Interdependent Costs of Precaution and Role-Type Uncertainty

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Abstract

Classic liability rules do not lead to efficient care choices by injurer and victim if there are interdependent precaution costs. This result of Dharmapala and Hoffmann (2005) is shown to depend on role-type certainty. We allow for role-type uncertainty and demonstrate that traditional liability rules can deal with the complication of interdependent costs of care. In a model with interdependent costs of care, the party at which the behavioral standard is directed takes efficient care, whereas suboptimal care is optimal for the residual bearer. The identity of the residual bearer, however, becomes uncertain in a frame with role-type uncertainty, which ameliorates the incentives for efficient care.

Keywords: interdependent costs of care, role-type uncertainty, liability rules

JEL-Classification: K 13, H 23

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1 Introduction

It is well established that numerous classic liability rules lead to efficient care in the standard economic model of tort law with bilateral care and full information. In a recent contribution, Dharmapala and Hoffman (2005) (DH in the following) show that this is no longer true in circumstances with interdependent costs of care. In fact, none of the standard liability rules induces socially optimal care in the common unilateral-harm context. This is attributed to a lack of available causes of action. Take the example of simple negligence as liability rule. Assume that the injurer adheres to standard care which is equal to socially optimal precaution. The victim bears the full damage and chooses individually optimal care taking into account the effect of her care on her costs and the expected damage. Hence, she does not internalize the effect of her care on injurer costs of care. If victim care lowers injurer costs of care, higher than optimal injurer costs of care result as a consequence of incomplete internalization of all marginal effects of victim care by the victim. The injurer has no cause of action for the damage that takes the form of higher precaution costs. Thus, the resultant equilibrium does not entail efficient care by both parties.

We show by generalizing the frame of DH that standard liability rules can induce efficient care. This generalization allows for uncertainty concerning the role in an accident. Kim and Feldman (2004) introduce this kind of uncertainty and highlight its relevance. Besides introducing the type of uncertainty, they provide an application which also might help here to grasp the idea of the context described later. Referring to car accidents, they argue that drivers of bigger cars such as SUVs are less likely to be the severely injured party in an accident. They model the victim probability as being dependent on the relative car sizes and, de facto, regard one of the damage levels as negligible. Thus, they create a situation that is best described by bilateral care, unilateral harm and role-type uncertainty.

Incorporating role-type uncertainty into the frame of DH is especially warranted as their main example provided as motivation for interdependent costs of care is very likely characterized by a lack of certainty. They use car driving and car accidents. They reason, for example, that SUVs may lower the precaution costs of the driver but raise the precaution costs of others, e.g. because the increased height of the vehicle impedes unobstructed sight. Now, being on the road, you can probably never be perfectly sure whether you might hit or get hit by someone.

Having role-type uncertainty 'heal' the effect of interdependent cost of care is very interesting because the inclusion of this type of uncertainty alone makes the equilibrium in efficient care less unambiguous (see Kim and Feldman, 2004). The reason why role-type uncertainty can to some extent incorporate the unaccounted-for cost externality is that every party recognizes the possible consequences of her care choice depending on the own role. It is optimal to choose individually optimal care which deviates from socially optimal care in a model with interdependent costs of care in case you turn out to be the residual bearer, e.g. the victim with simple negligence. It is, however, optimal to choose standard care, i.e. socially optimal care, if you turn out to be the party that can free itself from any liability. Thus, it is a question of weighing the role-independent increase in precaution costs against the consequence that takes effect only for one role, namely, the liberation from expected damages due to adherence to the behavioral standard. The expected individual costs turn out to be lower with standard care than with substandard care for certain subjective probabilities attached to the role at which the standard is directed. Then, role-type uncertainty is efficiency enabling in a frame with cost externalities and unilateral harm.

To elaborate more on this point, realize that interdependent precaution costs provoke socially suboptimal care, if victim care lowers injurer costs, as best response to due care by the injurer under simple negligence. Consequently, the additional precaution must generate some individual benefit in order to induce efficient care by both actors. Role-type uncertainty introduces a 'saving' in expected liability. If the actor responds to due care with substandard care, this actor bears full expected damages irrespective of the role. If the actor responds by taking standard care, she decreases her expected liability payment due to the fact that only victims bear the burden if both parties take efficient care. This 'saving' can legitimize the additional precaution costs for the respective individuals. Thus, we utilize a similar mechanism as the bilateral-harm model uses. In that frame, if an individual faces a nonnegligent party, the 'saving' generated by exerting standard care is the burden of the expected damages of the other party. That is why DH find that the problem of inefficient care choices does not result in the bilateral-harm case for sufficiently large damage levels.

This analysis provides an example for circumstances in which uncertainty furthers efficiency, whereas it is usually conceived as an obstacle to efficiency (see e.g. Dari Mattiacci, forthcoming). It has to be noted, however, that the uncertainty in this frame is not due to fuzzy legal standards or uncertain compensation levels, but results as a consequence of the inherent nature of the given activity.

We argue that the disquieting news provided by DH's analysis concerning the ability of classic liability rules to induce efficient care can be countered by our comforting result. Interdependent costs of care cause inefficient care equilibria only in a subset of conceivable szenarios, i.e. a subset of possible combinations of role probabilities.

In section 2, we first detail the generalized model. Then, we pinpoint the result of DH as a special case of our model and work out why role-type uncertainty can ensure efficient care. Throughout, we focus on simple negligence (SN) and only sketch the effect of role-type uncertainty for strict liability with a defense of contributory negligence and negligence with a defense of contributory negligence at the end of section 2. Section 2 also provides an illustrative example, while section 3 concludes.

2 The Model

2.1 The Generalization

We use the notation and assumptions of DH. The model that allows for interdependent costs of care is based on the standard model of bilateral care. The population of potential injurers and victims is homogeneous and consists of risk-neutral individuals. We consider two representative individuals I and V that take care x and y and bear precaution costs $C^I(x,y)$ and $C^V(x,y)$, respectively. The parties to the accident are unacquainted with no chance to bargain at reasonable costs and have complete information with regard to payoffs and the applying legal rule and standard. The court is well informed, so that it can, for instance, define behavioral standards at the efficient level.

The care of both, I and V, reduces expected damages $L(x,y)$ at a decreasing rate.

Assumption 1:(i) $L(x,y) \geq 0$; (ii) $L_x < 0$; (iii) $L_y < 0$; (iv) $L_{xx} > 0$; (v) $L_{yy} > 0$.

