Evaluating the effect of local monitoring on nuclear safety: evidence from France

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March 7, 2017

Abstract

This paper empirically studies the effect of monitoring intensity on safety care and non-compliant behaviour in French nuclear power plants. To do so, we analyse the consequences of a French policy enacting the monitoring of nuclear power stations by dedicated local agencies. Our analysis uses a dataset of safety incidents reported by French nuclear operators between 2007 and 2015, and local data describing the intensity of their monitoring agency. Our strategy first disentangles the effects of monitoring on safety care and on non-compliance with regulatory declaration standards by restricting to a subset of systematically detected and reported events. We also address the endogeneity of local incentives by using two instrumental variables: variation of political preferences and forecasting mistakes in department-level revenues. Our early results show that the incentives provided by local monitoring do not induce higher safety care levels, but significantly reduce non-compliance with declaration guidelines. A 30.000€ increase in the annual budget of a commission leads, on average, to a 10% increase in the number of events reported.

Keywords: nuclear power, safety, threat of regulation, local monitoring, transparency, incident data.

1 Introduction

Nuclear power plant operators have an inherent incentive not to comply with stringent declaration rules. In particular, the declaration of a significant decrease in safety might

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lead to more stringent and costly regulations or to public backlashes.[1] At the same time, empirical evaluations point out that non-compliance with regulatory rules might significantly increase the rate of abnormal activity in a nuclear reactor, see e.g. Feinstein (1989). This raises the question of how to design regulatory oversight in order to minimize non-compliance and increase safety.

In this paper, we empirically study the effect of local incentives (RI) on safety and non-compliance in French nuclear power plants. Despite the importance of this question, it has remained largely unanswered by the literature. Its empirical evaluation is hampered by three major problems. The first one, inherited by the general specifics of empirical evaluation of nuclear safety, is the one of data scarcity. In particular, severe nuclear accidents are very rare, so that proper statistical analysis in this context is hardly available. The literature has dealt with this issue by either using Bayesian methods in the context of technical probabilistic risk assessment (Rangel and Lévêque, 2014), or by using extended datasets with accidents from other fields, such as those occurring in nuclear fuel-cycle facilities (Sovacool, 2008; Hofert and Wüthrich, 2011; Burgherr and Hirshberg, 2014; Wheatley et al., 2016a,b). The second problem stems from the unobserved nature of non-compliance. Non-compliance is economically meaningful only if perfect observability of the behaviour of the agent by the principle is not feasible. This implies that information about non-compliance can be obtained only through detected non-compliance, and this measure is potentially prone to endogenous measurement error. This potential endogeneity source is common to all empirical studies on non-compliance, see Block and Feinstein (1986); Feinstein (1989) and Eckert and Eckert (2010). Finally, the stringency of regulatory rules is partially determined by perceived safety. As a result, safety effort (and non-compliance) and safety regulation are jointly determined, which might induce a simultaneity bias in the estimation.

We contribute to the literature on nuclear safety and non-compliance in several ways, with a particular focus on the three aforementioned problems. First, we use a rich novel dataset on declared safety incidents in French nuclear power stations.[2] These safety incidents, although of small magnitude, represent significant deviations from normal activities and are therefore associated with a decrease of safety.[3] For this reason, their declaration by the operators to the nuclear safety authority is mandatory. An important feature of these events is that they might remain undetected by the operator because of their limited real consequences, and that higher detection rate is associated with higher cost. In addition, the operator might have an incentive not to declare all events if she faces the probability of an introduction of more stringent (and hence costly) rules by the regulator (threat of regulation). We merge the data on safety incidents with local nuclear production data and data on local incentives. In particular, a political reform

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[1] Anecdotal example is the invasion of the French reactor Fessenheim by Greenpeace in 2014, after it became public that the operator has dramatically understated the magnitude of an accident that happened in early 2014.

[2] A precise definition of these events is given in the next section. Our strategy of using such events is related to the paper of Hausman (2014).

[3] Through a process of case-by-case scenario analysis performed by the operator and the regulator, an incremental probability of nuclear core meltdown is associated to each of these events.

passed in 2006 introduced mandatory monitoring agencies in all French departments that host nuclear power facilities.[4] These agencies, also referred to as local information commissions (or CLIs), have a direct access to the documentation of the power stations, can conduct expertise missions to challenge the operators, and organise regular meetings with the operator during which safety issues are discussed. The budget of a commission can be used as a measure for the intensity of local incentives. When analysing the effect of local incentives on non-compliance and safety, the rich heterogeneity in the size of these budgets provides a powerful source of identification.

Second, to disentangle the effects of local incentives on effort and non-compliance, we restrict in a first step the empirical analysis on a subset of events for which one of the effects is precluded. In particular, we look at automatic shut-downs of reactors, a type of events that is automatically registered and reported. Due to resulting changes in the production of electricity, this type of events cannot i) remain unregistered by the operator, and ii) be hidden from the regulator. Therefore, non-compliance is not possible for this subset of events. As a result, the effect of local incentives on effort is identified for this subset. In a second step, the estimated effect on effort can be subtracted from the total effect of local incentives on effort and non-compliance on the whole sample which results in an estimate for the partial effect on non-compliance. This approach is related in spirit to the control function approach in econometrics, see Wooldridge (2015). More fundamentally, the identification is related to the back-door-criterion in causality, see for example Theorem 3.2.2 in Pearl (2000) for a formal definition. Conditioning on the estimated impact of local incentives on effort effectively "closes the back door" of the flow of information from local incentives to observed events, which provides the identification of the non-compliance channel.

Third, we deal with the endogeneity of local incentives by using two different instrumental variables (IV). The first IV is based on geographic variation of political preferences. In particular, we use the share of green votes in departmental elections as an instrument for the size of the CLI's budget. Higher share of green votes is likely to be associated with a higher aversion towards nuclear power and hence a higher budget of the local agency. Although political instruments have been criticized in recent empirical studies as being prone to endogeneity, the specific features of the French nuclear market and regulation allow for a convincing defence of this instrument. First, the variation of small safety accidents is unobservable to the population, and hence reverse causality can be safely excluded. Furthermore, the instrument has also no direct effect (that is, other than through the CLI) on the safety policy of the operators through e.g. political pressure, as the major decisions about safety are made at a central level by EDF, the single owner of all French power stations. Our second instrument is based on a natural experiment triggered by forecasting mistakes. Specifically, we use the difference between the forecast and the realized annual financial revenue of the department. This forecasting error has several attractive features. First, a forecasting error, once realized, might lead

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[4] Most of these departments had already created such agencies before 2006, on a voluntary basis. The law made the existence of these agencies mandatory in all departments hosting either nuclear reactors or fuel-cycle facilities.

to a reassessment of the forecast for the current or coming fiscal year, and thus induce a change in the budget of the commissions. Second, such a forecasting error is almost per definition unanticipated, which prevents endogenous forward-looking behaviour of the local authorities. Finally, the source of the error is simply a financial miscalculation due to overall uncertainty or human failure related to tax returns, and thus it can be argued that it is not related to the unobserved factors affecting compliance and safety at the operator level. It is the second and the third property of these errors that qualify them as a natural experiment. This IV is similar in spirit to the natural experiment used in Bressoux et al. (2009), who utilise random administrative mistakes to instrument for the endogenous assignment of teachers to schools in France, and also to Bonev et al. (2017), who utilise random technological failures in heating services as an instrument for customer complaints. In all three cases, the source of exogenous variation is unforeseen random failures.

