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Article

What Can Politics Learn from Management Decisions? A Case Study of Germany's Exit from Nuclear Energy after Fukushima

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Abstract: The devastating nuclear disaster in Fukushima, Japan, in 2011, which was triggered by a tsunami in the wake of an earthquake, resulted in the decision to quickly phase out nuclear power and with it implicitly accelerated the German *Energiewende* (energy transition). To the outside observer, the decision appeared to be spontaneous and possibly due to a distorted perception of the associated risks of nuclear power. From the decision results not only the limiting uses of private property by conventional energy providers, but the exit from nuclear energy has also implications for the energy market. As with every human, political actors decide under uncertainty and incomplete information. Based on these parameters, we emphasize that the decision of a political actor is comparable to management decision-making. The paper takes this as an opportunity to examine the political decision to phase-out nuclear energy by discussing relevant parameters from the perspective of decision theory. We plead for a mandatory consideration of economic findings, especially from decision theory and risk management in political decision-making processes, especially in matters that affect future generations.

Keywords: nuclear energy; Fukushima; energy security; risk analysis; political economy; decision-making; energy transition; green energy reliability

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1. Climate, Energy and the Economics

There are certain events that burn themselves firmly into the memory of mankind. Two of these events are worth mentioning in the context of nuclear energy: The nuclear accident in Chernobyl, Soviet Union, in 1986, and the nuclear disaster in Fukushima, Japan, in 2011. Movements against even the non-military use of nuclear energy began to emerge in Western Europe in the seventies of the last century, especially when the construction of nuclear power plants increased as a result of the first so-called oil crisis (see, e.g., [1]. In the year 2000, Chancellor Gerhard Schröder (7th chancellor of Germany from 1998 until November 2005, Social Democratic Party) has commonly agreed with the operators of nuclear power plants to limit the electricity production from nuclear energy and to phase-out nuclear power (e.g., [2]). This nuclear consensus allowed some flexibility to the nuclear operators as residual electricity production could be transformed from one unit to another to optimize the use of installed fuel assemblies. After winning the election campaign in 2009, chancellor Angela Merkel (Christian Democratic Union) withdrew the nuclear consensus, which was referred to as the "Ausstieg vom Ausstieg" (phase-out from the phase-out) (e.g., [3,4]). This decision allowed to stick to nuclear energy at least until alternative forms of energy were capable of independently supplying an industrialized country such as Germany, however, approximately one and a half year after this decision to stick to nuclear energy, the accident in Fukushima led to a radical change in the energy policy of Germany (e.g., [3]), what can be described as "Fukushima Effect" [5] or "Fukushima Factor" [6]. The devastating disaster at Fukushima in Japan had a global

impact on the energy industry. It is striking, however, that the political consequences varied. While the USA and France, for example, continue to support nuclear energy in principle, Germany stands out with a radical departure. Ming et al. [7] (p. 148) report that "the attitudes for nuclear power around the world have divided after Fukushima nuclear accident." They emphasize that in addition to the U.S., Canada, China, Russia, or India also fundamentally adhere to nuclear power, but slow down the development of new power plants, and also place more emphasis on safety. Apart from Germany, only Belgium and Switzerland, both of which are significantly smaller than Germany, have carried out a complete phase-out [7]. How can we explain this difference in political assessment? It is conceivable, for example, that different governments have evaluated the risks differently. Another explanation could be seen in primarily political motives. This paper addresses this question and tries to provide an analysis that focuses on the political decision from the perspective of managerial economics in general and decision-making under uncertainty in particular. While other studies focus on lessons learned from the accident that focusses, e.g., technology issues such as nuclear cogeneration (e.g., [8]), the institutions of nuclear regulation, public perception and public engagement (e.g., [9]), we want to examine the political decision to abruptly phase out from a risk perspective, taking the special situation we find in Germany as a starting point. In this respect, we try to bridge three disciplines that are often analyzed separately from each other: energy economics, risk management, and political economy.

It seems quite surprisingly and prima facie hardly comprehensible that the German government—after decades of holding on to nuclear energy even against resistance—suddenly announces a phase-out, although the objective circumstances, both in technical and geographical terms, have not changed. In this respect, the event has influenced the speed of the German *Energiewende* (energy transition). However, it must also be mentioned that the German energy transition already started long before and latest in the year 2000 with the introduction of the renewable energy act (EEG) and is more than just the phase-out of nuclear power, because even at its peak, nuclear energy accounted for about 13% of Germany's primary energy balance (e.g., [10]).