Each party faces convex costs of precaution as a consequence of her care choice, x for individual I and y for individual V, and the care exerted by the other party, $C^I(x,y)$ for actor I and $C^V(x,y)$ are the costs of care for actor V.

Assumption 2:(i) $C_x^I > 0$; (ii) $C_y^V > 0$; (iii) $C_{xx}^I > 0$; (iv) $C_{yy}^V > 0$.

It is further assumed that care has at least a non-increasing effect on the costs of care of the other party. Thus, we, as DH, concentrate on an interdependency that yields a positive externality.

Assumption 3:(i) $C_y^I \leq 0$; (ii) $C_x^V \leq 0$.

Lastly, we follow DH in presuming that expected accident damages L are sufficiently large relative to the costs of care.

Assumption 4:(i) For any y and $x < x^*$, $L(x,y) > C^I(x^*,y) - C^I(x,y)$, with x^* being the socially optimal level of care by individual I; (ii) For any x and $y < y^*$, $L(x,y) > C^V(x,y^*) - C^V(x,y)$, with y^* being the socially optimal level of care by individual V.

This assumption ensures that increasing care to socially optimal care x^*, which shifts expected damages to the residual bearer, is always cost-justified based on the reduction in expected liability. This assumption maintains the discrete jump at the socially optimal precaution level well known from the literature without an interdependency in precaution costs (e.g. Shavell 1987).

We generalize this model by DH by allowing individuals that participate in the accident-prone activity to be uncertain about their role, injurer or victim. I and V might be injurer or victim in an accident, instead of the usual account of I and V being representative injurer and victim, respectively. Each forms subjective beliefs about the likelihood that she will be the victim. For that purpose take α $(1-\alpha)$ as person I's subjective probability that she will be the victim (injurer) and take $\beta(1-\beta)$ as person V's subjective probability that she will be the victim (injurer), with $\alpha, \beta \in [0,1]$. It is noteworthy and will be of importance later on to realize that α and β do not have to sum up to one, as they are subjective probabilities formed ex ante. For the sake of simplicity, these type probabilities do not depend on the care choice.

Both parties minimize individual costs which consist of care costs and apportioned expected damages. The apportioned expected damages are dependent on the liability rule and, for a given liability rule, on the care choices. We consider simple negligence. Thus, the court uses x^* (y^*) as the care standard if actor I (V) is the injurer.

We derive the cost function that individual I minimizes by taking care x for our case of simple negligence and role-type uncertainty. If $x < x^*$ and $y < y^*$, she bears expected damages only as injurer. Individual I attaches a likelihood to being an injurer of $(1-\alpha)$. Thus, the entry in her cost function for the given restriction on care is $C^I(x,y) + (1-\alpha)L(x,y)$. If $x \geq x^*$ and $y < y^*$, individual I will be compensated as a victim. In the role of the injurer, individual I adheres to the standard and therefore does not have to compensate individual V. Consequently, individual I's costs under this circumstance are simply precaution costs, $C^I(x,y)$. On the other hand, if $x < x^*$ and $y \geq y^*$ holds, I receives no compensation as victim because individual V follows the behavioral standard for care.

If I turns out as the injurer, she has to compensate V because care by I falls short of due care. Hence, I's costs are $C^I(x,y) + L(x,y)$. Finally, if $x \geq x^*$ and $y \geq y^*$ holds, individual I receives no compensation as victim because V complies. Individual I also does not need to compensate V. Thus, I carries expected damages in the role of the victim, leading to expected costs of $C^I(x,y) + \alpha L(x,y)$. Putting all these parts together yields IC, the cost function of individual I

$$IC(x,y) = \begin{cases} C^I(x,y) + (1-\alpha)L(x,y) & \text{if } x < x^* \text{and } y < y^* \\ C^I(x,y) & \text{if } x \geq x^* \text{and } y < y^* \\ C^I(x,y) + L(x,y) & \text{if } x < x^* \text{and } y \geq y^* \\ C^I(x,y) + \alpha L(x,y) & \text{if } x \geq x^* \text{and } y \geq y^* \end{cases} \tag{1}$$

By applying the same reasoning, we get VC

$$VC(x,y) = \begin{cases} C^V(x,y) + (1-\beta)L(x,y) & \text{if } y < y^* \text{and } x < x^* \\ C^V(x,y) & \text{if } y \geq y^* \text{and } x < x^* \\ C^V(x,y) + L(x,y) & \text{if } y < y^* \text{and } x \geq x^* \\ C^V(x,y) + \beta L(x,y) & \text{if } y \geq y^* \text{and } x \geq x^* \end{cases} \tag{2}$$

Whereas the individuals minimize the sum of care costs and expected liability, the social goal is the minimization of the sum of precaution costs and expected damages.

$$\min_{xy} SC(x,y) = C^I(x,y) + C^V(x,y) + L(x,y) \tag{3}$$

We find the socially optimal levels x^* and y^* as the care levels simultaneously solving the FOCs

$$C_x^I(x,y) + C_x^V(x,y) + L_x(x,y) = 0 \tag{4}$$

$$C_y^I(x,y) + C_y^V(x,y) + L_y(x,y) = 0 \tag{5}$$

The SOCs are ensured by the assumption taken by DH in their appendix, namely that the mixed cross partials are sufficiently small, which we will later on pick up.

2.2 The special case of Dharmapala and Hoffman (2005)

Our model allows α and β to be in $[0,1]$, whereas DH take the usual assumption that the injurer and the victim are certain as to their role. This means in our frame that, for instance, $\alpha = 0$ and $\beta = 1$, so that we appoint person I as the definite injurer and individual V as the definite victim. With reference to (1) and (2), we retrace the result found by DH that there is no equilibrium in efficient care by both parties. If injurer I chooses substandard care, victim V will choose a care level of zero since under that circumstance, there are only costs and no benefits to care expenditures. If the injurer chooses $x = x^*$, the victim minimizes her costs by choosing $\tilde{y} = \arg\min\{C^V(x^*, y) + L(x^*, y)\} < y^*$. The injurer will never choose supraoptimal care, since she thereby only increases her costs. The fact that the victim, as the residual risk bearer, does not take socially optimal care owes to the decreasing effect of victim care on the injurer costs of care that is not internalized by the victim. Hence, the equilibrium is $(x^*, \tilde{y})$, since the injurer takes due care as $C^I(x, y) + L(x, y) > C^I(x^*, y)$ holds for all $x < x^*$ and y by assumption 4 (i).