To the best of our knowledge, Hausman (2014) and Feinstein (1989) are the only two papers that analyse the impact of economic and local incentives on safety and noncompliance. Hausman (2014) identifies the effect of market deregulation in the U.S. on the safety levels of some nuclear reactors. Her proxy for safety consists of automatic reactor shut-downs and is thus closely related to our our identification strategy. Our main focus, however, is on non-compliance instead of safety and we use the subset of automatic shut-downs only to disentangle effort from non-compliance in a back-door-identification-type strategy. Feinstein (1989) uses data on inspections of US power plants to study the factors of non-compliance and the effect of non-compliance on safety. His identification depends crucially - much in the spirit of the time in which his paper was written - on strong parametric assumptions on the distribution of the unobservables. These assumptions, however, are not guided by economic theory and are in this sense rather arbitrary.

Our main results are that local incentives such as monitoring do not induce higher safety efforts and detection of events, but significantly reduce non-compliance. In particular, a 30.000€increase in the annual budget of a commission leads the operator to report one additional safety incident. Our results are robust to a variety of specifications. While the non-significant impact on safety contradicts the findings of Hausman (2014), the negative effect on non-compliance is in line with the findings of Feinstein (1989).

2 Institutional set up

2.1 Nuclear-power safety in France

The French nuclear fleet is constituted of 58 reactors, located in 19 sites, owned by a single utility, EDF. In the following of this paper, we will often refer to the management of each nuclear station as *the nuclear operators* . This abuse of language is motivated by the observation that many decisions, including the decision to report safety incidents, are left to the discretion of the management of each station.

The fleet is regulated by a safety authority (ASN in the following) who sets technical and procedural standards regarding the construction, operation and maintenance of the nuclear reactors. The regulator also defines a list of situations described as significant for safety. Upon the detection of such a situation, a nuclear operator is compelled to declare the situation to the safety authority. This declaration mechanism aims to foster spillovers across reactors, or to detect generic design weaknesses or organizational failures.

The reports made by the operators are audited several times a year by the regulator, during planned or unplanned inspections. In particular, inspectors have access to all the situations which were detected by the operator, but not deemed significant enough for declaration.[5] For any event, if the inspectors disagree with the judgement of the operator, they may require the operator to declare the event. Though, this mechanism includes no clear sanction when a non-compliant behaviour is detected by the regulator.

Safety incidents are much more numerous than large scale accidents, but their consequences are also much less severe. The incentives for the operator to exert sufficient effort in their detection, and to declare them transparently, are thus unclear. Indeed, declaring events can have good consequences for the operator, as it can be understood as a signal of transparency and compliance by the regulator. On the other hand, declaring too many events can also be understood as a signal of poor safety. The incentives faced by plant managers seem to be countervailing, as both transparency and safety may be valued by the regulator. Therefore, identifying safety variations and variations in transparency from the changes in the annual reports of safety events is the first issue faced when studying these event reports.

2.2 Local monitoring

In a note circulated in 1981 to the local representatives of the French State, French Prime Minister Pierre Mauroy argued in favour of the creation of local commissions dedicated to the monitoring of risky energy generation facilities[6]. This suggestion was motivated by the need to satisfy a "necessity to promote a real sharing of responsibilities among the local collectivities, the regions, and the State, with respect to the information of local populations [regarding the nuclear risk]"[7]. In 2006, a law made the existence of these monitoring commissions compulsory in all French departments[8] hosting nuclear power stations or fuel cycle facilities.

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[5] One may argue here that operators may simply hide the detection of an undeclared significant event, for inspectors not to be able to discover them during the inspections. This is actually not the case because significant safety events are the upper layer of a two-layer declaration process. Other events, of even more minor nature, have to be reported. Inspectors may thus look for significant safety events among these "interesting" safety events.

[6] This occurred one year after the Saint-Laurent-des-Eaux partial core melt down, and two years after the Three Mile Island nuclear accident.

[7] Translation provided by the authors. The original note in French can be downloaded on this website: http://www.cli-gravelines.fr/Services-en-ligne/Espace-documentaire/Documents-a-telecharger/Les-textes-reglementaires/Circulaire-MAUROY-du-15-decembre-1981.

[8] France's administration is organized in several levels below the national government. The French territory is first divided into thirteen administrative regions. Regions are then divided in a total of a hundred departments, which are divided in over thirty-six thousands counties.

These monitoring commissions are composed of four categories of members: elected officials, members of local environmental associations, members of EDF's workers unions, and competent inhabitants, such as scientists, doctors or members of the local chamber of commerce.[9] These members are not remunerated for their participation, and some restrictions regarding the composition of the commissions are set by law. Elected officials must represent at least 50% of the commission, while each of the other three groups has to account for at least 10% of the members.

The activities undertaken by the commissions are characterized by large heterogeneities. They are first required to organize at least two meetings a year, during which the local operator and the safety authority present the main recent actions undertaken in the station to the commission members. The commission may ask for specific questions or topics to be addressed during the meetings. To prepare these meetings, commission members are provided with a set of documents regarding the operation of the nuclear facility. In particular, they receive an account of the occurrences of significant safety events within each reactor of the power station. The press is in general invited to these meetings, which may or may not be open to the public.

Monitoring commissions can also engage in other types of missions. First, most commissions organize the diffusion of the information through dedicated websites. Some commissions participate in a wider diffusion by publishing communication materials that are available in city halls or mailed to local dwellers. A minority of commissions even organize additional open meetings for interested local inhabitants, and invite local populations from neighbouring countries[10]. These features are becoming more common, as France's 2015 energy law made them mandatory. Finally, local commissions can carry out independent missions of expertise regarding some aspects of the operation of the plant, or make public statements regarding some decisions made by operators or the safety authority. Commission-members are sometimes invited by the authority to participate in the inspections of the power stations.

The commissions are funded by the French departments, as well as by the Nuclear Safety Authority. The ASN's policy regarding these funding consists in matching the endowment granted by the Department. Hence, as commissions are endowed with very heterogeneous allowances, some large heterogeneity arises within the budgets of the commissions, which can spread between 10,000€/year to more than 150,000€/year. This partly explains why some commissions can afford to mandate counter-expertise missions, while other commissions only organize two annual meetings. The observation of this heterogeneity constitutes an additional motivation for this research, as one can wonder what the socially optimal level of investment in a local monitoring commission is.

