UiO : Det juridiske fakultet

Theory on the combination of tort law, regulation and pigouvian taxation in a two actor model

Analysis of the best use of policy instruments in combination in a two actor model with limited liability.

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1 Introduction

This thesis explores the joint use of tort law, regulations and taxation in theory. A simple two actor model is utilized.

The regulation of harmful activities has been analyzed in many different ways and with many different points of view by scholars within law, economics or both. The emphasis is usually placed on the use of one instrument, typically tort law, regulations, taxation or criminal law. However there are also plentiful examples of analysis of the use of two instruments. Examples include Shavell (1984), Kolstad et al. (1990) who consider the use of liability and safety regulations, Christiansen, V and Smith, S (2012) and Eskeland, Gunnar S (1994) who look at regulations and taxation. Shavell (2010) analyzes taxation versus liability. It seems interest has picked up recently to study several instruments in combination.

Indeed a main point of this thesis is to show the interconnectedness of the different instruments at hand to regulate harmful activities. I have picked out three. These are tort law, taxation and regulations. By regulation I mean the ability to determine the specific care level or the specific set of rules to comply with for engaging in an activity that implicitly gives the level of care to comply with. This is a very crude way of looking at the large scope of instruments and strategies that is contained in the term “regulations”. The point is that there are other forms of instruments available besides tort law and taxation and that these are fundamentally different from each other. A nuanced treatment of the regulations available would ruin the analytical clarity of the model.

I claim however, that these three instruments in the general case cannot be analyzed in isolation. I will show, with my point of view and with my set of assumptions, that in general one cannot determine the optimal tort regime without considering other instruments that could be used instead or in combination. Likewise, the optimal excise tax for a harmful activity is seldom independent of the tort regime used and the regulations applied. The best use of direct regulations as well is not independent of the possibilities of applying tort law and taxations.
I have picked out these three instruments because I consider them the three main tools for analyzing harmful activities not involving crime. It is also a matter of analytical clarity. A model of everything within harmful activities is highly unlikely. It’s better to explore a limited phenomenon in an orderly fashion. The assignment must be limited not only in instru-

ments used, but with assumptions and thus scope of application. Of course, the real world is full of complexities missed in an orderly and presentable model of economics. I hope the model shed light on some aspects or regulation of harmful activities, although only contingent conclusions can be drawn. Every theoretical analysis within economics and law is based on specific assumptions and takes on a specific point of view, and of course this one is no exception.

It is interesting to note that these three instruments, tort law, regulation and taxation, typically belongs to the three different branches of government. The judiciary applies the law of torts, the executive has an active hand on regulations and the legislative deals with taxes. Of course this is a crude picture. In any way the use of instruments is likely to be fragmented, and the best response for a benevolent part of the public authorities will depend on the actions of the other parts. This is also essential in assessing the optimal policy mix. For instance, and as shall be demonstrated, must the optimal externality correcting tax set by the legislative be adjusted to the expected level of liability which is usually set by courts, that is if liability is present.

This assignment is founded in the subject of economics and law, and the analysis is primarily an economic one. However, I wish to raise legal issues as well. The law of torts clearly determines the optimal use of excise taxes, but the use of excise taxes should also have legal consequences, for instance applying strict liability on a part already subject to an excise tax on his activity or production could mean a potential unfair double burden, as well as economic inefficiency.

A central part of this thesis is also the normative analysis between different tort rules, primarily the choice between negligence and strict liability. I will show that in many circumstances the optimal tort rule cannot be analyzed aside from the applicability, use, or optimal use of other instruments such as excise taxation and regulations.

The scope of the assignment is harmful activities. The model setup is based on a probability of accidents depending on care level. However this could also be interpreted as a more deterministic or expected externality of an activity, broadening the relevance of the results. I try to give the reader examples of possible applications of the theory during the setup and analysis.

Further, I consider only cases where there is potentially an identifiable defendant and where lawsuit is a feasible. Since I don't consider solutions based on bargaining the scope of the thesis is harmful activities under situations of high transaction costs and where government or court involvement is necessary for improving the situation. In general all instruments considered in the analysis should be applicable in order for the conclusions to hold. The scope of the analysis is thus restricted as there are many circumstances where liability is unlikely, and many circumstances where taxation or levying a fee is unlikely.

As I set out in the following chapter on basic theory, there are in the mainstream literature four ways of looking the economics and law of harmful activities. There are unilateral and bilateral damages and one can analyze with fixed or flexible activity level, yielding four combinations. I will consider all these situations in my model. The greatest emphasis is however placed on the situation of unilateral damages with flexible activity level. This analysis is used as a benchmark when the more complex case of bilateral damages is considered.

I will include two caveats to optimality: These are risk distribution and limited liability. Limited liability is treated as simple as possible with a share of damages less than one to be paid by liable parties. Risk distribution, meaning that the actors involved create different degrees of damages when an accident occurs, or that accidents for some happens more often, is treated simply by letting the two actors in the model have different damages following an accident.

My model is strongly inspired by Steven Shavells model from 1984 and must be said to build on this. In relation to Shavells model, mine contain both simplifications and extensions. The risk distribution is treated simpler here, with two types of actor. On the other hand I look at three different instruments and consider both main types of liability rules explicit, that is negligence and strict liability.

While many works on the regulation of harmful activities focus on the possibilities for optimality, I try to analyze what is likely the best policy. I reality it's unlikely that one can find policies that are truly optimal. Even in theory the scope of situations where one can find optimal policies is very limited. I also analyze how the best policy is likely to change according to changes in the risk distribution of actors in the economy. Such changes could for instance stem from developments in technology or social norms.

The outline of the thesis is as follows: First, in chapter two, the basic theory is presented. Here I will show the theory that my model is based on. Chapter three presents the extended model that I rely on in my analysis. In chapter four to six the model is applied to situations of unilateral damages. In chapter seven to nine bilateral damages is analyzed and in chapter ten conclusions are drawn. In chapter ten I consider a few momentums not considered in the model.

I sometimes use the term "production" for activity level, this is to vary the language at times, and it need not mean production in the strict economic sense. I also use the term "policy" for the combined package of means to regulate harmful activities, that is, regulations, taxation and torts. This could cause confusion as the term "policy" is not typically attributed to the rulings of courts.

I rely on mathematical equations and stick to these so long as they can be given fairly nice looking solutions. I also present solutions that are solved numerically. To avoid too much mathematical clutter I rely quite a bit on simulations with following graphical figures to show some main results. I try to present the core of the theory in precise mathematical terms. More advanced discussions and extensions are either left to simulation or discussed verbally. I consider the mathematics necessary to form the model and to show its relation with the current literature. It should however be possible to understand the main arguments of the thesis by just following the text.

For the sake of simulations and some of the solutions I have made an Excel workbook with a Visual Basic procedure. This is of course available on request.

2 The basic theory

The basic theory of accident law as it is laid out in Shavell(1987) separates the matter into four scopes of analysis. Unilateral and bilateral damage, and for each, with or without activity level included in the analysis:

	Care	Care and activity level
Unilateral damage		
Bilateral damage		

Table 1: Scope of analysis

Of course, the lower right option is the most complicated and perhaps most applicable. However several situations can be analyzed successfully, if not better in a simpler setting. Indeed a part of the analysis of any problem within the economics of accident law is to determine which setting that best describes the case under study.

Situations that can be realistically modeled with the care-only setting include situations where it is unlikely that the potential injurer will adjust the amount of times she gets in the situation where damage can occur as a result of the risk of harm and damages. An example is a mechanic being negligent and wrongly approving a machine or vehicle in a periodic control, which later causes harm to someone. The amount of controls is fixed and set by a regulatory agency. An example of where activity level certainly does matter, is for local polluted emissions or noise from a factory or installment. In this case the way of operation or cleaning technology can be thought of as care and the activity level is hours of operation or amount of pollution emitted.

Whether damage is unilateral or bilateral is not a matter of whether there are two parts to the harm, as there always is. Rather the point is whether or not the victim in any way can be expected to be able to lower the amount of harm suffered by adjusting his own level of care or activity level. A prominent example of unilateral damage is a situation in which the victim is unaware of the danger at the time of being exposed to it, as can be the case with toxic material in food or drink for instance. An example of the contrary is hunters and mushroom pickers sharing a forest during fall, not only will the care of both parties (as wearing bright colors and only hunting when sober) matter for the amount or probability of accidents, but the amount of hours spent in the forest will matter as well.

A further qualification on the best setting of analysis is also whether there is a point in separating care and activity level at all. As is pointed out in Shavell(1987), if courts could include the amount of activity in the question of negligence, the problem would be one-dimensional. However this would in many circumstances prove difficult. Not only will activity level be private information in many cases, but courts may also find it awkward to find someone negligent for doing a certain activity too often, although it is not unthinkable. Involving activity level to be dealt with by courts would also involve a more difficult end tedious task for courts.

I start the presentation of the important basic theory to be used in the thesis by exploring the four cases in the accident law analysis matrix above, then the fundamentals of excise taxation and regulation is presented. At last follow some basic theory on limits to liability and a distribution of risk amongst actors in the economy.

2.1 Unilateral damage

We start with a few assumptions. Activity level can be taxed perfectly, the parties involved have perfect information about the damages their activities inflicts and about their likely damage payments to follow and all parties behave rationally.

I will follow Shavell (1987) when outlining the basic theory of accident law. We use the following notation:

$$x = The\ level\ of\ care\ of\ an\ injurer; measured\ as\ the\ costs\ of\ taking\ care, x \geq 0$$

$$l(x) = expected\ accident\ losses\ caused\ by\ an\ injurer\ given\ x, l(x) \geq 0, l'(x) < 0, and\ l''(x) > 0\ where\ l\ is\ positive$$

The negative sign of the first derivative of the function determining accident losses from level of care means that for all levels of care, still more care will decrease accident losses. The positive sign for the second derivative means that the effect of more care is decreasing in the level of care. If care is already very high more care will decrease losses by a small amount, while if care is low more care will decrease losses by a greater amount, as is reasonable.

$$s = level\ of\ activity\ of\ an\ injurer; s \geq 0$$

$$u(s) = Gross\ utility\ to\ an\ injurer\ of\ engaging\ in\ an\ activity\ at\ level\ s; u(s) > 0, u'(s) > 0, u''(s) < 0\ for\ s < s^{\Delta}\ where\ u'(s^{\Delta}) = 0$$

Here the signs of the derivatives tells that utility is always increasing in the activity level, but that the increase in utility from one more unit of activity is less the greater the activity level is. There is thus decreasing marginal utility in activity, as is reasonable.

$t = Uniform\ tax\ on\ the\ activity$

$A(arg) = Administrative\ cost\ of\ different\ torts\ and\ tax\ schemes$

Without considering activity level, for a unilateral kind of damage the social goal would be simply to minimize the sum of accident and care costs.

1) $\min_{x} x + l(x)$

With our assumptions this gives the solution:

2) $1 = -l'(x)$

The marginal cost of care x equals the marginal benefit in terms of a reduction in expected accident costs. Optimality will occur with both strict liability and negligence, in the last case of course, this is conditional on courts setting the due care at its optimal level.

