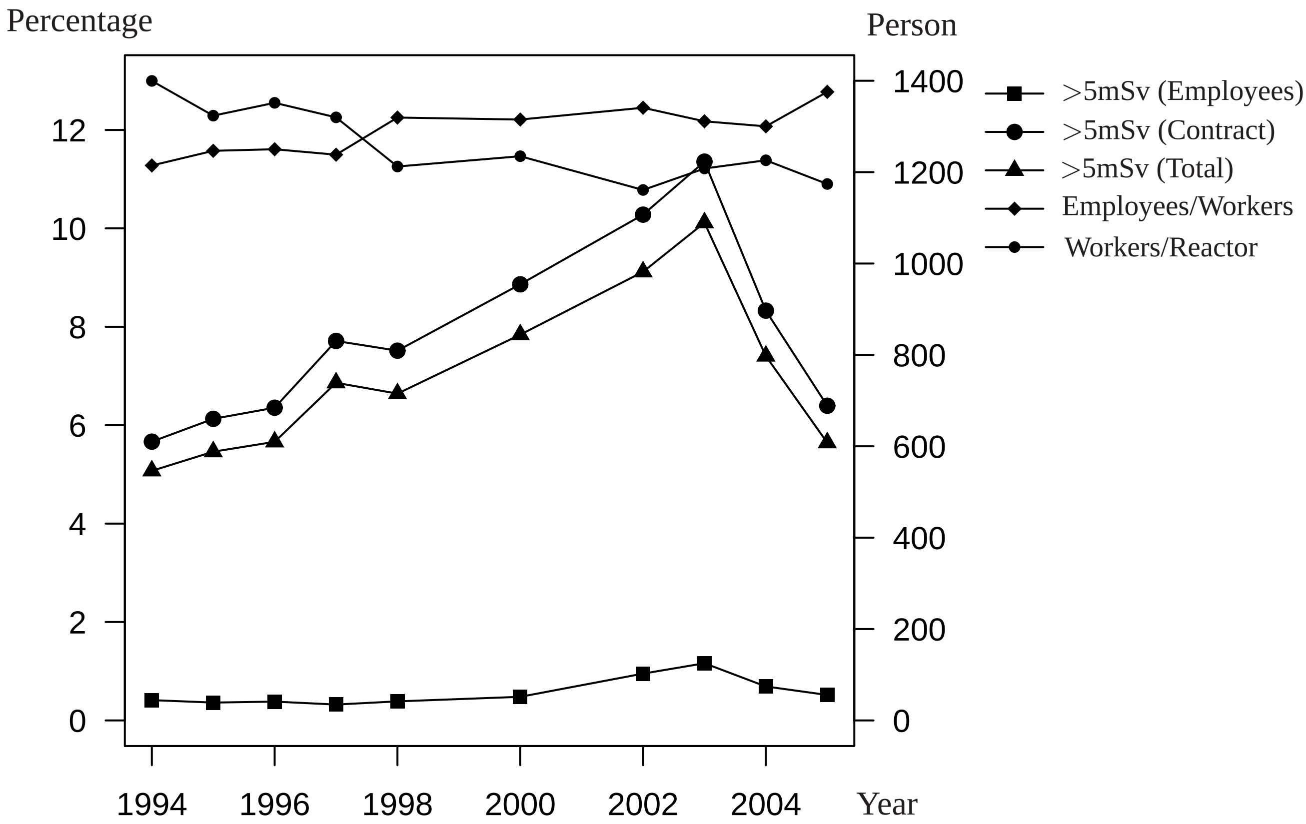

Figure 1. Number of workers per reactor, percentages of employees, percentages of workers exposed to radiation greater than 5 mSv in nuclear plants hiring employees and contract workers (annually).