By conducting missions of expertise regarding the impact of a power station on the environment, or on public health and safety, and by having the operator to challenge their results, we hypothesize that local commissions somehow participate in the extraction of the private information of the operator. By doing so, they may help reduce the informa-

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[9] Additional examples can be found on the website of the commission of the Paluel and Penly nuclear power stations.

[10] Some French power stations are close to the Belgian, German and Swiss borders.

tion gap between the regulator and the operator, allowing the former to shift the outcome of its contractual relation with the latter from a second-best level of effort towards its socially optimal level. In order to measure this level of threat, we use the annual budgets of the local commissions, as commissions endowed with larger allowances will be able to engage in more numerous actions dedicated to the oversight of the operator's actions. It thus seems fair to make the assumption that more budget means more threat.

On the other hand, budgets are allocated by department councils, some members of which are also members of the local commissions. Therefore, it can be argued that the budget variable is endogenous due to potential reverse causality. In other words, an increased intensity of monitoring may lead a nuclear operator to modify his behaviour, but the monitoring intensity may also be fostered by the awareness of the department officials that a nuclear power station has an abnormal level of declaration of events. This is the second identification issue discussed in the next paragraphs.

3 Identification strategy

3.1 Formal description of the setup and hypotheses

To formalize our analysis, suppose that an agent A (he) runs a utility for which there are safety standards imposed by a principal P (she). Denote by E a binary random variable that indicates whether a safety-relevant event (incident) has occurred ($E = 1$) or not ($E = 0$). For now, we subsume all types of events under E regardless of their severity. Denote by O the binary random variable which indicates whether the operator observes an event, $O = 1$. To make an important distinction, $O = 1$ means only that the operator *thinks* that there has been an event, so $O = 1$ does not automatically imply $E = 1$. Further, the operator A might declare an event to the regulator P, $D = 1$, or make no declaration $D = 0$. For now, we do not require that $D = 1$ implies $O = 1$. More important, an operator can observe an event, $O = 1$, and hide it from the regulator, $D = 0$.

The principal gathers information on events with the purpose to ensure higher safety s, which the agent can increase by increasing his level of effort e:

$$\frac{\partial s}{\partial e} > 0. \tag{1}$$

This increase of effort might mean hiring additional staff to supervise and maintain the facility, or investing in new technology to observe and analyse the operational activities. In both cases, we assume that higher effort would also lead to a higher detection rate $d := P\{O = 1 \mid E = 1\}$.[11]

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[11] In this framework, we differentiate safety s from safety care, or effort, e. This difference is often made in the economic literature on moral hazard and safety regulation, where s usually stands for the probability of an accident and e for the level of effort exerted by a firm to avoid the accident. When considering nuclear power, the difference between e and s becomes unclear, as the hopeful rareness of accidents impede a statistical assessment of s. For instance, the International Atomic Energy Association

If she observes too many events, or detects bad practices during routine or unplanned inspections, the principal might issue new safety standards or fine the agent for bad operation management. Both cases would induce a cost f for the agent, which might create adverse incentives for the agent in the sense that he might not declare all events in order to avoid regulation. Denote by q the declaration rate of the agent, $q = P\{D = 1 \mid O = 1\}$. The adverse incentives provided by the threat of regulation can be formalized as:

$$\frac{\partial q}{\partial f} < 0. \tag{2}$$

In addition to his interaction with the principal, the agent is also monitored locally by a commission. The commission can both communicate with the population on the activity of the operator, for instance through periodic reports, or accident prevention campaigns; and conduct independent inquiries regarding the effect of the activity of the operator on the overall safety of his plant.

Denote by i the intensity of the monitoring. Local monitoring has two potential effects. We make the assumption that a commission whose activity is more intense will be more likely to communicate on observed non-compliant behaviours, enhancing the probability of a public backlash, or increasing the probability that the regulator will set more stringent standards. In any case, we assume that increasing the intensity of the commissions' monitoring activity will increase the costs faced by operators when choosing to adopt non-compliant behaviours.

Therefore, the intensity of monitoring can affect the observed declaration in two ways. First, it might reduce the probability that the operator will hide an observed event:

$$\frac{\partial q}{\partial i} \geq 0. \tag{3}$$

Second, by identifying bad management or additional safety concerns, the activity of the commissions can induce higher effort from the agent:

$$\frac{\partial e}{\partial i} \geq 0. \tag{4}$$

As a result, higher intensity of monitoring could lead to a better detection of events,

$$\frac{\partial d}{\partial i} \geq 0, \tag{5}$$

and to a higher safety,

$$\frac{\partial s}{\partial i} \geq 0. \tag{6}$$

Therefore, there are two different channels through which the intensity of monitoring i can change the number of observed events Y: through a reduction of non-compliance (Channel 1) or through higher effort (Channel 2). This relations are depicted by the causal graph in figure 1.

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defines nuclear safety as the set of systems, equipments and procedures which reduce the likelihood of major core-meltdowns, or mitigate their consequences. Hence, according to this definition, exerting more effort dedicated to these systems, equipments or procedures, consists in an increase of nuclear safety.

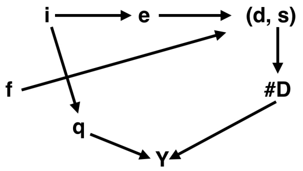


Figure 1: Intensitiy of inspection and safety events declaration

Here, $\#D$ is defined as the number of detected events (by the agent). A directed arrow represents a causal relation, with the direction of the arrow corresponding to the direction of causality. Our primary interest is to evaluate Channel 1, i. e. to test the hypothesis (3). The variable i is proxied by the budget of the local inspector, something we elaborate on in section 4.

