Ex-ante and ex-post regulation: Does the joint use improve on social welfare?

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Abstract: A principle-agent model is applied to discuss the relationship between ex-ante regulation (standards) and ex-post regulation (firm and worker fines). Accident risks (e,g, medical errors) are affected by decisions made both by the firm (hospital) itself and the employees of the firm (healthcare workers), the regulator observes the safety efforts of the firm and (a share of) the occurrences of accidents, while worker safety efforts are non-contractible. We find that standards and firm fines are substitutes since their joint use does not improve social welfare relatively to their exclusive use. However, standards and worker fines become complements (the joint use improves social welfare relative to their exclusive use) in the presence of firm-related accident costs.

JEL Classifications: D62, D82, K20, K32, I18, L51

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1. Introduction

The regulatory literature typically distinguishes between ex-ante and ex-post regulatory instruments. Ex-ante regulation is policies that affect an activity before an externality is generated, such as safety standards, guidelines and prohibitions. Ex-post regulation is policies affecting an activity after the externality is generated, such as liability and sanctions. The possibility of the joint use of ex-ante and ex-post regulation has triggered a literature seeking to identify the implications from the combined use of the two types of regulation. The two policies (ex-ante and ex-post) are defined as complements in correcting externalities if their joint use adds to social welfare. If their joint use does not add to social welfare they are defined as substitutes implying that the usual policy advice has been to choose the least resource-demanding policy (Kolstad et al., 1990).

There are numerous real-world examples of ex-ante and ex-post policies being used in combination (joint use). Important examples are identified for environmental regulation and the regulation of healthcare markets. Firms that produce environmental externalities might adhere to environmental standards as well as being exposed to accident-related sanctions (liability). Health care authorities apply unannounced inspections and planned supervisions in combination with

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event-based measures (incident investigations). Unannounced inspections (random checks) and planned supervision include cite visits, interviews and the reviewing of documents to identify nonconformities with standards, rules and requirements (ex-ante regulation). Event-based regulation (ex-post regulation) include actions taken in response to reported adverse events and near misses (error-reporting) that again might lead to individual disciplinary reactions (reprimands, warnings and loss of license) and/or organizational fines.

Shavell (1984) and Schmitz (2000) use a multi-firm approach and find that the joint use of standards and strict liability can be superior to the exclusive of standards and the exclusive use of strict liability (complements). In both works, the exclusive use of ex-ante regulation (standards) is inefficient due to the use of a uniform standard when harm levels differ across injurers. In Shavell (1984), the exclusive use of strict liability becomes inefficient since not allowing for penalty multipliers. The non-allowance of penalty multipliers is common in models being concerned with liability since now compensations (awards) to victims, (τ) are set equal to damages (D). Given conviction uncertainty, a probability of being held liable, q, being less than one, implies that awards that provide the full internalization will be of the following type $\tau = (1/q)D,$ where $1/q$ is denoted the penalty multiplier. For models that do not allow for penalty multipliers, $\tau = D,$ it follows that the first-best solution can not be reached. Schmitz (2000) allows for penalty multipliers but introduces wealth differences in this way introducing the judgment-proof problem as an inefficiency source. The judgment-proof problem refers to the situation where a firm may not have verifiable resources to pay for the damage it caused which implies that the injurers have a positive probability for escaping a suit (regulatory inefficiency). Other works on joint use include Innes (2004), De Geest and Dari-Mattiaci (2007), and Bhole and Wagner (2008). Innes (2004) shows that ex-ante regulation and ex-post regulation can be complements in the presence of enforcement costs (monitoring- , enforcement- and judicial costs). De Geest and Dari-Matticai (2007) shows in a single-firm model, where the judgment-proofness problem causes suboptimal ex-post regulation, that joint use may improve the situation since standards enforces some minimal care that may reduce or eliminate the judgment-proofness problem. Bhole and Wagner (2008) do not allow for penalty multipliers in the presence of conviction uncertainty and ignores the judgment-proofness problem. This model contains one decision-maker that makes two preventive care decisions where one of the care decisions is unobservable for the regulator. They find that joint use in some cases may add to social welfare.

In this work, we study if the joint use of ex-ante regulation and ex-post regulation will improve social welfare (complements). Our model extends the model presented by Grepperud (2020) by introducing ex-ante regulation (standards) in addition to ex-post regulatory instruments.[2] The model is closest to Bhole and Wagner (2008) since studying a single firm and multi-dimensional safety care where the degree of contractibility varies across the safety decisions. However, in contrast to Bhole and Wagner (2008), the safety decisions in our model are under the control of two different decision-makers within the same firm. This choice has two important implications; (i) sequential decision-making as concerning safety efforts, and, (ii) the two safety decisions are being determined by two different sets of preferences (the worker and the firm). A worker-firm perspective seems relevant in many situations since both the management of firms (e.g. hospital management) and the employees of firms (health care workers) make decisions that impact accident risks (patient safety).