2.3 Role-Type Uncertainty Can Enable Efficiency

We now return to our more general setting in which $\alpha, \beta \in [0, 1]$ and illustrate that role-type uncertainty, a feature usually troubling the uniqueness of the efficient-care equilibrium, can induce efficiency in the presence of interdependent costs of care.

The claim is that for certain combinations of subjective victim probabilities, there exists only an efficient-care equilibrium. To reason our claim, we proceed as follows. First, we will define requirements for the subjective victim probabilities that make standard care optimal, given standard care by the other actor. Thus, we will first establish conditions for an equilibrium in standard care. Second, we turn to the possibility of a substandard-care equilibrium. However, whereas both involved individuals should desire to exert standard care given the standard care by the other individual, we only have to identify victim probabilities that make at least one individual willing to deviate by exerting standard care, given substandard care by the other individual.

Let us consider the attainability of an equilibrium in efficient care. Assume that I chooses $x = x^*$. Individual V will then choose efficient care, if

$$C^V(x^*, \tilde{y}) + L(x^*, \tilde{y}) > C^V(x^*, y^*) + \beta L(x^*, y^*)$$

with $\tilde{y} = \arg\min\{C^V(x^*, y) + L(x^*, y)\}$ being smaller than y^* because of the positive cost externality of care. We can define a critical victim probability that makes individual V indifferent between choosing y^* and $\tilde{y}$ and denote it β^*.

$$0 < \beta^* = \frac{C^V(x^*, \tilde{y}) - C^V(x^*, y^*) + L(x^*, \tilde{y})}{L(x^*, y^*)} < 1 \tag{6}$$

For all $\beta < \beta^*$, individual V rather adheres to due care, given that I takes standard care. Recognize that $0 < \beta^* < 1$ since the numerator is strictly positive by assumption 4 (ii) and $C^V(x^*, \tilde{y}) + L(x^*, \tilde{y}) < C^V(x^*, y^*) + L(x^*, y^*)$ is true because otherwise $\tilde{y}$ would not be cost minimizing. This condition $\beta < \beta^*$ can be easily interpreted. As individual V faces the trade-off of higher care costs against the saving of expected damages in case individual V is the injurer, the investment in care is worth it for low victim probabilities.

We can proceed likewise for individual I, with $y = y^*$ given, and find

$$0 < \alpha^* = \frac{C^I(\tilde{x}, y^*) - C^I(x^*, y^*) + L(\tilde{x}, y^*)}{L(x^*, y^*)} < 1 \tag{7}$$

For all $\alpha < \alpha^*$, individual I rather adheres to the standard because the expected individual costs are lower, given individual V exerts standard care. As for β^*, it holds that $0 < \alpha^* < 1$ based on assumption 4 (i) and the fact that $\tilde{x} = \arg\min\{C^I(x, y^*) + L(x, y^*)\}$.

The respective individuals face the trade-off that increasing care to the standard level will lift the expected damages burden if she turns out as injurer, whereas this increase is a waste if she turns out as victim, because the standard care is more than individually justified. For small probabilities of being the victim, this balancing leans towards exerting standard care.

So far, we deduced that a pure strategy equilibrium exists for $0 \leq \alpha < \alpha^*,\ 0 \leq \beta < \beta^*$. In pursuit of our claim that for certain victim probabilities there is only an efficient-care equilibrium, we turn to the second question, that is what victim probabilities prevent substandard care by both actors to be an equilibrium.

To confront the second part, suppose an equilibrium in substandard care exists. For our further analysis, we need to know how the optimal behavior of actors I and V and the equilibrium values of care vary with the victim probabilities. For the case of substandard care, isolating a critical victim probability is less straightforward than for the existence of a standard care equilibrium because there is more interdependency to consider. With $x < x^*$ and $y < y^*$, the respective first entry in (1) and (2) is the relevant individual cost function. Consequently, I minimizes

$$\min_{x < x^*} C^I(x, y) + (1 - \alpha)L(x, y) \tag{8}$$

with respect to her care. The FOC

$$C^I_x(x, y) + (1 - \alpha)L_x(x, y) = 0 \tag{9}$$

yields that optimal care by I is a function of the care exerted by V and the victim probability α, $x = x(y, \alpha)$. We apply the implicit function theorem to see that

$$\frac{dx}{dy} = -\frac{C^I_{xy}(x, y) + (1 - \alpha)L_{xy}(x, y)}{C^I_{xx}(x, y) + (1 - \alpha)L_{xx}(x, y)} \tag{10}$$

and

$$\frac{dx}{d\alpha} = \frac{L_x(x,y)}{C^I_{xx}(x,y) + (1-\alpha)L_{xx}(x,y)} < 0 \tag{11}$$

result as response to changes in the parameters for I.

Proceeding for V as for I, we find likewise that the optimal y is a function of the care taken by I and the victim probability β, $y = y(x, \beta)$.

$$\min_{y<y^*} C^V(x,y) + (1-\beta)L(x,y) \tag{12}$$

with the FOC

$$C^V_y(x,y) + (1-\beta)L_y(x,y) = 0 \tag{13}$$

We apply the implicit function theorem to find

$$\frac{dy}{dx} = -\frac{C^V_{xy}(x,y) + (1-\beta)L_{xy}(x,y)}{C^V_{yy}(x,y) + (1-\beta)L_{yy}(x,y)} \tag{14}$$

and

$$\frac{dy}{d\beta} = \frac{L_y(x,y)}{C^V_{yy}(x,y) + (1-\beta)L_{yy}(x,y)} < 0 \tag{15}$$

We see that in order to use $\frac{dx}{dy}$ or $\frac{dy}{dx}$ for our reasoning, we need information regarding the mixed cross partials, in this case C^I_{xy}, C^V_{xy} and L_{xy}. The only statement of DH in this respect is made to ensure that the social optimum is in fact a minimum, already alluded to above. For our purpose, we need more information. That is why we add an assumption concerning the relation of x and y.

Assumption 5: The care of I and of V are substitutes, i.e. $C^I_{xy}(x,y) + (1-\alpha)L_{xy}(x,y) > 0$ for $\alpha \in (0,1)$ is true.

