The year of the cat: taxing nuclear risk with the help of capital markets

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Jakob Eberl

Darko Jus

Center for Economic Studies
University of Munich

Address: Schackstr. 4, D-80539 Munich
Phone: +49 (0) 89 21803105
Fax: +49 (0) 89 218017845
Email: jakob.eberl@lmu.de

Center for Economic Studies
University of Munich

Address: Schackstr. 4, D-80539 Munich
Phone: +49 (0) 89 21803104
Fax: +49 (0) 89 218017845
Email: darko.jus@lrz.uni-muenchen.de

ABSTRACT

This paper proposes new regulation for nuclear power reactors aimed at increasing their safety. We begin by describing how limited liability leads to risk-loving behaviour in nuclear power companies and unsafe nuclear power reactors. By reviewing current regulatory regimes, we show that this issue is not being sufficiently addressed today. Therefore, we evaluate five regulatory instruments: (1) safety regulation, (2) minimum equity requirements, (3) mandatory insurance, (4) risk-sharing pools, and (5) catastrophe bonds. We conclude that any of these instruments either cannot be recommended in its pure form or is infeasible in reality. We therefore propose a new approach that, in its core, consists of a two-stage procedure. In the first stage, capital markets assess the risk stemming from each nuclear reactor via catastrophe bonds. In the second step, the regulator uses this private risk assessment and intervenes by charging an actuarially fair premium in the form of a Pigouvian risk tax. Society ultimately acts as an explicit insurer for nuclear risk and is, on average, fairly compensated for the risk it is taking over.

KEYWORDS: nuclear risk-taking, limited liability, catastrophe bonds
1 Introduction

According to the Vietnamese zodiac, it was the year of the cat when in March 2011 the Fukushima catastrophe occurred. While this was pure coincidence, the need for improved regulation of the nuclear industry has never been greater and catastrophe (cat) bonds could become a cornerstone of it, as we argue in this paper.

The Three Mile Island, Chernobyl, and Fukushima catastrophes are terrifying events in the history of civilian nuclear power use, which goes back to the 1950s. The probability of a severe accident occurring at a nuclear power plant on a randomly chosen day is microscopically small, yet, many people are afraid of this risk. Nuclear power is still being used after those catastrophes because energy is essential for the functioning of modern societies and an alternative way of generating a continuous supply of energy using other climate-friendly technologies at reasonable costs has not yet been found. It is important, however, its risks are properly addressed as long as a society decides to use nuclear power.

Many countries around the world are currently expanding their civilian nuclear programs. The list of countries with the most nuclear power plants under construction is headed by China, Russia and India, but plants are also currently being built in the European Union. The fact that nuclear fission will remain an important source of energy in the future is also the content of the Energy Roadmap 2050, published by the European Commission (EC) in December 2011. It emphasises the current and future role of nuclear energy as an ‘important part of Europe’s power generation mix’ and considers it to be ‘needed to provide a significant contribution in the energy transformation process’ (see EC, 2011). Thus, despite a general reassessment of nuclear risk after the Fukushima catastrophe, nuclear power is likely to become or remain a significant determinant of many countries’ electricity supply. On the downside, the Fukushima accident, with only clean-up costs that could reach or exceed
JPY 20 trillion over the next ten years (cf. JCER, 2011), has shown how strongly a society can be affected by the use of nuclear power while also sensitising people to the reality that many nuclear reactors may be carrying a substantial risk.

We argue in this paper that the problem at heart is the existence of *de facto* (through the amount of equity capital) or *de jure* (by law) limited liability of nuclear power companies (NPCs). The basic mechanism is the fact that an NPC cannot lose more than the legally defined liability capital or, in the worst case, its equity capital, even if the damage of a nuclear accident is much higher. This reduces the incentive to invest in costly nuclear safety and leads to an inefficient safety level in nuclear reactors. For example, the Tokyo Electric Power Company (TEPCO) reported equity capital in the amount of JPY 2.47 trillion for 2010 (see TEPCO, 2011). This does not seem small at first glance; however, this amount only constitutes a small proportion of the actual costs of the Fukushima catastrophe, the remainder of which cannot be borne by TEPCO and must therefore eventually be absorbed by Japanese society. Similarly, the liability of other NPCs around the world is, in the case of catastrophic accidents, limited *de jure* or *de facto* (see Tab. 1 for a brief overview and Section 3 for a more detailed discussion).

Tab. 1: *De facto vs. de jure* limited liability, selected countries/NPCs

<table>
<thead>
<tr>
<th>Selection of countries with <em>de jure</em> limited liability&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Countries with <em>de facto</em> limited liability&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>China RMB 300 million</td>
<td>E.ON EUR 39.6 billion</td>
</tr>
<tr>
<td>Czech Republic CZK 8 billion</td>
<td>RWE EUR 9.9 billion</td>
</tr>
<tr>
<td>France EUR 91 million</td>
<td>EnBW EUR 6.1 billion</td>
</tr>
<tr>
<td>India INR 5 billion</td>
<td>Vattenfall SEK 138.9 billion</td>
</tr>
<tr>
<td>United Kingdom GBP 140 million</td>
<td>Japan TEPCO JPY 2.47 trillion&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>United States USD 375 million</td>
<td>Switzerland Axpo CHF 7.6 billion</td>
</tr>
</tbody>
</table>

<sup>a</sup> right column: *de jure* national liability limitation; <sup>b</sup> right column: NPCs’ equity capital in 2011; <sup>c</sup> as of March 2010
One of the original goals of nuclear power liability regulation was to protect NPCs against potentially ruinous claims by setting a limit to their liability. In this way, regulators increased the profitability of the industry and contributed to its development. Currently, the countries using nuclear power can be broken down into two groups. The first group of countries – Germany, Japan, and Switzerland – do not limit the NPCs’ liability by law; thus, NPCs enjoy a *de facto* limited liability. The second group, comprising all other countries, impose strong *de jure* liability limitations.