[2] The analysis presented by Grepperud (2020) is close to the analysis presented in section 3.2.

Furthermore, it is assumed that the safety decisions of the firm are observable and verifiable (contractible) for the regulator, while the safety decisions made by the employees of the firm are non-contractible. These assumptions lie with the fact that a hospital's safety investments, such as clinical guidelines, staff training, organizational routines and various safety equipment installations (e.g. electronic journals and computerized medication monitoring systems), are believed to be less costly to observe for a regulator compared with the day-to-day (clinical) decisions made by health care workers. Health care workers typically utilizes the safety systems implemented by hospitals. Additionally, it is assumed that the regulator observes a share of accidents (e.g. medical errors) at no costs and can use fines that represent transfers of wealth without any real resource costs.[3] The occurrence of accidents may harm a third-party, the firm itself, and the employees of the firm. Our single-firm perspective also implies that we abstract from heterogeneous harm levels across injurers as an inefficiency source. Furthermore, we also ignore other inefficiency sources such as (*i*) the judgment-proofness problem, (*ii*) regulatory costs, and, (*iii)* the presence of conviction uncertainty when not allowing for penalty multipliers.

The remainder of this paper is organized as follows. The next section presents the model and the first-best solution. In section *3,* we present the optimal ex-ante regime (standards) and the two optimal ex-post regimes (firm and worker fines). In section *4,* the welfare implications of the various regimes are discussed. Section *5* presents the answers to the research question while section *6* concludes.

2. The model and the first-best solution

Consider a model consisting of a firms' management (hereafter denoted the firm), an employee of the firm (worker), and, a regulator. All three agents are risk-neutral and both the firm and the worker can influence the probability of an accident (e.g. a medical error). Thus, the accident probability function, $P(E,e)$, depends on the safety efforts of the firm, E, and the worker, e. The marginal safety effort costs of the firm (K) and the worker (k) are strictly positive; $k > 0$ and $K > 0$. It is assumed that an increase in both E and e reduces the accident probability at a diminishing rate; $P_E'(E,e) < 0, P_e'(E,e) < 0, P_{EE}''(E,e) > 0, and\ P_{ee}''(E,e) > 0$.[4] The cross partial derivative of the accident probability function can be positive, negative, or zero. $P_{eE}''(E,e) = P_{Ee}''(E,e) > 0$ implies that more careful worker behavior is less effective in reducing the accident probability; the more careful the firm behaves. $P_{eE}''(E,e) = P_{Ee}''(E,e) < 0$ imply that more careful worker behavior is more effective in reducing the accident probability; the less careful the firm behaves.

The expected social costs associated with an accident (D) are defined as the sum of firm-related accident costs (βD), worker-related accident costs (αD), and accident costs inflicted upon a third-party (γD) where $\beta \geq 0, \alpha > 0, \gamma \geq 0\ \ and\ \ \beta + \alpha + \gamma = 1$.[5] In the case of medical errors (adverse events), third-party accident costs are the costs inflicted upon patients due to prolonged treatment and human sufferings, firm-related accident costs are hospital costs in terms of treatment costs that follow from complications and re-treatments due to adverse events, while worker-related accident costs are costs in terms of emotional distress and an adverse reputation.

[3] In many cases, a share of the medical errors is observed at very low costs by health authorities due to patient complaints and voluntary reporting by healthcare workers. However, depending on the health care system under consideration, administrative and legal costs associated with the occurrences of adverse events might be significant.

[4] First and second order derivatives are denoted as follows: $\partial P(E,e)/\partial E \equiv P_E'(E,e),\ \partial^2 P(E,e)/\partial E^2 \equiv P_{EE}''(E,e)$.

[5] In this work, only interior solutions are considered (ignore minimum effort constraints). In order to ensure interior solutions, α must be strictly positive (see eq. 5 in section 3.1).

