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Capping Environmental Liability: The Case of North American Nuclear Power

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The liability of operators of nuclear power stations for off-site damage done by accidents is capped by the Price-Anderson Act in the U.S. and the Nuclear Liability Act in Canada. Such capping constitutes a subsidy to nuclear *vis-à-vis* other sources of energy. We report the results of analyses aimed to estimate the size of that implicit subsidy.

1. Introduction

Much of the case for or against the adoption and extension of nuclear power as a source of electricity revolves around the disputed safety of the technology in use in the sector.

Despite ongoing contention about the health implications of low-level radioactive contamination, most informed opinion is that in day-to-day, routine operation nuclear power plants pose comparatively low risks to the health of employees and the general public. The great unknowns in the environmental assessment of the industry are those surrounding the probabilities and implications of large-scale catastrophic releases of radioactive materials during nuclear accident. Whilst occurrences of nuclear incidents leading to significant off-site damage have been mercifully rare (Chernobyl being by far the biggest), it is the spectre of catastrophe which has made electorates in many countries wary of embarking on nuclear development in the first place, and has lead to curtailment of programmes elsewhere.[1]

Simple economics tells us that in a first-best setting, provided the external costs of the operation of a nuclear power plant can be internalized – that is brought to bear upon the operator – then the incentives for technology selection, maintenance and operation should be efficient. There are, however, a number of fundamental constraints that prevent such an ideal from being achieved. These are primarily related to informational issues.

In addition to the fundamental constraints that preclude the effective operation of a system of strict and unlimited liability for nuclear damages done, it is also true that in all of the major nuclear-using countries legislative caps have also been put in place to protect the wealth of operators (and, where applicable, their shareholders) from the impact of large accidents.

Liability for nuclear operators in Canada is limited to the first C$75 of off-site damage by the Nuclear Liability Act of 1970.[2] In the U.S. the Price-Anderson Act enacted in 1957 placed

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[1] Ontario-Hydro is the largest energy utility in North America and is the monopoly supplier of electricity in Ontario. Within the province it operates 19 reactors at three sites. In August 1997 Ontario-Hydro shelved production at seven of its reactors (at the Pickering and Bruce sites) after publication of a report criticising management and training at the plants and declaring safety to be only "minimally acceptable" (see *The Economist*, 23 August 1997, p. 57).

[2] The cap in Canada has been subject to long-running (and ultimately unsuccessful) legal challenge from a coalition of concerned parties, including the City of Toronto. For detailed legal analysis of the passage of litigation see various issues of *Environmental Liability Report* in the early to mid-1990s.

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a cap at US$160 (C$195) (the cap has since been revised upward to reflect inflation). In both the U.S. and Canada the legitimacy and desirability of liability caps in the industry are subject to regular discussion. Similar caps are legislated in the Netherlands, Sweden, Japan, the U.K. and elsewhere (see the Appendix in Laing, 1992, for a list).

The political processes underlying the instigation of caps varies by country. It was generally accepted in the early years, however, that the scope that the technology of nuclear power had for inflicting catastrophic environmental and health damage meant that effective liability for worst-case accidents would have to be borne by the public (or public sector) if the development of the civil nuclear industry was not to be quashed at birth. Congress's primary motive in enacting the Price-Anderson Act of 1957, it has been contended, was to remove the deterrent of (potentially crippling) liability to participation in nuclear activities. The 1988 Amendments affirmed the original rationale for the Price-Anderson system by continuing to protect those potentially liable for the consequences of major accidents.

The placing of a (contingently binding) upper bound on accident liability can be expected to have at least two sets of effects:

- Once a nuclear plant is installed, safety incentives are inefficiently low. In particular, the operator has too little incentive (a) to prevent accidents (since some of the costs associated with accident are externally borne), and (b) to prevent an accident, once it has occurred, from escalating (once the cap is passed the marginal liability of the operator is zero).
- By providing implicit subsidy to the use of nuclear technology it encourages excessive installation of nuclear capacity in the first place.[3]

The severity of the former problem has been examined by, amongst others, Dubin and Rothwell (1989). The focus of the results reported in the current paper is on the second impact. In particular, we address the question: How big is the implicit subsidy given to nuclear power by the truncation of accident liability? We report the results of numerical (non-econometric) analyses conducted for the U.S. and Canada.