If we include the activity level in the analysis, the utility of activity as well as the risk of the activity, being a function of care taken, is included. Then the social objective is rather to maximize the following:

3) $\max_{s,x} u(s) - s[x + l(x)]$

The optimal level of care for a given activity level is the one that minimizes $s[x + l(x)]$ and is given by the solution to equations 1 and 2, denoted by x^*. Then the optimal level of activity, s^*, is given by the level that satisfies the following condition:

4) $u'(s) = x^* + l(x^*)$

With the negligence rule injurers will chose x^*, but as they are without liability so long as the due care standard is satisfied they will chose to maximize $u(s) - sx^*$, and their chosen activity level, s^θ, will be given by the solution to:

$$5)\quad u'(s) = x^*$$

Which is excessive in comparison to the optimal level since $u''(s) < 0$. Only with strict liability will injurers internalize both the effect of lowering their level of care and the effect of increasing their level of activity, thus choosing s^*.

However, if we add the opportunity of taxing the activity level in a standard Pigouvian fashion, then a regime involving negligence and taxation could also yield optimality. The choice between the two regimes, negligence and tax versus strict liability will be a matter of administrative costs of the different regimes.

To see this we expand the model in two steps. First a tax of t must be paid per unit of activity. And we also add in the administrative costs of the different tort regimes. The social goal is now to maximize:

$$6)\quad \max_{t, tort\, regime} u(s) - s[x + l(x)] - ts + T - A(t, tort\, regime)$$

Subject to the utility-maximizing behavior of the actors in the economy. We see that setting the tax equal to $l(x^*)$ will induce the potential injurer to maximize $u(s) - s[x + t]$ with the first order condition:

$$7)\quad u'(s) = x^* + t$$

Which will give optimal behavior with $t = l(x^*)$. The tax is set equal to the marginal damage of increasing the level of activity with the level of care at the standard of due care (at an optimal level). Considering administrative cost the best solution will be to choose tax and negligence if

$A(no\ tax, strict\ liability) > A(t = \ l(x^*), negligence)$ and vice versa.

The level of administrative costs of tort regimes is an empirical question. Two effects are central, one point in favor of strict liability while the other is arbitrary. Negligence will give a more expensive case on average as the matter of negligence must be tried. And the amount of suits could be higher in either. For negligence increased doubt over correct outcome will tend to reduce the probability of an out of court settlement but strict liability could give more cases where someone can successfully bring suit. Of course, there are administrative costs of introducing taxes as well.

A general lesson from the theory with unilateral damage is that the choice of liability rule depends not only on the specific properties of different liability rules in certain circumstances, but also on the feasibility of using other instruments such as taxation (or what other instrument that in fact is used), and the properties of those other instruments in the specific circumstances.

2.2 Bilateral damage

Here the model is extended by introducing the behavior of the victim as a variable. Damage does not simply occur, but depends on the care taken by the victim and the level of activity exercised by the victim as well. We are still following Shavell's model.

$Subscripts\ v\ and\ i\ for\ vitctim\ and\ injurer, s_i, s_v\ and\ x_i, x_v.$

$The\ utility\ function\ has\ the\ same\ properties\ for\ the\ vitim\ denoted\ by\ v$

Expected damage is equal to $s_i s_v l(x_i x_v)$, that is the product of the activities of victim and injurer. The social goal is now to maximize:

8) $u(s_i) - s_i x_i + v(s_v) - s_v x_v - s_i s_v l(x_i x_v)$

The sum of utilities minus the expected damages and costs of care. First order conditions for s_i^*, s_v^*, x_i^* and x_v^* are:

9) $1 = -s_v \frac{\partial l(x_i x_v)}{\partial x_i}$

10) $1 = -s_i \frac{\partial l(x_i x_v)}{\partial v_v}$

11) $u'(s_i) = x_i + s_v\ l(x_i x_v)$

12) $u'(s_v) = x_v + s_i\ l(x_i x_v)$

Here a warning is at hand, because in many settings of bilateral damage corner solutions may prove better than interior solutions. The first order conditions only hold for interior solutions, where both parties have positive activity and care levels. In many settings the optimal solution to a bilateral problem could very well be a corner solution, where one party is blocked from the activity altogether and the other part can perform the activity unconstrained and without inflicting or suffering damages. Indeed, many important regulatory measures are based on corner solutions where only certain activities are allowed. Zoning is an example where this idea is prominent.

For interior solutions the interpretation is the same as before. Equations 9 and 10 give optimal levels of care and 11 and 12 gives the optimal levels of activity. We note however how the expressions have changed. The different policies turn out as follows:

Strict liability: Injurers take optimal care and chose an optimal level of activity given the behavior of victims which will not take care and chose an excessive level of activity.

Strict liability with defense of contributory negligence: Victims and injurers both chose an optimal level of care, but victims will chose an excessive level of activity given the behavior of injurers.

Negligence: Both injurers and victims will chose due care, but injurers will chose an excessive level of activity.

There is a general result here: There is no pure liability regime that ensures full optimality (Shavell 1987). Constrained to the torts instrument the choice will depend on whose activity level it is most important to control. Introducing taxes in the model however will enable optimal solutions. The first order conditions for optimal behavior is the same, but maximizing behavior by the other party will be altered by an eventual tax. It is a reasonable assumption that it is only practical to tax injurers.

It's an important point that since it's possible to regulate injurer's behavior by taxation, the liability rule should induce victims to act optimally given the activity level of injurers. For optimality, a tort scheme should induce victims to choose an optimal level of care *and activity* and the tax should be used to pick up any slack in the incentives for injurers to optimize their level of activity. For instance the negligence rule combined with taxation could give optimality, while there would be no point in combining taxation with strict liability under these assumptions.

Under the negligence rule victims will chose their care and activity level according to (10) and (12) for a given level of injurers activity. And the injurers activity could be induced to choose an optimal activity level by a tax equal to $s_v\ l(x_i x_v)$. It's worth noting that the optimal tax depends on the level of victims activity, otherwise the argument is analogous to the case of unilateral damage. The optimal tax is the one that is equal to damages per unit of activity times the optimal level of injurers activity, $s_v^* l(x_i x_v)$. It is perhaps less realistic, but the reasoning will work vice versa should it be possible to tax victims behavior only. If so, a tax on victim's activity should be combined with strict liability for injurer's.

The general point is, as is recognized in the literature, that it is fully possible to achieve optimality for both care and activity level when instruments such as a tax is used in combination with tort law. For unilateral damage the optimal choice between negligence and tax on the one hand or just strict liability on the other will depend on the feasibility of taxes and administrative costs. Several incentive optimal schemes are possible. While for bilateral damages there is one degree of freedom less because the fundamental problem no-optimal-tort-scheme must be coped with. If only injurer's activity level can be taxed, one must combine a negligence-type rule with taxation for optimality. Administrative cost could still justify choosing a scheme that does not induce optimal behavior.

2.3 Limited liability

The assumption has been throughout that injurers pay damages in full. This means that all damages caused can be accurately measured and traced back to the source, the one right injurer that has caused the damages. Also, suit must be brought by the damaged party or parties, courts must give the correct verdict, and the defendant must be able to pay damages in full. In reality there are many reasons why this needs not be the case. And these tend to pull in the direction that liability is limited, that is, those responsible for harm will on average pay less than they should.

First, as is pointed out in Shavell (1986), the probability of suit is less than one, perhaps greatly so in some cases. Time between the damaging activity and the manifestation of damage is especially detrimental to successful suit. With time, evidence withers. Also for harms that are widely dispersed, risk of legal action and high transaction costs of the potential plaintiffs may hinder litigation.

Another difficulty also pointed out in Shavell (1986) is the judgment-proof problem. Basically, all actors' assets are limited. This means that for damages exciding the available assets of the defendant at the point of verdict, only a share of damages will be paid. Another interesting feature about damages in this setting is that one usually only has easily verifiable and strictly economic costs reimbursed. Time, effort, frustration and other more soft losses are usually not compensated under a liability regime. At least, this is the case for Norwegian law. For some types of damages this is an important factor contributing to making paid damages in general less than actual damages.

While one can achieve optimality even for bilateral damages with flexible activity levels for injurer and victim as long as one can utilize a tax or another similar instrument (there may be other optimal schemes as well, but not purely tort), limits to liability fundamentally alters this picture. When strict liability no longer works perfectly, one side, either the injurers or the victims will be given some slack unless one can tax activity on both sides.

2.4 Differences in risk

The theory so far concerns a single actor or a group of actors with similar characteristics. In general however, different actors are likely to differ in many respects. Most importantly, different actors are likely to differ in their risks of creating an accident or more generally in their creation of negative externalities by performing an activity.

Shavell (1984) shows how tort can be combined with regulation in order to increase the overall regulatory efficiency under differences in risk amongst actors. The model is based on varying magnitudes of harm among potential injurers, and thus varying levels of optimal care. Introducing a regulatory standard of care has an advantage of coping with the judgment-proof problem and probability of suit problem, but could also induce low risk actors to take a too high level of care, thus a tradeoff.

The concept that actors differ in their riskiness actually has several useful interpretations. The most obvious is the ability of actors to prevent harm from occurring. But differences in risk could also mean higher damages when accidents happen or in general higher external effects of production. As such, location is one way in which otherwise equal actors could be considered to differ with respect to risk. For instance, factories located near residential areas will cause higher external damages when accidents occur than factories located in rural areas.

3 The extended model

Having touched upon the basic theory which forms the foundation I turn the model itself. As mentioned I wish to evaluate the use of three different instruments in combination. I also wish to have the model encompass differences in risk and limited liability.

To treat differences in risk, we first assume that there are two types of actors involved in a potentially harmful activity; these are denoted by l for low harm/risk actors and h for high harm/risk actors. I use upper subscripts to denote type of actor. For now we shall assume, as in Shavell (1987), that the high risk actor in the event of an accident causes damage equal to d^H and that the low risk actor in the event of an accident causes a damage of d^L. The parties' level of care will determine the probability of having an accident in any time period (we assume accident or no accident over a specific time span).

We assume that the regulator knows roughly the amount of low risk and high risk actors involved in a specific activity, but that each specific actors risk characteristic is private information. This means that the regulators, being the government, courts or legislator knows the proportions of high- and low risk actors, but not which is which. It is assumed however that actors reveal their degree of risk in the event of an accident.

First best behavior is given by each party operating at a level of care where the marginal damage of decreasing the level of care equals the marginal cost of extra care, just as above.
When it comes to limited liability, I will have all possible reasons for imperfect torts-payments be included in one variable, q. I assume then that “judgement-proofness” and lowered probability of suits all work to lower the expected damage-payments by this factor. This could be unrealistic for several reasons, but the approach is chosen here to keep things simple. One way of looking at it is to consider it as a world where parties can and must insure against large damage payments in a way that copes with the judgment-proof problem, leaving the lowered probability of suit as the main problem to deal with (Shavells analysis includes both the judgementproof problem and the lowered probability problem with separate treatments). One justification is also that the nature of the results hinges mainly on there being a limit to torts in any form.