The anti-nuclear movement in Germany that emerged in the 70s and that can be seen as the birth of Germany's Green Party (e.g., [3]) is now being joined by a climate movement supported, especially by young people, of whom the Swedish Greta Thunberg is probably the most prominent representative of a so-called "climate-neutral" (energy) policy. From a political economy perspective, this is obviously the dominant strategy. Government actors seek to maximize their electoral votes. In doing so, policymakers anticipate the public's perception of certain events and adjust their actions accordingly [11]. From an energy-economic perspective, the efforts of both interest groups to push through their ideas politically also result in a dilemma for Germany. If one assumes the country's energy demand to be constant, the elimination of nuclear energy shall mainly be compensated by additional renewables, however, the challenge of secured capacity remains, which most likely will be solved in the mid-term by additional conventional gas power plants (see e.g., grid extension plans of the four transmission system operators). Kemfert and Canzler [12] emphasize that coal-fired power generation would increasingly have to be abandoned as part of the energy transition. In this context, they refer to environmental and health damage. At the same time, Kemfert and Canzler [12] criticize the construction of new nuclear power reactors, e.g., in England, and points to the costs of nuclear power. It has to be mentioned that with steadily increasing amounts of weather-dependent renewable energies, the need for base load power is continuously decreasing, while most likely additional peak (or back-up) capacities are required This can easily be demonstrated with the help of the peak-load-pricing model [13]. With the feed-in from weather-dependent renewable energies, the sorted residual load curve nearly does not change for the peak demand. As a high peak demand occurs over several days, it is likely that at one of these days no or a low feed-in from renewables occurs resulting in a nearly unchanged maximum of the residual load. In contrast, in off-peak times, high renewable feed-in

may occur at a timeslot resulting in a steep reduction of the off-peak time residual load. In consequence, the change of the residual load curve decreases the need for capacity in the base load segment, while higher capacities are required for peak load or back-up capacities [14] Within this market equilibrium, fewer base-load capacities are required and in consequence, a market-driven phase-out of nuclear and lignite as well as coal capacity is most likely in the next decades, while a regulated coal and nuclear phase-out may accelerate this expected market development (depending on the speed of the phase-out).

For decades, economists have also been concerned with human consumption of natural resources and the negative externalities that result (e.g., [15–17]). Economists think in scarcities and use the marginal principle to model human decision-making. Basically, individuals calculate the expected costs and expected benefits of an action (e.g., [18,19]). Since there are no objective probabilities—e.g., based on physical laws—for most future states, people make decisions under uncertainty; this is true for entrepreneurs and politicians alike (see [20]). Challenges of global climate change and increasing pollution can also be solved. However, there is an efficient level of control, where the marginal damage from the use of natural resources equals the marginal costs of the reduction (e.g., [17,21–23]). Therefore, abandoning lifestyle habits can only ever make economic sense to a certain extent. From an economic point of view, it would be more beneficial to counter climate change or the energy problem with technological innovations. From this point of view, our argumentation is in line with Renn and Dreyer [24] who emphasize that the complexity of energy risks in general requires a multidisciplinary approach by technical and social science disciplines. The close link between energy economics and politics applies to foreign and geopolitical policy on the one hand (e.g., [25], who point this out by the example of the North Caucasus Region), and to domestic policy on the other—which is the focus of our analysis—although there are of course interdependencies between the fields.

Given the current energy policy debate in Germany, we ask to what extent the Merkel government's turnaround in 2011 can economically justify its decision to abruptly phase out nuclear energy. Here, we apply a concept familiar from economic research and focus on decisions under uncertainty. It should be emphasized that—in order not to succumb to a potential hindsight bias—we consider the relevant and publicly available information at the time. Our analysis does not intend to take any normative position. We do not want to make judgments about either the phase-out or the energy transition. Rather, our aim is to show that such important decisions must be subject to a certain process logic, since political actors are making decisions here whose costs will be borne by the population and future generations.

The remainder of the paper has the following structure: in Section 2, we consider as a theoretical background the political decision-making situation in the context of pervasive uncertainty and limited information. Based on the fundamental work of Slovic [26] we would like to work out that situations such as the nuclear accident in Fukushima can lead to distorted information processing in individuals, which changes the subjective perception which can be used by self-interested political actors. Section 3 analyzes the case of Germany's exit from nuclear energy from a risk management perspective. In Section 4 we discuss our main findings with respect to the political economy and suggest an institution that could reduce the discretionary potential in political decision-making. Finally, Section 5 summarizes the results.

With our paper, we pursue two main goals:

1. We would like to show that energy policy decisions can be made based on economic approaches even under high uncertainty and demonstrate this using the example of the German nuclear phase-out.
2. It is our aim to raise awareness for the link between decision theory and political economy on the one hand and for the importance of methods from business economics for political decision-making on the other.