2. Data, method and applications

Heyes and Heyes (1998a, 1998b) apply a numerical (non-econometric) technique to fit a curve relating scale of accident (in terms of aggregate off-site losses) to probability of occurrence (per reactor-year of operation) using (i) market-based information contained in liability-insurance premia and (ii) existing "expert" views about worst-case accident scenarios. The methodology used is an adapted version of that developed by Dubin and Rothwell (1990) and applied by them in the U.S.

Canada

The 1970 Nuclear Liability Act limits the liability of a nuclear operator in Canada to the first $75 million of off-site damage inflicted by any single accident. This is what we will refer

[3] In Canada, for example, Charles Bair, Vice-president of New Brunswick Power with particular responsibility for operations made it clear in 1994 that "... the statutory cap on liability was a prerequisite for the utility having chosen to build the Point Lepreau station to begin with and would certainly influence the planning of other stations in the future" (Environmental Liability Report, 1994).

to as "contingently binding" in that it falls below any plausible estimate of the maximum damage that a worst-case accident would cause.

Consider, for purposes of illustration, reactor i. If $f(q)$ is the annual probability of that reactor incurring an accident inflicting off-site damage worth q million dollars, then the operator's expected liability (in \$m per reactor year) can be written[4]

$$EL_i = \int_1^{\infty} \min(q, 75) f(q) \mathrm{d}q \tag{1}$$

Utility operators (in the Canadian case Ontario-Hydro) buy insurance to cover these potential losses. In 1995 the amount paid for a reactor at Darlington in central Ontario, which we use as the case study here, was \$125,000 per reactor per year. Assuming the premium approximates the expected payout on the policy (after appropriate allowance has been made for the insurer's overheads, rate of return etc., assumed here to be 30 per cent). Then the "pure" insurance component is \$87,500 per reactor year. Thus the evaluation of Equation (1) for a reactor at this site should equal 0.0875, i.e.,

$$\int_1^{75} q f(q) \mathrm{d}q + 75 \int_{75}^{\infty} f(q) \mathrm{d}q \approx 0.0875 \tag{2}$$

This will be one of the equations that will be used in trying to "fit" a curve $f(q)$ a little later.

The other type of information available are expert estimates of the likelihood and damage implications of a "worst-case" accident at a CANDU-design reactor of the sort used at Darlington. These estimates vary widely and depend, of course, upon local conditions (population density and so on) as well as on the design of the plant itself. A survey of the "Probabilistic Risk Assessment" (PRA) technique used to evaluate risks in this area is provided by Heyes (1995) and citations therein. The probability of an accident in the "FDC-0" category (the severest type, involving uncontrolled release of core material into the environment) has been estimated at 3.8×10^{-6} per reactor year (by Ontario-Hydro), 1×10^{-5} (Laing, 1992), 8.5×10^{-7} (Rosen, 1987), whilst Thompson (1992) regards 1.1×10^{-5} as a lower bound. The results here are presented for two probability scenarios: 1×10^{-5} and 1×10^{-6}. There is also little expert consensus about the off-site damage that an accident of this type would inflict. Inspection of a number of studies using alternative techniques suggest that a "reasonable" estimate could be anything between \$1 billion and \$100 billion, with the preponderance of opinion being that it would be in the lower half of this range. We present results for five cases spanning the range \$1, 10, 20, 40 and 100 billion.