A body of literature has analysed how limited liability affects individuals’ decision making, generally finding that it induces a distortion towards risk-loving behaviour (see, for example, Sinn, 1983; Shavell, 1986). The literature on NPCs’ risk choice similarly emphasises that it might be too excessive owing to limited liability (see Tyran and Zweifel, 1993; Strand, 1994; Trebilcock and Winter, 1997; van’t Veld and Hutchinson, 2009, who also provide a review of other related literature). Further literature discusses both conventional and innovative remedies for overcoming this problem (see, for example, Tyran and Zweifel, 1993; Trebilcock and Winter, 1997; Radetzki and Radetzki, 2000; Faure, 2004; Cummins and Weiss, 2009). Particularly closely related to our work are Tyran and Zweifel (1993) and Radetzki and Radetzki (2000), who elaborate on the possibility of using capital markets to deal with limited liability and cover the potential damages from nuclear accidents.

We contribute to this literature in three ways: Firstly, we explain how limited liability affects the risk-taking behaviour of NPCs and illustrate its relevance by reviewing current regulation. Secondly, we consider various regulatory instruments and evaluate their ability to set the desired incentives such that NPCs choose the optimal level of risk. We conclude that any of them either cannot be recommended in its pure form or is infeasible in reality. Thirdly, we propose a new approach and emphasise its advantages compared with other instruments. The core of our proposal consists of a
two-stage approach, in the first of which capital markets evaluate the risk stemming from each reactor via catastrophe bonds; in the second step, the regulator uses this private risk assessment and intervenes by charging an actuarially fair premium, thereby (under ideal conditions) inducing the optimal level of risk-taking. Society then acts as an explicit insurer for nuclear risk but is, on average, fairly compensated. While we are aware that our proposal faces a couple of difficulties when applied in a world that is not ideal, we discuss these issues and explain how their impact can be reduced.

The remainder of this paper is structured as follows: in Section 2, we outline an aspect of the theory of limited liability that is important for our argument and define the negative externality stemming from excessive risk-taking. In Section 3, nuclear power liability regulation around the world is briefly summarised, serving as a framework within which to evaluate several regulatory instruments on their ability to internalise excessive risk-taking in the nuclear industry in Section 4. In Section 5, we elaborate a new regulatory proposal, a market-based nuclear risk tax and Section 6 offers some conclusions.

2 Limited liability and risk-taking by an NPC

This section develops a theoretical argument about how the limited liability of NPCs affects their risk-taking behaviour. According to Sinn (1982, 1983), the existence of limited liability generates a kink and hence, a *de facto* convexity in a firm’s profit or an individual’s utility function, as all losses beyond the factual or legal liability are truncated and thus not taken care of. This also applies to both risk-averse and risk-neutral NPCs, which are liable, at most, with their equity capital. As nuclear catastrophes imply extremely large economic losses, and as the equity capital of NPCs is comparatively tiny (see Tab. 1), the nuclear industry is a prime example of firms
operating under limited liability. This is intensified when the liability is *de jure* limited to an even smaller amount.

Because of limited liability, an NPC’s incentives to engage in measures that lower the probability of catastrophic accidents are reduced. The socially inefficient excessive risk-taking resulting from private profit maximisation under limited liability is illustrated in Fig. 1 and explained in the following.²

![Fig. 1: Limited liability and kinked utility, cf. Sinn (1983)](image)

Suppose there are two possible states of the world, one in which ‘no accident’ occurs and a ‘catastrophic accident’-state. The abscissa shows the NPC’s actual wealth \( V \) determined by its equity capital on the one hand and profits it makes on the other hand. The profits are increasing in the NPC’s risk-taking as a lower level of safety is less costly. Naturally, the probability of an accident rises with the risk taken. The ordinate depicts the corresponding utility \( u(V) \). If no accident occurs, the NPC’s wealth is given by \( V \), whereas, in the case of an accident, the NPC is confronted with losses in the amount of \( L \) that reduces its wealth to \( V - L \). If the losses exceed its initial equity, the NPC’s liability is (*de facto*) limited to its amount of equity. According to Shavell (1986), the NPC is in this case ‘judgment proof’. Thus, because of limited liability, the
NPC’s utility function is horizontal for any negative amount of wealth as zero is the lower bound.

To determine the NPC’s risk preference, let us consider its expected wealth $E(V)$ and the corresponding safety equivalent $S(V)$ given the two-point distribution of possible states of the world. If the potential loss $L$ is sufficiently large, the utility function becomes effectively convex, which implies risk-loving behaviour in the sense that the safety equivalent of the NPC’s wealth distribution exceeds its expected wealth. The NPC then chooses a socially excessive risk level by taking into account that a share of the loss would not need to be borne by it, but could be shifted to a third party. The social optimum would be achieved if the NPC were fully liable for any outcome, in which case the full social costs of nuclear power would be internalised.

Two schools of thought, both developed in the twentieth century, could be applied in order to overcome the problem stemming from the existence of a negative externality like the one described here. The first one, the Coasian solution (drawing from Coase, 1960), would argue that defining property rights and letting the involved parties negotiate potential outcomes would solve the problem at hand. The other one, the Pigouvian approach, calls for (stronger) government intervention in the form of setting a price on the activity generating the externality (Pigou, 1920).

Applying the former framework to the nuclear industry, one could interpret a laissez-faire situation as a case in which the property rights for any potential damage are given to the NPC. In this case, the NPC could choose any level of risk without being liable for the consequences. The defining of a liability limit is similar, with the only difference being that property rights for a (small) share of the damage are given to the injured party. One could argue in line with Coase (1960) that negotiations between potential victims and the NPC could result in a Pareto-optimal level of risk-taking. However, this kind of negotiation is hardly practicable since nuclear risk is dispersed
over very many individuals and any attempt to specify private contracts over an efficient risk level would suffer from the public good problem, in addition to other fundamental barriers such as incomplete information. Hence, society is not able to obtain a contractual relationship with the NPC, and the NPC could thus not be forced to pay for a potential damage *ex ante*, whereas *ex post* liability is limited.