The argumentation does not crucially depend on this assumption. Thus, the following reasoning does not substantially differ from that for the case of complements. However, the argumentation would loose clarity and require further differentiation, as we also point out in a footnote below. It is commonly assumed that care of the individuals are substitutes (see e.g. Ganuza and Gomez, 2002). Assumption 5 states that this is not overturned by the positive cost externality, i.e. the increased care by the other actor decreases the marginal benefit more than it decreases marginal costs of care. The mixed cross partials of the respective cost functions are sufficiently small and the effect of care of the respective actors on expected damages L is substitutional.

Both reaction curves fall, as a consequence of assumption 5, in the (x, y)-plane and shift toward the origin for larger values α and β, respectively. Thus, for $(\alpha, \beta) = (1, 1)$, we get a substandard equilibrium of $(x, y) = (0, 0)$. We assume that we can deduce from the assumptions of DH concerning the SOCs that

$$[C^I_{xx} + (1-\alpha)L_{xx}][C^V_{yy} + (1-\beta)L_{yy}] > [C^I_{xy} + (1-\alpha)L_{xy}][C^V_{xy} + (1-\beta)L_{xy}] \tag{16}$$

is true, i.e. that the slope of the reaction curve of individual I has a larger absolute value, as (16) is only a rearrangement of the respective slopes of the reaction curves. This inequality will usually hold based on the smallness of cross partials and ascertains that if there is a substandard equilibrium, it is unique.

If there is an equilibrium in substandard care, the care values will be determined by the subjective victim probabilities, equilibrium values being $\hat{x} = \hat{x}(\alpha, \beta)$ and $\hat{y} = \hat{y}(\alpha, \beta)$. As we seek critical values for the subjective victim probabilities, we inquire how the equilibrium would change in response to different victim probabilities. After applying Cramer's rule, we get

$$\frac{\partial \hat{x}}{\partial \alpha} = \frac{L_x(C^V_{yy} + (1-\beta)L_{yy})}{T} < 0 \tag{17}$$

$$\frac{\partial \hat{x}}{\partial \beta} = (-1)\frac{L_y(C^I_{xy} + (1-\alpha)L_{xy})}{T} > 0 \tag{18}$$

$$\frac{\partial \hat{y}}{\partial \beta} = \frac{L_y(C^I_{xx} + (1-\alpha)L_{xx})}{T} < 0 \tag{19}$$

$$\frac{\partial \hat{y}}{\partial \alpha} = (-1)\frac{L_x(C^V_{xy} + (1-\beta)L_{xy})}{T} > 0 \tag{20}$$

with $T = [C^I_{xx} + (1-\alpha)L_{xx}][C^V_{yy} + (1-\beta)L_{yy}] - [C^I_{xy} + (1-\alpha)L_{xy}][C^V_{xy} + (1-\beta)L_{xy}] > 0$ by (16).

Recall that to support our claim, we only need to find conditions that make it preferable for at least one individual to exert due care as response to substandard care. We take a closer look at individual I and ask whether we can find a critical level for the subjective victim probabilities, so that she becomes indifferent between a solution in substandard care and her exertion of standard care, given the substandard care of individual V. For this purpose, we define a function $D(\alpha, \beta)$ that takes positive values whenever it is advantageous for individual I to take standard instead of the substandard care that would otherwise result, always taking as given that individual V chooses substandard care.

$$D(\alpha, \beta) = C^I(\hat{x}(\alpha, \beta), \hat{y}(\alpha, \beta)) + (1-\alpha)L(\hat{x}(\alpha, \beta), \hat{y}(\alpha, \beta)) - C^I(x^*, \hat{y}(\alpha, \beta)) \tag{21}$$

By using this function, we, for the time being, presume that individual V will always behave according to her FOC defined only for $y < y^*$. Thus, it is not considered that individual V might, for some considered combinations of (α, β), rather 'jump' to y^* as the comparison of the respective costs for individual V proves this to be advantageous. We furthermore allow $\hat{y}(\alpha, \beta) > y^*$ and $\hat{x}(\alpha, \beta) > x^*$ which would not actually result because individuals behave according to (9) and (13) for interior solutions only if $x < x^*$ and $y < y^*$ is true. Not imposing a restriction on $\hat{x}(\alpha, \beta)$ and $\hat{y}(\alpha, \beta)$ has two effects. On the upside, D is a continuous function which we need for our further argumentation. On the downside, the restrictions on the subjective victim probabilities may turn out stricter than necessary. The latter effect realizes because the function D in fact assumes more substandard equilibria possible than there are. All the cases in which individual V 'jumps' to y^* or $\hat{y}(\alpha, \beta) > y^*$ results do not represent substandard equilibria because individual V rather complies with the behavioral standard. In other terms, individual V leaves the substandard equilibrium whereas we use $\hat{y}(\alpha, \beta)$ in function D and continue to search for conditions under which individual I will leave the substandard equilibrium. We indeed continue to search by varying the victim probability as higher care by individual V makes the substandard equilibrium relatively more attractive for I, as can be seen by differentiating D with respect to y. Given the restrictions from above, $0 \leq \alpha < \alpha^*$, $0 \leq \beta < \beta^*$, hold, we know that once one individual takes standard care, the other responds with standard care. Thus, there is no problem of circularity, i.e. the change of $y < y^*$ to y^* does not lead to adaptations in $x < x^*$ which make $y < y^*$ attractive and the process starts all over again. As to the case that we consider $\hat{x}(\alpha, \beta) > x^*$, our function D will simply yield positive values and thereby denote substandard care as undesirable for individual I.

The function D is continuous because costs and expected damages vary continuously in care and care varies continuously in the victim probabilities.[1] Because D is continuous and $D(0, \beta) > 0$ by assumption 4 (i) and $D(1, \beta) < 0$ as zero care has no consequence for negligent victims given negligent injurers, we can use the intermediate value theorem. There must be at least one α^{**} for every $\bar{\beta}$ which yields $D(\alpha^{**}, \bar{\beta}) = 0$. To see that there is exactly one critical level, we derive D with respect to α

$$\frac{\partial D(\alpha, \beta)}{\partial \alpha} = \frac{\partial x}{\partial \alpha}[C_x^I(x(\cdot), y(\cdot)) + (1-\alpha)L_x(x(\cdot), y(\cdot))] \tag{22}$$

$$+\frac{\partial y}{\partial \alpha}[C_y^I(x(\cdot), y(\cdot)) - C_y^I(x^*, y(\cdot)) + (1-\alpha)L_y(x(\cdot), y(\cdot))] - L(x(\cdot), y(\cdot)) < 0$$

[1]Again, remind that this argumentation only applies to cases where substandard-care equilibria are possible. This excludes, for example, cases where due to a change in α the reaction curves no longer intersect.