We assume that the costs of monitoring the safety care of a worker, *e*, is prohibitively high (non-contractible), thus the firm can not steer the behavior of the worker (fixed wage contracts). The worker earns the expected reservation utility of $\bar{U}$, where expected utility, *U*, is the sum of the fixed wage, *A*, expected worker accident costs, $P(E,e)\alpha D$, worker care costs, *ke*, and the expected sanction costs *P(E,e)st.* The expected sanction is a function of the worker fine, *t*, and the probability of being penalized in the occurrence of an accident, *s*, where $0 < s < 1$. A positive probability, *s*, implies that some accidents are freely detected by the regulator and this probability being less than *1* means that there is conviction uncertainty. The expected worker utility now becomes;

$$U(E,e) = A - P(E,e)\alpha D - P(E,e)st - ke \geq \bar{U} \tag{1}$$

We observe from (1) that the firms' safety effort, *E*, being contractible for the regulator, affects worker utility via the probability function. The firms' expected costs are defined as the sum of fixed wage, *A*, firm accident costs, $P(E,e)\beta D$, safety effort costs, *KE*, and the firms' expected sanction costs *P(E,e)rT*, where *T* is the firm fine and *r* is, given the occurrence of an accident, the probability of the firm being sanctioned where $0 < r \leq 1$. The expected firm costs now become;

$$C(E,e) = A + P(E,e)\beta D + P(E,e)rT + KE \tag{2}$$

The regulator is concerned with the expected social costs, *S(E,e)*, being the sum of social accident costs, *P(E,e)D*, and safety effort costs, thus the social costs, when assuming fines that have no real resource implications, become as follows;

$$S(E,e) = P(E,e)D + KE + ke. \tag{3}$$

Now we present the first-best solution that acts as benchmark to the forthcoming discussions. The regulator, if perfectly informed, minimizes the expected social costs with respect to *E* and *e*. The equation system that defines the first-best levels becomes (superscript * refer to first-best levels);

$$-P_e^{'}(E^*,e^*)D = k \tag{4a}$$

$$-P_E^{'}(E^*,e^*)D = K \tag{4b}$$

The first-best conditions (4ab), coincide with the standard optimality rules identified in the accident literature, where for each safety effort variable, the expected marginal reduction in society's expected accident costs is to equal the marginal safety effort cost. The social costs that follow from the first-best solution is in the following denoted as $S(E^*, e^*)$.

3. Optimal regulation

In the following, we derive the optimal regulation for the following three regimes; (*i*) the exclusive use of standards, (*ii*) the exclusive use of firm fines, and, (*iii)* the exclusive use of worker fines.[6] In the model analyzing the optimal standard, the regulator first decides on the safety standard, *E*, thereafter the firm decides on the wage level, *A*, and, finally the worker decides on the safety effort,

[6] The second-order conditions are available from the appendices.

e. This model is a three-stage model with three endogenous variables (*E, e* and *A*). In the case of ex-post regulation (fines), to simplify the presentation, we derive optimal regulation when considering the use of both fines (firm - and worker fines). In this case, the regulator first decides on the two fine levels (*t* or *T*), then the firm decides on *A* and *E*, and finally the worker decides on *e*. This is a game with three stages and five endogenous variables (*t, T, E, e* and *A*). Thereafter, we present two special cases where each of the two fines are set equal to zero (the exclusive use of a fine).

3.1 Optimal Ex-ante regulation (the use of a standard; t=T=0)

At the third (and last) stage of the game, the worker maximizes (1) with respect to *e* which produces the following condition:

$$U_e(e,E) = -P_e(e,E)\alpha D - k = 0 \tag{5}$$

Optimal worker effort is defined by the equality between the expected marginal change in the workers' expected accidents costs and the marginal effort cost. Eq. (5) defines the following response function;

$$e = e(E) \tag{6}$$

$$\text{where } e'_E(E,t) = \frac{P''_{eE}(E,e)}{P''_{ee}(E,e)} \geq (<)0 \tag{7}$$

From former assumptions, we know that $P''_{ee}(E,e)>0$, thus the sign of (7) will depend on the sign of the cross partial derivative of the accident probability function. According to Bulow et al. (1985), the safety efforts are strategic complements (strategic substitutes) when the response of the worker is to increase (decrease) own safety effort, as the firm invest more safety effort. Given this, we have the following relationships; *e* and *E* are strategic substitutes if $P''_{eE} > 0 \Rightarrow e'_E < 0$, strategic complements if and strategic independent variables if $P''_{eE} = 0 \Rightarrow e'_E = 0$.[7]

In the second stage of the game, the only decision left for the firm is to decide on the fixed wage, *A*, since the safety effort of the firm, *E*, is under the control of the regulator due to the standard-setting.

In the third (and last) stage, the optimal standard follows from the regulator solving the following minimization problem;

$$\min_{E} \; S(E,e) = P(e.e)D + KE + ke \qquad s.t. \; e = e(E). \tag{8}$$

Solving (8) yields the following condition for the optimal standard ($\bar{E}$);

$$S'_E(E,e) = \left[P'_e\big(E,e(E)\big)D + k\right]e'_E(E) + P'_E\big(E,e(E)\big)D + K = 0 \tag{9}$$

From (9) we observe that the optimal standard is a function of the first derivatives of the accident probability function and the strategic properties of the two safety effort variables.