Therefore, Coasian irrelevance does not apply, and the risk allocation can be improved only if the government, representing the interest of society, implements measures that increase the liability of the NPC or Pigouvian type of price mechanism on the activity that causes the externality, or both.

3 Liability regulation of the nuclear power industry

A major goal of nuclear liability regulation is to protect NPCs against potentially ruinous claims. In essence, the liability limitation has been justified by the social benefits of nuclear power and has created a tacit acceptance of nuclear risk by the society while also increasing the profitability of the nuclear industry, thereby fostering its development.

In what follows, we sketch the development of nuclear power liability regulation and its current state. We refer to Faure and Vanden Borre (2008) for an extensive analysis of international nuclear liability.

The Price-Anderson Act (cf. US NRC, 2012), passed in the United States in 1957, was the first comprehensive nuclear liability law and has been central to the issue of liability in nuclear accidents. It has repeatedly been renewed (with amendments), the last time in 2005 for another 20 years; the defined amount of an NPC’s liability has increased gradually over time. Today, coverage in the case of accident is provided by the nuclear industry itself on a two-tier basis. On the first layer, all NPCs are strictly and individually liable, being required to purchase USD 375 million of liability
coverage per reactor, provided by a private insurance pool. On the second layer, coverage is supplied by a mutual and solidarity risk-sharing agreement among the NPCs. This risk-sharing pool is funded through retrospective payments in the case of a nuclear accident, which can reach up to USD 112 million per reactor. In total, this two-tier system provides an aggregate sum of USD 12 billion of liability capital.

Liability regulation of the nuclear industry outside the United States is based on two conventions, the Paris Convention (NEA, 1960) and the Vienna Convention (IAEA, 1963), and on individual countries’ national regulation. Whereas the Paris Convention covers European states, countries from all over the world are parties to the Vienna Convention. The national regulation in most of the countries that are party to one of these two conventions usually follows the proposed liability framework, with only few exemptions where the liability of NPCs is considerably higher than demanded by the conventions.

The basic characteristics of the Paris Convention can be summarised as follows: (1) nuclear companies are strictly liable for any third-party damage; thus, their liability is irrespective of own fault;³ (2) liability is fully channelled to the NPCs; thus, only they can be sued; and (3) liability is limited to a pre-defined amount and a specified period of time within which claims can be made. More specifically, liability was originally supposed to be limited to SDR 15 million at most, whereas the minimum was supposed to be SDR 5 million;⁴ however, national legislation was allowed to provide for a higher, but necessarily limited, amount. Finally, (4) the liability has to be covered by mandatory insurance or some other financial security, to be held by the NPCs. The Paris Convention was amended in 1964, 1982 and in 2004. According to the 2004 amendment the minimum liability of nuclear operators is supposed to be raised to 700 million (cf. NEA, 2004, Art. 7). Moreover, the sentence which excluded any liability for damage owing to ‘a grave natural disaster of an exceptional character’
has been taken out (cf. NEA, 1960, and NEA, 2004). It was also the first amendment that has allowed countries that have a *de jure* unlimited liability in place (Germany and Switzerland), to participate, thereby implicitly agreeing to this kind of national liability legislation. The 2004 amendment is, however, not yet in force as until now only Switzerland and Norway have ratified it.

In 1963, the Brussels Convention, supplementing the Paris Convention, introduced that not only the NPC, but also the state in which the nuclear accident occurs is liable; the limit for this was set at SDR 70 million. Moreover, all signatory states agreed to be jointly liable for claims, whereby each state is obliged to supply up to SDR 50 million.

Parallel to the Paris and Brussels conventions, the IAEA’s Vienna Convention of 1963 introduced a regulatory framework signed by 38 countries, including the Russian Federation, Ukraine, the Czech Republic, but also a large number of countries that do not even have a civilian nuclear program. It shares the basic principles of the Paris Convention, with the minimum liability of the NPCs only supposed to be USD 5 million initially. It was amended once in 1997 with the main difference being a seemingly higher minimum liability limit of NPCs in the amount at least of SDR 300 million. However, this may be reduced to SDR 150 million or only SDR 5 million, whereby the lower amounts are allowed if public funds are provided to cover the sum of SDR 300 million (cf. IAEA, 1997, Art. 7).

Following the 1986 nuclear accident at Chernobyl, efforts to clarify the applicability of the two ‘competing’ conventions lead to establishment of a Joint Protocol. According to it, only one of the two conventions shall apply to a nuclear accident, and it shall be that one to which the country is a party within whose territory the nuclear reactor is situated (cf. NEA and IAEA, 1988).
The heterogeneity in national regulation stems from a few countries, which have substantially stricter rules than demanded by the conventions. In Germany, for example, liability legislation far exceeds the requirements of the (amended) Paris Convention. Together with Japan and Switzerland, Germany is one of only three countries with a legally unlimited liability of NPCs. In order to ensure a desired minimum amount of financial security, it requires the amount of EUR 2.5 billion per reactor to be guaranteed by both a nuclear insurance pool and a risk-sharing agreement between the NPCs. In addition to financial security, the European Union provides EUR 300 million in accordance with the Brussels Convention in case of an accident. For any loss exceeding the aggregate amount, the NPCs’ liability is legally unlimited; however, this definition of unlimited liability constitutes only a legal property that cannot actually be sustained. In Switzerland, where NPCs are also de jure unlimitedly liable, they are required to hold financial security in the amount of CHF 1 billion. In France, by contrast, the liability regulation of NPCs is weaker: the liability of the state-owned NPC is de jure limited to an amount of EUR 91 million (projected to increase to EUR 700 million according to the 2004 amendment), which must be insured. This is also the case in the Czech Republic, where the de jure liability limit of CZK 8 billion necessitates insurance.