The first term is either equal to zero for interior optima or negative as $\frac{\partial \hat{x}}{\partial \alpha} < 0$ by (17). The second term is negative as we have assumed in assumption 5 that the mixed cross partials are sufficiently small.[2] Thus, with reference to (17) and (20), we can say that in reaction to an increase in α, individual I decreases her care choice as it is more likely that she is not the type at which the standard is directed. Individual V increases her care as x and y are substitutes. The change in y affects precaution costs in the last term in (21) more or equal to the effect on precaution costs in the first term, but this is more than compensated by the effect of the increase in y on expected damages. In sum, D falls in α so that we can say that D is continuous and monotonous in α, leading to a unique α^{**} for a given $\bar{\beta}$.

Basically the same reasoning applies to the derivative with respect to β

$$\frac{\partial D(\alpha, \beta)}{\partial \beta} = \frac{\partial x}{\partial \beta}[C_x^I(x(\cdot), y(\cdot)) + (1-\alpha)L_x(x(\cdot), y(\cdot))] \tag{23}$$

$$+\frac{\partial y}{\partial \beta}[C_y^I(x(\cdot), y(\cdot)) - C_y^I(x^*, y(\cdot)) + (1-\alpha)L_y(x(\cdot), y(\cdot))] > 0$$

The first term, again, equals zero for strictly positive optimal $\hat{x}$ and is positive in case $x = 0$ is optimal if marginal benefits of care are smaller than marginal costs. The last term is positive by (19) and our assumption concerning the smallness of mixed partials. Thus, it becomes more advantageous for individual I to 'flee' from a substandard equilibrium if the individual V increasingly believes to turn out as the victim. Actor V takes less care as a consequence, which increases individual I's precaution costs if she takes standard or substandard care. It also increases expected damages, which individual I expects to bear with probability $(1-\alpha)$. To compensate the decrease in care by V, actor I increases her care which elevates her costs in the substandard equilibrium.

Piecing all of the above for the second task together, we can expect to find a critical victim probability level α^{**}, so that for $\alpha < \alpha^{**}$, individual I rather expends on standard care as long as $\beta \geq \bar{\beta}$. This critical level α^{**} for α increases in $\bar{\beta}$, as the substandard equilibrium becomes less and less attractive for I if individual V considers it less and less

[2] With reference to assumption 5, we restate that the assumption is not crucial. However, considering the case of complements would at this stage, for instance, require to differentiate. First, it is possible that $\frac{\partial D(\alpha,\beta)}{\partial \alpha} > 0$ because the under this circumstance negative $\frac{\partial y}{\partial \alpha}$ in combination with the negative brackets overshadows the other negative terms. Second, $\frac{\partial D(\alpha,\beta)}{\partial \alpha}$ is still negative because the positive term is smaller than the negative ones. But again, all we need is unambiguous variation of D in the respective victim probabilities which would also be possible under care as complements.

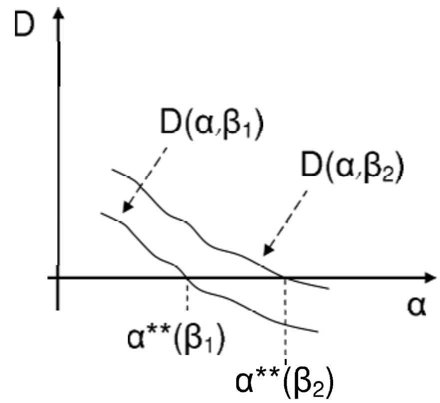

Figure 1: Function D for different β, $\beta_2 > \beta_1$

likely to be the injurer at whom the behavioral standard is directed.

$$\frac{d\alpha^{**}}{d\bar{\beta}} = (-1)\frac{\frac{\partial y}{\partial \beta}[C^I_y(x(\cdot),y(\cdot)) - C^I_y(x^*,y(\cdot)) + (1-\alpha)L_y(x(\cdot),y(\cdot))]}{\frac{\partial y}{\partial \alpha}[C^I_y(x(\cdot),y(\cdot)) - C^I_y(x^*,y(\cdot)) + (1-\alpha)L_y(x(\cdot),y(\cdot))] - L(x(\cdot),y(\cdot))} > 0 \tag{24}$$

Figure 1 represents the fact that D falls in α and that larger β shift D to the right. Thus, an increase in $\bar{\beta}$ implies a larger α^{**} as a consequence.

Having found such a critical α^{**} for which $D = 0$ holds, we can rearrange the expression in (21) to find that

$$0 < \alpha^{**} = \frac{C^I(\hat{x},\hat{y}) - C^I(x^*,\hat{y}) + L(\hat{x},\hat{y})}{L(\hat{x},\hat{y})} < 1 \tag{25}$$

with $\hat{x}$ and $\hat{y}$ as the equilibrium substandard care levels for α^{**} and $\bar{\beta}$. This critical value is strictly positive by assumption 4 (i). Hence, there is a strictly positive α^{**} for every $\bar{\beta} \in [0,1]$, which makes the individual I indifferent between $\hat{x} < x^*$ and x^*. This indifference means that for $\alpha < \alpha^{**}$ and $\beta \geq \bar{\beta}$ an equilibrium in inefficient care is impossible. Note that we can find a positive α^{**} for every β, so that we could define the prerequisites for an efficient care equilibrium without adding substantially more concerning the victim probability of actor V to the condition $\beta < \beta^*$ from above, by choosing a very small $\bar{\beta}$, possibly with a small α^{**} as ramification.

As the second part of our task only requires to make it advantageous for at least one individual to 'escape' the substandard-care equilibrium, the above said suffices to prove our point. However, by applying the same procedure to individual V, we find a critical level β^{**} for every $\bar{\alpha}$.