3.2 Identification problems

There are two main problems for identification in our setup. First and most important, the rate of declaration q and the effort level e are unobservable to the regulator (and hence, to the econometrician). q is per definition not observable because non-compliance is possible only as long as it is not observable to the principal. One possible proxy for the level of effort e is the number of employees in relation to some size parameter of the reactor. The number of employees per reactor and time period, however, is not available to us from publicly available websites or from the information records that we obtained from EDF. To see why this is a problem for identification, write

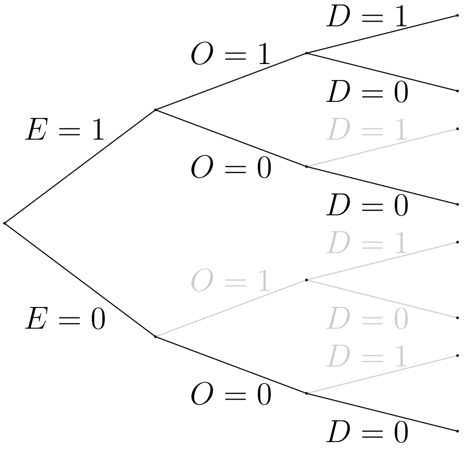
$$\frac{\mathrm{d}Y}{\mathrm{d}i} = \frac{\mathrm{d}Y}{\mathrm{d}q}\frac{\mathrm{d}q}{\mathrm{d}i} + \frac{\mathrm{d}Y}{\mathrm{d}e}\frac{\mathrm{d}e}{\mathrm{d}i}, \tag{7}$$

where $\frac{\mathrm{d}Y}{\mathrm{d}i}$ is the total effect of i on Y and the summands on the r.h.s are the two mediation channels. Any change of Y which is due to a change in i can be either through the non-compliance channel ($i \to q \to Y$) or the effort channel ($i \to e \to (d, s) \to Y$). Since, however, we are not able to close any of the possible information paths from i to Y, we do not know how the total effect is split into the two mediation effects. This is a fundamental problem for identification. We refer to it as the *Channel problem* .

Second, an identification problem that formally and logically precedes the Channel problem is the identification of the total effect (that is, regardless through which mediation channel) of i on Y. This problem stems from two potential endogeneity sources. First, the budget variable is potentially endogenous due to reverse causality: a local commission may have a high level of activity because the department council is aware that the power station has an abnormal level of declaration of events. Reverse causality would induce endogeneity of the instrument in the first stage. Second, the incentives provided by the regulator (f) might be related to the intensity of the monitoring i. In a period of intensified political and public debate, for example, both the threat of new regulation f and the expenditures for local monitoring might be increased. Since we do not measure f, i could be endogenous due to an omitted variable bias (OVB). This threat to identification is represented in the causal graph 1 by the inverted fork $f \rightarrow q \leftarrow i$. We refer to the first endogeneity problem as to the Reverse causality problem, and to the second as to the OVB problem.

An additional concern arises from the information content of Y about the rates q and d. In particular, variation in Y might pick up not only variation in q and d, but also an additional source of error, which we for simplicity - and in a slight abuse of statistical terminology - refer to as the type-I error source. It considers the probabilities that an event might be wrongly detected, $P\{O = 1 \mid E = 0\}$, and that declaration might be done without a detection, $P\{D = 1 \mid O = 0\}$. Clearly, these two possibilities can be treated as errors and not as the result from a deliberate decision, as there are no incentives that induce such behaviour. The noise in the data that might result from these possibilities, however, makes the interpretation of the results less clear. In addition, if the second type-I error $(D = 1 \mid O = 1)$ arises because of intensified inspection, then this will lead to a downward bias of the effect of i on the rate of non-compliance. According to experts from both EDF and ASN, however, the nature of the detection and declaration process do not allow for these type of errors. Indeed, the declaration process involves a detailed reporting procedure, during which the regulator verifies that every reported event is properly reported. We therefore assume that M1) $P\{O = 1 \mid E = 0\} = 0$ and M2) $P\{D = 1 \mid O = 0\} = 0$. The possible outcomes under these two assumptions are depicted in figure 2.

Figure 2: Event tree of the generating process of reported events



Given the representation of the declaration process described on figure 2, we can state the Channel identification problem in simple terms. First, define safety s as $s = P\{E =$

$0\}$. Under M1 and M2, we have

$$\begin{aligned}
P\{D=0 \mid E=1\} &= P\{D=0 \mid E=1, O=0\}P\{O=0 \mid E=1\} \\
&\quad + P\{D=0 \mid E=1, O=1\}P\{O=1 \mid E=1\} \\
&= 1.(1-d) + (1-q)d = 1 - qd,
\end{aligned}$$

and

$$\begin{aligned}
P\{D=0\} = & \qquad P\{D=0 \mid E=0\}P\{E=0\} + P\{D=0 \mid E=1\}P\{E=1\} \\
= & \; 1.s + P\{D=0 \mid E=1\}(1-s) = s + (1-qd)(1-s) = 1-(1-s)qd,
\end{aligned}$$

so that

$$P\{D=1\} = (1-s)qd. \tag{8}$$

Expression (8) has a straightforward interpretation. First, observable data depends on the three main factors safety, the detection probability and the rate of declaration q. Second, holding q and d fixed, more safety leads to fewer observed events ("observe" is used here from the regulator/econometrician perspective, and is equivalent to "declared"). Third, holding the safety constant, both higher declaration rate and higher detection rate lead to more observed events. Thus, equality (8) is closely related to the fundamental Channel identification problem formulated in equation (7).

3.3 Solutions to the identification problems

3.3.1 The channel identification problem

We deal with the Channel identification problem by identifying a subset of events for which one of the channels of information is closed. This subset consists of the two subcategories of events Automatic Shut-Downs of reactors (ASD) and Unplanned Uses of Safeguard mechanisms (SFG). These two types of events were identified jointly with the safety authority and the operator as being subject to perfect (quasi-automatic, as the name suggests) detection and declaration due to their importance, the specifics of their technical parameters and impact on the electrical output.[12] As a result, for this subset of events, $q = 100\%$ and $d = 100\%$. Hence, any variation in Y due to variation in i is mediated solely through variation in e and s. This is depicted in Figure 3.

Comparing figures 1 and 3, the main difference is that Channel $1(i \to q \to Y)$ is omitted in figure 3. In addition, there d is depicted as equal to 1.

Knowledge of the effect of i on safety s can help identify the two mediation effects under additional assumptions. Denote the subset of events consisting of the ASD and SGD events by Type 2 events, and all other events (for which Channel 1 is not closed) by Type 1 events. The probability of occurrence of events of type k is denoted by $1-s_k$, and

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[12] Automatic shut-downs for example have an impact on the electrical output of the power station, and are thus impossible to hide. Events requiring the use of safeguard mechanisms are deemed particularly severe by the authority, and inspectors carry out specific efforts for their detection during routine and unplanned inspections.

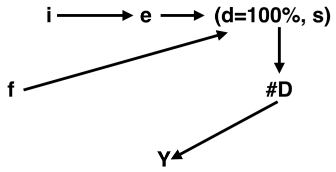

Figure 3: Intensitiy of inspection and safety events declaration for Type 2 events.

their detection rate by d_k. The level of effort exerted in order to limit their occurrences is denoted by $e_{s,k}$, while the effort exerted to detect events of type k is denoted by $e_{d,k}$, $k = 1, 2$. Our assumptions can be stated as follows.

Assumption EE (effective effort): $\frac{\partial s_k}{\partial e_{s,k}} > 0$.

Assumption CE (common effort): a) It holds $e_{s,1} = e_{d,1} = e_1$. b) In addition, $e_1 = e_2 = e$.