[7] The most reasonable situation is probably for $P''_{eE} > 0$, if so the safety efforts are strategic substitutes.

4.1 Optimal Ex-post regulation (the joint use of firm- and worker fines and no use of standards)

In the third (and last) stage of this game, the worker maximizes (1) with respect to e, which again produces the following interior solution:

$$U_e'(e,E) = -P_e'(E,e)\left[\alpha D + st\right] - k = 0, \qquad (10)$$

From (10) it follows that optimal worker effort is now defined by the equality between the expected marginal change in the workers' accident cost and the marginal effort cost, however, in contrast to (5), the expected marginal change in accident costs is now depending on the expected worker fine (st).

Eq. (10) defines the workers' response function;

$$e = e(E,t) \qquad (11)$$

$$where \quad e_t'(E,t) = -\frac{P_e'(E,e)s}{P_{ee}''(E,e)(\alpha D + st)} > 0 \qquad (12)$$

(the expression for $e_E'(E,t)$ is available from eq. 7).

In stage two of the game the firm decides on the fixed wage (A) and own safety effort (E). By inserting a binding version of (1) into (2) taking (11) into consideration, we arrive at the following minimization problem for the firm;

$$\underset{E}{Min}\, C(E) = \overline{U} + P(E,e)\Psi + ke + KE \quad s.t. \;\; e = e(E,t), \qquad where \quad \Psi \equiv (\alpha + \beta)D + rT + st\,. \qquad (13)$$

From (13) we observe that the firm internalizes worker-related accident costs (αD) and the expected worker fine (st). This property follows from the participation constraint since the worker must be compensated financially by the firm for the exposure to risks. The first-order condition for the firm now becomes;

$$C_E'(E) = [P_E'(E,e(E,t))\Psi + K] + e_E'(E,t)\left[P_e'\big(E,e(E,t)\big)\Psi + k\right] = 0 \qquad (14)$$

By inserting (10) into (14) and rearranging, we get;

$$P_E'(E,e(E,t)) = -\frac{1}{\Psi}\left[K + \left(1 - \frac{\Psi}{\alpha D + st}\right)ke_E'(E,e(E,t))\right] = -\frac{1}{\Psi}\left[K - \frac{(\beta D + rT)}{\alpha D + st}ke_E'(E,e(E,t))\right] < 0\,. \qquad (15)$$

The term on the right side of (15) must be negative since the term on the left side of (15), $P_E^{\cdot}\big(E,e(E,t)\big)$, is negative. Eq. (15) also defines the response function of the firm;

$$E = E(T,t) \qquad (16)$$

From the second term of the parenthesis of (15) it follows that the optimal choice of E depends on the strategic properties of the safety efforts (see 7). For example, if the safety efforts are strategic substitutes $(P''_{ee}(E,e)>0 \Rightarrow e'_E(E,e)<0)$, the firm pays attention to the discouraging effect a higher level of E has on e.

In the first stage, the regulator minimizes (3) by deciding on t and T when taking the response functions (11 and 16) into account, which yields the following optimization problem;

$$\underset{T,t}{Min} \quad S(E,e)=P(E,e)D+KE+ke \quad s.t. \; e=e(E(T,t),t) \; \text{ and } \; E=E(T,t) \tag{17}$$

Solving (17), yields the following optimality conditions for the joint use of fines;[8]

$$S'_T(E,e)=\left[P'_e(*)D+k\right]E'_T(*)e'_E(*)+\left[P'_E(*)D+K\right]E'_T(*)=0 \tag{18}$$

$$S'_t(E,e)=\left[P'_e(*)D+k\right]\left(E'_t(*)e'_E(*)+e'_t(*)\right)+\left[P'_E(*)D+K\right]E'_t(*)=0 \tag{19}$$

By using (10) and (15), (18-19) can be expressed as follows;

$$\frac{st-(\gamma+\beta)D}{\alpha D+st}k=0=\frac{1}{\Psi}\left[(rT+st-\gamma D)K+\frac{(\beta D+rT)D}{(\alpha D+st)}ke'_E(*)\right]. \tag{20}$$

It follows that (20) is fulfilled for the following fine levels (in the following, superscripts Tt refer to the joint use of firm- and worker fines while $S(E^{Tt},e^{Tt})$ refers to the social costs from the joint use of firm – and worker fines);

$$st^{Tt}=(\gamma+\beta)D \qquad \text{and} \qquad rT^{Tt}=-\beta D \tag{21}$$

It follows from (21) that the optimal firm fine, rT^{Tt}, is negative. This finding follows because the worker per definition internalizes worker-related accident costs while the optimal worker fine in (21) leads the worker also to internalize firm-related and third party accident costs. In this case, all three accidents costs (the social accident costs) will also be internalized by the firm via the participation constraint and since the firm per definition internalizes own accident costs. In sum, the incentives directed at the firm will be too strong from a social perspective and consequently need to be modified by introducing a subsidy in the event of an accident.