2. Theoretical Framework: Imperfect Conditions and Political Economy

2.1. Politicians, Lobbyists and the Population

As an immediate reaction to the terrible nuclear accident in Fukushima, Japan, which was a result of an earthquake, the German government decided to phase out nuclear energy. This massively accelerated the energy turnaround initiated in 2000 with the introduction of the EEG and latest in 2010 with the publication of the energy concept of the German government [27]. Germany was suddenly faced with the challenge of reducing its fossil fuel energy supply from 80 percent of the national primary energy consumption to less than 20 percent by the year 2050 [24,28]. We want to focus here on the decision to phase out nuclear energy. To this end, we would first like to characterize the political decision as a decision under uncertainty that can be supported by findings from the corresponding economic research within the field of decision theory (e.g., [29]).

We assume that individuals generally strive to maximize their utility; this has been assumed by many economists since Schumpeter [30] and Downs [31], especially for political actors in general and governments particularly. In this respect, politicians seek to maximize their votes, which allows them to continue consuming the rents from their position. In doing so, according to the understanding of modern economics, they act under incomplete information and uncertainty regarding future states (on this wide version of rational choice theory see e.g., [32–34]). Mises [35] (p. 106) points out the close relation between acting and uncertainty:

> "*The uncertainty of the future is already implied in the very notion of action. That man acts and that the future is uncertain are by no means two independent matters. They are only two different modes of establishing one thing.*"

Given this, a decision must deal with the uncertain future in terms of its consequences. This applies to political and entrepreneurial decisions as well as decisions of daily life. Hoppe [36] (p. 49) describes our uncertain world as follows:

> "*There are in our world surprises. Our knowledge of future events and outcomes is less than perfect. We make errors, can distinguish between failure and success, and are capable of learning. Unlike for an automaton, for us knowledge is valuable.*"

We are aware that almost all human decisions are made under uncertainty, so that in the Knightian [20] sense no (objective) probabilities about future states are known, this of course also applies to the probability of a nuclear accident in Germany [29,37]. However, if we want to deal with political decision-making, we are forced to use heuristics [38,39] For this reason, we do not use a sharp distinction between uncertainty and risk here. In this respect, in our study we try to apply risk management techniques to the situation, knowing well that they are by no means able to solve the uncertainty problem [40] (p. 807).

Additionally, to the problem of future-oriented decision-making discussed above, information is distributed asymmetrically, so that expert knowledge prevails in certain groups, which leads to lobby groups having an information advantage over the government, which opens up lobbying opportunities for them to exploit rent-seeking potential (e.g., [41–44]). However, politicians are not only under the influence of certain interest groups but also anticipate the preferences of their potential voters.

2.2. Perception of Uncertain Events

Numerous psychologists and economists have identified certain anomalies to which people can be subject (e.g., [45,46]). Slovic [26] points out that this research strand discovered different mental strategies that are used by people as heuristics in decision situations within an uncertain world. Well-known problems include biased processing of probabilities or media coverage that can lead to misinterpretation of uncertain hazards. For example, Fischhoff et al. [47] can demonstrate that people pay greater attention to rare causes of death and systematically overestimate their probability.

Slovic, Fischhoff and Lichtenstein [48] as well as Slovic [26] present a model of risk perception that is based on different characteristics. Following the list of seven variables

that determine risk perception [49] for our analysis especially the parameters "control", "knowledge" and "catastrophic potential" seem to be the crucial determinants of the risk perception of an average citizen—understood as a lay in nuclear technologies.

The starting point of our considerations is the thesis of Slovic [26], who in his important paper in Science points out the importance of the knowledge of research on the perception of risks—according to the Knightian differentiation, strictly speaking, is meant the perception regarding unsafe conditions—for the political level.

> "*The basic assumption underlying these efforts is that those who promote and regulate health and safety need to understand the way in which people think abound and respond to risk. If successful, this research should aid policymakers by [. . .] predicting public response to new technologies [. . .] [and], events*" [26] (pp. 208–281)

Further evidence for linking behavioral economic aspects with the politico-economic level is provided by Bagus, Peña-Ramos and Sánchez-Bayón [50]. The authors present a framework that shows how mass hysteria can develop from certain information, for example from social and mass media. The authors also draw on the findings of psychological research on risk perception. Slovic [26] sees accidents as signals that alter hazard perception with often high consequential costs that can result from stricter regulation of the nuclear industry, a worldwide decline in reactors, greater public opposition and, ultimately, dependence on more expensive energies. The German Ethics Commission [28] (p. 25), translated by the authors also recognizes the importance of changing risk perception while the general conditions remain constant:

> "*The risks of nuclear energy have not changed with Fukushima, but the perception of risk has. More people have become aware that the risks of a major accident are not only hypothetical, but that such major accidents can actually occur. Thus, the perception of a relevant part of society has adapted to the reality of the risks.*"

With respect to the economic analysis of political actors in parliamentary democracies, which are mostly characterized by a short planning horizon and correspondingly high rates of time preference (e.g., [35,51]), the findings regarding the (distorted) perception of future uncertain events appear as a guide for the political actors to secure his re-election by anticipating the perception of the population—at least of a median voter—and integrating it into the political decision-making calculus. From our point of view, it is irrelevant whether one calls these distortions irrational or explains them as rational behavior under incomplete information. What is important to point out is that, from the perspective of Public Choice theory, politicians will tend to try to exploit these distorted perceptions of danger in the sense of their objective function (e.g., [11]).