Assumption EE is a mild assumption which only requires that the effort carried out by the operator have an effective impact on the real probability of occurrence of safety events. In other words, we assume that the operator does not waste his resources into unnecessary or ineffective safety efforts.

Assumption CE-a is valid when common technological and labour resources are employed to decrease the probabilities of occurrence while increasing the detection rates for the first type of events (this assumption is not required for Type 2 events as the detection there is automatic and the detection rate is 100%). In other words, we assume that effort for safety and effort for detection are perfect complements.

Assumption CE-b states that both efforts spent on increasing safety for a type of event can be regarded as a common effort. Once again, this boils down to assuming that efforts dedicated to Type 1 and Type 2 events are perfect complements. The rationale for this hypothesis is that exerting efforts dedicated to one type of events may have positive spillovers on the other type of event. Indeed, when exerting effort requires to hire new workers or to better train others, to invest in new equipments or to design new measures for the oversight of the station, it can be argued that these changes will not only affect one particular category of safety events, but the overall level of safety of the power station.

CE-b is the most crucial assumption in our identification strategy, and could be challenged by the fact that nuclear operators have some monetary incentives to focus their efforts on specific safety events. For instance, as automatic shut-downs stop the production of electricity of a nuclear reactor, they directly reduce the profits of the operator. Specific efforts dedicated to limiting their numbers could thus exist. In the results section, we discuss the potential consequences of violations of these assumptions on our conclusions.

Under CE (and M1 and M2), identification of $\partial q/\partial i$ can be achieved when the intensity of inspection i has no impact on security s_2. In particular, if $\partial s_2/\partial i = 0$, then due to assumption EE, it must be that the inspection intensity does not increase effort, $\partial e_{s,2}/\partial i = 0$. However, as effort is considered common across types of events and across types of safety and detection activities (assumption CE), we necessarily have that $\partial e_{s,2}/\partial i = \partial e/\partial i = \partial e_{d,1}/\partial i$ and hence $\partial d_1/\partial i = 0$. We summarise this finding in the following proposition.

Proposition 3.1 (Closing of Channel 2) *Suppose that* $\frac{\partial s_2}{\partial i} = 0$. *Then under assumptions M1-M2, CE and EE, it holds*

$$\frac{\partial d_1}{\partial i} = 0. \tag{9}$$

With this proposition, identification of the causal effect of i on q is straightforward because any variation in Y caused by a variation in i can be only mediated by q. We state this result in the following corollary.

Corollary 3.3.1 (Identification) *Under the assumptions of proposition 3.1,* $\frac{\partial q_1}{\partial i} = 0$ *is identified and it holds*

$$\frac{\partial q_1}{\partial i} = \frac{\partial Y}{\partial i}. \tag{10}$$

The proof is straightforward and follows from equation (7).[13]

3.3.2 Endogeneity of the monitoring intensity

A second identification issue raised in the introduction is the potential endogeneity characterizing the measurement of the intensity of the monitoring performed by the local monitoring agencies. To measure this intensity, we use the yearly budgets granted to these agencies, which are constituted of a subsidy from the nuclear safety authority, and of a second subsidy granted by the departmental councils. In any French department, the department council gathers the elected representatives from each county that constitute the department.

This budget may be an endogenous measurement of the intensity of the monitoring for two reasons. The first issue is reverse causality, as some elected officials sit in both the department council and the monitoring commission, the subsidies granted to a commission may be influenced by the prior declarations of safety incidents. Second, it can also be argued that safety efforts and monitoring budgets are simultaneously determined by two players, based on their anticipations of one another's decisions.

To circumvent the potential biases due to this endogeneity, we use two instrumental variables. The first instrumental variable is based on local variations of political preferences. More specifically, we define a *green* instrument as the quantity of counties in which a candidate from the French green party was listed during the first round of the past county-level elections. This instrument is supposed to capture the aversion of local

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[13] Heuristic explanation why $\frac{\mathrm{d}Y}{\mathrm{d}q} = 1$: Suppose that the total number of observed events is n_O, and that the total number of declared events is n_d. Then, $q = n_d/n_O$ can be one of $(0, 1/n_O, \ldots, 1)$. The "step" is $1/n_O$. $\frac{\mathrm{d}Y}{\mathrm{d}q}$ gives precisely the change of Y when q changes with 1 step. But a one step change in n_d/n_O is precisely equal to a unit change in Y. Therefore, $\frac{\mathrm{d}Y}{\mathrm{d}q} = 1$.

populations towards the use of nuclear power, and hence the incentives of their representatives at the department councils to grant large subsidies to the monitoring conditions. A second motivation for this specification of the *green* variable is the fact that, even if green candidates are not elected, it may be easier for them to lobby their interests when they are more numerous in a given a department. On the other hand, political instruments have been criticized recently as being prone to endogeneity (see e.g. Lewis-Beck et al. (2008); Pickup and Evans (2013)). Yet, the French nuclear industry is characterized by specific features which allow to defend the instrument. First, reverse causality is excluded as declarations of significant safety events are not observable to the population. Furthermore, as environmental associations and elected officials are members of the local commissions, it seems that the instrument cannot have a direct effect on safety policy other than through the commissions' activities, such as local level political pressure.

Our second instrumental variable, *shock*, is based on a natural experiment triggered by forecasting mistakes. More precisely, we use primitive budget data published every year by department councils, in which a forecast of the balance of their revenues and expenditures for the upcoming year is provided. We also use ex-post data on the departments realized financial revenues in order to compute the forecasting errors made by the departments. These errors are attractive in many respects. They are first, by nature, unanticipated, which precludes endogenous forward looking behaviours of local authorities. Second, as these errors are the results of a failure from the local officials to predict accurately the revenues levied by local taxes, it seems fair to argue that this error will be independent from the unobserved factors influencing the commissions' budgets. Finally, failing to predict accurately their revenues may lead local officials to reassess the funding provided to local monitoring commissions. As was mentioned in the introduction, this instrument is similar to the natural experiment used in Bressoux et al. (2009).

4 The data

4.1 Data collection

The data gathered in order to carry out this study originates from three sources: the French Nuclear Safety Authority, the French utility EDF, and fourteen local commissions in charge of the monitoring of the nuclear power stations. Our unit of observation is set at the level of the reactor.year. In other words, our variables describe the important parameters associated with the operation of a reactor during a particular calendar year. Our datasets hence consists in an unbalanced panel of 236 observations of reactor.years, spread across 50 different nuclear reactors and the years 2007 to 2015. As the French fleet contains 58 nuclear reactors, the largest possible dataset that we could have gathered over the same time period would have contained 522 observations. This missing data issue is mostly due to the fact that many commissions could not provide us with financial data prior to 2010. The following paragraphs describe our different variables as well as their sources.