The two alternative values for probability of occurrence of an accident of this category and the five alternative values for damage implications are combined to yield ten "expert scenarios", and we conducted the analysis for each of the ten scenarios. Expert data, then, tell us something about the right-hand tail of $f(q)$. If, for example, we adopt the scenario that the probability of worst-case accident is 1×10^{-5} and that such an accident inflicts damage equal to or greater than \$10 bn then $f(q)$ must be such that:

$$\int_{10^{10}}^{\infty} f(q) \mathrm{d}q \approx 10^{-5} \tag{3}$$

4 Note that only events inflicting off-site damage greater than \$1 million are regarded as significant events.

The work of Chow *et al.* (1990) and Chow and Oliver (1988) allows extra restriction to be put on functional form. They use Bayesian escalation models – models in which a serious accident occurs as a result of a sequence of independent failures – to determine an appropriate functional form for $f(q)$. More concretely, if we define

$$Q \equiv a + b\ln(q) \tag{4}$$

then their theoretical work suggest that

$$f(Q) = \frac{e^{-Q}}{(1 + e^{-Q})^2} \tag{5}$$

It should be understood that we are not deriving (5) from (4) here. We are importing the expert judgement contained in the two cited papers (itself based upon a fundamental analysis of the way in which accidents develop in complex engineering systems) that if Q is a linear-logarithmic transformation of q then the probability density function of Q is logistic.

The numerical problem then becomes to the fitting of a curve with the required functional form (consistent with (5)) which is consistent with (i) observed insurance premia and (ii) the expert scenario chosen, in other words to choose values for a and b such as to satisfy both (2) and (3) as closely as possible. Values for the parameters are selected for each of the ten expert scenarios, such as to make the ratio of the left and right hand sides of Equation (2) multiplied by the ratio of the left and the right hand sides of Equation (3) close to one. Such an optimization criterion ensures that both ratios are close to one simultaneously and was developed by Dubin and Rothwell (1990).

This optimization was carried out for each of the ten scenarios, and the results are reported fully in Heyes and Heyes (1998b). The numerical results are summarized in Table 1. Each cell corresponds with one scenario. In each case values of a and b have been selected by means of the optimization procedure outlined and in each cell (i.e. for each scenario) we report: (a) the implied expected value of off-site damage TQ; (b) the implied expected value of uninternalized damage TUQ; and (c) the dollar value of the implicit subsidy. (The implicit subsidy is calculated on the basis that if liability were extended the operator would be able to secure insurance for the additional liability at an actuarially fair premium plus add-ons at the 30 per cent rate used above. We ignore the very real issues of the extent to which insurance

Table 1:
Total off-site damage, total uninternalized damage and implicit subsidy for alternative expert assessments of worst-case scenarios. All figures \$ million per reactor year of operation

	1×10^{-6}			*1×10^{-5}*		
Worst-case scenario	*TQ*	*TUQ*	*Implicit subsidy*	*TQ*	*TUQ*	*Implicit subsidy*
\$1 bn	0.56	0.47	0.67	1.04	0.96	1.37
\$10 bn	10.41	10.31	14.74	11.51	11.42	16.33
\$20 bn	22.08	21.99	31.44	22.71	22.63	33.36
\$40 bn	45.48	45.39	64.91	48.75	48.66	69.58
\$100 bn	114.92	114.83	164.20	145.68	145.69	208.35

Source: Based on Heyes and Heyes, 1998b.

would actually be available to cover these risks. All are expressed in 1995 C$'s per reactor year.

The most interesting figures for current purposes are those relating to *TUQ* which provide a measure (for any given expert scenario adopted) of the externality imposed by the operation of a reactor at the sample site. Moving down or right in the grid implies you are adopting a more pessimistic experts view on worst case scenarios, and it is not surprising that *TUQ* rises. As we have noted, accident liability is limited by the Nuclear Liability Act. Since the (net) cost of insurance paid by the operator corresponds to the uninternalized part of expected damage, the ratio of 0.0875 to *TQ* measures the proportion of expected damage borne internally and represents a good measure of how tight the current liability cap is. In most cases the proportion is small. Looking at the top left hand cell (corresponding with the most optimistic expert scenario) only 17.3 per cent of *TQ* is incident upon the operator. This percentage falls quite rapidly as we move right and/or down in the grid. Even though a substantial proportion of *TQ* remains uninternalized, it is worth stopping to note that the *TQ* totals in themselves are smaller than one might have expected. The gross values from Table 1 are translated in c per kWh equivalences in Table 2. For most scenarios *TEQ* is less, often substantially less, than 1 c/kWh. Only taking the most pessimistic views of catastrophic risk – one of the cells in the bottom row of the table – does the implicit subsidy climb to 2 to 4 c/kWh.