Obviously, our assumption is hardly testable empirically. However, we would like to build the bridge between decision theory, risk management and political economy to emphasize that there seems to be a need for institutions that reduce the discretionary potential for politicians to disregard an economic analysis which includes a fundamental study of uncertain events and future costs.

3. Analysis of Germany's Political Decision-Making after Fukushima

3.1. Uncertainty, Risks and Relevant Information

The political decision to bring forward the phase-out of nuclear energy in Germany 2022 is discussed below. For the sake of simplicity, other aspects of the energy turnaround are largely abstracted from. We are concerned solely with the decision of the earlier exit. The fundamental discussion as to whether nuclear energy should continue to be promoted or not was a political decision that must be taken as given. Indeed, many other strategies for the energy turnaround would have been possible even without the reduction in the operating life of German nuclear power plants triggered by the Fukushima accident. For example, the promotion of renewable energies could have been used to substitute coal-fired power plants more quickly and thus reduce CO_2 emissions, which would have been obvious at least regarding the measures against climate change [21,23].

To reduce the complexity of our theoretical analysis, only two possibilities that ultimately remained after a preliminary selection process—however detailed—are considered below:

1. No change in the useful life of nuclear power plants vs.,
2. phase-out of the use of nuclear energy by 2022 ("phase-out"). To reduce the complexity of our analysis, only a period of 20 years is considered below for the assessment of the decision problem. It is thus assumed that, instead of a phase-out in 2022, it would have been possible to continue using (all) German nuclear power plants until 2031 by adjusting legal requirements and technical business measures, if necessary.

Regarding the realized risk—an accident in a Japanese nuclear power plant—the political decision can therefore be interpreted as a decision with the aim to reduce a specific risk—i.e., the risk from a possible nuclear accident in Germany. In such a decision to manage a risk, various effects known from risk management and especially from insurance economics must be discussed (e.g., [52]). The measure can contribute to

- avoid a risk,
- reduce the probability of occurrence or frequency of occurrence of a risk,
- reduce the negative effects (losses) of a risk, which are usually uncertain, or
- to transfer a risk to a third party.

When analyzing the decision-field, we must highlight two different levels:

1. "Early phase-out of nuclear energy from German nuclear power plants" (in short: phase-out), risks are basically to be considered on three respective two sub-levels:

1a. The risk in the goal of the political decision:

The goal of the decision (measure) is to reduce "damage" resulting from a possible reactor accident in Germany (maximum conceivable accident). The measure can reduce the probability of occurrence and possible damage of the risk. A measurement of the risk is necessary, whereby potentially economic damage to national wealth and national income as well as damage to health (such as lost years of life) must be considered and weighed against each other (see e.g., [53]).

1b. Additional risks (side effects) triggered by the measures:

Many measures to reduce a specific risk could lead to an increase in other risks. In the present case, the decision to phase out nuclear power results directly in increasing risks of the security of electricity supply [54], the effects of which are to be measured according to the "primary risk" from 1a. i.e., with reference to economic and health effects [55,56]. Additionally, it must be mentioned that increasing electricity prices can be seen as a further risk (e.g., [57]).

1c. Risks due to uncertainty of measure effects:

Measures have uncertain effects; on the one hand, the costs (direct and indirect) associated with them are uncertain (see 1b). On the other hand, the effects on the risk level itself are uncertain, which can be called parameter uncertainty, that must be solved heuristically by estimations of (subjective) distributions (e.g., [58–60]). For example, the phase-out could lead to increased investment in nuclear energy in other countries. Furthermore, investment risks arise from the need to expand the grid.

To assess the effect of a measure on the scope of risk, all three aspects (1a–c) must be considered and mapped onto a change in the overall scope of risk [37]. As is also common in health economics, in addition to different types of risk, the different effects, especially the economic and health effects, must also be considered and transformed into monetary figures (e.g., [55,58]).

2. Future costs (and impacts) of the measures. To keep our analysis simple, we do not discount future impacts. For such a discounting, a social discount rate (SDR) could be used, see e.g., [21,22].

2a. Direct costs of the measure:

Direct costs of the measure are those that arise directly from the substitution of nuclear power plants that can continue to operate per se with new power plants to be built plus the associated infrastructure, as well as the change in operating costs (especially those of capital costs). In addition to the uncertainties of the costs themselves, uncertainties regarding the energy demand and, particularly, the electricity demand must also be considered.