As they are not party to any international conventions, thus relying on their own arrangements, China, India and Japan have a special position in global nuclear liability legislation. China passed an interim law on nuclear liability in 1986 that contains the basic properties of the international conventions. In 2007, NPCs’ liability limit was increased to RMB 300 million, above which the state is legally liable for up to RMB 800 million. This legal regime is under revision, however. Along with its nuclear expansion, China aims to modify its nuclear energy law (see WNA, 2012a). In 2010, the Indian government passed the so-called Nuclear Liability Act, which brings its
liability regulation broadly in line with international conventions. The act makes NPCs liable for nuclear accidents up to an amount of INR 5 billion (although not exclusively). In Japan, NPCs’ liability is strict, exclusive, and legally unlimited. Furthermore, a financial security in the amount of JPY 120 billion must be provided. In addition, Japan’s 1961 Act on Compensation for Nuclear Damage (cf. NSC of Japan, 1961) allows for an NPC to be relieved of liability in claims resulting from ‘a grave natural disaster of an exceptional character’, the relevance of which came under discussion after the Fukushima catastrophe. Regardless of this paragraph, the catastrophe has provided evidence that the costs of a large-scale nuclear accident can easily exceed the means of an NPC and that society must eventually step in. In this context, the Japanese government decided to provide financial assistance for compensation payments and clean-up costs, for which it demands an annual fee from TEPCO. The main reason for bailing out TEPCO was its essential role in maintaining adequate power supply and the need for ensuring the safety of its other power plants.

According to government estimates, TEPCO will be able to complete its repayments in 10 to 13 years, after which it is supposed to revert to being a fully private company with no government involvement (cf. WNA, 2012b).

The main insight gleaned from studying nuclear liability regulation around the world is that the liability for losses from catastrophic accidents is either *de facto* limited by the NPCs’ equity capital (as in Germany, Switzerland, and Japan) or *de jure* limited by national legislation (as in all other countries). Thus, some countries have chosen to limit NPCs’ liability explicitly while, in other countries, firms by their nature are liable, at most, with their equity capital. In both cases, the consequences of limited liability, as discussed in Section 2, become relevant. Taking this as a cue, the following section critically discusses the regulatory instruments that could be applied by a regulatory authority.
4 Evaluating regulatory instruments

In Section 2, we explained the possibly severe implications of limited liability for NPCs’ risk-taking decisions. Section 3 has shown that current liability regulation does not sufficiently address these problems and that, therefore, nuclear risk might not be properly taken care of. This section reviews various regulatory approaches and evaluates their ability to reduce the NPCs’ incentives to take excessive risks.

4.1 Safety regulation

Recognizing that in theory nuclear reactors are on average not sufficiently safe, several papers propose the setting of safety standards or its joint use with other instruments (see, for example, Shavell, 1984, Kolstad et al., 1990; Schmitz, 2000). The setting of safety standards attempts to improve (or optimise) the level of precaution by defining a large set of measures that have to be implemented or followed by NPCs.

A repeated criticism of command-and-control measures set by a (central) regulatory authority is that this authority might possess only imperfect information and therefore, is unable to define safety regulation properly (see, for instance, Baumol and Oates, 1971; Shavell, 1984). This may hold particularly strongly for the regulation of nuclear power, which by its nature requires an understanding of very complex processes. Trebilcock and Winter (1997) discuss the implications of this kind of complexity for regulation, whereas Bredimas and Nuttall (2008) comprehensively analyse this issue in the context of several countries. Faure and Skogh (1992) also point out that obtaining necessary information is difficult for a regulator; thus, he might eventually depend on information provided by the nuclear industry itself. However, since the industry acts in its own interest, it is likely to provide inaccurate signals; in which case regulation may then become too lax in some respects and too strict in others.
In a very general sense, it is unclear whether a regulator is better able to achieve the proper level of care by setting safety standards or whether (more) market-based instruments, which we propose and discuss later, are more effective. There are, however, various other reasons why the efficient level of care cannot be implemented by safety regulation alone. One reason is that enforcement is not (or only incompletely) guaranteed even when safety regulation is defined by law; see Downing and Watson (1974) for the first enforcement model in the context of environmental policy, and for related work, for instance, Harrington (1988), Kambhu (1989), and Wang et al. (2003). A second reason is that nuclear reactors are unequal and therefore, uniform safety regulation cannot perfectly internalize the externality; it may be too strict for some reactors or processes and too lax for others. Thirdly, as safety regulation concerns also the continual monitoring and reassessment of precautionary measures, it would need to follow technological progress closely, to recognize potentially harmful developments, and to demand the implementation of new standards quickly. However, given that even the ratification of the international conventions has taken many years (often five or more), it must be doubted that a regulator is able to achieve this sufficiently well. Fourthly, regulatory competition between states may arise, resulting in inefficiently low safety standards. If a country demanded higher standards, the NPC might decide to build the reactor in a neighbouring country, which would harm the country with strict standards in several ways. This kind of ‘regulatory race to the bottom’ was discussed in similar contexts by Wilson (1996), Wilson (1999), and Oates (2002). Fifthly, complementing the initial argument in this subsection, the regulator might not have the incentive or the ability to be sufficiently informed in order to elaborate a comprehensive and appropriate regulatory framework. Whereas Poterba and Rueben (1994) investigate wage differentials between public and private sector employees, Borjas (2003) finds, in line with this argument, that the public sector is not able to
attract the most qualified individuals of the labour force as it cannot compete in wages with the private sector. Finally, command-and-control measures are often accused of creating enormous inefficiencies. Taken to the extreme, some scholars, such as Coase (1960), argue that generally direct regulation might not necessarily provide better results than leaving the problem to the market.