United States

In Heyes and Heyes (1998a) the authors rework and correct an earlier attempt by Dubin and Rothwell (1990) to perform a similar exercise for nuclear stations in the United States. The analysis is more limited, conducted for only a single (though authoritative, USNRC) expert scenario.

Off-site liability in the U.S. is limited by the Price-Anderson Act (to $560 million from 1959; legislative amendment raised this to $7 billion in 1988). Dubin and Rothwell estimated the implicit subsidy to a representative nuclear plant to be $60 million and $21 million per annum before and after the Amendment. In fitting their curves, however, they misinterpreted the terms of the insurance. It is indeed true that American Nuclear Insurers cover losses between $1 million and $160 million; our understanding is that this means that they cover the

Table 2:
Implicit subsidy accorded by terms of Nuclear Liability Act expressed as cents per KWhr of electricity generated

Worst-case scenario	1×10^{-6}	1×10^{-5}
$1 bn	0.01	0.02
$10 bn	0.25	0.29
$20 bn	0.54	0.58
$40 bn	1.12	1.20
$100 bn	2.83	3.58

Source: Based on Heyes and Heyes, 1998b.

first \$160 million of damage done by any accident, however big that accident may be, not that they cover the full amount of damages for and only for an accident that inflicts *total* damage within those limits. The insurer supplies what is known in insurance parlance as a "tranche" of insurance.

Their U.S. figures are reworked in Heyes and Heyes (1998a) and shown to overestimate the implicit subsidy due to the Price-Anderson Act by a factor of between 4 and 10. The two simultaneous equations (corresponding to Equations 2 and 3 in the Canadian example) are

$$\int_{1}^{160} qf(q)\mathrm{d}q + 160\int_{160}^{\infty} f(q)\mathrm{d}q \approx 0.28 \tag{6}$$

and

$$\int_{10^{10}}^{\infty} f(q).\mathrm{d}q \approx 0.0000008 \tag{7}$$

respectively (for full details of the derivation see Heyes and Heyes, 1998a). Applying the same optimization technique yields estimates of the implicit subsidy due to the Price-Anderson Act as being approximately \$13.3 million per reactor year before Amendment, \$2.3 million after. Again, after revision these numbers, whilst significant, are not particularly large in the context of a power station balance sheet.

3. Conclusion

Liability for off-site damage done by the operation of nuclear power stations is capped in all countries using the technology. Such capping implies an implicit subsidy to nuclear over other energy sources. In this paper we have outlined a technique (along with reporting application of the technique to Canada and, more briefly, the U.S.) for estimating the size of that subsidy.

The analysis fits into the developing literature on the social costing of alternative energy sources (see Ottinger *et al.*, 1991). The results of the procedure used depend upon the expert scenario adopted. The analysis summarized here suggested, in the Canadian case, that whilst the capping of liability by the Nuclear Liability Act does indeed shield Ontario-Hydro from responsibility for a substantial proportion (80 per cent or more) of expected off-site damage, that expected damage is smaller than might have been anticipated – typically less than 1 c/kWh. This is below the estimates of externality typically derived in analogous studies of alternative energy sources. A 1992 study of Ontario-Hydro's non-nuclear operations estimated the externality imposed by existing coal plants with scrubbers to be 3.5 c/kWh; for IGCC, 2.5 c/kWh; for gas-combined cycle generation, 1.4 c/kWh; and for GCCC 1.2 c/kWh (Chernick *et al.*, 1992) – all figures in 1995 \$C for comparability.

Whilst discussion of how policy should be tailored to take account of such estimates is beyond the scope of this paper, it is apparent that from an environmental perspective nuclear power does not come off badly – according to the analysis presented here – in comparison with its competitors. The same can be said about the U.S. case. Of course, a lot of environmental and other social impacts of energy exploitation are not internalized. Second-best economics is notoriously ambiguous; certainly we make no claim that the imposition of an "adder" equal to the marginal external impact of nuclear generation would constitute "good" policy.

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