2b. Indirect costs of the measures:

Indirect costs are those that result from adjustments in the economic structure because of the decisions and their effects on companies. If possible, only the economic costs in the event of a deterioration in the competitiveness of companies based in Germany due to (possible) increased electricity costs because of the measure are considered here below. Further indirect costs result (potentially) from additional CO_2 emissions if the largely CO_2-free nu-clear power plants are replaced by fossil-fueled power plants (the CO_2 certificate price, also uncertain, can be used as a guide for the additional costs arising here). In the following, the relevant information about our political decision under uncertainty is compiled in a structured way. It is essential to note that only information that was "new", i.e., that resulted directly from the nuclear disaster in Fukushima, can be relevant for the decision of the German government. This is information about the assessment of the primary risk (1a).

In the following analysis, a "representative" year is considered for the sake of simplicity (the year 2023, i.e., the first year in which the German nuclear power plants are no longer to be in operation according to the decision).

To prepare management as well as a political decision, we suggest firstly an analysis of the risks, which can be used especially, to show which opportunities and threats are associated with it and how the overall scope of risk would change as a result of the decision [61,62]. In addition, a decision document must state objectives, constraints, courses of action, and projections of benefits made, with underlying assumptions. Finally, an overall assessment of the various options for action is required, taking into account the projected benefits and risks (risk-adequate assessment).

We want to discuss whether the nuclear accident in Fukushima significantly increased the risk of using nuclear energy in Germany. The catastrophe in Fukushima, triggered by earthquake and tsunami [63], is in this sense of course new information. However, at least three crucial questions must be considered regarding the assessment of the risk situation caused by nuclear power plants in Germany:

1. How does the assessment of the probability of occurrence of a severe nuclear acci-dent (maximum conceivable accident) at nuclear power plants in Germany change as a result of the nuclear accident that has occurred?
2. How does the assessment of the range of possible damage, in particular regarding fatalities, change because of the information from Japan?
3. Are the changes in the information on the scope of risk from 1 and 2, frequency of occurrence and amount of damage, significant and relevant?

Basically, for the political decision on an early nuclear phase-out, the following decision problem or weighing situation is given:

- Status quo: Retention of the current regulations for the (slow) phase-out of nuclear energy at the end of the economic service life of the existing nuclear power plants.
- An accelerated phase-out, for the implementation of which there were several options, but in which it was ultimately decided to phase out nuclear power by the end of 2022 (end of the operating license for the last nuclear power plants in Germany).

Obviously, the relevant effects of the decision are uncertain and must be taken into account in the decision-making process. In the political discussion, different aspects are considered to be particularly relevant, namely those risks, whereby different sub-facets are to be distinguished.

(a) Life or health risks, measurable in terms of loss of life years or deaths (e.g., but not only, because of a possible severe nuclear accident), and

(b) Risks related to electricity supply security, again with a variety of impacts (from economic damages to possible fatalities).
(c) expected costs (economic).
(d) Cost risks (i.e., uncertainty in the form of possible deviations in expected costs).
(e) Risks that electricity from nuclear generation will be imported from neighboring countries.

3.2. Measuring the Risk

Regarding the dimension "risk", a measurement concept is required (e.g., [37]). If several facets are to be considered, a uniform scale and aggregation of the sub-facets is re-quired. The analysis here refers to risks from the perspective of the Federal Republic of Germany and its inhabitants. In line with our theoretical framework of political economy, we want to concentrate on the political reputation and ultimately votes, i.e., the uncertain effects of decision alternatives ultimately also election results.

To classify the risks from a nuclear accident, the following estimate can be made using the data available up to 2011, particularly the Chernobyl accident: Including long-term effects, the nuclear accident in Chernobyl caused less than 10,000 deaths, according to WHO [64] data [65–67]. However, there is some uncertainty as other sources claim deaths in the magnitude of up to 125,000 liquidators [65,68]. Additionally, cancer and other physical consequences caused by radioactivity must be taken into account as well as psychological consequences [64]. However, if we consider for a rough estimate a period from 1970 to 2010, i.e., 40 years, with a nuclear accident, the WHO figure corresponds globally to 250 deaths per year. In Germany, one can assume higher safety standards, while on the other hand a higher density of population must be kept in mind. As exemplary comparison, the number of deaths caused by natural radon (mainly caused by lung cancer) is 2000 or car accidents 2700 in Germany can be mentioned. However, it is important to note that the number of deaths cannot be the only measurement of consequential effects. For example, there are economic, social, and psychological consequences due to sudden resettlement and areas that are no longer usable.

Whether there is any new information relevant for Germany regarding question 1 (Section 3.1) is debatable. The trigger of the nuclear catastrophe in Japan, earthquake plus tsunami, is not to be expected in Germany. The basic fact that severe accidents can occur for "any" reason—including human error as in Chernobyl (e.g., [69])—was known.