Proposition 1 *An equilibrium in efficient care exists in a model with interdependent costs of care and simple negligence as liability rule, if $\alpha < \alpha^*$ and $\beta < \beta^*$ holds. Possibly existing substandard care equilibria can be excluded by requiring $\alpha < min\{\alpha^*, \alpha^{**}\}$ and $\bar{\beta} \leq \beta < \beta^*$ or $\bar{\alpha} \leq \alpha < \alpha^*$ and $\beta < min\{\beta^*, \beta^{**}\}$.*

Proof. Follows from the above. ■

These intervals for α and β, respectively, which enable efficiency always exist. For example, $\min\{\alpha^*, \alpha^{**}\}$ is strictly positive even as we take a very small α^{**} to enable a low $\bar{\beta}$. Thus, we do not argue that there might be circumstances under which role-type uncertainty can enable efficiency but that there always are. Therefore, considering interdependent costs of care as a realistic feature of certain accident contexts no longer carries the drastic connotation with respect to standard liability rules implied by DH.

The intuition for our result is straightforward. If an individual expects to be the injurer, i.e. the party at which the behavioral standard is directed, with a probability of a specific magnitude, she rather bears the additional expenditure on care. The alternative is to possibly take over the damage burden because of substandard care. In other terms, it is a trade-off of certain additional costs against a stochastic saving. Small victim probabilities achieve both necessary effects, firstly, that standard care is the best response to standard care and, secondly, that standard care turns out to be better than substandard care in response to substandard care. The simultaneous requirement on the victim probability of the other individual owes to two reasons. First, it is a consequence of the fact that standard care ought to be the best response to standard care for both actors. Second, taking standard care as a response to substandard care is more desirable if the other party considers it likely to be the victim, because this evokes lower care by this party.

2.4 An Example

A better understanding of the requirements concerning the subjective victim probabilities can be generated by a specific and simple example. For that purpose, we take

$$C^I(x,y) = 2x - y \tag{26}$$

$$C^V(x,y) = 2y - x \tag{27}$$

as individual precaution costs. Further, $P(x,y) = \frac{1}{x+xy+y}$ is the accident probability and $H = 100$ the level of harm. Recognize the cost interdependency in the respective precaution cost functions and the fact that, inter alia, $P_x H < 0$, $P_{xx} H > 0$ and $C^I_{xy} + (1-\alpha)P_{xy}H > 0$ hold, as required by our assumptions. The social costs as sum of individual precaution costs and expected damages is thus

$$SC(x,y) = C^I(x,y) + C^V(x,y) + L(x,y) = x + y + \frac{100}{x + xy + y} \tag{28}$$

The socially optimal care levels for this minimization problem are $(x^*, y^*) = (3.782, 3.782)$.

This example ought to add meaning to the conditions stated in proposition 1. Thus, we start with the requirements imposed for the existence of an efficient-care equilibrium and, consequently, illuminate the meaning with respect to the exclusion of substandard equilibria.

First, we search for critical values α^* and β^* that make standard care by both individuals a care equilibrium. For this, we take standard care by actor V as given and inquire what victim probability α makes actor I prefer to respond with standard care instead of individually optimal care, where the latter is smaller due to the cost externality. Generally, α^* solves the equation

$$C^I(x^*, y^*) + \alpha^* L(x^*, y^*) = C^I(\tilde{x}, y^*) + L(\tilde{x}, y^*)$$

Since $\tilde{x} = 2,443 = \arg\min\{2x - y^* + \frac{100}{x + xy^* + y^*}\}$, we find $\alpha^* = 0.828$ solving

$$2x^* - y^* + \alpha \frac{100}{x^* + x^* y^* + y^*} = 2\tilde{x} - y^* + \frac{100}{\tilde{x} + \tilde{x} y^* + y^*}$$

The symmetry of the problem yields the same for β^*, i.e. the critical victim probability for actor V responding to $x = x^*$ as given.

Second, we turn to the possibility of substandard care equilibria and illustrate combinations of $(\alpha^{**}, \bar{\beta})$ that prevent substandard care equilibria and, therefore, in combination with the first set of conditions make efficient care by both actors the only equilibrium. Behavior is governed by the respective FOC

$$IC_x(x,y) = 2 - (1-\alpha)\frac{100(1+y)}{x + xy + y} = 0$$

$$VC_y(x,y) = 2 - (1-\beta)\frac{100(1+x)}{x + xy + y} = 0$$

Let us take a reasonable case as a starting point, the case that both parties appoint equal probability to both states, $(\alpha, \beta) = (0.5, 0.5)$. The intersection of the reaction curve yields $(\hat{x}, \hat{y}) = (2.14, 2.14)$ as care levels. Would this actually result as substandard care equilibrium? To answer this question, we insert the relevant values in the function $D(\alpha, \beta)$ from

(21), to find that, given these victim probabilities, individual I rather exerts standard care.

$$D(0.5,0.5) = C^I(x(0.5,0.5),y(0.5,0.5))+(1-0.5)L(x(0.5,0.5),y(0.5,0.5))-C^I(x^*,y(0.5,0.5))$$

$$= C^I(2.14,2.14) + (1-0.5)L(2.14,2.14) - C^I(3.782,2.14) = 1.97 > 0$$

In fact, for $\bar{\beta} = 0.5$, the corresponding critical victim probability for actor I that makes her indifferent is $\alpha^{**} = 0.64$. This α^{**} increases in $\bar{\beta}$ as found in the text. For example, whereas given $\bar{\beta} = 0.7$, the corresponding α^{**} is 0.725, the comparison yields $\alpha^{**} = 0.525$ for $\bar{\beta} = 0.2$.

Summarizing the above and using the terminology of proposition 1, we state the following for the specified example: An equilibrium in efficient care exists in a model with interdependent costs of care and simple negligence as liability rule, if $\alpha < 0.828$ and $\beta < 0.828$ holds. Possibly existing substandard care equilibria can be excluded by requiring $\alpha < 0.64$ and $0.5 \leq \beta < 0.828$.

By choosing another $\bar{\beta}$, the requirements change, e.g. broadening the interval for β by lowering $\bar{\beta}$ requires lower α as α^{**} decreases.

This example demonstrated that the circumstances that need to hold for efficient care to be the only equilibrium are not necessarily extreme cases. Thus, the analysis at hand is more than a theoretical exercise but does truly dampen the negative conclusion made by DH.

2.5 Role-Type Uncertainty and other Liability Rules

Liability rules affect the apportionment of the damage burden dependent on care. Above, we have established that role-type uncertainty can lessen the impact of interdependent costs of care in a frame with simple negligence (SN) as liability rule. A feature of SN is that it directs a behavioral standard at only one party to the accident, namely the injurer. Once the injurer acts according to the legal prescription, the damage burden is shifted. This fact is important as will become clear momentarily. In the following, we sketch to what extent our result carries over to frames with strict liability with a defense of contributory negligence (SLCN) and negligence with a defense of contributory negligence (NCN).