By using (15) and (10) in combination with (21), we arrive at expressions for the optimal use of firm safety effort and worker safety effort. It follows that the two conditions become identical to the first-best conditions (see 4ab) thus $S(E^{Tt},e^{Tt})$ = S(E^*,e^*).

3.2.1 The optimal exclusive firm fine (no standard and *t=0*)

In the case of an exclusive use a firm fine, the optimal fine level follows from solving (17) with respect to T when $t=0$. This procedure yields the following response function for the firm $E=E(T,0)$ while the relevant response function for the worker follows from (6). Doing this, we arrive at the following optimality condition for the exclusive use of a firm fine;

$$[P'_e(*)D+k]E'_T(*)e'_E(*)=-[P'_E(*)D+K]E'_T(*) \tag{22}$$

[8] In the following, to simply notation, we apply (*) to denote the arguments of functions.

Now, by using (10) and (15) (keeping $t=0$), and solving (22) with respect to rT, we arrive at the following expression for the optimal exclusive firm fine ($\bar{T}$):

$$r\bar{T} = \gamma D. \tag{23}$$

It follows from (23) that the optimal fine only depends on third party accident costs. This conclusion follows since firm-related accident costs are internalized by the firm per definition while worker-related accident costs are internalized by the firm via the participation constraint.

3.2.2 The optimal exclusive worker fine (no standard and $T=0$)

In the case of the exclusive use of a worker fine, the optimal fine follows from solving (17) with respect to t (for $T = 0$) where the firm response function is $E = E(0,t)$ and the relevant response function of the worker is described by (11). Solving this problem yields the following optimality condition;

$$P_E^{'}(*)D + K = -\left[P_e^{'}(*)D + k\right]\Phi \quad \text{where} \quad \Phi \equiv \left[e_E^{'}(*)E_t^{'}(*) + e_t^{'}(*)\right](1/E_t^{'}(*)). \tag{24}$$

Inserting (10) and (15) (for $T = 0$) into (24), yields the following optimality condition;

$$\left[\frac{s\bar{t} - \gamma D}{s\bar{t} + (1-\gamma)D}\right]K = -\left[\left(\frac{s\bar{t} - (\beta+\gamma)D}{s\bar{t} + (1-\beta-\gamma)D}\right)\Phi + \frac{\beta D^2}{[s\bar{t} + (1-\beta-\gamma))D](s\bar{t} + (\alpha+\beta)D)}e_{E(*)}^{'}\right]k \tag{25}$$

The expression in (25) is rather complex but insights can be gained from studying some particular cases. First, consider the case where firm-related accident costs and third-party accident are absent, $\gamma = \beta = 0$. Given this, it follows that (25) is fulfilled for $s\bar{t} = 0$ (no regulation). From (21) we observe that such a regime (laissez faire) will produce the first-best solution. Second, consider the case where third-party accident costs are present, $\gamma > 0$, while firm-related accident costs are absent, $\beta = 0$. Given this, it follows that the expected optimal worker fine that fulfills (25) has to equal third-party accident costs ($s\bar{t} = \gamma D$). From (21) it follows that this fine level will produce the first-best solution. Third, consider the case where third-party accident costs are absent ($\gamma = 0$) while firm-related accident costs are present ($\beta > 0$). In order to analyze this third case we reformulate (25) in the following way;

$$\left[\frac{s\bar{t}}{s\bar{t} + D}\right]K = -\left[\left(\frac{s\bar{t} - \beta D}{s\bar{t} + (1-\beta)D}\right)\frac{e_t^{'}(*)}{E_t^{'}(*)} + \left(\frac{s\bar{t}(s\bar{t} + (1-\beta)D)}{[s\bar{t} + (1-\beta)D][s\bar{t} + D]}\right)e_{E(*)}^{'}\right]k \tag{26}$$

Now, by inserting for $s\bar{t} = \beta D$ into (26), it follows that this particular fine level does not satisfy (26), thus $s\bar{t} \neq \beta D$. Furthermore from (21) it follows that the optimal fine level will not produce the first-best solution. $s\bar{t} = \beta D$ provides adequate worker incentives, but this level induces the firm to internalize own accident costs via the participation constraint despite such costs already being internalized by the firm per definition. Consequently, we have an “overprecaution” problem when it comes to the decision-making of the firm and this problem must be addressed by the regulator in the setting of the optimal worker fine. Our above discussions show that for $\beta = 0$, the optimal worker fine produces the first-best solution. For $\beta > 0$ this is not the case and now the optimal worker fine can be both higher or lower than the sum of firm-related accident costs and third-party accident costs; $st > (<)(\beta+\gamma)D$. It follows that $s\bar{t} < (\beta+\gamma)D$ for $e_E^{'} \geq 0$ and $E_t^{'} > 0$, while $s\bar{t} > (\beta+\gamma)D$ for $e_E^{'} \leq 0$ and $E_t^{'} < 0$.