If one ignores the causes that are not decisive for Germany and considers only "an additional case", one could make the following statement for the political decision under uncertainty: The probability of a maximum conceivable accident" has doubled. In a simple consideration without reference to the number of nuclear plants in operation, the political estimation is thus changed from 1 divided by 40 years to 2 divided by 40 years.

The political discussion has primarily focused on the threat to health and life so that this aspect of the risk is considered especially below (possible damage to health and deaths in the event of a maximum conceivable accident). The opposing positions were costs of nuclear phase-out, with implications also for the competitiveness of German companies, and risks to supply security in the event of an (excessively) accelerated nuclear phase-out.

A significantly different picture than that of the "probability of occurrence" of a maximum conceivable accident emerges regarding the effects. Studies have quickly shown that no number of deaths comparable to the Chernobyl accident is to be expected because of the power plant accident in Fukushima [70]. Studies by the United Nations (UN) and the World Health Organization concluded that health risks from radiation released during the Fukushima accident are minimal, even for those "most affected" and there are essentially no health effects outside Japan [63]. According to WHO, there are no deaths in Fukushima caused by the radiation itself [64]. However, because of the evacuation and the associated health burden, a smaller number of deaths, e.g., from heart attacks, were recorded. Overall, it must be assumed that the number of deaths caused by Fukushima was significantly lower than that caused by Chernobyl. This new information now leads to the fact that the

damage estimation would have to be reduced. Assuming zero deaths as a simplification, a halving of the estimate of damage to health/life would be appropriate because of the new information from Fukushima (with a comprehensible higher weighting of the more recent information with the technically different reactor type one could even see a greater reduction in the estimate: In Chernobyl, an in-core steam explosion, caused an intensive ejection of the overheated core material and an extensive burning of graphite. The release was not confined because that type of reactor (graphite-moderated reactor) did not have a containment structure as designed in German (and Japanese) reactors. As a result, radioactivity had a direct open path to the environment, enhanced by entrainment in the smoke from the burning graphite. At Fukushima, a light-water reactor is used: Progressive heating (due to the lack of cooling), oxidation and meltdown of the cores occurred over a much longer period of time. The radioactive products were thus released from the core much more gradually, while a large share of radioactive material was confined by the containment structures).

3.3. Assessment of the Changed Risk Situation

For the political decision under uncertainty, this means the following from the perspective of a simplified Bayesian statistics: the additional accident of a nuclear power plant in Japan may lead to a higher—e.g., twice as high as two instead of one event occurred—estimate of the damage frequency, becausebefore the accident in 2011 there was *one* catastrophic accident (Chernobyl); after that, there were *two*. This results in a doubling of the estimated probability (). On the other hand, with the same logic—and uncertainties regarding the low data situation—one would then also have to arrive at a comparably lower estimate of the damage effects. Despite the additional reactor accident, an increase in the risk to human life from nuclear accidents cannot be deduced. Since the causes in Japan are not transferable to the situation of the German nuclear power plants, an objective increase of the risk by German nuclear power plants is not ascertainable. The political decision is thus essentially shaped by the perceived risk, and the perceived risk has certainly increased. It is the perceived risk that has determined the political decision. But if the risk perceived by the population, which is considered by the political decision-makers when making decisions, becomes decisive, a further conclusion can be drawn: for the political decision-makers, whose behavior follows the laws of political economy, well-founded data on the actual changes in the extent of the risk posed by German nuclear power plants, which can be derived from the new information, are not at all essential. This is the only way to explain that the decision for the "energy turnaround with the accelerated phase-out of nuclear energy" (by 2022) was made three days after the nuclear accident in Fukushima [71]. A proper preparation of the information required for a complex political decision under uncertainty, especially regarding the risks (see above), could not be provided in this short time. Obviously, the decision-makers were prepared to make a complex decision under uncertainty without the information required for such a decision being available. The conceivable option of postponing a decision until a later point in time, when a better informational foundation had been reached, was ignored.

4. Discussion and Implications

4.1. Some Remarks on the Political Economy of Nuclear Phase-Out

As shown, contrary to the first impression, the new information from the nuclear accident in Japan, triggered by the earthquake and tsunami, is not as unambiguously relevant to decision-making as it appears at first glance. It is not even clear whether, considering the probability of occurrence and possible damage levels, the new information of another accident justifies a higher assessment of the objective risk posed by nuclear power plants, especially in Germany. However, it is decisive for the analysis of the political decisions made shortly after the nuclear disaster in Fukushima that the information required for such a complex decision under uncertainty, especially about the risks, was not available at the time of the decision and that a well-founded preparation of such a decision was not