SLCN is the mirror image of simple negligence, as this rule also entails only one standard, however, directed at the victim. DH found with their assumptions concerning (α, β) that $(\tilde{x}, y^*)$ is the equilibrium, with $\tilde{x} < x^*$. The cost functions are similar to the case of SN except for the fact that negligent victims pay irrespective of the behavior of the other party, whereas under SN, the negligent injurer pays irrespective of the behavior of the other party. The fact that SLCN is like SN reversed leads to the observation that the terms α $[\beta]$ and $(1-\alpha)$ $[(1-\beta)]$ appear under reversed conditions for the care choices in the respective individual cost functions. Extending this reasoning leads to the conclusion that role-type uncertainty can also help under SLCN, but we need to be above critical values for the subjective victim probabilities instead of below.

Proposition 2 *An equilibrium in efficient care exists in a model with interdependent costs of care and SLCN as liability rule, if $\alpha > \alpha^*$ and $\beta > \beta^*$ holds. Possibly existing substandard care equilibria can be excluded by requiring $\alpha > max\{\alpha^*, \alpha^{**}\}$ and $\bar{\beta} \geq \beta > \beta^*$ or $\bar{\alpha} \geq \alpha > \alpha^*$ and $\beta > max\{\beta^*, \beta^{**}\}$.*

Proof. See the appendix. ■

As SLCN reverses the conditions on the victim probabilities but aside from this parallels simple negligence, the intuition for the result follows the interpretation given for the case of simple negligence. Standard care is preferable without any uncertainty only if you are the victim. If uncertainty about the role is allowed, the difference in precaution costs is possibly overshadowed by the potential burden of expected damages. This motivates actors to exert standard care, so that they free themselves in the role of the victim.

Under negligence with a defense of contributory negligence, negligent injurers are required to compensate the victim as long as the victim takes at least standard care. The victim bears expected damages in case both parties are negligent, in case only she is negligent and in case both parties are non-negligent. The cost functions under this liability rule reveal that for role-type uncertainty to enable efficient care choices, we would need a small victim probability, on the one hand, in order to make standard care the best response to standard care. On the other hand, too small victim probabilities make potential substandard equilibria attractive. Thus, the victim probabilities that allow for pure strategy equilibria in efficient care need to fall between two critical values.

Proposition 3 *An equilibrium in efficient care exists in a model with interdependent costs of care and NCN as liability rule, if $\alpha < \alpha^*$ and $\beta < \beta^*$ holds. Possibly existing substandard care equilibria can be excluded by requiring $\alpha^{**} < \alpha < \alpha^*$ and $\beta < min\{\bar{\beta}, \beta^*\}$ or $\beta^{**} < \beta < \beta^*$ and $\alpha < min\{\bar{\alpha}, \alpha^*\}$.*

Proof. See the appendix. ■

The case of NCN differs from SN and SLCN in that the same party is responsible if both parties are either non-negligent or negligent. For SN and SLCN, we had one role responsible for expected damages if both parties do not take standard care and the other party responsible if both parties take standard care. Thus, in those cases the direction for the personal victim probability to enable efficiency was clearly one way. In the case of SN, small victim probabilities can enable efficiency, as the injurer is burdened by the standard. In the case of SLCN, large personal victim probabilities can enable efficiency, as the victim is burdened by the standard. Now, NCN burdens the victim not only in one but in both cases. To be preferable for the individual to exert standard care as a response to standard care out of a cost perspective, the victim probability should not be too large, because the decrease in expected liability shall not compensate the difference in precaution costs. However, for small victim probabilities, the burden of expected damages is not sufficiently threatening as to yield standard care as best response to substandard care. This creates a tension between a minimum and a maximum level, where it is not certain whether the maximum is always larger than the minimum, i.e. whether $\alpha^{**} < \alpha^{*}$ or $\beta^{**} < \beta^{*}$ holds.

Hence, after we have considered three different liability rules, we find that role-type uncertainty always allows efficiency under SN and SLCN for specific bands of victim probabilities. This is not the case under NCN, where the requirements may in some cases never be fulfilled.

3 Conclusion

This paper considered the case of interdependent precaution costs and showed the beneficial effects of uncertainty. We demonstrated that the case considered in Dharmapala and Hoffmann (2005) is only a special case of a more general model. The generalization allows for role-type uncertainty. Their result that the efficient care equilibrium cannot be achieved with interdependent costs of care is a consequence of their assumption concerning the role probability. We remove this assumption and show for simple negligence that for a band of type probabilities, efficient care by both parties results as equilibrium. Concluding, we consider strict liability with a defense of contributory negligence and negligence with a defense of contributory negligence. For the former we find that role-type efficiency enables efficiency, although the conditions for the victim probabilities are reversed as the liability rule reverses the apportionment in comparison to simple negligence. We find for the latter that there may be circumstances in which role-type uncertainty cannot enable the efficient care equilibrium, because it is conceivable that the conditions regarding the victim probabilities are not fulfilled.

Appendix

To proof **proposition 2**, let us consider how the individual cost functions look under SLCN. For individual I

$$IC(x,y) = \begin{cases} C^I(x,y) + \alpha L(x,y) & x < x^* \text{and } y < y^* \\ C^I(x,y) & x \geq x^* \text{and } y < y^* \\ C^I(x,y) + L(x,y) & x < x^* \text{and } y \geq y^* \\ C^I(x,y) + (1-\alpha)L(x,y) & x \geq x^* \text{and } y \geq y^* \end{cases} \tag{29}$$

and similarly for individual V

$$VC(x,y) = \begin{cases} C^V(x,y) + \beta L(x,y) & y < y^* \text{and } x < x^* \\ C^V(x,y) & y \geq y^* \text{and } x < x^* \\ C^V(x,y) + L(x,y) & y < y^* \text{and } x \geq x^* \\ C^V(x,y) + (1-\beta)L(x,y) & y \geq y^* \text{and } x \geq x^* \end{cases} \tag{30}$$

We outline the argumentation done above for simple negligence for the case of SLCN. Thus, we first consider the move into the efficient equilibrium. Given $y = y^*$, individual I takes standard care if $\alpha > \alpha^*$ with

$$0 < \alpha^* = \frac{C^I(x^*,y^*) - C^I(\tilde{x},y^*) - L(\tilde{x},y^*)}{L(x^*,y^*)} + 1 < 1 \tag{31}$$

The first term is negative by assumption 4 (i) and therefore α^* always strictly less than 1. Thus, there is an interval that makes individual I choose x^* given y^*. By the same reasoning, we find a β^*, so that individual V takes standard care for $\beta > \beta^*$ and $x = x^*$.