4 The three regulatory regimes and social costs

In the following, we compare each of the three regulatory regimes with the first-best solution.

4.1 Social costs and the exclusive use of the optimal standard *(t=T=0)*

From (5) and (9), we arrive at the following first-order conditions for the safety efforts;

$$-P_e^{'}(\bar{E},\bar{e})D = \frac{1}{\alpha}k \tag{27a}$$

$$-P_E^{'}(\bar{E},\bar{e})D = K - \frac{(1-\alpha)}{\alpha}ke_E^{'}(\bar{E}) = K - \frac{(\beta+\gamma)}{\alpha}ke_E^{'}(\bar{E}) \tag{27b}$$

By comparing (27ab) with the first-best solution (see 4ab), it follows that the optimal standard does not produce the first-best solution since the worker ignores firm-related and third-party accident costs when deciding on safety care (see 27a). Furthermore, from (27b) we observe that the optimal standard is a function of an indirect effect. The presence of this effect shows that the regulator, when setting the optimal standard, pays attention to the effect the standard setting has on the safety decision of the worker. This term reflects the regulators' inability to steer worker safety care. When the two safety efforts are strategic independent, the indirect effect becomes zero and (27b) now coincides with the corresponding first-best condition (4b). However, the equation system presented by (27ab) still differs from the first-best solution since (4a) differs from (27a). Hence, we can conclude that the optimal ex-ante regime is a second-best regime. This conclusion can be expressed as follows;

(I) $S(\bar{E},\bar{e}) > S(E^*,e^*)$

4.2 Social costs and the exclusive use of the optimal firm fine (no standard and *t=0*)

Using (10) (when $t = 0$) and substituting (23) into (15) (when $t = 0$) , we arrive at the following conditions for the optimal safety effort levels (superscripts T denote the optimal effort levels for exclusive firm fine);[9]

$$-P_e'(E^T,e^T)D = \frac{1}{\alpha}k \tag{28a}$$

$$-P_e'(E^T,e^T)D = K - \frac{(\beta+\gamma)}{\alpha}ke_E'(*) \tag{28b}$$

The equation system in (28ab) differs from the first-best solution (see 4ab), thus the exclusive use of a firm fine will not produce the first-best. Furthermore, the optimality conditions in (28ab) coincide with the optimality conditions that describe the optimal standard regime (see

[9] Note that Ψ (see 13) is equal to 1 when $st = 0$ and $rT = \gamma D$.

27ab). This means that the exclusive use of an optimal standard and the exclusive use of an optimal firm fine do equally well in terms of social costs. Our conclusion as concerning social costs can be expressed as follows;

(II) $S(E^T, e^T) = S(\bar{E}, \bar{e}) > S(E^*, e^*)$

From *(II)* it follows that the optimal ex-post regime (the exclusive use of firm fines) is a second-best regime and that this regime produces the same level of social costs as the optimal standard regime.

4.3 Social costs and the exclusive use of the optimal worker fine (no standard and *T=0*)

We know from the fines that describe the optimal ex-post regime (see 21), that the exclusive use of a worker fine $(T = 0)$ will not produce the first-best solution. However, this conclusion changes in the absence of firm-related accident costs $(\beta = 0)$ since from (21) the optimal expected worker fine is to equal third-party accident costs ($s\hat{t} = \gamma D$ and $r\hat{T} = 0$). Our findings can be summarized as follows (superscripts *t* denote the optimal effort levels for exclusive worker fine);

(III) $S(E^t, e^t) > S(E^*, e^*)$ for $\beta > 0$

(IV) $S(E^t, e^t) = S(E^*, e^*)$ for $\beta = 0$

4.4 A comparison of social costs across the three regimes

From the (II) and (IV), we know that in the absence of firm-related accidents costs $(\beta = 0)$ that the optimal exclusive worker fine achieves the first-best solution while the remaining two regimes do not. The ranking of the exclusive optimal worker fine and the other two regimes in terms of social costs becomes more complex when firm-related accident costs are present. In the following, we consider two cases that shed light on the relative social attractiveness of the various regimes.