While often neglecting the problems discussed in the previous paragraph, safety and liability regulation are sometimes viewed as substitutes for correcting externalities. Consequently, the policy recommendation has been to choose the instrument that causes the least administrative cost for achieving a given goal (see, for example, Calabresi, 1970, and Wittman, 1977, for early discussions of related issues). In practice, however, we observe that both instruments are often used jointly, as, for instance, in nuclear power regulation. Building upon this observation, Shavell (1984), Kolstad et al. (1990), and Schmitz (2000) find that safety regulation and liability rules may complement each other, as their joint use can correct the inefficiencies of using either of the two alone. Shavell (1984) argues that under asymmetric information and enforcement problems, it is better to use both safety and liability regulation. In this case, the regulatory standard can be set lower than if only safety regulation was used. Kolstad et al. (1990) as well as Schmitz (2000) argue similarly, whereby the former paper bases its reasoning on an imperfection in the definition of legal standards. The latter finds that wealth differences between firms do not change this result.

In line with these arguments, we consider safety regulation as an important means of complementing liability regulation, in particular by defining a minimum level of precaution. The setting of safety standards would – if actually enforced – guarantee a lower bound on the precautionary measures of an NPC and provide a basis for the application of other instruments. We elaborate on this potential advantage of safety regulation in Section 5 where we explain under which conditions safety regulation
would be neutral, beneficial or even harmful as a complement to our proposed regulation.

4.2 Minimum equity capital requirements

Defining minimum equity requirements (in equity-to-assets ratio terms) is an instrument commonly used to regulate the problem of limited liability in the banking sector (cf. Sinn, 2003). Although the causes and consequences in the banking sector appear to be very similar, there is one crucial difference in the nuclear industry: whereas a bank’s maximum third-party loss, even under the assumption of perfectly correlated risks, is at maximum defined by the bank’s liabilities (stated in the balance sheet), the potentially catastrophic damages of a large-scale nuclear accident are not represented on an NPC’s balance sheet. Thus, even the requirement to finance all assets with 100 percent liable equity capital would not fully internalise excessive nuclear risk-taking (as long as there are fewer assets than a potential catastrophic damage would be). However, it would lower the extent of the negative externality, since the NPCs’ de facto liability capital would increase.

4.3 Mandatory insurance

Among others, Trebilcock and Winter (1997) suggest mandatory liability insurance to reduce the incentives for excessive risk-taking. This proposal is followed by several countries, where NPCs are required to cover a specified amount with insurance. These amounts are, however, tiny compared with the potential damage of a catastrophe and therefore, the effectiveness in terms of setting incentives for improving safety is very limited. A more effective alternative would be to require the entire potential nuclear damage to be insured, thereby transferring the full risk from the NPC to a third party. It could be argued that this would induce an efficient outcome, as the NPC would have to
pay a premium at least equal to the expected loss. Consequently, the insurer would punish the NPC for excessive risk-taking, which would become costly, and the negative externality would vanish.

However, imposing a full mandatory insurance for potential nuclear accidents has several shortcomings. First of all, the insurability of catastrophic events – characterised by a low occurrence frequency, but highly severe impacts – has generally been questioned by the literature.7 As a prime example, nuclear risk has been repeatedly regarded as non-actuarial (see, for example, Litzenberger et al., 1996; Kunreuther, 1997; Cutler and Zeckhauser, 1999; Radetzki and Radetzki, 2000).

The most important reason why mandatory insurance might not be a reasonable alternative, however, is that the capital resources available to the insurance industry may also well be insufficient to cover the damages of nuclear catastrophes. As insurance companies are in the same way judgment-proof, they might not have the incentives to calculate and charge actuarially correct premiums (even if this were possible), but would also maximise their profits taking into account their own limited liability. In this case, the insurance premiums charged upon the nuclear industry would not reflect the true expected loss. Consequently, the effect of limited liability on risk-taking would only be shifted from one industry to another, without solving the core problem.8

4.4 Mutual risk-sharing pools
In contrast to insurance, where risk is transferred to a third party, the risk in a mutual risk-sharing pool is shared among the parties creating the risk. Here, the NPCs agree on an *ex post* sharing of the costs of a catastrophic accident. Whereas insurance presumes an *ex ante* pricing of nuclear risk, mutual risk-sharing has an advantage: just paying the actual costs eliminates the need to estimate potential damages and probabilities in
advance. The advantages of mutual risk-sharing over insurance have been extensively discussed and emphasised by, among others, Skogh (1999), Faure (2004), Faure and Fiore (2008), and Skogh (2008), who elaborates on the theoretical foundation of mutual risk-sharing. Skogh (1999) explains why it is advisable for parties facing similar risks to share these in common pools. Faure (2004) investigates whether an extended mutual agreement between NPCs could serve as an alternative to the nuclear power liability regulation in place today. Faure and Fiore (2008) discuss possible structures and the potential for a more comprehensive mutual risk-sharing agreement among Europe’s NPCs.

There are several examples of mutual risk-sharing agreements; for instance, in the United States, the Nuclear Electric Insurance Limited (NEIL) and the Overseas NEIL (ONEIL), or in Europe, the European Mutual Association for the Nuclear Industry (EMANI) and the European Liability Insurance for the Nuclear Industry (ELINI). In general, mutual risk-sharing creates a collective responsibility for risk-taking. Making NPCs liable generates incentives to prevent accidents, which implies a reduction of excessive risk-taking. However, risk-sharing pools suffer from the fundamental problem of collective action: the higher the number of NPCs financing the pool, the stronger the tendency towards free-riding, as individual responsibility shrinks and peer-monitoring becomes more costly. Moreover, the effectiveness of this kind of regulation diminishes as an NPC’s share of the pool declines.