We shall follow the standard matrix and thus start simple; the model is extended as we go to encompass further moments. Functions are given precise mathematical expressions rather than keeping them in the abstract with stated properties. It is insured that the relevant expression have the desired and reasonable properties (this is typically a matter of the signs of the first and second derivatives).

4 Unilateral damage, fixed activity level

We start with the simplest setting and with only the torts instrument at hand, in different forms.

4.1 Torts only

The different tort regimes considered will be strict liability and negligence.

4.1.1 Strict liability

Sticking to the former notation in the outline of the basic theory, our two types of actor in the economy will, facing strict liability minimize costs by choosing a level of care given by:

$$1 = -p'(x)d^H q \quad \text{for the high risk actor}$$
$$1 = -p'(x)d^L q \quad \text{for the low risk actor}$$

Thus the actors will set the marginal cost of taking care (1) equal to the marginal gain of increasing the care-level in terms of expected damages-payments, which is given by the marginal reduction in accident probability multiplied with the damage in the case of an accident, and lastly multiplied with the expected share of damages to be paid.

Optimality on the other hand requires:

$$1 = -p'(x)d^H \qquad \text{for the high risk actor}$$
$$1 = -p'(x)d^L \qquad \text{for the low risk actor}$$

With standard assumptions, strict liability and $0 < q < 1$ this will give a too low level of care in comparison to the optimality criterion. We take on the following values and expressions:

Marginal costs of care:	$MC_{care} = 1$
Probability of accident:	$p = \frac{1}{1+\sqrt{x}}$
Damages in the event of an accident:	$d = 100$
Expected share of damages to be paid:	$q = 0{,}75$

Here the marginal damage-payment under full and partial liability for the low risk actor is given by:

$$\frac{\partial p(x)d^L}{\partial x} = \frac{-50}{(1+\sqrt{x})^2\sqrt{x}}$$

And

$$\frac{\partial p(x)d^L q}{\partial x} = \frac{-37{,}5}{(1+\sqrt{x})^2\sqrt{x}}$$

Which gives levels of care by approximately:

$x^*_{Full\ liability} \approx 9{,}3$

And

$x^*_{Partial\ liability} \approx 7{,}4$

As the below figure shows, partial liability makes actors subject to torts select a lower level of care.

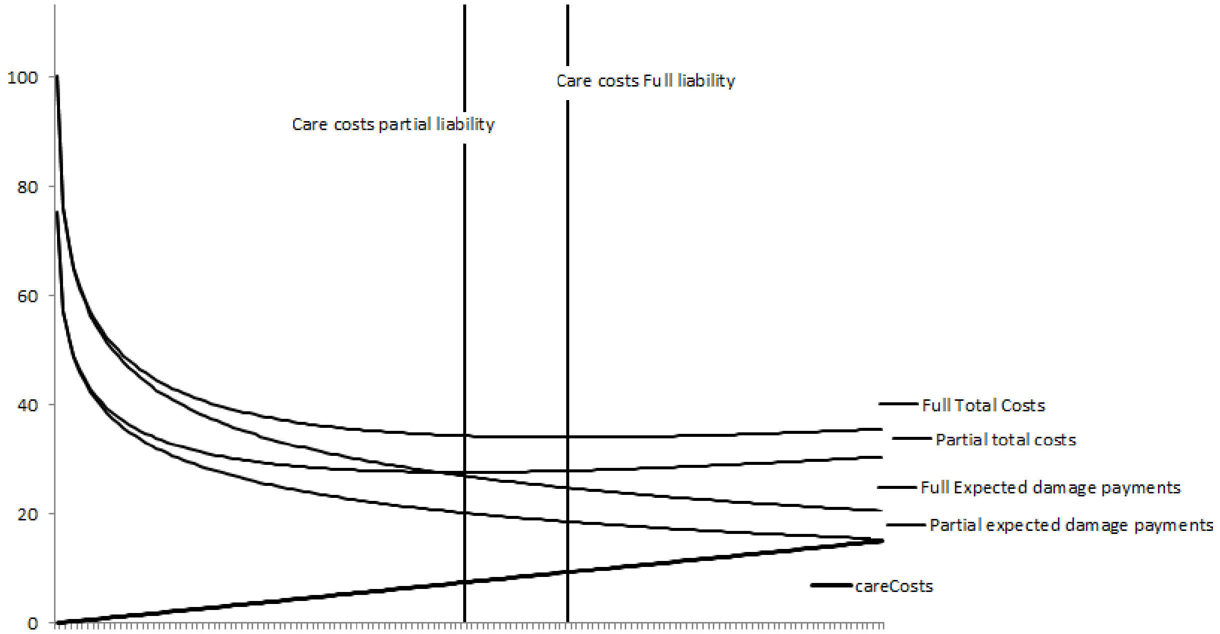

Figure 1: The effects of limited liability on the level of care under strict liability

As can be seen from the figure, actors will set their care level to that which minimizes total costs. And with limited liability, this level is lower than under full liability.
In marginal terms we can see clearer the loss of partial liability.

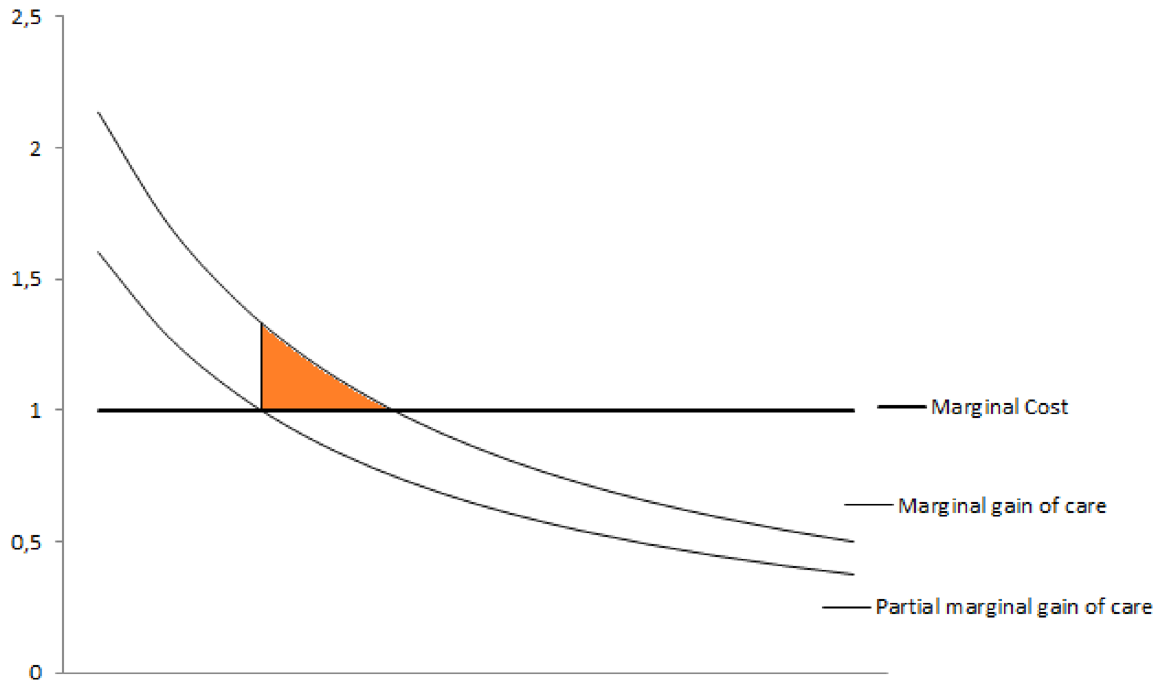

Figure 2: The effects of limited liability on the level of care under strict liability in marginal terms

For the level of care chosen under partial liability, the marginal gain of care is higher than the marginal costs, thus a potential gain could be realized from increasing care. This is the marked area in the graph. Mathematically, the area is given by

$$Efficiency\ Loss = \int_{x^*_{Partial\ liability}}^{x^*_{Full\ liability}} \left(\frac{-50}{(1+\sqrt{x})^2\sqrt{x}} \right) dx \ \approx 0{,}3$$

Form this we can calculate the efficiency loss under different values of q. With $q = 0{,}5$ we would have an efficiency loss of 1.6 and with $q = 0{,}25$ the efficiency loss would be 5.9. The efficiency loss is increasing exponentially in the degree of limited liability.

As was already known form the basic theory, with limits to liability, the use of strict liability on its own cannot induce optimality. With marginal costs of care constant and the marginal gain of taking care decreasing, the efficiency loss from partial liability increases more than linearly with the share of damages that parties are not held accountable for.

4.1.2 Negligence

By altering the example to have negligence instead of strict liability things will look a bit different. With negligence the actors in the economy will only chose to set a lower level of care if their total damage payments plus lowered care costs is less than the care costs at the negligence level of care. In our above example, adhering to a negligence standard set at 9.3 will give total payments of just 9.3. Adhering to the partial liability private optimum of the previous section for instance, will give a total payment of $7{,}4 + \frac{1}{1+\sqrt{7{,}4}} \cdot 75 \approx 14{,}1$, and indeed there is no level of care giving a lower expected damage payment than that of following the due care standard. It is thus a nice property of the negligence type rules of liability that they have an overcoming effect on the limits to liability problem. It is the threshold-effect of adjusting below the negligence standard of care that creates this effect.

A clarification is necessary here because I assume limited liability on the one hand, but still that courts are able to find the optimal due care standard in the aftermath of an accident. If limited liability was due to courts underestimating damages, then the due care standard would be set below optimality as well. It is thus an assumption I make that the source of limited liability is not due to underestimation of damages. I keep this assumption throughout.

4.2 Regulation

Unlike for torts, regulations is an ex ante instrument, meaning that the regulation cannot be made to depend on an outcome such as an accident.
In this analysis regulation is taken to be a minimum standard of care that the actors can and will comply with (there may for instance be very high fines for breach). The assumption that actors will comply with regulations is also for analytical clarity.

It is also a simplification to assume that the standard of care is a one-dimensional size that can be neatly included in one single regulatory scheme with the existing problems of monitoring and enforcement. I shall stick to this assumption for analytical clarity. In many cases the assumption is a reasonable basis for analysis.

We start out by looking at the properties of regulations as the sole mean of controlling risks, before we turn to see how in fits in with other policy means.