First, we consider the case with firm-related accident costs but now third-party accident costs are absent ($\beta > 0$ and $\gamma = 0$). Given these assumptions, neither regime (optimal worker fine and optimal firm fine) will produce the first-best and the optimal firm fine is now zero (see 23) while the optimal worker fine is strictly positive (see 25). If now both fines are set equal to zero (laissez faire), the social costs will be the same for the two regimes, consequently, the exclusive optimal worker fine must always do better than the exclusive optimal firm fine (and the exclusive optimal standard).

Second, consider the case with firm-related accident costs and third-party accident costs ($\beta > 0$ and $\gamma > 0$). Now, let both fines be equal to third-party accident costs $(st = rT = \gamma D)$. From (23) we know that an exclusive firm fine being equal to γD is the optimal one. From (25) it follows that an exclusive worker fine equal to γD does not produce the first-best. Despite this, a worker fine equal to γD, ceteris paribus, will outperform the optimal firm fine ($rT = \gamma D$). This conclusion follows, since for $st = \gamma D$, the worker, in addition to own accident costs, will internalize third-party accident costs. The firm, internalizing own accident costs and worker-related accident costs, will for $rT = \gamma D$, also internalize third-party accident costs (via the worker's participation constraint). Consequently, a worker fine creates prevention incentives for both decision-makers. For $rT = \gamma D$, the worker will not internalize third-party accident costs, however, the firm will do so. This means that a positive exclusive firm fine only provides prevention incentives for the firm. Furthermore, the ability of the regulator to steer the behavior of the worker might be relative more important than steering the behavior of the firm since, in the absence of any fines, the worker internalizes a lower share of the social accident costs relatively to the firm.[10] This means that as long as worker safety care is not significantly less productive relatively to the safety care of the firm, we arrive, independent of the firm-related accident costs being zero or positive, at the following conclusion;

(V) $S(E^T, e^T) > S(E^t, e^t)$

5 Ex-ante and ex-post regulation: substitutes or complements?

In order to answer our research question we need to compare the social costs that follow from ex-ante regulation (an exclusive standard) with the social costs that follow from ex-post regulation (an exclusive firm fine or an exclusive worker fine). The conclusions arrived at in section 4 (ranking *I*- *V*) can now be summarized as follows;

(VI) $S(\bar{E}, \bar{e}) = S(E^T, e^T) > S(E^t, e^t) = S(E^*, e^*)$ for $\beta = 0$

(VII) $S(\bar{E}, \bar{e}) = S(E^T, e^T) > S(E^t, e^t) > S(E^*, e^*)$ for $\beta > 0$

From (*VI*) we observe the ranking of the social costs across the various regimes when firm-related accident costs are absent ($\beta=0$). It follows from (*VI)* that the optimal exclusive worker fine produces the first-best solution while the optimal standard and the optimal firm fine both produce the same second best solution. From this we can conclude that standards and worker fines are substitutes in the sense that their joint use does not increase social welfare (reduce social costs). This conclusion follows directly from the finding that the exclusive use of a worker fine achieves the first-best solution. Standards and firm fines are also substitutes because the exclusive use of a standard and the exclusive use of a firm fine produce the same safety effort levels (*E* and *e*).

From (*VII*) we observe the ranking of social costs across the various regimes when firm-related accident costs are present ($\beta > 0$). In this case, neither of the three regimes produces the first-best solution. However, the optimal worker fine does better than both the optimal standard and the optimal firm fine, while the optimal standard and the optimal firm fine do equally well. From this we can conclude that standards and firm fines are substitutes while standards and worker fines are complements. Standards and firm fines are substitutes because they produce the same safety efforts levels. Both instruments are concerned with steering the same safety care decision - the safety care decision of the firm, meaning that the joint use cannot improve on social welfare. Standards and worker fines, however, are complements because each regulatory instruments addresses different safety care decisions. The standard is concerned with steering the behavior of the firm while the worker fine is concerned with steering the behavior of the worker. Consequently, the joint use of a standard and a worker fine will always do better in social terms than the exclusive use of each of them.

[10] The worker internalizes own accident costs, while the firm internalizes own - and worker-related accident costs. This is seen by comparing the first-order condition of the worker for the two regimes; $-P_e^{'}(E,e)D = k/\alpha$ (exclusive firm fine) and $-P_e(E,e)D = \frac{k}{\alpha D + st}$ (exclusive worker fine).

6 Conclusions

This paper studies optimal regulation in the presence of accident externalities where the probability of accidents is influenced by two decision-makers being in a contractual relationship (a firm and a firm employee). The firms' safety effort is contractible and the regulator observes, at no costs, a share of the accidents that occur. However, both the regulator and the firm are unable to contract on the safety care decisions of the employees. Besides third-party accident externalities, the relationship between the firm and its' employees is characterized by mutual external effects.