As the next step, we consider equilibria in substandard care. The respective FOCs of individual I and V are in this case

$$C_x^I(x,y) + \alpha L_x(x,y) = 0 \tag{32}$$

and

$$C_y^V(x,y) + \beta L_y(x,y) = 0 \tag{33}$$

As above, we find that the equilibrium values will depend on the victim probabilities, $\hat{x} = \hat{x}(\alpha,\beta)$ and $\hat{y} = \hat{y}(\alpha,\beta)$.

These equilibrium values vary with α and β according to

$$\frac{\partial \hat{x}}{\partial \alpha} = (-1)\frac{L_x(C^V_{yy} + \beta L_{yy})}{T} > 0 \tag{34}$$

$$\frac{\partial \hat{x}}{\partial \beta} = \frac{L_y(C^I_{xy} + \alpha L_{xy})}{T} < 0 \tag{35}$$

$$\frac{\partial \hat{y}}{\partial \beta} = (-1)\frac{L_y(C^I_{xx} + \alpha L_{xx})}{T} > 0 \tag{36}$$

$$\frac{\partial \hat{y}}{\partial \alpha} = \frac{L_x(C^V_{xy} + \beta L_{xy})}{T} < 0 \tag{37}$$

with $T = [C^I_{xx} + \alpha L_{xx}][C^V_{yy} + \beta L_{yy}] - [C^I_{xy} + \alpha L_{xy}][C^V_{xy} + \beta L_{xy}] > 0$ with reference to (16). Note that the equilibrium values change in directions opposite to the case for simple negligence, as the weight attached to the expected damage L is α $[\beta]$ instead of $(1-\alpha)$ $[(1-\beta)]$.

This change in signs foreruns the fact that the partial derivatives of the relative advantage function D change accordingly, so that

$$\frac{\partial D(\alpha, \beta)}{\partial \alpha} > 0 \tag{38}$$

and

$$\frac{\partial D(\alpha, \beta)}{\partial \beta} < 0 \tag{39}$$

As $D(0, \beta) < 0$ is true because negligent injurers do not have to compensate negligent victims and the choice of $x = 0$ therefore is without consequence and $D(1, \beta) > 0$ is true by assumption 4 (i), there is a critical value α^{**} for every $\bar{\beta}$ which makes individual I indifferent.

$$0 < \alpha^{**} = \frac{C^I(x^*, \hat{y}) - C^I(\hat{x}, \hat{y})}{L(\hat{x}, \hat{y})} < 1 \tag{40}$$

Actor I prefers standard care to substandard care if $\alpha > \alpha^{**}$ and $\beta \leq \bar{\beta}$.

Mirroring the above for individual V would yield critical values β^* to make standard care a best response to standard care and β^{**} to make standard care a best response to substandard care for $\alpha \leq \bar{\alpha}$.

This argument leads to proposition 2 from above: An equilibrium in efficient care results in a model with interdependent costs of care and SLCN as liability rule, if $\alpha > \max\{\alpha^*, \alpha^{**}\}$

and $\bar{\beta} \geq \beta > \beta^*$ or if $\bar{\alpha} \geq \alpha > \alpha^*$ and $\beta > \max\{\beta^*, \beta^{**}\}$.

We now turn to **proposition 3**, thus, we delineate the effects for NCN. NCN is a liability rule that entails standards directed at the injurer as well as at the victim. The respective cost functions change to

$$IC(x,y) = \begin{cases} C^I(x,y) + \alpha L(x,y) & x < x^* \text{and } y < y^* \\ C^I(x,y) & x \geq x^* \text{and } y < y^* \\ C^I(x,y) + L(x,y) & x < x^* \text{and } y \geq y^* \\ C^I(x,y) + \alpha L(x,y) & x \geq x^* \text{and } y \geq y^* \end{cases} \tag{41}$$

and similarly for individual V

$$VC(x,y) = \begin{cases} C^V(x,y) + \beta L(x,y) & y < y^* \text{and } x < x^* \\ C^V(x,y) & y \geq y^* \text{and } x < x^* \\ C^V(x,y) + L(x,y) & y < y^* \text{and } x \geq x^* \\ C^V(x,y) + \beta L(x,y) & y \geq y^* \text{and } x \geq x^* \end{cases} \tag{42}$$

To recognize this, let us again first consider the best response of individual I to $y = y^*$. For standard care to be the best response, we need an α smaller than

$$0 < \alpha^* = \frac{C^I(\tilde{x}, y^*) - C^I(x^*, y^*) + L(\tilde{x}, y^*)}{L(x^*, y^*)} < 1 \tag{43}$$

As the second step, we need to consider individual I's best response to $y < y^*$. The argumentation is the same as for the case of SLCN, as the relevant entries into the respective cost functions are identical.

Putting both requirements together shows that we need α to fall in the interval

$$0 < \alpha^{**} = \frac{C^I(x^*, \hat{y}) - C^I(\hat{x}, \hat{y})}{L(\hat{x}, \hat{y})} < \alpha < \frac{C^I(\tilde{x}, y^*) - C^I(x^*, y^*) + L(\tilde{x}, y^*)}{L(x^*, y^*)} = \alpha^* < 1 \tag{44}$$

In addition to this being the case, we would require that $\beta \leq \min\{\bar{\beta}, \beta^*\}$. Although it is possible that there is a span between the critical values for α, it cannot be ascertained in our assumptional frame. As a consequence of the case in which no α falls between the critical values, we cannot pinpoint a sole pure strategy equilibrium. In their quest, DH found that no pure strategy equilibrium results for NCN with their assumptions regarding (α, β).

This explains proposition 3: An equilibrium in efficient care results in a model with interdependent costs of care and NCN as liability rule, if $\alpha^{**} < \alpha < \alpha^*$ and $\beta < \min\{\bar{\beta}, \beta^*\}$ or $\beta^{**} < \beta < \beta^*$ and $\alpha < \min\{\bar{\alpha}, \alpha^*\}$.

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