The explanatory variables are defined as follows:

$$
\begin{aligned}
\text{F\_SIZE}_i &: \text{Total size of company's businesses} \\
&:= \text{Average of total ordinary revenues}, \\
\text{AGE1}_{it} &: \text{Degree of reactor aging} \\
&:= \Big(\sum_{\text{reactors}} \text{Accumulated years from beginning of operation} \\
&\quad \times \text{Generating capacity of the reactor}\Big) \\
&\quad /\Big(\sum_{\text{reactors}} \text{Generating capacity of the reactor}\Big), \\
\text{AGE2}_{it} &: \text{Degree of reactor aging (squared)} \\
&:= \Big(\sum_{\text{reactors}} (\text{Accumulated years from beginning of operation})^2 \\
&\quad \times \text{Generating capacity of the reactor}\Big) \\
&\quad /\Big(\sum_{\text{reactors}} \text{Generating capacity of the reactor}\Big), \\
\text{N\_RATE}_{it} &: \text{Dependence on nuclear power} \\
&:= \text{Nuclear electricity output}/\text{Electricity sales volume}, \\
\text{FEE}_{it} &: \text{Contractor fee per capita} \\
&:= (\text{Repair expenses for nuclear} \\
&\quad + \text{Outsourcing expenses for nuclear branch}) \\
&\quad /\text{Number of contract workers}, \\
\text{TREND} &: \text{Time trend (fiscal year 1994} = 0), \\
\text{AFTER\_F}_{it} &:= 1 \text{ if } t > 2002,\ 0 \text{ otherwise}, \\
\text{C\_DUMMY}_{it} &:= 1 \text{ if the concerned worker is a contract worker},\ 0 \text{ otherwise}.
\end{aligned}
$$

The variables are chosen on the basis of 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_{it} if government regulations require a level of safety management that exceeds the plant's optimal level. Otherwise, it is expected to be negatively correlated due to the economies of scale. In the second model, this variable is 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) The length of time after the plant commences operation is expected to be positively correlated with P_{it}, since old plants generally tend to have more accidents.

(3) 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_{it}.

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

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

(6) The post-2002 dummy should correlate negatively with P_{it} if measures to improve safety were effective after the falsifications scandal.

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

Table 3 summarizes the data. The number of radiation workers is almost proportional to that of reactors: 10–20% 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.

4.3. Results of Estimation

Results of our estimations appear in Table 4. The two columns labeled 1 and 2 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 second column (Model 2) is the results of the worker type choice model aimed at revealing why utilities use contract workers. Standard errors are in parentheses.

If Model 1 is regarded as a model of occupational safety, the signs of the coefficients of AGE1, N_RATE, TREND, AFTER_F and C_DUMMY should be positive, negative, negative, negative, and positive, respectively. The estimates show that the signs for all variables except TREND are as expected at reasonable significance levels. The coefficient of AFTER_F was -0.287 and significantly negative, as expected. This indicates that safety improved following the falsification scandal. It also justifies our use of radiation exposure as a proxy for safety conditions.

The coefficient of F_SIZE was 0.149. This might imply that larger utilities generally choose a lower level of safety training for all workers. Many regulations imposed on Japan's nuclear power industry are intended to maintain the safety of both plant workers and residents around nuclear facilities. Compliance costs might have identical effects on risk management and safety conditions at nuclear plants among all utilities, since they would pay the costs that barely meet regulations at most. According to the imperfect information model in Section 3, utilities can control this cost by hiring contract workers, and the selected safety level can differ among companies since each chooses a level that

Table 3. Summary of Variables for Nuclear Power Sections of Utility Companies 1994–2005