possible in the short time available. The fact that such a political decision under uncertainty was nevertheless made shortly after the nuclear accident, and that the decision was not postponed until an adequate basis of information was available, must be explained by other approaches: The political decision-makers were not primarily concerned with an "optimal" decision from a social or economic perspective (however specified), in which the risks of using nuclear power plants in Germany would have to be weighed against the risks of the accelerated energy turnaround, e.g., with regard to security of supply. From a political perspective, the only parameter that can be relevant to the decision is that the new information about a nuclear accident in Japan had led to a change in the perception of risk among the population (Section 2.1), especially among voters in Germany. The perceived risk of the population, the increasing fear of a nuclear accident in Germany, was relevant for the political decision because this risk perception—regardless of the actual change in the risk situation—potentially influences the voting behavior. In terms of political economy and based on the assumption of behavior of politicians aiming at maximizing votes, the significantly changed risk perception of the population is thus the actually relevant information. Thus, it is also irrelevant for political decision-making under uncertainty that even "after Fukushima" life and health risks from nuclear energy are numerically negligible compared to other life risks, from infectious diseases to deaths from natural radon. However, the fact that political decision-making is based on voter preferences and only on the risk perceived by the population, and not on the actual risk, explains why the informational basis required for a complex political decision under uncertainty, in particular a proper risk analysis, was not even awaited. The quick political decision three days after the nuclear catastrophe in Japan proves that a well-founded political decision under uncertainty based on a proper assessment of the associated risks for life, health and prosperity of the population was not even considered.

4.2. Decision, Liability and Political Judgment Rule

We now want to ask what consequences can be drawn from the realization that political decisions follow first and foremost the self-interest axiom of Political Economy. First, it should be noted that the characteristic of all decisions, both for entrepreneurs and on a political level, is that all consequences of action are uncertain (e.g., [20,29]). It is also an everyday problem that several relevant decision parameters are not (yet) known due to the scientific studies. It is also often overlooked in scientific studies that a decisionmaker cannot expect optimal "scientific evidence" for all decisions. However, political actors must decide, and they must deal with real, always imperfect data situations [39]. If decisionmakers clearly communicate these parameters and assumptions of their decision, they can therefore not be blamed (see on the Business Judgment Rule, e.g., [61,72,73]—by analogy, Follert [72,73] suggests a *Political Jugdment Rule*). Thus, it is only a matter of evaluating the currently available information in the best possible way. Again, the marginal costs of obtaining information must not exceed the marginal utility (e.g., [74]), but in a real decision situation, this can often only be assessed by means of plausible estimates and heuristics [75]. Obviously, uncertainty about the data situation, and especially the quantification of risks [37], must also be considered in the decision-making process—for which adequate methods have long been developed in risk research and risk management.

To reduce the agency problem between the shareholders of a corporation and the management (e.g., [76]), corporate law in many jurisdictions provides for a so-called Business Judgment Rule, the main features of which could also be applied to political decisions (e.g., [72,73,75]).

The idea of the Business Judgment Rule is simple: every entrepreneurial activity is associated with risks and, particularly, the effects of entrepreneurial decisions are also uncertain. Entrepreneurial decisions are basically particularly important management decisions under uncertainty, i.e., due to existing opportunities and threats (risks), the effects are uncertain. (e.g., [61,77,78]). However, if risks must be taken, such risks will occasionally materialize and lead to negative deviations from plan, losses or, in the worst

case, insolvency. As a result of the Business Judgment Rule, however, no one should be liable for the misfortune that risks can also occur. To be able to make use of this "liability privilege", however, the German legislator requires careful preparation of decisions ("duty of care") with Section 93 of the German Stock Corporation Act (AktG)—the Business Judgment Rule (e.g., [79]). It is required that the "appropriate information" necessary for preparation is available for all "entrepreneurial decisions". The burden of proof for an appropriate decision lies with the management board, which should accordingly prepare a transparently documented decision. To be able to assume that "adequate information" is available, a decision-preparing risk analysis must particularly show which opportunities and risks are associated with the decision and how the overall scope of risk would change because of the decision (e.g., [61] on the valuation of options for action). In addition, a decision document must state objectives, constraints, possible courses of action, and forecasts of benefits made, with underlying assumptions. Finally, an overall assessment of the various options for action is required, considered the projected benefits and risks (risk-adequate assessment). It is precisely the intention of the Business Judgment Rule to improve the quality of the decision through such well-founded decision preparation and ultimately to achieve the goals of the company and its owners as far as possible.