4.5 Catastrophe bonds

Catastrophe (cat) bonds represent one way to spread the risk of potentially large losses via financial instruments (that is, via capital markets). A cat bond offers investors a return above the risk-free rate when a specified catastrophic event does not occur, but requires the sacrifice of interest or principal otherwise. The general idea of cat bonds is
explained by Cummins and Weiss (2009), who also give an overview of the relevant literature. So far, cat bonds have generally been employed by insurers as an alternative to traditional re-insurance and by re-insurers, usually to atomise the risk of natural catastrophes such as earthquakes or hurricanes (see Evans, 2011; for a comparison between cat bonds and re-insurance, see Gibson et al., 2007; Cummins, 2012). Mexico was the first sovereign to offer cat bonds, thereby protecting itself against the risk of natural catastrophes (see, for example, Cardenas et al., 2007; Michel-Kerjan et al., 2011). An overview of the development and current state of cat bond markets can be found in Cummins (2012) and Swiss Re (2012). It can be clearly seen that issuance volumes declined sharply in 2008 owing to the financial crisis and have still not fully recovered. In 2011, they reached a volume of USD 5 billion.

The idea to employ cat bonds for not only natural catastrophes, but also nuclear accidents was discussed by Tyran and Zweifel (1993). The paper gives a description of how to internalise environmental risks such as potential nuclear catastrophes via capital markets. They observe that NPCs could emit cat bonds by which nuclear risk is spread among a large number of investors. The principal received for each cat bond issued is supposed to be placed in risk-free assets, for example, in certain treasury bonds. The spread between the cat bond interest and the interest on a risk-free bond represents the market assessment of the risk of a nuclear accident, if this is specified as the trigger for the cat bonds’ default. Hence, as nuclear risk is priced by capital markets, risk-taking becomes costly for the NPCs. Consequently, NPCs taking excessive risk may either revise their strategy to reduce the premiums to be paid on cat bonds or even leave the market if this business becomes too costly for them. Another advantage of catastrophe bonds is that risks can be diversified internationally, reducing the strong impact on the economy where the accident occurs. Tyran and Zweifel (1993) argue that investors
would have an incentive to be well-informed and that they would estimate the risk correctly on average.

Leaving for the moment some well-known problems of cat bonds (such as high transactions costs) aside, the main issue in the case of nuclear power is that NPCs would not voluntarily emit cat bonds. Paying a premium on cat bonds would imply additional costs and undermine the benefits of limited liability. Thus, the regulatory authority would have to stipulate their emission. Although the global cat bond market is currently relatively small, one could argue that if the supply of cat bonds was made perfectly inelastic by regulation, it would only be a matter of the price of the cat bonds for the demand to emerge.

Concerning the externality from limited liability, a cat bond would achieve full effectiveness on risk-taking if any potential damage would need to be covered for every nuclear reactor. To give an example, suppose that – given the currently estimated damages of the Fukushima accident – the regulatory authority could demand an emission volume of USD 200 billion per reactor. This would likely outbalance any reasonable scope of the cat bond market given that there are more than 400 nuclear reactors operating worldwide and therefore, an amount in excess of USD 80 trillion would need to be invested in cat bonds. For the purpose of comparison, Fig. 2 depicts the total global financial stock, measured as the sum of debt and equity outstanding, which constituted USD 212 trillion in 2010. Hence, the argument of a correct pricing of risk of even a large volume of cat bonds is likely of a theoretical nature since in reality, a constraint on the properly functioning market size certainly exists. Although there is a surge for diversification and nuclear cat bonds have the favourable property of generally not being affected by other shocks to the economy, a full coverage for all reactors seems impossible.
Therefore, although the idea of cat bonds sounds very promising, the nature of their implementation has to be debated. Demanding any smaller amount of cat bond emissions than potential damages would re-introduce the negative externality of limited liability partially. For this reason, the next section offers a proposal that partly relies on cat bonds, thereby making use of their favourable properties, and that has the potential to overcome the above-stated market-size problem to a large degree.

5 Taxing nuclear risk with the help of capital markets

After having pointed out that current liability regulation might imply severe incentives for excessive risk-taking and having reviewed various regulatory instruments, we now propose a new way for liability in the nuclear industry to be regulated. The major aim is to internalise the externality of excessive risk-taking, which we think is best accomplished by combining the strength of private markets with a Pigouvian-type of public intervention. We propose to use the ability of capital markets to evaluate risk-
taking and society’s reserve capacity to absorb high risks in order to achieve the desired level of nuclear reactor safety.

Our basic idea can be summarised as a two-stage approach and is depicted in Fig. 3. In the first stage, capital markets, by pricing a specified volume of cat bonds, provide an assessment of the risk stemming from each nuclear reactor. In the second stage, the regulatory authority employs this observable risk-assessment and intervenes by charging a Pigouvian tax equal to an actuarially fair premium, thereby – under ideal conditions – inducing the socially optimal level of risk-taking. Eventually, society adopts the role of an explicit insurer for nuclear risk. We outline the main arguments in favour of this solution below, before discussing the details relevant to its implementation.

Our analysis has pointed out several issues leading us to the conclusion that neither public safety regulation nor market-based instruments in pure form alone can solve the problem of excessive nuclear risk-taking. In contrast to Tyran and Zweifel (1993), our
approach does not aim to establish comprehensive loss coverage on capital markets. Instead, our idea uses cat bond markets for risk assessment only and delegates any further responsibility to the regulator. Specifically, our proposal demands that NPCs be obliged to issue cat bonds for each reactor in a volume that represents only a fraction of the potential costs of a large-scale accident. One could think of an amount of, for example, USD 10 billion per nuclear reactor, which seems large at the first glance. However, even if this would be done for the more than 400 reactors worldwide, the total sum would only lead to a market size of just over USD 4 trillion or about 30 percent relative to current US public debt. Given that the recent crises have revealed that investment portfolios were often not sufficiently diversified, it seems reasonable to assume that there might be sufficient demand for even large amounts of cat bonds. From this perspective it seems that it is now the time for introducing a cat bond model, since the inclusion of nuclear accident related securities would increase the portfolio diversification.