Utility Company		Number of Workers	Rate of Employees (%)	Exposed (Employees) (%)	Exposed (Contract) (%)	Total Revenue (F_SIZE)	AGE1	AGE2	N_RATE	FEE
Tokyo	Mean	23536	10.1	0.9	9.6	5.01	14.1	265.8	37.6	6.7
	S.D.	897	0.9	0.5	2.6	0.17	3.9	112.6	9.7	1.1
	Min.	21855	9.2	0.5	5.6	4.76	8.9	128.8	14.5	5.0
	Max.	24976	11.7	2.1	14.6	5.27	19.6	440.5	47.2	8.5
Chubu	Mean	5376	13.4	1.0	10.4	2.11	10.8	202.6	19.7	8.4
	S.D.	511	1.2	0.8	4.8	0.06	2.9	86.2	5.0	1.4
	Min.	4511	11.7	0.0	2.5	2.03	6.8	97.4	8.7	7.1
	Max.	6039	15.7	3.0	18.4	2.22	15.1	336.0	24.2	11.8
Kansai	Mean	11893	12.5	0.4	7.5	2.51	18.5	406.5	48.6	9.8
	S.D.	1398	1.0	0.3	1.1	0.07	4.0	148.1	4.6	0.9
	Min.	10058	11.4	0.1	6.1	2.39	13.1	221.3	41.4	8.3
	Max.	13483	14.3	1.1	10.0	2.61	24.1	631.7	54.6	11.1
Chugoku	Mean	2662	13.5	0.4	7.9	0.99	16.9	350.3	16.7	7.0
	S.D.	486	3.3	0.6	6.3	0.03	4.0	135.0	2.9	1.1
	Min.	1826	10.5	0.0	1.9	0.92	11.5	182.9	12.4	5.1
	Max.	3203	19.3	2.1	22.6	1.04	22.5	556.9	20.7	8.5
Hokuriku	Mean	1993	16.0	0.2	2.5	0.48	2.0	18.2	16.4	5.3
	S.D.	606	8.0	0.3	3.5	0.02	1.1	16.5	5.4	3.5
	Min.	912	10.6	0.0	0.0	0.44	0.5	0.8	6.5	1.7
	Max.	2770	31.9	0.7	11.5	0.51	3.6	45.7	28.5	12.6
Tohoku	Mean	3163	14.0	0.0	2.7	1.50	4.2	55.3	15.2	6.3
	S.D.	755	1.8	0.0	3.2	0.05	2.0	32.7	3.9	1.2
	Min.	2265	11.6	0.0	0.0	1.43	1.7	18.8	6.7	4.6
	Max.	4542	17.0	0.0	9.3	1.59	7.3	109.5	21.2	8.1
Shikoku	Mean	2781	14.2	0.0	5.4	0.53	14.1	270.6	58.5	10.3
	S.D.	275	2.8	0.1	2.9	0.02	4.0	113.0	4.6	1.5
	Min.	2391	9.0	0.0	1.1	0.51	8.7	133.5	50.4	7.9
	Max.	3197	16.8	0.2	10.3	0.56	19.7	445.7	66.1	12.0
Kyushu	Mean	5468	13.3	0.3	5.5	1.38	12.2	212.2	49.0	10.4
	S.D.	367	1.1	0.3	2.2	0.04	3.8	97.4	4.5	0.9
	Min.	4847	11.7	0.0	2.7	1.32	7.2	95.7	41.4	8.3
	Max.	6181	15.2	0.7	9.7	1.42	17.7	365.0	54.3	11.7
Hokkaido	Mean	1897	16.6	0.0	1.1	0.53	10.3	120.5	31.9	9.2
	S.D.	223	2.6	0.0	1.0	0.02	4.0	83.0	4.0	1.4
	Min.	1547	13.3	0.0	0.1	0.51	4.9	24.6	27.0	7.1
	Max.	2275	21.0	0.0	3.1	0.55	15.9	253.0	38.8	11.4

Exposed (Employees): proportion of exposed workers ($>$ 5mSv) among utilities' employees;
Exposed (Contract): proportion of exposed workers ($>$ 5mSv) among contract workers;
Total revenue: index of firm size (¥trillion); AGE1: degree of reactor aging;
N_RATE: dependence on nuclear power (%); FEE: contractor fee (¥million / person)
Source: White Paper on Nuclear Safety (1994–1998, 2000 and 2002–2005)