4.2.1 Regulation as the sole means of decreasing risk

If regulations where the sole means of controlling risk the optimal regulatory standard would depend on the amount of high risk and low risk actors in the economy:

Let α^H be the share of high risk actors and α^L the share of low risk actors, with $0 < \alpha^H < 1$ and $0 < \alpha^L < 1$. The social goal would be to maximize welfare by setting a regulatory standard, r inducing the level of care x^r. The government should thus try to minimize the following expression:

$$C = \alpha^H\ (\mathrm{p(x)}d^H + x) + \alpha^L(p(x)d^L + x)$$

With the first order condition

$$\frac{\partial C}{\partial x} = \ \alpha^H\ (\mathrm{p'(x)}d^H + 1) + \alpha^L\ (\mathrm{p'(x)}d^L + 1) = 0$$

Where we assume standard second order conditions fulfilled. We can note first that with $d^H = d^L$ the condition for optimality collapses into $1 = \ -p'(x)d$ as $\alpha^H + \ \alpha^L = 1$. So without any differences in type of actor the optimal level of care can be achieved by setting a regulatory standard equal to the due care level, obviously. Otherwise the condition for optimality is that

$$\alpha^H\ (\mathrm{p'(x)}d^H + 1) = \ -\alpha^L\ (\mathrm{p'(x)}d^L + 1)$$

With the following interpretation: For the high risk actor the optimal level of care is given by $\mathrm{p'(x)}d^H = -1$, thus $\mathrm{p'(x)}d^H + 1 \neq 0$ means there is a deviation from the optimality criterion. Since we know that $d^H > d^L$ the optimal solution involves having a too high level of care for the low risk actor and a too low level of care for the high risk actor. The expression simply says that on the margin, the loss of increasing care for the low risk actor should equal the gain from increasing the level of care for the high risk actor. Thus x^r is set somewhere in the middle of $x^{H*}\ and\ x^{L*}$, with $\alpha^H, d^H \alpha^L\ and\ d^L$ determining the exact level.

Another useful interpretation is found by reorganizing:

$$-p'(x)d^H = 1 + \frac{\alpha^L}{\alpha^H}[p'(x)d^L + 1]$$

The marginal gain of increasing the level of care for the high risk actor should be higher, above marginal cost, and thus the level of care lower, the higher the share of low risk actors and the lower the potential damage of the low risk actors are ($p'(x)d^L$ is negative). Looking at the total social loss compared to the optimal levels of care this is given by:

$$Social\ Loss = \alpha^L \int_{x^{L*}}^{x^r} (1 + p'(x)d^L)dx + \alpha^H \int_{x^r}^{x^{H*}} (-p'(x)d^H - 1)dx$$

Using values from the previous example, with $d^L = 100,\ d^H = 200$ and $\alpha^H = \alpha^L = 0{,}5$ we get marginal gains of increasing care given by $\frac{\partial p(x)d^H}{\partial x} = \frac{-100}{(1+\sqrt{x})^2\sqrt{x}}$ for the high risk actor and $\frac{\partial p(x)d^L}{\partial x} = \frac{-50}{(1+\sqrt{x})^2\sqrt{x}}$ for the low risk actor.

Inserting this into the optimality criterion we have:

$$\left(\frac{-100}{(1+\sqrt{x})^2\sqrt{x}} + 1\right) = -\left(\frac{-50}{(1+\sqrt{x})^2\sqrt{x}} + 1\right)$$

Giving $(1+\sqrt{x})^2\sqrt{x} = 75\ and\ then, x^r \approx 12{,}8$. The optimal level of care for the parties seen in isolation is $x^{L*} \approx 9{,}3$ and $x^{H*} \approx 16$.

Inserting in the social loss function we get:

$$Social\ Loss = 0{,}5 \int_{9{,}3}^{12{,}8} \left[1 + \left(\frac{-50}{(1+\sqrt{x})^2\sqrt{x}}\right)\right]dx + 0{,}5 \int_{12{,}8}^{16} \left[-\left(\frac{-100}{(1+\sqrt{x})^2\sqrt{x}}\right) - 1\right]dx$$

Yielding a loss of approximately 0.61. The loss stemming from making the low risk actor be more than optimally cautious is 0.65 times the weight, 0,5. And the loss form allowing the high risk actor a lower level of caution than optimally is 0.56 times 0,5.
With equal shares of high- and low risk actors in the economy the figure below shows the tradeoff graphically.

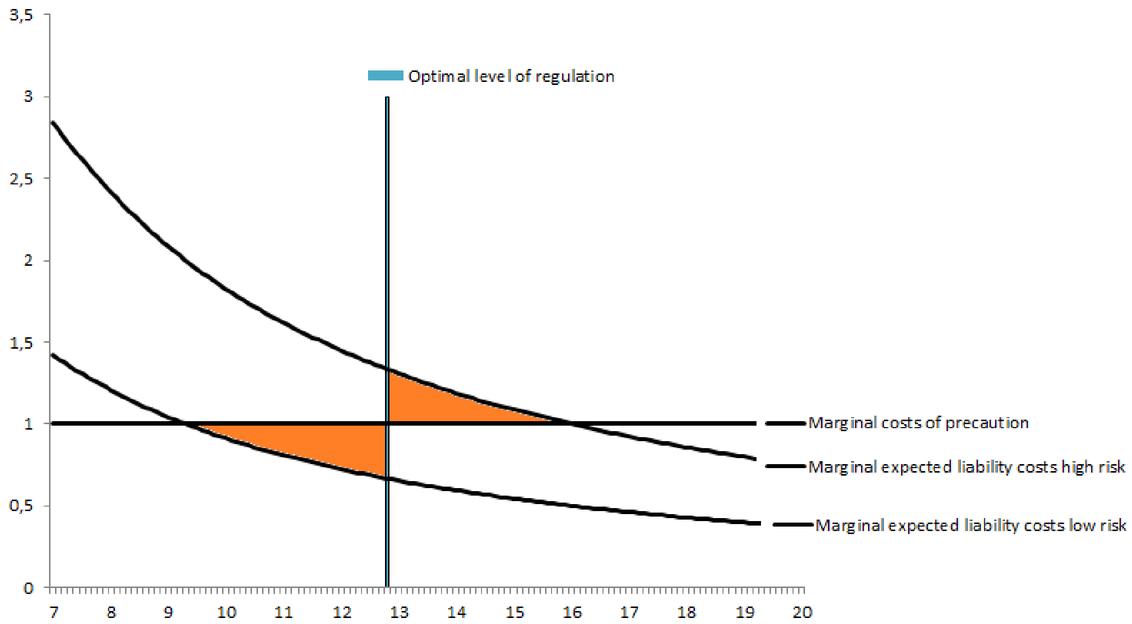

Figure 3: Utility loss form a single regulatory standard with differences in risk

In summary; if only regulation can be used, there is a tradeoff between making low risk actors overcautious and making high risk actors less cautious than optimality calls for.

4.3 Taxation

As long as the activity-level remains fixed, there is no point in including taxation in the analysis as taxation is in essence an activity-level instrument. Although, one could imagine schemes with firms paying a higher tax for different levels of care. In such an event, the tax will equal a regulation with a given fine-structure for compliance with all the problems associated (as monitoring the care level), which analytically belongs in the regulation-domain. I will keep the analytical distinction between regulations and taxation by holding taxation as a simple charge on easily measurable entities, such as units of production or consumption, making taxation an activity level regulating instrument.

4.4 Combining regulations and strict liability

With limits to liability and a distribution of the riskiness of the actors involved in an activity, regulations could be used to ameliorate the limits to liability problem. The level of regulation chosen will balance the tradeoff between making low risk actors overcautious and high risk actors under cautious.

In our example, using the same values as above and with $q = 0{,}75$, the marginal expected damage payments for the high risk and low risk actor is given by

$$p'(x)d^L = \frac{-37{,}5}{(1+\sqrt{x})^2\sqrt{x}}$$

$$p'(x)d^H = \frac{-75}{(1+\sqrt{x})^2\sqrt{x}}$$

This will then give a lower precaution than what is optimal. We now have two instruments with different shortcomings. Regulation copes with the limits to liability problem, but does not handle differences in risk. Liability on the other hand is subject to the known limitations, but does handle differences in risk. For society the objective is to minimize the sum of accident and precaution costs:

$$\min C = \alpha^H\ (\mathrm{p}(\mathrm{x}^H)d^H + x^H) + \alpha^L(p(x^L)d^L + x^L)$$

Subject to the behavior of the actors involved. The actors will now minimize their costs subject to the condition that $x^i \geq x^r$, where i is subscript for type of actor.

We find that the low risk actor will choose a level of precaution at approximately 7.4 facing only torts, and for the high risk actor it's 12.8. The optimal levels would be 9.3 and 16 respectively. It can be shown that the optimal solution is simply to set the regulatory standard at the optimal precaution level of the low risk actor. Looking at it graphically, it's easy to see why:

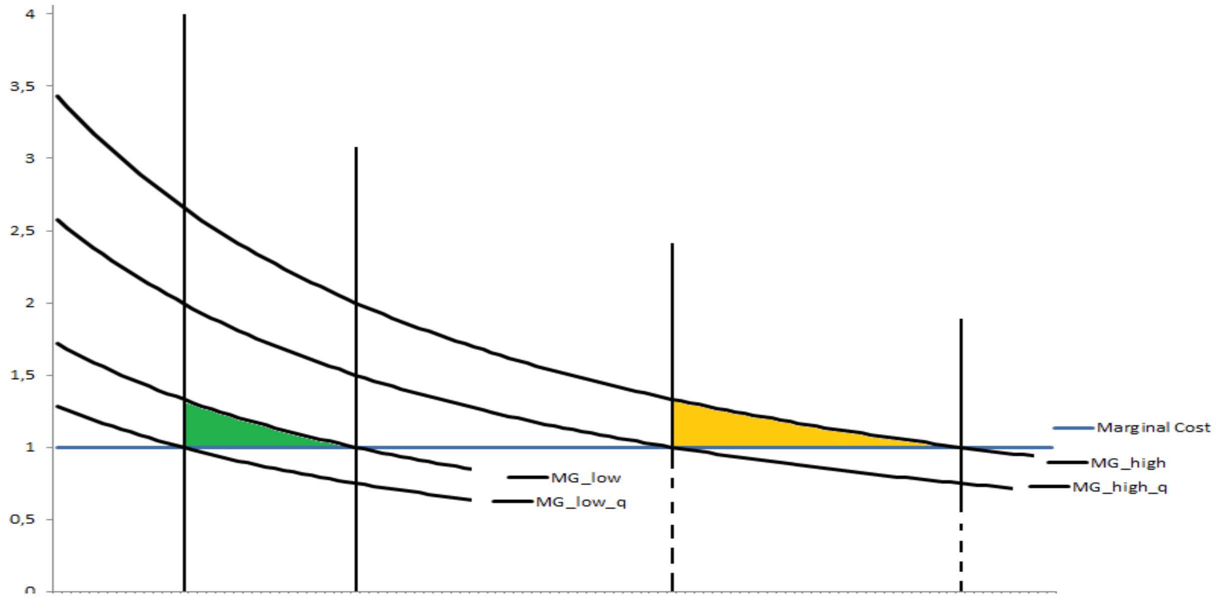

Figure 4: Optimal regulation with two types of actor with different risks

At the outset the torts-only solution gives the same kind of efficiency losses as in section 1.1. Now there are two losses portrayed in the figure as there are two types of actor.

If we imagine starting at the lowest thinkable level of regulatory standard, which is the level chosen by the low risk actor with limited liability, we see that increasing the regulatory standard diminishes the loss stemming from the low risk actors. When the regulatory standard is at the optimal care level of the low risk actor this loss is fully ameliorated, and in our case further increasing the regulatory standard to also cope with the loss from the high risk actor is not worthwhile, as the resulting efficiency loss to the low risk actors will be greater than the efficiency gain to the high risk actor. This is a result of the specific example, or more exactly the binary properties of the model, but in a setting with two types of actor like this the regulatory standard should be set to the first best level of care for the low risk actor. In our example the result also holds for any level of damage for the high risk actor above the level of damage for the low risk actor.