We first gathered data describing the activities of 16 Commissions for Local Information. This dataset was constituted based on the yearly activity and financial reports of these commissions. The dataset hence contains information regarding the yearly budgets obtained by the commissions, e.g. the endowment received from the Department council (*budget*) and the subsidy granted by the ASN (*subsidy*). We also retrieved information regarding the administrative statuses (*status*) and composition of the commissions. We finally gathered data regarding the frequency of their meetings (*meet*), and whether these meetings are open to the press or the public. We looked for additional counter-expertise studies led or ordered by the commission members. Finally, we tracked-down the commissions which had multiple facilities to monitor (*multiple*), since some nuclear sites in France host more than one nuclear facility.

The *budget* variable is used in order to capture the intensity of the monitoring exerted by the local commission on the nuclear operator. We deem this variable to be a good proxy for the intensity of the commissions as the commissions' budgets are used in practice to conduct missions expertise in order to verify or challenge the information presented by the operator, in order to train the commission-members, or to widen the diffusion of the information gathered during the commission's meetings toward the population. All of these actions suggest an increase in the potential cost for the operator of the monitoring performed by the local commissions. The *meet* and *multiple* variables are time invariant and are used as control variables, along with a specific $saint-laurent$ variable, introduced to acknowledge the specific interests of the Saint-Laurent Commission in the study of safety significant events. These specific efforts may be due to the fact that Saint-Laurent is one of the first station to have been subject to this monitoring scheme after the partial core meltdowns which occurred in 1975 in another plant based on the same site.

In order to construct the instrumental variable *green*, we use a dataset describing the French county-level elections from 2004 to 2015.[14] This dataset contains detailed information regarding these county-level elections, such as the candidates' names in each county, their political party and their local scores. For any given reactor.year, the instrumental variable *green* is constructed as the number of counties within the department hosting the reactor in which a green candidate participated to the first round of the previous county-level election. In both cases, during non-election years, the instrument takes the values corresponding to the preceding elections, which occurred in 2004, 2008, 2011 and 2015. For instance, the values of *green* in 2007 are those corresponding to the 2004 elections.

The second instrument, *shock*, is defined by using public financial data from French departments[15]. More precisely, we used the detailed reports describing both the anticipated and realized budgets for each department hosting a nuclear power station. These budgets include two main sections: revenues and spendings, whose total are equal. Within the each section of these budgets, one can find two main categories: investment revenues/expenditures, and operating revenues/spendings. Both categories are separated: investment revenues can only finance investment expenditures, while operating revenues

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[14] This dataset was provided to us by the French Network for Social Sciences Data (Quetelet).

[15] Yearly datasets are publicly available on the French website dedicated to the finances of local territories. This website is accessible here

are used to finance operating expenditures. Operating budgets account for approximately 85% of the budget of the French departments. Yet, it appeared from a careful analysis of these datasets that the total forecast error is mostly driven by the investment revenue forecast error. Though, subsidies granted to the monitoring commissions are part of the operating budgets of the departments. Therefore, the $shock$ variable was thus defined, for each reactor and every year between 2007 and 2015 as the two-year lagged value of the operating revenue forecast error. The two-year lag is introduced as realized budgets are usually published with a one-year delay. This suggests that forecasting errors may affect the decision to subsidize local monitoring commissions after two years.

As a proxy for nuclear safety, we use a dataset obtained from the Nuclear Safety Authority which gathers the significant safety events reported by EDF. Although these events only have minor consequences, their number is substantially larger than the number of nuclear accidents. This dataset indeed contains over 19.000 safety events, declared between 1973 and 2015 in currently operated power stations. Nevertheless, we will restrict this dataset to the period 2007-2015, in order to match our data regarding the local commissions' activities.

We focus on counts of events annually declared in the French reactors. In order to implement the strategy described in the identification section, several counts of events will be considered: the count of all events declared during a reactor.year (ALL), and the count of events declared during a reactor.year which are not subject to detection or declaration failures (SDD). Within this set of events which are systematically detected and declared, we will distinguish two subcategories of events: automatic shut-downs (ASD) and unplanned uses of safeguard mechanisms (SFG). These two types of events were identified jointly with the safety authority as being subject to perfect detection and declaration. Automatic shut-downs have an impact on the electrical output of the power station, and are thus impossible to hide. Events requiring the use of safeguard mechanisms are deemed particularly severe by the authority, and inspectors carry out specific efforts for their detection.

In order to control for the various differences across reactors that may also explain the occurrences of safety events, we rely on two datasets obtained from the Nuclear Safety Authority and the French utility EDF. These datasets contain detailed information regarding the annual levels of electricity produced per reactor ($energy$), as well as information regarding their unavailability. Data regarding unavailability can be separated in two categories: data on planned unavailability, such as the length of the reactors' scheduled shut-downs for maintenance ($maintenance$); and data regarding the unplanned unavailability, such as the share of electricity lost due to overruns in the maintenance schedules ($overruns$).

In addition, we construct several variables that account for the history and technological design of the reactors. In order to capture possible learning-by-doing effects, we introduce two dummy variables $FOAS$ and $FOAK$, which respectively describe the first reactors built within each site, and the first reactors built within each kind. The different kinds of reactors are captured by three dummy variables: $900MW$, $1300MW$ and $1450MW$. These variables match the nominal power of the three types of reactors that constitute the French fleet. When added to our empirical specifications, these variables can be understood as “type” fixed-effects. As a robustness check, we can also define “design” fixed-effects as dummies corresponding to the six different designs of nuclear power reactors. Finally, the age (AGE) of the reactors at the time of observation is also included in the data.

4.2 Descriptive statistics

Table 1: List of variables and descriptive statistics

Variable		**Mean**	**Std. Dev.**	**Min.**	**Max.**
Event counts	ALL	12.856	4.778	2	27
	SDD	1.017	1.13	0	5
	ASD	0.809	0.955	0	5
	SFG	0.208	0.492	0	3
Commission controls	$budget$	52.415	48.146	4	198
	$meet$	2.271	0.446	2	3
	$multiple$	0.169	0.376	0	1
	$SaintLaurent$	0.051	0.22	0	1
Instrument	$green$	16.356	9.44	0	33
Reactor controls	age	28.169	5.659	8	37
	$size$	3.966	1.38	2	6
	$FOAS$	0.559	0.498	0	1
	$FOAK$	0.008	0.092	0	1
	$production$	6.866	1.747	2.165	11.622
	$maintenance$	67.568	49.839	0	279

236 observations in 50 reactors from 2007 to 2015 (522 possible)

These variables are described in table 1. The first four lines describe the counts of events reported per reactor and per year. These variables will be used in the next section as dependant variables. They respectively describe the total number of declaration per reactor.year and the number of declaration of specific categories of events. It is to be noticed that we have $SDD = ASD + SFG$.