Our analysis ignores ex-post and ex-ante regulation inefficiencies that are introduced in former works. As concerning ex-post regulation we abstract from the judgment-proofness problem, ignore regulatory costs, and allow for penalty multipliers in the presence of conviction uncertainty. As concerning ex-ante regulation, given a single-firm perspective we do not consider the inefficiency that arises with a uniform standard when harm levels differ across injurers. In our model, ex-ante regulation is inefficient since worker safety care cannot be directly steered via the use of standards (worker care is non-contractible).

As concerning ex-post regulation there are two different inefficiency sources. For firm fines, the inefficiency arises for the same reason as is the case for standards - worker safety care cannot be directly steered via the use of firm fines. For worker fines, however, the situation is different since such fines have an impact on the safety decision of the firm via the participation constraint of the worker. The presence of worker fines impose additional risks onto the worker and such risks must be financially compensated by the firm in order to induce participation, thus creating an incentive for the firm to reduce such risks by investing into own safety effort. However, given the presence of an exclusive worker fine, the regulator is left with two objectives (safety efforts of both the firm and the worker) but only one policy instrument. For this reason, optimal regulation cannot reach the first-best solution and trade-offs between the regulators' concerns for the two safety care decisions have to be made. In this case, the introduction of an additional policy instrument that addresses the safety decisions of the firm (standards or firm fines) will make such trade-offs obsolete and the first-best solution becomes attainable. However, in situations where firm-related accidents costs are absent, the exclusive use of a worker fine will produce the first-best solution. This finding follows because now the regulator is left with a single objective – the steering of the safety care decision of the worker. In this particular situation, the optimal worker fine reflects the third-party accident costs and these costs together with worker-related accident costs create adequate safety care incentives for the firm via the participation constraint of the worker.

We find that the two groups of policy instruments (ex-ante and ex-post) are complements in one particular case – for standards and worker fines in the presence of firm-related accidents costs. This finding might explain why we observe the combined use of disciplinary reactions and standards in promoting patient safety. The occurrences of medical errors (adverse events) are typically imposing costs onto healthcare providers in terms of reputational costs and prolonged treatments if being reimbursed by prospective payments (firm-related costs). In such cases, the use of incentives, directed at individual healthcare workers (individual fines) in combination with incentives directed at the firm (standards), is expected to improve social welfare. Our analysis has also shown that the two ex-post instruments considered (firm – and worker fines) are complements in the presence of firm-related accident costs. However, for such a regulatory regime, optimal regulation implies the use of a firm subsidy in the event of an accident. Due to legitimacy reasons among stakeholders, a subsidy of this type might be difficult to implement in practice. This might suggest why standards and individual sanctions are the most common regulatory instruments that are applied in promoting patient safety.

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Appendix

Appendix A: Second-order conditions (section 3).

The second-order condition for the problem of the worker is (see the problems in 3.1 and 3.2):

$U''_{ee} = -P''_{ee}(E,e)\left[\alpha D + st\right]\alpha D < 0$ which is fulfilled since $P_{ee}(E,e) > 0$.

The second-order condition for the problem of the firm (see problem in 3.2, see 14) is

$C_{EE} = P_{EE}(,)\Psi + e_{EE}(,)\left[P_E(,)\Psi + k\right] + e_E\left[P_{Ee}(,)e_t(,)\right] > 0$

The second-order condition for the problem of the regulator (the problem in 3.3 see 18) is:

$d = \begin{vmatrix} S''_{TT} & S''_{Tt} \\ S''_{tT} & S''_{tt} \end{vmatrix}$ >0, where the determinant of the Hesse-matrix $d_R = S''_{TT}S''_{tt} - S''_{Tt}S''_{tT} > 0$.

The second-order condition for the regulators' problem (the problem in section 3.2, see 8) is $S''_{EE} > 0$. Assuming all third derivatives of the accident probability function being zero, we get; $S_{EE} = \left[P''_{EE} + P''_{ee}(e'_E)^2 + 2P''_{eE}e'_E\right]D$, which from former assumptions is strictly positive.

Appendix B: Second-order conditions (section 4).

The second-order condition for the regulators problem (see 26ab) is $d = \begin{vmatrix} S''_{ee} & S''_{eE} \\ S''_{Ee} & S''_{EE} \end{vmatrix}$ >0, where *d* is the determinant of the Hesse-matrix. $d = P''_{ee}P''_{EE} - P''_{eE}P''_{Ee} > 0$ is fulfilled from former assumptions.