As is in line with the results in Shavell (1984), we can see from this that when facing a distribution of risk amongst actors doing a certain activity, as well as limits to liability, the combination of regulation and torts is superior to any of them alone.

We have seen that a regulatory standard reduces the loss from the limits to liability and it's also easy to see that the combination is better than regulation only. If only regulation could be used in the above example, this regulatory standard would have to face the full tradeoff of over-caution and under-caution, while in combination with torts, decreasing the level of regulatory standard from the liability induced level of the high risk actor does not cause the high risk actor to reduce caution further. Indeed, in that example the optimal regulatory standard was set at 12.8, the same as the liability induced caution level here (by construction of example), a level then inducing a loss on account of over caution from the low risk actors.

We have thus seen that the possibility of using regulation in combination with strict liability betters the outcome somewhat, but in order for strict liability in combination with regulation of the care level to be preferred to negligence the, administrative costs of the combined approach must not only be lower than simple negligence, but must also be sufficiently lower as to offset the remaining efficiency loss from strict liability that regulation cannot repair. For substantial limits to liability this is unlikely. Making negligence, in many cases, the preferred approach for unilateral damage and a fixed activity level when there is limits to liability and a distribution of risk amongst actors in the economy.

From this section we thus have the results that with limits to liability, negligence have an obvious advantage in that the threshold effect of being in line with the negligence standard in itself can cope with the problem of limited liability. With the use of strict liability this effect is not in play and the limits to liability is more likely to create a substantial efficiency loss. It is shown that regulations can decrease, but not remove, this efficiency loss.

5 Unilateral damage with activity level included in the analysis

As we saw from the basic theory, negligence type liability will introduce an efficiency loss as the actors will not internalize the risk of their activity when choosing the activity level. Introducing the activity level in the analysis means thus, that the problem of externalities from the activity should be coped with somehow. One way would be to set a strict liability standard, another the use of taxation. Below both are analyzed in turn. We will stick to the assumptions that liability is limited and that regulation of the level of care can be used.

We now have two types of actors, each wanting to maximize the utility of their activity. (The utility could of course also be interpreted as profits). The actors in the economy will act according to the following maximization problem, as before, just with the tax included in the decision problem.

$$\max_{s^i, x^i} u(s^i) - s^i[x^i + p(x^i)qd^i + t] \ for\ i = L, H$$

It's known that with the negligence rule set at the optimal due care standard, a tax set at

$$t = p(x^{i*})d^i$$

will realize the efficient solution for a uniform type of actor, as this correspond to the un-internalized effect on society from increasing the activity-level from the optimal level of activity when the due care standard is met .

One problem now however, is that due to the differences in risk for the two types of actor, giving different marginal external damages from activity means that ideally there should be one specific tax for each type of actor. The tax rate however must be the same for all. This is a feature of the activity level flexibility and differences in risk put together. Thus, moving from the situation with fixed activity level to the one with flexible activity level we have introduced a new tradeoff.

Letting x^{i*} denote the due care standards given by courts, the problem for the authorities is to set the tax that maximizes the above expression under the condition of optimal care for the actors. We know that the actors in the economy will not internalize the external effect of their activity, $p(x^*)d$. Each actor will maximize by adjusting their activity level to:

$$u'(s) = [x^* + t]$$

With one actor the optimal tax rate is easily found to be $t = p(x^*)d$. For two actors however, the tax rate must strike a balance between the two actors with differing marginal damages from their activities. We know however that for unilateral damage, strict liability solves the activity-level problem first hand.

We thus have a situation where on the one hand we can use the tort-regime that solves the problem of limited liability, or on the other hand a tort regime that solves the problem of different marginal external cost when the actors set their activity level. I shall now explore the two options in terms of efficiency. We assume a utility function for the two actors given by:

$$u(s^i) = A \cdot \sqrt{s}$$

This function has the necessary properties.

5.1 Negligence and taxation

For society, the problem is to maximize the sum of utilities of the activities for the two types of actor, minus total damages from the activities:

$$\max C = \alpha^H \left[\mathrm{A} \cdot \sqrt{s^H} - \mathrm{s}^H(\mathrm{p}(\mathrm{x}^H)d^H + x^H) \right] + \alpha^L \left[\mathrm{A} \cdot \sqrt{s^L} - \mathrm{s}^L(\mathrm{p}(\mathrm{x}^L)d^L + x^L) \right]$$

Knowing that the courts will set the optimal due care standard concerning care only, the legislative authorities can set the tax with this in mind.

We know already that due care will be set to satisfy the following condition:

$$p'(x) = -1/d^i$$

Which implies that at the marginal risk of decreasing the activity level at optimal care, in terms of probability will equal the negative inverted of the damages. If for instance the marginal probability increase is 0.01 (decreasing x by 0.1 increases the probability of an accident by approximately 0.001) the gain from lower precaution costs should outweigh this risk increase exactly. This would be the case if damages where 1000. With damages of 100, the derivative should be higher and thus precaution lower.

We have then that the actors follow the optimal care level given by the cost-benefit approach to negligence, and that the authorities can take this into account when setting the optimal tax. From previous we know that the low risk actor will thus set a care level of $x \approx 9{,}3$ and the high risk actor $x = 16$. This gives an external damage effect of $p(x) \cdot d$ per unit of activity for each type of actor. In our case this is approximately 24.7 for the low risk actor and 40 for the high risk actor. A tax somewhere in between these two levels is thus called for.

Utility maximization for the two actors means to maximize the following.

$$\sqrt{s^i} - s^i(p(x^i)d^i + x^i + t)$$

Given that $p(x) \cdot d = 0$ if the negligence is standard satisfied. Normal optimization gives a chosen activity level for each type of actor given by:

$$s^i = \left[\frac{A/2}{x^i + t}\right]^2$$

It is worth noting that $p(x) \cdot d$ is not in the expression as this is the core of the negligence induced externality problem.

We know the external cost of each type of actor and we can denote these by e^i. Inserting for the chosen level of activity, we can express the total utility from the activity as such:

$$K = \sum_{i=1,2} \alpha^i \left[\frac{A/2}{x^i + t} - \left(\frac{A/2}{x^i + t}\right)^2 \cdot (e^i + x^i)\right]$$

Numerical optimization gives an optimal tax of 30.6. It's within the expected range, but it's worth noting that it's below the mean of the external damages of the two actors, which is 32.35. As the marginal utility of the actors is decreasing in activity level, it is more costly to restrict the high risk actor's low activity than it is to restrict the low risk actor's higher activity. So also this feature of the result is as expected.

5.2 Strict liability

Strict liability gives another level of care compared to the negligence scenario.

$$p'(x) = -1/d^i q^i$$

As we have seen (with q = 0.75) this leads to a lower level of care for both actors. Strict liability could be combined with taxation, but for now we analyze without. The expression for the realized activity level is now:

$$s^i = \left[\frac{A/2}{x^i + p(x^i)d^i q^i}\right]^2$$

And we can derive overall utility as follows:

$$K = \sum_{i=1,2} \alpha^i \left[\frac{A/2}{x^i + p(x^i)d^i q^i} - \left(\frac{A/2}{x^i + p(x^i)d^i q^i}\right)^2 \cdot \left(p(x^i)d^i q^i + x^i\right)\right]$$

Before going any further, a quick comparison with the negligence and tax scenario could be interesting.

	Negligence and taxation		Strict liability		Optimality	
	Low risk	High risk	Low risk	High risk	Low risk	High risk
Activity level	**157**	**115**	**329**	**120**	216	79
Care level	9.3	16	**7.4**	**12.8**	9.3	16
P(accident)	24.7%	20%	**26.9%**	**21.8%**	24.7%	40%
Exp.damage	24.7	40	**26.9**	**43.7**	24.7	40
Total utility	5737.9		5514.0		5909.3	

Table 2: Comparison between Negligence with taxation and strict liability

It is no surprise that none of the two policies reaches optimality. Optimality can only be attained with optimal care level and optimal levels of activity for both parts. And as have been seen, the two policy packages has different shortcoming. With negligence, the optimal care level is attained, but the activity level tradeoff to be dealt with by the single tax leaves low risk activity level too low and high risk activity level to high. On the other hand, strict liability cannot give optimal care levels, but the liability that is makes the activity level more adapted to the specific risks of each actor, but too high for both. In this case negligence with taxation came out better than strict liability.

5.3 Strict liability with taxation

If it was known that there was a limit to liability. This could be helped with a small tax charge. Ideally the government should know the size of the liability problem. With the same parameter values, adding a tax of 7.67 is found to be optimal.

Filling in the same table as before, we get the following new values:

	Negligence and taxation		Strict liability with taxation		Optimality	
	Low risk	High risk	Low risk	High risk	Low risk	High risk
Activity level	157	115	**201**	**88**	216	79
Care level	9.3	16	7.4	12.8	9.3	16
P(accident)	24.7%	20%	26.9%	21.8%	24.7%	40%
Exp.damage	24.7	40	26.9	43.7	24.7	40
Total utility	5737.9		5847.6		5909.3	

Table 3: Comparison of negligence and taxation and strict liability with taxation

With taxation to complement the regime of strict liability we see first that the activity level has been drawn down to a level much closer to optimality. Secondly, we see that now the activity level tradeoff is also in play for the strict liability, only to a much lower extent. While taxation must cope with the entire activity level problem in the negligence case, it suffices in the strict liability case to cope with the part not dealt with by liability, that is a share given by 1 - q. We see that adding the possibility of taxation has left the strict liability with taxation package the preferred policy.

It may seem a bit peculiar to combine taxation with strict liability. It is perhaps also an unfamiliar arrangement, even though practical applications are highly thinkable. It is common to have strict liability type rules for some types of automobile accidents and it is common to tax driving with the motivation of, amongst other things, limiting the activity of driving, in turn partly justified by accidents or other external costs, in addition to attaining tax revenues. This means that drivers pay for the expected damages of driving both through the tax bill and through their insurance premiums. This is an example of where the legal and financial policy instruments interconnect. For one thing, if the degree of liability is not adjusted to the level of taxation, drivers may overpay for expected accidents and inefficiently low levels of driving may result. On account of law, a balanced solution would be for liability to be limited in response to the tax instrument, and for the government to pay a share of damages to cover the rest. In sum the two instruments should handle the externality efficiently be adjusting the combined burden of the two instruments close to optimum.

The case of driving is one where many different instruments, regards and actors intertwine, but the combination of taxation and strict liability is possible for other more transparent situations as well. Consider for instance a factory emitting a specific pollutant causing a variable degree of harm to surrounding residents. The government may find the production taking place at the factory to be desirable in spite of damages caused, but may want to ensure that the factory uses the efficient technology to treat the emissions (which is likely to be private information) and that the amount of production and emissions is adjusted optimally to the damages caused. The government may also expect courts to grant damages to plaintiffs on the basis of strict liability. However, it may be reasonable to expect that not all parties suffering harm will sue or will be granted damages by the court. One reason for this could be weak evidence. The government or legislators may thus set an emissions tax based on the expected share of liability.