However, stipulating a cat bond issuance of some specified amount lower than the potential damage of a nuclear accident would, like our previously made arguments, not fully overcome the problem of excessive risk-taking. There is, however, a crucial advantage of capital market participation: regulators would be able to obtain an assessment of the probability of a catastrophe, given that the cat bond defaults when such an event occurs. Measured against a risk-free interest rate the interest premium would exactly reflect the accident probability. Alternatively, it could be measured against the safest reactor, according to capital markets, which could be a good approximation of the risk-free interest rate.

Of course, there are certain problems to be overcome which we discuss below; nevertheless such a scheme would have two advantages: (1) it would overcome potential liquidity/capacity problems in capital markets, thus isolating the actual risk
from other capital market imperfections, and, (2) as the cat bond issuance is reactor-specific, the risk assessment is transparent and the risks of various reactors become comparable.

It is disputable whether capital markets are able to properly evaluate the risks of nuclear power. One could argue that, having failed to price a number of risks correctly in the recent past, capital markets are generally likely to fail. On the contrary, one could, however, also argue that precisely because of these events, the future assessment will be more cautious and possibly even overestimate certain risks. While neither of both can be proven, it is important to note that even an incorrect risk-assessment by capital markets does not necessarily lead to an inefficiently low level of precaution. What matters is the pricing of safety differences and of safety improvements, not the pricing of the level of safety. For instance, if a reactor is assessed as relatively safe by capital markets, while actually being rather unsafe, an incentive for safety improvements would still be set as long as the NPC could improve sufficiently the conditions at which it can issue cat bonds. Under certain conditions this may (even in the case that the risk of nuclear power is under-priced) lead to an excessive level of safety if capital markets would too generously reduce the interest premium when the NPC improves safety.

To a large degree, the correct assessment of safety differences and safety improvements can be reduced to the question of whether investors can obtain information at sufficiently low costs. If it was too costly for potential cat bond underwriters to acquire information about differences between reactors or safety changes in a specific reactor, capital markets would no longer be able to set the adequate incentives. Thus, it is all the more important to establish a set of measures to make this market more efficient. As already argued by Tyran and Zweifel (1993), (private) nuclear rating agencies could emerge, where, however, moral hazard
problems as were discussed for existing rating agencies would need to be avoided (see, for instance, Bolton et al., 2012, Dittrich, 2007, and Pagano and Volpin, 2010). However, it would also be in the self-interest of the NPCs to provide information (for instance, by issuing reports) about the safety of their reactor and to be as transparent as possible since a lack of transparency could be interpreted by financial markets as a sign of not being safe.

Moreover, two reasons run in favour of believing that capital markets would not neglect the risks of nuclear accidents: on the one hand, the recent crises have sensitised investors that even highly improbable events may actually occur; and on the other hand, the Fukushima catastrophe itself has shown that the specific risk of nuclear power is existent. A similar argument was discussed by Dell’Ariccia et al. (2006) who show that the non-bailout of Russia in August 1998 has increased the cross-country spreads, that is, sensitized investors that risks do exist. Furthermore, Cummins and Weiss (2009) argue that securities markets are more efficient at reducing information asymmetries and facilitating price formation than insurance markets.

Having outlined the first stage of our proposal, we will now explain what the regulatory authority should do in the second stage. We emphasise again that a Coasian solution to the problem is not feasible, and that the regulator must intervene in a Pigouvian way if a full liability of NPCs is not implementable (see Section 2). Observing the reactor-specific interest premium of a cat bond over a risk-free bond, the regulator defines a tax for each nuclear power reactor to be paid by the NPC. The tax is proportional to the interest premium, hence lower for safer reactors and higher for those assessed to pose a higher risk. In this way, the regulator, representing society, becomes the insurer for nuclear risk by charging a premium that depends on actual risk and in return agrees to absorb the costs of large-scale accidents. Under ideal conditions, this proposal fully overcomes the negative consequences of limited liability, as the
reactor-specific risk becomes the crucial factor of the tax an NPC has to pay. Moreover, society has the capacity to absorb the costs of nuclear accidents – better than privately owned companies (like insurers). Societies have in the past managed to overcome severe catastrophes and would also look for the best possible way to deal with a nuclear accident.

One aspect to be discussed concerning this solution is whether an incentive to manipulate the cat bond market could exist. Since the cat bond issuance is supposed to be relatively small compared with the amount on which the Pigouvian tax is to be levied, an NPC could theoretically reduce its costs by engaging in (illegal) activities that drive the interest spread below its true level, thereby having to pay a smaller Pigouvian tax. Trivially, the incentive for manipulation depends on the costs of manipulation, that is, on the supervisory power of the state and the size of penalty if an NPC is caught cheating. For two reasons it can be believed that the manipulating costs are reasonably high in the outlined case: the market size to be manipulated would be comparably large, if the regulator demands issuance of cat bonds in the amount of, for instance, USD 10 billion, and, secondly, underwriters could be prohibited to buy a share of more than a few percent of the issued volume, which would also reduce the possibility for manipulation.

Moreover, since bringing transparency into the system is crucial, a supervisory agency would be needed. A lot of lessons can be applied from the banking sector, which has established this kind of supervision and is in the process of improving it after the problems that became obvious during the recent crisis.

The advantage of the outlined proposal is that nuclear power companies are internalising the social costs of their activity, and society is, on average, fairly compensated for the risk it is taking over. This is all that can be demanded from an economic perspective, and it remains up to the NPCs to decide whether it is still
profitable to operate. Of course, this decision would also be influenced by
developments in electricity prices, which could rise if an unsafe reactor had to close,
thereby making safer ones sufficiently profitable even though the tax would have to be
paid. By the same token, renewable energy sources would also profit, as nuclear power
would become more costly owing to this proposal.