The next four lines of table 1 describe the activity of the local commissions. As was announced earlier, the budgets of the commissions varies in the data from 4 000 €/year to 200 000 €/year. Notice also that most commissions only organize two meetings a year, and that only 15% of them have multiple sites to monitor. The next line considers our instrumental variable, *green*, and shows that an average of 16 green candidates were listed during the last four county-level elections in the Departments hosting nuclear power stations.

The final six lines describe our control variables for the local specificities of each nuclear reactor. We can see that the age of the reactors considered in this dataset ranges from 8 to 37, that sites include from 2 to 6 reactors, each of which produced an average of 7 TWh per year over the elapsed period of time. We can finally see that, on average, reactors undergo 68 days of maintenance every year.

Table 2: Declaration of events as a function of local commissions' budgets

	$budget \leq 50k€$		$50k€ \leq budget \leq 100k€$		$100k€ \leq budget$	
	mean	N	mean	N	mean	N
ALL	13.5	148	12.4	56	10.6***	32
SDD	1.08		0.8		1.06	

***difference between subgroup-means is highly significant

In table 2, we present the mean levels of declaration for the two categories of events of interest, for different subgroups of reactors defined with respect to the budgets of their local commission. We run simple mean difference test between the three proposed subgroups. We can observe that reactors overseen by a wealthy commission tend to declare less events in general, whereas there seems to be no significant differences in the declaration of systematically detected and declared events across the commissions' budgets. These two suggestions are somehow contradictory, as the latter suggests the existence of a positive impact of threat on safety whereas the former does not suggest any significant effect. This first statistical observation calls for an in depth analysis of the determinants of the declarations of safety events, which is performed in the next two sections.

5 Empirical Results

5.1 Econometric framework

A linear specification allowing to estimate the formal model presented in the identification section is the following:

$$reports_{it} = \beta \cdot X + \beta_{threat} \cdot budgets + \delta_t + \epsilon_{it} \tag{11}$$

where indices i and t respectively refer to the reactor and the year of observation. *reports* will be defined in turn as the number of declaration (per reactor and per year) of events systematically detected and declared (SDD), and as the total number of declaration of events per reactor and per year (ALL). δ_t represents year fixed-effects, and controls for potentially varying declaration guidelines, or particular time-varying factors, such as generic efforts exerted by the operator at a national scale. Reactor fixed-effects are not included in all specification as they cancel out most of our explanatory variables (technological dummies and commissions activity variables *meet* and *multiple*) which only vary from one nuclear site to another. Yet, we include "type" fixed-effects as defined in the data section.

Control variables X first include age, electrical production[16] and maintenance durations. Additional control variables describe the commissions' activities: *meet* captures the number of yearly meeting organized by the commissions, while *status* describes whether local commissions are part of the department's administration or are constituted as an independent association. A $Saint - Laurent$ variable captures a specific Saint-Laurent effect due to the particular activity of its members[17]. A *size* variable containing the number of reactors located in a given power stations is included in order to capture potential scaling effects. Finally, we control for potential learning effects by including the $FOAS$ and $FOAK$ variables.

Given the possible endogeneity of the *budget* variable, we propose to estimate equation 11 using three instrument sets. For each specification, one regression will be estimated using our set of site-specific control variables, while the second regression will replace these controls by reactor fixed effects. In specification 1 (regressions (1) and (2)), the *budget* variable is instrumented by the *green* variable. Specification 2 (regressions (3) and (4)) uses the *shock* instrument. Specification 3 (regressions (5) and (6)) uses both instruments. Finally, We also conduct a simple OLS regression (regression (0)) using specification 1 in order to study the direction of the bias. In addition, we run two regressions ((7) and (8)) in which the *report* variable is defined as the counts of Type 2 events, whose detection and declaration is systematic. These two regressions use the *shock* instrument. Regressions (1) to (8) are estimated using a generalized method of moments instrumental variable (GMM-IV) estimator with robust standard-errors.[18] We choose to use a GMM-IV estimator as it is known to be approximatively unbiased and to achieve close to perfect nominal coverage in the just-identified case (see e.g. Angrist and Pischke (2009b,a)).

5.2 Estimation results

5.2.1 First-stage and test statistics

The results of our regressions are presented in table 3 on page 20. The first-stage regression results for regressions (1) to (6) are reported in the appendices.[19] These first-stage regressions support both of our instruments. The first-stage coefficient of the *green* instrument is both positive and highly statistically significant in the first-stage of regressions (1), (2), (5) an (6). Likewise, the coefficient of the *shock* variable is positive and significant in the first stage of regressions (3) to (6).

Second, the test statistics reported in 3 provide various levels of support for our three

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[16] Production can be seen as a proxy for exposure, as all power stations do not produce the same amount of energy each year.

[17] Saint-Laurent experienced two partial core meltdowns in the late sixties in an older power reactor, and was the first site to voluntarily create an information commission.

[18] As we only have one endogenous regressor and one instrument, the GMM-IV, two-stage least-square and limited information maximum likelihood estimators are equivalent, see for instance p.189 in Wooldridge (2002), or chapter 8.6 in Hayashi (2000).

[19] Appendices and robustness checks are available upon demand to the author.

Table 3: Regression results for several models and robustness checks

	OLS	IV						IV	
	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	ALL	ALL	ALL	ALL	ALL	ALL	ALL	SDD	SDD
budget	-0.0160**	0.0614***	-0.0948*	0.0571***	0.132*	0.0593***	-0.00466	-0.00560	-0.0230
Status	7.100***	9.489***		9.356***		9.443***		-0.0116	
meet	-0.649	7.992***		7.510**		7.744***		-0.871	
multiple	0.688	-2.533*		-2.353**		-2.408**		0.451	
SaintLaurent	-9.299***	-1.515		-1.949		-1.752		-1.034	
age	0.570***	0.155	-0.0461	0.178	-0.473**	0.166	-0.216	0.165***	-0.0439
size	-0.0995	1.651**		1.554**		1.605**		-0.383**	
production	-1.372***	-1.123*	-1.971***	-1.137*	-0.942	-1.159*	-1.563***	-0.368***	-0.487***
maintenance	0.00650	0.0127	-0.00508	0.0124	0.0135	0.0120	0.00231	-0.00208	-0.00401
FOAS	-0.953*	-0.453		-0.481		-0.467		-0.433**	
FOAK	2.415*	-0.732		-0.556		-0.661		1.410*	
1300 MW	6.258***	9.362***		9.189***		9.339***		0.890*	
1450 MW	16.75***	20.40***		20.20***		20.42***		2.187**	
Constant	10.77**	-13.40		-12.06		-12.51		4.152*	
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Reactor FE	No	No	Yes	No	Yes	No	Yes	No	Yes
Instrument	-	*green*	*green*	*shock*	*shock*	both	both	*shock*	*shock*
R-squared	0.419	0.140	0.337	0.171	0.157	0.155	0.385	0.240	0.131
KP rk LM		17.76	9.729	17.32	8.197	23.97	10.91	17.32	8.197
KP rk Wald		29.37	9.310	26.86	10.05	25.13	7.662	26.86	10.05
Wu-Hausman		12.73	2.925	13.46	5.022	18.37	0.0114	0.270	0.461
Hansen						0.872	0.00841		