5.4 Strict liability with regulation and taxation

If we add in the possibility of regulating the care levels of the actors, the strict liability policy can be further strengthened. The optimal regulation is found to be just below the perceived optimal level. The reasons for this will be elaborated upon below, when we take a deeper look at the properties of the policy packages under different circumstances.

	Negligence and taxation		Strict liability with taxation and regulation		Optimality	
	Low risk	High risk	Low risk	High risk	Low risk	High risk
Activity level	**157**	**115**	**203**	**89**	216	79
Care level	9.3	16	**9.2**	**12.8**	9.3	16
P(accident)	24.7%	20%	**24.8%**	**21.8%**	24.7%	40%
Exp.damage	24.7	40	**24.8**	**43.7**	24.7	40
Total utility	5737.9		5868.7		5909.3	

Table 4: Comparison of Negligence and taxation with Strict liability with taxation and regulation.

6 Policy regimes compared in dynamic settings

As strict liability helps to solve the activity level problem and negligence helps to solve the limits to liability problem, the optimal policy will depend on the magnitude of these two problems. The problem of limited liability is expressed by the parameter q, while the problem concerning activity level is the problem of different marginal externality of activity. This is expressed by the spread of the distribution of different actors in the two-actor model, thus the parameterα^L. An α^L at 0 or 1 means no differences and thus no problem of activity level tradeoff in the model, while a value of 0.5 gives the maximum spread possible.

Of course in an actual choice of policy mix, the administrative costs of each policy should be taken into account. Depending on circumstances, the administrative costs of negligence and strict liability will differ.

There will also be significant administrative costs of introducing a policy, such as a regulation or a tax. For a tax it is most likely that the introduction of the tax gives a rise in administrative costs, while the level of the tax does not matter all that much. For a regulation the same pattern is likely, but to a greater extend then for a tax, the level of regulation will have an impact on the total cost.

We begin with a few examples, before we turn to simulations over a continuous spectrum of situations:

$\boldsymbol{\alpha^L = 1}$, $\boldsymbol{q = 1}$

With these values all the policy-mixes considered will achieve optimality. Strict liability seems attractive as it does not need to be combined with a tax, as must negligence, to achieve optimality. Strict liability with regulation or taxation or both is ruled out on account of administrative costs. It is interesting to note that for unilateral damages, without differences in risk of the actors or limits to liability, the choice of tort regime (that is for instance strict liability or negligence or another type of rule) depends on the administrative costs of the different rules considered, but also on the administrative costs of other instruments, in this case taxation.

$\boldsymbol{\alpha^L = 0,5 \quad q = 1}$

When there are no limits to liability, but a distribution of risk amongst the actors, we would expect policy packages based on strict liability to perform better. And indeed all policy packages except negligence and taxation achieves optimality in this case. This shows that for situations not involving limits to liability, strict liability will generally perform better in cases of unilateral damage.

$\alpha^L = 1 \quad q = 0,5$

When on the other hand there is a serious limit to liability and no distribution of risk amongst the actors, one would expect negligence based policy packages to perform better. Indeed, negligence and taxation achieves optimality in this case, but so does the policy mix where strict liability is combined with taxation and regulation. The reason for this being that without any distribution of risk regulation can be brought to the efficient level without striking a balance between optimal care levels of two different actors. Then the added taxation picks up the slack in the activity level adjustment. In fact no tort regime is required at all, a policy mix consisting of only regulation and taxation would achieve optimality as well, of course the tax would need to be higher in this case.

$\alpha^L = 0,5 \quad q = 0,5$

In the worst case considered, none of our policy packages archives optimality. Strict liability with regulation and taxation is closest, followed close behind by negligence and taxation. Strict liability comes in third place and plain strict liability performs the worst. When applying the policy mix with strict liability, taxation and regulation it can be shown that it's best to set the regulatory standard above the optimal level of care for the low risk actor in order to set a lower bound on the high risk actor's level of care. With the limits to liability so severe the high risk actors will not want to be near their efficient level of care, but rather give priority to less costly production. A regulation tradeoff thus comes into effect. The result is higher than optimal care for the low risk type of actor and lower than optimal care for the high risk type of actor. Without taxation they would still both chose a higher than optimal level of activity, the high risk type relatively more so than the low risk type because of their slackened care level. Taxation brings the low risk actors below their optimal level of activity, while high risk actors will still be above theirs.

As for negligence and taxation, both actors are on their optimal care levels. However, the activity level tradeoff to be balanced by a single tax becomes severe. Here strict liability has an advantage; still half the activity level burden is adjusted to the specific damage risks of the actors, making the activity level tradeoff less severe.

6.1 A closer look with q = 0,5

Having looked at a few cases, a more general comparison is at hand. Starting with $q = 0,5$ we look at how the policy packages performs under different circumstances. Below the utility of the different policy packages are graphed against the risk distribution of actors in the economy. To the left is the situation of only high risk actors, the share of low risk actors increase as we move to the right in the figure:

Figure 5: Policy packages compared with q = 0,5

The point of this chart is to show the differences in performance of the policies. Optimality is given by the upper blue line. Moving from $\alpha^L = 0$ to the left towards $\alpha^L = 1$ to the right social utility will necessarily increase as the activities can be performed with less risk. The lowest grey line is strict liability alone (S) and the blue in between is strict liability with regulation (S_R). The yellow line is Strict liability with taxation (S_T) and the green line is strict liability with taxation and regulation (S_R_T). The line for negligence with taxation (N_T) is not distinguishable from the line for Strict liability with taxation and regulation. Summed up, the two instruments N_T and S_R_T performs close to optimality, with S_T close behind. S_R is in comparison much further from optimality and plain strict liability is no way near.

Looking closer at the source of these discrepancies we plot the use of different instruments where they are available. Stippled lines are taxation while solids are regulation:

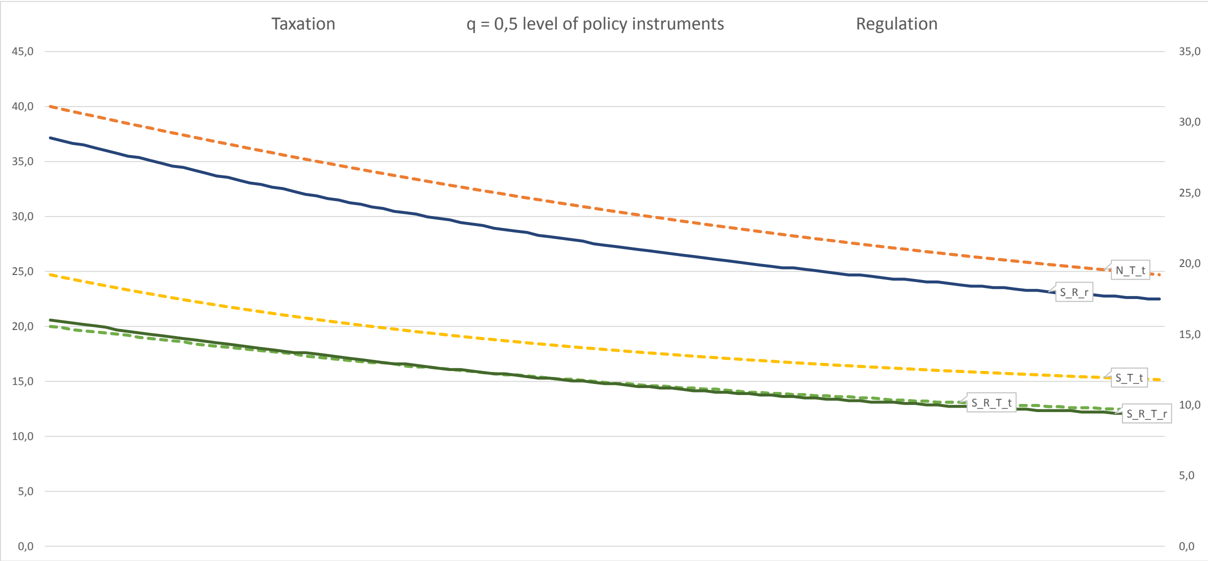

Figure 6: Use of the instruments with q = 0.5

Taxation is plotted against the right column, while regulation against the left. For negligence and taxation the mechanism of setting the level of taxation is straight forward. The higher the share of high risk actors the higher the tax. As could be seen from the previous chart, the utility cost of striking the balance is highest when the distribution is at its most balanced with half of each type.

The S_R (S_R_r shows the level of regulation under the policy package S_R, Strict liability with regulation) policy uses a regulation that is significantly higher than S_R_T. This is because with this policy mix available, regulation should also be used to curb activity levels by increasing the costs of production. This is clearly seen at$\alpha^L = 0$; the regulatory standard is above the optimal care level of the high risk actor. As the share of low risk actors increases, the regulatory level of care should naturally decrease gradually.

S_T has only the taxation instrument available. This is applied to a lesser degree than N_T naturally, as the actors pay half their damages by $q = 0{,}5$. On the other hand, the level of taxation should be higher than S_R_T, as there is no instrument to increase the care level of the actors, the level of activity should be tightened further than if care was higher.
Lastly S_R_T can balance the use of taxation with the use of regulation and then naturally employs less of both than S_T and S_R.
Plotting the activity levels and care levels of the high and low risk actors for S_T, S_R and S_R_T we can follow the performance of these instruments closer. N_T is more straightforward, care levels are optimal and taxation balances the activity level tradeoff.

Figure 7: Levels of care compared with optimality for different policy packages with q = 0,5

The optimal care levels for low risk and high risk respectively are plotted by the green straight lines in the chart. The chosen care level of the high risk actor coincides with this for the high risk actor for the S_T policy, so the line is stippled red - c denotes the level of care and h/l denotes the type of actor - l for low risk and h for high risk. S_R_cl is thus the chosen care level of the low risk actor under the strict liability with regulation policy package. Chosen care levels for the low risk actor is given by the blue lines in the three different policy packages considered. Red is used for high risk. Firstly we note that for S_R the care levels of the high and low risk actors coincide perfectly with levels above the optimal care level for the high risk type. This is the upper curve of the graph; for no distribution of actors is it worthwhile to lower the regulatory level even to the optimal level of the high risk actor. It is more important to use regulation to curb the activity levels of the different actors.

For S_T where regulation is not available the actors will optimize their production taking into account that half of all damages must be paid. This means a care level of approximately 5.3 for the low risk actor and 9.3 for the high risk actor.

Lastly with S_R_T the care levels of the two actors also coincide all along. As demonstrated by the case of S_T the high risk type will, in absence of regulation choose the care level of 9.3. This is also the optimal level of care for the low risk type. In use of regulation one faces a care level tradeoff where the distribution of actors gives the optimal balance.

We turn now to the activity levels under the same three policies before we change the level of q and see how this affects optimal policies.