Of course, no government can be forced to participate in such a regulation and
adopt a Pigouvian nuclear risk tax in order to internalize the externality. We argue,
however, that it ought to be in the interest of them to do so. However, a lack of
participation of some countries would not directly affect the effort undertaken by the
participating countries, which makes it different from climate change protocols as the
world climate is a global public good. The risk of nuclear catastrophes constitutes to
some degree a rather regional or even local (if the most severe consequences are
looked at) externality. Moreover, if a country is not willing to charge the Pigouvian
nuclear risk tax because it fears the adverse effects for its nuclear industry, it could
redistribute the collected revenues on a lump-sum basis back to the nuclear industry,
thereby enhancing the safety level without harming the industry on average.

Moreover, to give NPCs the opportunity to improve their assessment and thus
reduce the Pigouvian tax that is to be paid, cat bond issuance and the determination of
the tax could be repeated according to a pre-defined schedule, every two or three years,
for instance. The maturity of the bonds could also be defined according to this
schedule.

As it was already argued in the subsection on safety regulation, we regard the
setting of standards by the regulator as a useful complement to our proposal: on the one
hand, safety regulation, if enforcement is guaranteed, provides information for
potential underwriters as NPCs have to implement at least the safety level that is
demanded. Thus, safety regulation that leads to a reduction of risk would be valued by
capital markets and the interest premium would shrink. If safety measures are concerned which, owing the valuation by potential underwriters, would have been implemented by the NPC anyway, safety regulation would be fully neutral. On the other hand, there are cases in which safety regulation would not be neutral: (1) if it demands a level of safety that is inefficiently high, or (2) if the standards are actually important, but would not be sufficiently priced in by capital markets. The latter is the most important argument in favour of safety regulation since it means that a failure of capital markets to punish a lack of safety can be replaced by safety regulation. In this case, safety regulation improves allocative efficiency. There is, however, the possibility that safety regulation stipulates measures for which the social costs are higher than the social benefits, in addition to the problems we have outlined in the respective section.

6 Conclusions

Currently, NPCs enjoy limited liability with respect to potential catastrophic nuclear accidents. This has been seen as necessary to protect NPCs from ruinous claims and was essential for the development of this industry, but it may nowadays be re-interpreted as a major source of excessively risky nuclear reactors. As the number of nuclear reactors worldwide is expected to rise over the next decades, it is all the more important to discuss ways in which the use of nuclear power can be made safer. Therefore, we have evaluated several known instruments and concluded that any of these instruments either cannot be recommended in its pure form or is infeasible in reality.

We have thus proposed a new regulatory approach, based on the general idea of catastrophe bonds that may be superior to the other instruments. The core of our proposal consists of a two-stage procedure: in the first stage, capital markets evaluate
the risk stemming from each nuclear reactor via catastrophe bonds issued on a smaller scale than actually required to cover the potential losses, but whose value can be used as an indicator for the riskiness of a reactor. In the second stage, the regulator uses this private risk assessment and intervenes by charging an actuarially fair premium, a Pigouvian nuclear risk tax that, if conditions were ideal, would induce the optimal level of risk-taking. Society then acts as an explicit insurer for nuclear risk and is, on average, fairly compensated for the risk it is taking over.

The implementation of such a scheme would make the use of nuclear power (privately) more expensive, since the risk of accidents would now also be priced. Consequently, some nuclear reactors (in particular the unsafe ones) may become unprofitable and could disappear from the market. The other ones that remain privately profitable are then also socially profitable according to the monetary risk that they impose on society.

Neither the ethical nor the moral arguments against nuclear power have been considered at this stage; even after the optimal level of risk-taking is implemented, society may decide not to use nuclear power. This decision must not be taken on the basis of nuclear power plants that are too risky, however, but given that the level of care satisfies allocative efficiency. Therefore, solving the problem of limited liability and excessive risk-taking is both an important element of the future use of nuclear power and a necessary basis for decisions regarding nuclear phase-outs.

References


1 Although the behaviour of a firm is studied, we write ‘utility function’ in the following. It could be replaced with ‘profit function’ if we considered the case of risk neutrality. The use of the term utility function enables us to study the case of risk-aversion, which would be appropriate and more general if the NPC is owned by a risk-averse individual.

2 For an analysis of how liability rules and insurance affect incentives for risk-taking and the allocation of such risks, see Shavell (1982). In contrast to Sinn (1983) and Shavell (1986), who emphasise the role of limited liability on the individual’s risk-taking decision, Shavell (1982) evaluates two different kinds of liability rules – when liability is strict and when it is based on the negligence rule. Furthermore, he elaborates on the influence of these forms of liability and the presence of insurance markets on the incentives to engage in inefficient risk-taking.

3 Cf. Shavell (1980) for a comprehensive analysis of the incentives strict liability and negligence rules have on risk-taking.

4 A Special Drawing Right (SDR) is a unit defined by the International Monetary Fund (IMF). As of March 2012, the value of one SDR equals USD 0.66, EUR 0.423, JPY 12.1, and GBP 0.111.

5 As of August 2012, the French state holds 84.8 percent of the shares of Électricité de France (EdF), the owner of all French nuclear power plants.

6 The idea to require the purchase of liability insurance to correct for certain inefficiencies is widespread; consider, for example, automobile or professional liability insurance.

7 This is the case for both natural and man-made catastrophes, to different extents. See, among others, Kunreuther (1997) and Cutler and Zeckhauser (1999).

8 See Buck and Jus, 2009, for a similar argument concerning the possibility of securitization in the banking industry, which opens a channel for circumventing the introduction of stricter equity requirements on one layer of banking.

9 For analyses of other private and alternative, arrangements for transferring risk, see Wagner (1998); Radetzki and Radetzki (2000).