It is immediately apparent that this logic of the Business Judgment Rule is largely transferable to political decisions. Political decisions, e.g., by the government, are also associated with uncertain effects. The possible defensive behavior mentioned above, which finds a for-ward-looking orientation of a state, can be avoided if a "liability privilege" is made clear in the same way. No politician should be liable for chance, i.e., the effect of luck or bad luck. But analogous to the business judgment rule, this liability privilege should only be granted if political decisions are properly prepared. This is the only way to ensure that the goals of the state and the population are achieved as well as possible, considering existing scarce resources, especially taxpayers' money. In line with the intention of the business judgment rule, it is also an imperative for the state to use scarce economic resources as efficiently as possible to achieve its goals (whatever those goals may be). In principle, political decisions under uncertainty are no different from management decisions under uncertainty—although in the case of the former, political economy has taught us that politicians take into account their implications for election results in addition to factual considerations. But it is precisely such purely "electoral" considerations that can at least be contained by proper and transparent preparation of decisions. The challenges and contents involved in preparing political decisions, which are detached from electoral calculations, are largely identical to those involved in business decisions under uncertainty. It is a matter of clarifying the objectives, pointing out the options for action as well as their expected effects and, of course, the risks associated with them (see [75] with the case study EU vaccine procurement policy). As with strategic management decisions, an option for action may well be associated with a specific increase in certain risks, with the aim of reducing other and higher risks.

4.3. Limitations: Information, Economic Calculation and Ownership

There are some factors that limit our analysis. It should be pointed out that politicians always face the fundamental information problem in a society [80,81]. Because of the decentralized nature of this knowledge [78], central planning is inconceivable in purely theoretical terms, what also makes an economic calculation in socialism impossible ([82–84], for a brief overview on this debate see [85] (pp. 7–10). In this respect, the costs of a decision cannot be determined a priori, because these only arise in competition on a market, i.e., they must be discovered (see e.g., [86,87]). As we have already emphasized in Section 2, political actors are faced with incomplete and asymmetric information. However, the knowledge problem is not the only obstacle within political decision-making. If we neglect the incompleteness of information and also drop the assumption of self-interested or even opportunistic behavior, we are left with a property problem that cannot be avoided (e.g., [88,89]). A meaningful cost-benefit, i.e., economic calculation, which includes a risk

assessment, requires the unification of the rights of disposal of property on the decision-maker (the politician), which is by definition not given in a democracy [90]. (Subjective) valuation is always based on the individual opportunities available to the owner of a good [82,91]. However, a government that merely "manages" assets within their legislature can neither know nor evaluate these opportunities. It is simply impossible to calculate costs and benefits for political actors. In our case: the opportunities of further investments in nuclear power plants can therefore hardly be assessed by the government in terms of the costs and benefits associated with a phase-out of nuclear power because the government does not hold the property rights to the power plants. This does not mean, however, that it would make sense to nationalize nuclear power plants, since there would then be no market at all and thus no prices as indicators [82,91].

If there is no sufficient economic criterion against which the decision must be justified, this opens up discretionary potential for political actors, which is also exploited under the condition of voter maximization. Since we have the government's position as administrator as the legal status quo, we can only try to reduce the discretionary potential through appropriate institutions. One possibility, for instance, is the politician liability addressed here. Even if we take the theoretically justified objections seriously, our focus in this paper is primarily on applied political decision-making. Therefore, we try to approximate the arising costs and benefits in a heuristic way.

5. Conclusions

The aim of our case study is explicitly not to judge whether and in what form the energy turnaround and a phase-out of the use of nuclear energy in Germany make sense. Nor it is intended to provide a well-founded and objective assessment of the risks associated with the use of nuclear energy on the one hand and those of the energy turnaround on the other, e.g., via a conceivable reduction in supply security.

Instead, we want to focus the political decision under uncertainty, which the German government took already three days after the nuclear catastrophe in Fukushima. Essential for every decision and for political decisions particularly is only the information that has been newly added by the nuclear disaster in Japan. Due to the information situation on the day of the announcement of the nuclear moratorium (14 March 2011) by the German government and the speed of the decision only three days after the accident in Fukushima, it is easy to see that a change in the perception of risks can be assumed as the reason for the decision. As a finding from the case study, we suggest that certain institutions within the political decision-making process are needed to push governments to make certain decision preparations and to conduct a risk analysis. One such institution is known from corporate law. Following Follert [72,73], and Gleißner et al. [75], we therefore propose to introduce a corresponding *Political Judgment Rule*, which has the effect that political decisions are necessarily made based on appropriate information and risk analysis. A comparable case to the nuclear phase-out decision discussed in this paper could be the so-called new *Klimaschutzgesetz* [92] (climate protection law) that was hastily introduced after the judgment of the German federal court, which claimed missing climate targets after the year 2030. Here, future research will have to investigate to what extent an adequate assessment of the resulting risks was made by the political decision-makers. Nevertheless, a fundamental problem arises in decision-making by democratic politicians. They are not the owners of the goods they are supposed to valuate in their decisions, so that an economic calculation is not possible. In this respect, the only goal can be to reduce the resulting discretionary potential through appropriate institutions.

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