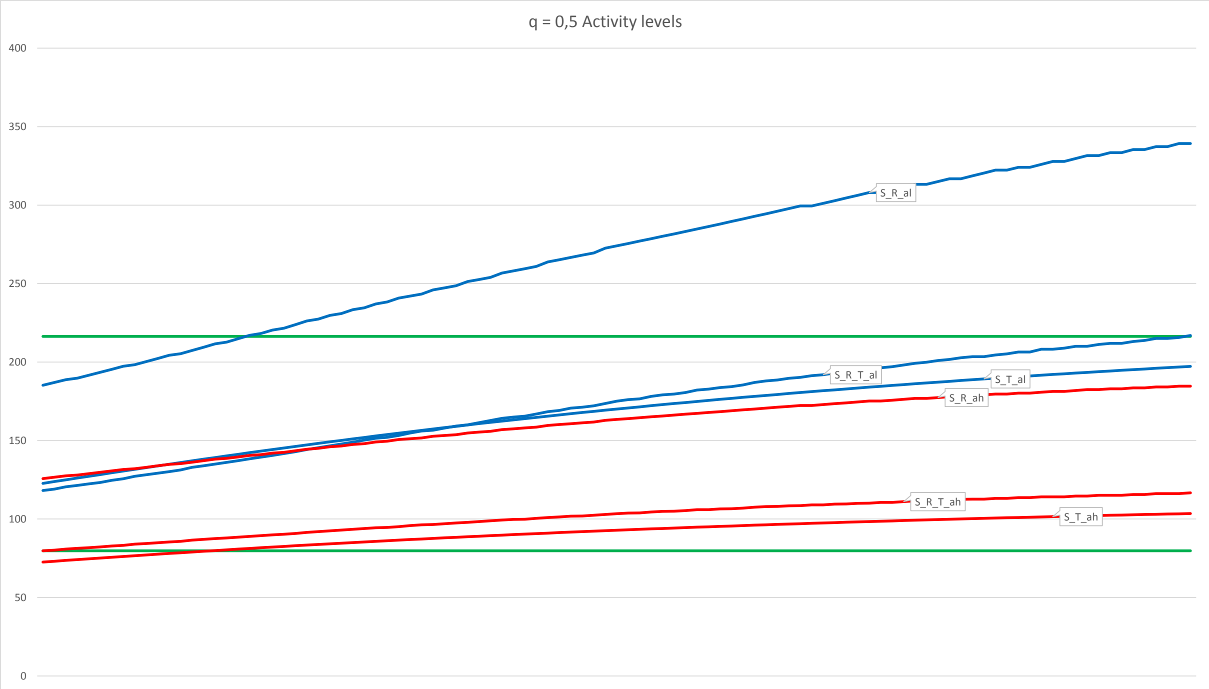

Figure 8: Levels of activity compared with optimality for q = 0,5

Here the lower green line represents the optimal activity level of the high risk actor while the upper is for low risk. For S_R the activity levels of the high risk actor are above optimality throughout. This is also the case for the most part for the low risk type also with an exception of the distributions with very low shares of low risk actors. As it is costly in terms of production-efficiency to curb the activity level using regulation and as this is mostly felt for the low risk type, it is better to allow the activity level to be above optimality also for the low risk type as long as there is a sufficiently high share of those. As was seen from the previous graph, regulation is above high risk optimal care levels throughout and thus the care levels of both are the same.

For S_T we learn that starting out with only high risk actors in the economy, the tax-only policy keeps at first the production of the high risk actors below the optimal level (the level which would be optimal with optimal care). This can be seen from the above chart displaying taxes and regulations; a tax of 25 is used at$\alpha^H = 1$. With optimal care this would be in excess for strict liability with $q = 0{,}5$ (20 would be optimal). Since lower than optimal care applies however, the optimal activity level is also lower. The low risk actor will also choose a lower than optimal care level, but a tax as high as 25 will crumple low risk activity to excess even with lower care. So obviously, as the share of low risk actors increase, the activity level goes up as the balance of the tradeoff shifts.

For S_R_T we note first that optimality in activity level is achieved for the two extremes of $\alpha^H = 1$ and $\alpha^L = 1$. Here regulation gives optimal care and the tax is adjusted to optimal production. As the distribution changes regulation will no longer give optimal care levels, but instead make the low risk actor careful to excess and the high risk actor vice versa. Likewise the tax must be set to tradeoff a lower than optimal production for the low risk type and vice versa for the high risk type.

6.2 A closer look with q = 0,75

The first thing to notice is that the utility difference between the different packages is now much smaller throughout. The effect is perhaps above expectation, moving from a situation where half of liability is paid to a situation where three quarters are.

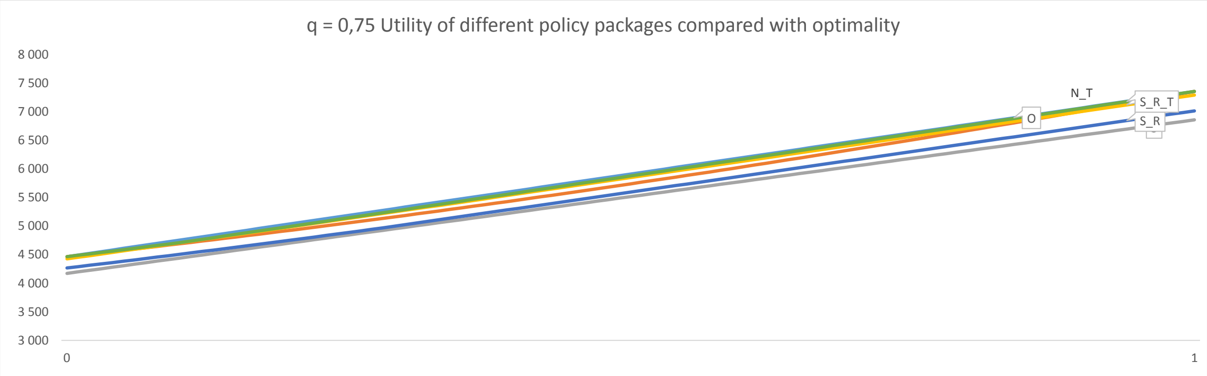

Figure 9: Utility of policy packages with q = 0,75

The reason is of course that an increase in liability has a double effect on the two policy packages that performed the worst under half liability. For S and S_R production is made with care levels closer to optimality, but also the production comes down to a level closer to optimality. Of course, as the liability problem becomes lesser there is less left to be corrected with other instruments and the difference in performance between them is smaller. It could very well be that a simpler instrument such as pure strict liability could be clearly outperformed by other packages under hard felt limits to liability, but that with minor improvements in liability strict liability can outperform more complex policy packages on grounds of administrative costs. Of course the utilities are a direct result of the chosen theoretical model, but the concept of the double improvement is very much real.

With a tighter liability regime interesting things happen to the optimal use of tax and regulations under different regimes. That is, with exception of the tax curve for N_T which is identical.

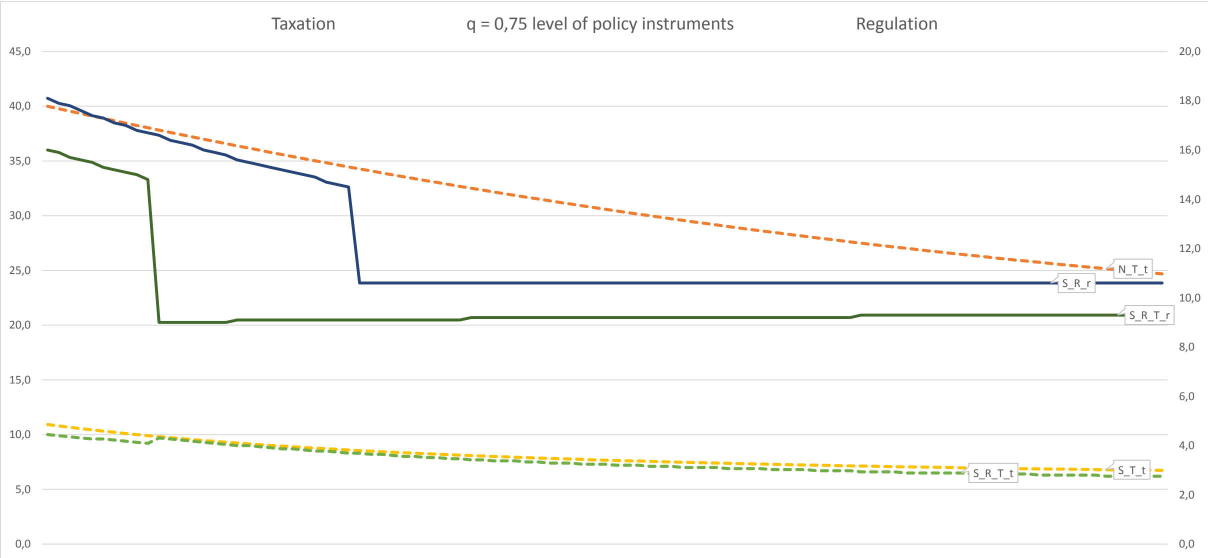

Figure 10: The use taxation and regulation with q = 0,75

The levels of taxes and regulations fall as expected. It is interesting to note the kink in the regulation curves for S_R and S_R_T. It's of course an effect of the binary nature of our model, but it still portrays an interesting point: For S_R regulation should, as discussed already, at the same time heighten care and curb production. As the share of low risk actors increase, regulation should be lowered with the changing balance of the tradeoff. However as we remember from figure 4 the optimal regulatory strategy in the binary model is often to set regulation at the point where optimal care is ascertained for the low risk actor. Depending on the liability regime, tightening regulation beyond this point would perhaps only make low risk production less efficient without affecting high risk production at all. However as we can imagine, it could be worthwhile to heighten regulation to a point where high risk production is affected if this was sufficiently important or if there was a particularly high share of high risk actors in the economy. But it would clearly not be wise to move in small steps, regulation should either be at the level best suited to handle low risk production or on a level that also affect high risk production. This is what's happening to the regulation profile of S_R with $q = 0{,}75$; as the share of low risk producers increase we suddenly reach the point where it's better to just regulate low risk production. This would mean a regulatory standard of 9.3 if liability was perfect, but as that is not the case a higher standard is chosen to also curb low risk activity level. We can see that this remains at 10.6 for all distributions with a higher share of low risk actors than at the specific kink point. What is happening is that beyond this point the regulatory regime is used solely to optimize low risk behavior, while high risk behavior is left to the tort regime too be dealt with. As the share of high risk actors diminishes this is more allowable. We did not see this kink in the case of $q = 0{,}5$, because the slacker liability made it less advisable to leave high risk behavior to the torts system *and* because the regulation best suited to low risk behavior was much higher and throughout above the level of optimal care for high risk actors, meaning that care was equal for both actors throughout.

We have the same phenomenon for S_R_T just with another subtlety as well. First of all the point where it is better to leave high risk behavior to the torts system (and tax-payment) arrives earlier because regulation is accompanied by a tax. Second we see that when this point arrives, optimal regulation drops below the level of optimal care for low risk actors, that is, 9.3. Why is this? It is connected to another detail in the graph, namely the small elevation of the tax curve at the exact same point as the regulation kink. As taxation is used in a tradeoff between over curbing low risk production and under curbing high risk production, low risk production is necessarily below optimality. And as regulations will also affect the activity level, under-regulation should actually be applied to boost low risk production a little bit.