Table 4. Analyses of Radiation Exposure and Worker Type 1994–2005

Model	(1)	(2)
Constant	-7.19 ***	1.38×10^{-1} ***
	(7.80×10^{-2})	(3.31×10^{-2})
F_SIZE	1.49×10^{-1} ***	-8.65×10^{-3} ***
	(4.28×10^{-3})	(3.11×10^{-3})
AGE1	2.28×10^{-1} ***	-2.14×10^{-3}
	(9.18×10^{-3})	(5.40×10^{-3})
AGE2	-4.99×10^{-3} ***	-9.82×10^{-8}
	(2.89×10^{-4})	(1.76×10^{-4})
N_RATE	-1.43 ***	-7.44×10^{-2} **
	(5.44×10^{-2})	(3.79×10^{-2})
FEE	2.65×10^{-2} ***	8.27×10^{-3} ***
	(4.36×10^{-3})	(2.96×10^{-3})
TREND	2.72×10^{-3}	5.05×10^{-3} **
	(2.92×10^{-3})	(2.15×10^{-3})
AFTER_F	-2.87×10^{-1} ***	-2.66×10^{-2} *
	(1.99×10^{-2})	(1.57×10^{-2})
C_DUMMY	2.68 ***	
	(5.05×10^{-2})	

(1): Logit of the exposure probability

(2): Odds of the proportion of employees

***, **, and * are significant at 1%, 5%, and 10% levels, respectively.

Standard errors are in parentheses.

maximizes profit. Alternatively, we can suggest another hypothesis. Contract workers primarily perform maintenance and inspection jobs, where risk of radiation exposure is higher. Periodic inspections occur about one year after the previous inspection and take three or four months for each reactor facility. Therefore, it is likely that a specific cohort of workers performs the same jobs cyclically at multiple facilities if the utility operates many reactors. As a result, the percentage of workers having higher exposure to radiation increases as the size of the utility increases. This paper does not examine these hypotheses further.

The coefficients of AGE1 and AGE2 are 0.228 and -0.00499, respectively. This indicates that the aging of nuclear plants increases the probability of exposure and that the marginal increase in probability will decline until aging exceeds a certain threshold. For example, if a utility operates only one nuclear reactor, the probability will increase for 19 years.

The coefficient of N_RATE is -1.43, 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, they focus on avoiding accidents 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, the risk premium for the nuclear power generation is increased.

The coefficient of FEE is 0.0265, indicating that the compensating wage differentials hypothesis applies. Kniesner and Leeth (1991) found that the premium payment for the risk of occupational injury was very small for Japanese firms. Our result does not support their finding. Kniesner and Leeth explained their result by pointing out that an internal labor market within a group of companies was common and that inter-firm mobility of workers was low in Japan. However, since the proportion of contract jobs is large for nuclear utilities, the labor market structure may differ in the nuclear industry. The coefficient of TREND is not significant, indicating there is no evidence that technical progress reduces the probability of exposure when other variables are controlled. The coefficient of C_DUMMY is 2.68, 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 -0.00865. As mentioned, the negative correlation with $r_{it}^{E}/(1-r_{it}^{E})$ indicates that the utility hires contract workers to avoid employer responsibilities.

The coefficient of N_RATE is -0.0744. This suggests that nuclear plants demand more contract workers than other types of power plants. If utilities recognize 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 0.00827, a positive value. This is natural, as it indicates that employees and contract workers are substitutes.

According to the two models, we obtained two results. First, the level of occupational safety in nuclear plants is indicated by the level of workers' exposure to radiation. Second, the host firm (the utility) hires contractors primarily to avoid employer responsibilities.

5. Conclusions

When asymmetry of safety-related information occurs between on-site contractors and companies, an information rent for ensuring the level of safety training for contract workers could arise. We investigated the laws and regulations governing Japan's nuclear power industry, which hires sizable numbers of on-site contract workers and for which safety training costs are high. We discovered several incentives to 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. 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. Another important factor in securing safer working environments is improving the information flow between contracting agencies and host plants about safety training, direction and supervision, and occupational injuries of contract workers.

Factor analyses indicated that occupational safety conditions differ among nuclear plant operators, even though identical regulations are imposed. Results also indicated that higher radiation exposure reflects lower occupational safety and health conditions. Accordingly, replacing contract workers with employees may increase social welfare by decreasing the risk of huge losses incurred due to accidents. We are not able to evaluate this relationship because data about worker characteristics, jobs, and plants are unavailable.

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