Robust standard errors in parentheses - *** p<0.01, ** p<0.05, * p<0.1

One sided t-tests considered for β_{budget}

234 Observations - 48 reactors

instrument sets. In all specifications, the Kleibergen-Paap rank LM statistic is greater than the 10% Stock-Yogo statistic when no fixed-effects are included. When fixed-effects are included, the strength of the instrument diminishes, but the Kleibergen-Paap rank LM statistic remains greater than the 15% Stock-Yogo statistic. On the other hand, the Durbin-Wu-Hausman test fails to reject the endogeneity of the budget variable in specification 1 and 3, when the green instrument is included as an exogenous instrument. Therefore, in the following, we will focus on the results of specification 2 (regression (3) and (4)).

5.2.2 First-step results: monitoring and safety

Regressions (7) and (8) are based on the set of systematically detected and declared events, or type 2 events. In these two regressions, it appears that the intensity of the commission's monitoring has no significant impact on the quantity of events declared to the regulator. In other words, we cannot reject the hypothesis that $\frac{\partial s_2}{\partial i} = 0$. Provided the assumptions made in the identification section are valid, we can thus infer from this result that the intensity of local monitoring does not significantly affect the level of safety care exerted by nuclear operators.

Furthermore, in these two regressions, the Wu-Hausman test statistics no longer allow to reject the exogeneity of the commissions budgets, which is consistent with the interpretation that local monitoring budgets and the level of safety care exerted by the operators are independent. This brings a first answer to our research question: we can reject the hypothesis according to which the intensity of local monitoring may lead to an increase in nuclear safety, defined as the probability of occurrence of significant incidents.

These two regressions also show that age of nuclear reactors does not have a significant impact on the quantity of declarations, once year-fixed effect are included. This suggests that the variations in declaration may be related to regulatory modifications in the declaration criteria rather than by an increase or decrease in safety due to the ageing process of the French nuclear reactors. Another takeaway from these first two regressions is that a significantly superior number of SDD events are reported when reactors decrease their production. This result is satisfactory, as events seldom occur when the power station is producing electricity at its nominal capacity. Finally, we can see that an important driver of the variations in declarations is the technological design of the reactor: larger reactors tend to declare significantly more numerous SDD events.

On the other hand, these regressions show that being the first reactor of a site (or of a kind) has no significant impact on the occurrences of events. This can be interpreted as a signal that learning-by-doing may not be important within nuclear stations or within similar types of reactors. This conclusion could have also been expected, as the declarations of significant safety events aim to foster fleet-level improvements of safety through a sharing of best practices and the detection of generic technical or organizational failures.

5.2.3 Second step results: monitoring and compliance

Regressions (1) to (6), based on the complete set of events declared by nuclear operators between 2007 and 2015, propose several takeaways similar to those obtained under specification (8) and(9). Higher levels of production lead to smaller number of declaration of events. The technological design of the reactors seem to explain a large share of the variations in the declaration of events: the technological dummies $1300MW$ and $1450MW$, whose coefficients are positive, large and significant in all regressions. Finally, year fixed-effects suggest that there is a learning by doing effect at the global level over time, while there is no evidence of learning-by-doing among sites or among types of reactors sharing the same design.

We now come to the main result of this paper. It appears from regressions (1) and (5) that increasing the intensity of the local monitoring leads nuclear operators to increase significantly the number of safety events declared. Under the hypotheses presented in the identification section, we can conclude that local monitoring enhances the transparency of operators. In addition, given the fact that regression (8) and (9) ruled out the possibility of a variation in detection abilities, we can infer from this observation that the compliance of nuclear operators with the declaration criteria set by the regulator increases when the intensity of the monitoring performed by local commissions increases.

According to the model proposed in the identification section, we can conclude from this observation that there exists a significant impact of the threat of regulation on the level of transparency chosen by the operators. We can also conclude that if the threat exerted by the commission's activity has an impact on safety, then this effect is (significantly) less important than the one at work through the transparency channel. This is due to the fact that the coefficient from the regression captures the effects of threat on both safety and transparency. The coefficient β_{threat} obtained in the regression can be interpreted as a lower bound for the indirect effect of threat on declarations. From regression (2), we conclude that a budget raise of 20.000€ leads to *at least* one additional declaration of events, keeping everything else constant.

The comparison of regression (1) with a simple OLS regression, whose results are presented in column (7) in table 3, shows that endogeneity biases the estimation downwards, leading to a negative and significant coefficient for the *budget* variable. The sign of this bias can be interpreted as the consequence of the reverse causality between the commissions' budgets and the declarations of safety events. For instance, a commission wary of the relative lack of information provided by its operator may want to challenge the operator in a more thorough way, and in turn ask for larger budgets, leading to this downward bias.

6 Conclusion and policy implications

This paper conducts an analysis of the impacts of a French policy requiring the local monitoring of nuclear power plant operators. As local commissions may extract valuable information regarding nuclear safety, we argue that this policy may be seen as a form of threat of regulation by the operators. We therefore design an original empirical strategy designed to identify the causal impact of this policy on the choices of the operator regarding both safety and transparency, based on declarations of safety incidents declared by the nuclear operators. The results of the paper are twofold. First, local incentives have an unambiguous positive and significant impact on non-compliance. A budget raise of 30.000€ leads to at least one additional declaration of events. Second, local monitoring has no effect on the choice of safety care exerted by nuclear operators.

These results rely on the strong assumption that safety efforts cannot be event-specific. We nevertheless show that even when relaxing this assumption, our empirical evidence shows that local monitoring has a positive and significant impact on the overall *transparency* of nuclear operators, where transparency is defined as the combination of an operator's ability to detect event, and propensity to declare them.

Regarding policy implications, we believe that this paper's results call for optimism, as they suggest potentially cost-effective ways of improving the institutional design of nuclear safety. There has been a debate in France regarding the subsidies given to local monitoring commissions. Indeed, a French law states that department should provide commissions with a fixed share of the special tax imposed on nuclear installations. This law is not applied in practice. Given the findings of this paper, it seems that applying this law could yield significant "safety" upgrades, where safety is understood in a broader sense than the one defined in the core of this paper. Indeed, if subsidizing local monitoring could lead to an increase in the operators' level of transparency, this measure could help to improve the general level of safety of the French fleet. More importantly, in terms of impact, this measure would probably be more cost-effective than traditional upgrades of technical standards, given the gap in cost that separates the yearly investments made in nuclear maintenance or safety improvements and the total endowments of the French Commissions for Local Information.

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