In contrast to S_T, with S_R_T high risk production is never really left entirely to the torts system. The tax is always adjusted to the distribution of actors. And as the share of high risk actors gets lower the tax is lowered and there is less to gain from under-regulating low risk behavior. Therefore the level of regulation slowly reaches the optimal level of care for low risk actors.

Stopping to explore this phenomenon a bit further we shall vary the value of q and look at how the regulation profile for S_R and S_R_T varies with the degree of liability. Under are portrayed three different profiles for S_R. We see that with sufficiently lenient liability the kink never comes, while the stricter the liability regime is the earlier the kink will come as expected. In a way the kink will always be there (except for perfect liability where any level of regulation below a certain value will give optimality) as it will always be optimal to employ a higher regulation for $\alpha^H = 1$.

This analysis has relevance not only in a static setting where the distributions of risk are given. It could also be that with advances in technology different methods of production spread with increased safety as an effect. At some point it might be wise to change the policy response to the activity.

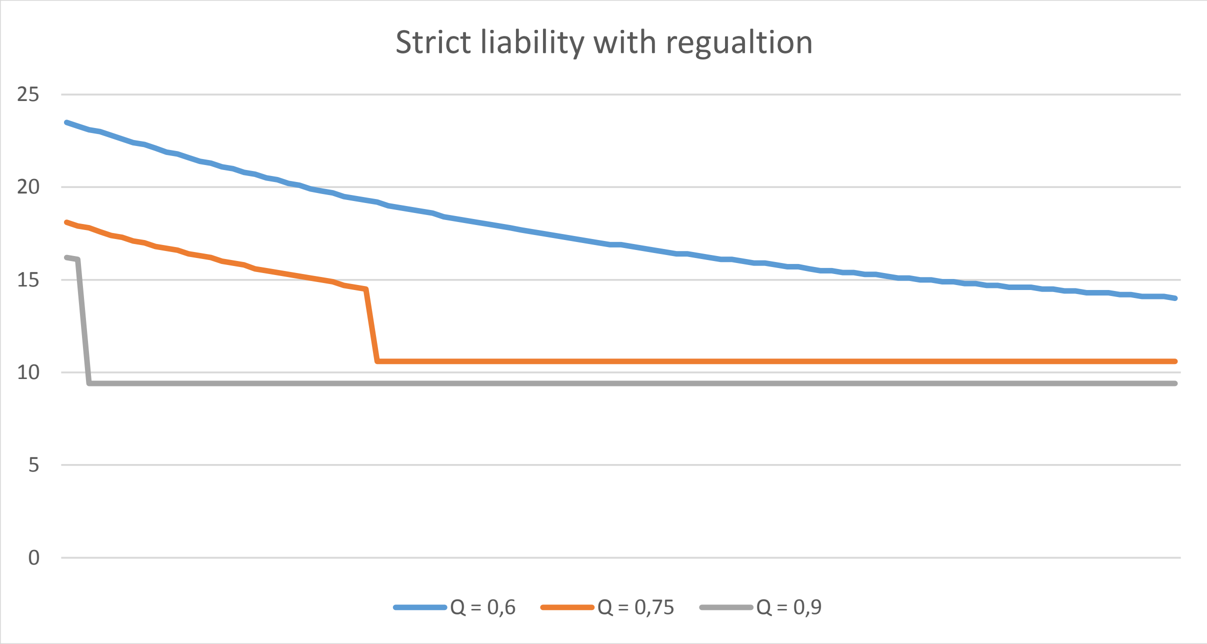

Figure 11: Optimal regulatory standard in the strict liability with regulation package under different degrees of liability.

For S_R_T we have the following picture:

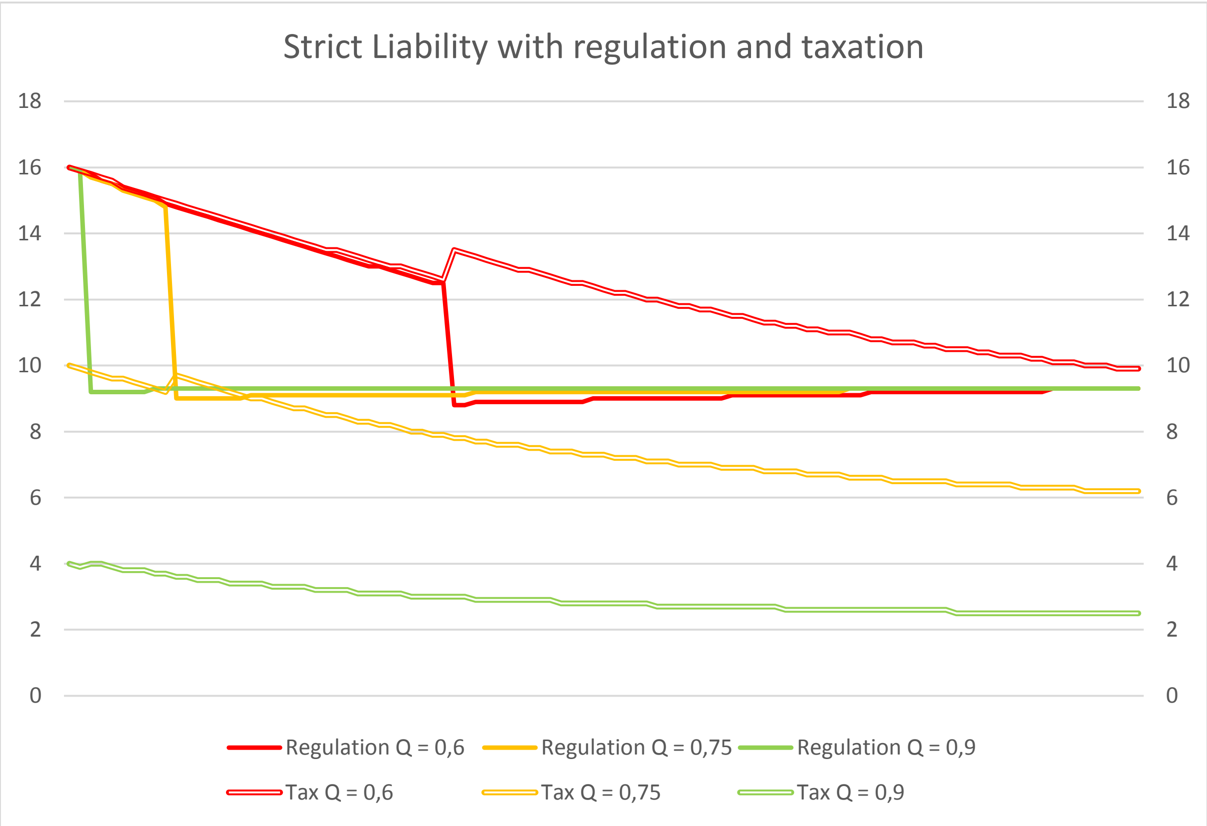

Figure 12: Optimal taxation and regulation under strict liability with taxation and regulation package for different degrees of liability

The general image is the same, while we here find the kink point in all three situations. The Offsetting effect of the tax is higher when the kink point arrives, the higher is the value of q. The reason is that a lenient liability regime places a higher corrective burden on the tax.

Returning to $q = 0{,}75$ and looking at care levels we see that these trace the kinks in the regulatory patterns found above. S_T makes for constant care levels below optimal levels as before. S_R and S_R_T now makes for an interesting pattern, low risk care levels follow the regulatory pattern exactly while high risk care levels follows the same pattern until the kink point arrives. Here high risk care drops to same level as for S_T (and S) for the remaining distributions.

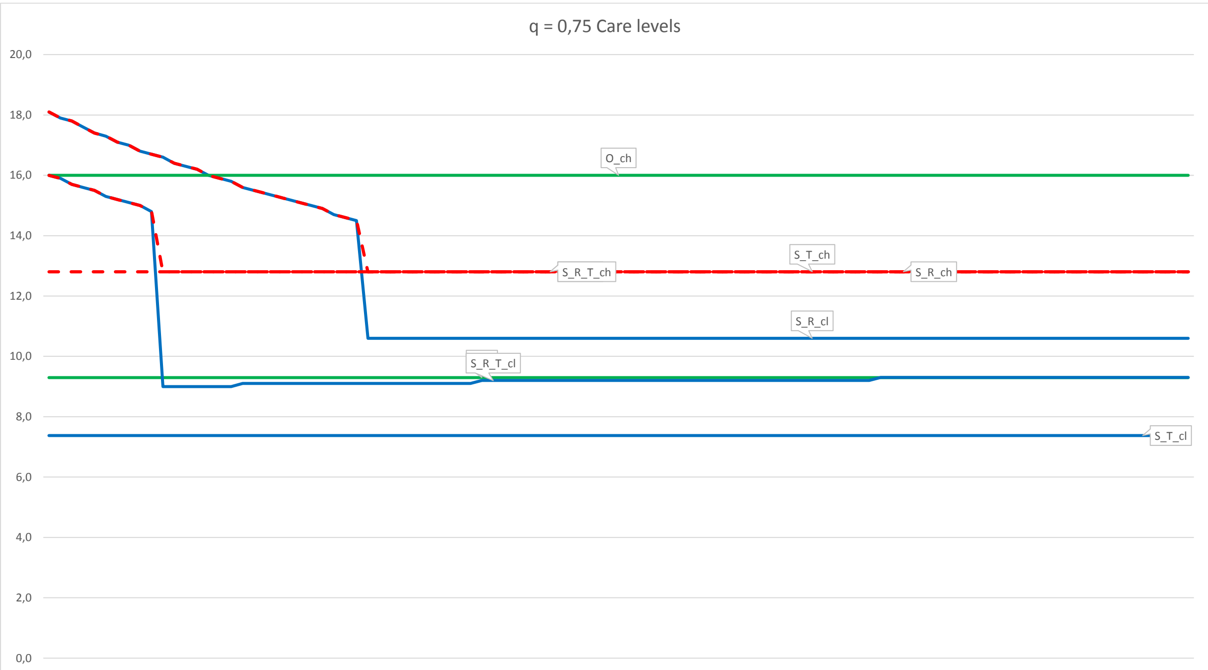

Figure 13: Care levels under different policy packages with q = 0,75

Turning to the activity levels we see that S_T follows the same pattern given by the activity level tradeoff. For S_R both type's activity levels start off above optimality at $\alpha^L = 0$. For both types, the activity level increases further as regulation is slackened (as regulation is a costly way to curb activity level) as the share of low risk actors increase. When the kink point arrives regulation is only pointed at low risk behavior and both types of actor follow a constant level well above optimality for the remaining distributions. Even though regulation is solely aimed at low risk behavior, an activity level well above the optimal level (with optimal care) is accepted, as tighter regulation would be even costlier in terms of production efficiency.

The same pattern can be seen for the high risk actor but the tax keeps activity level well below the one for S_R. And while both care and activity level is constant for S_R after the kink point, this only holds for care with S_R_T. The tax is still adjusted for the activity level tradeoff.

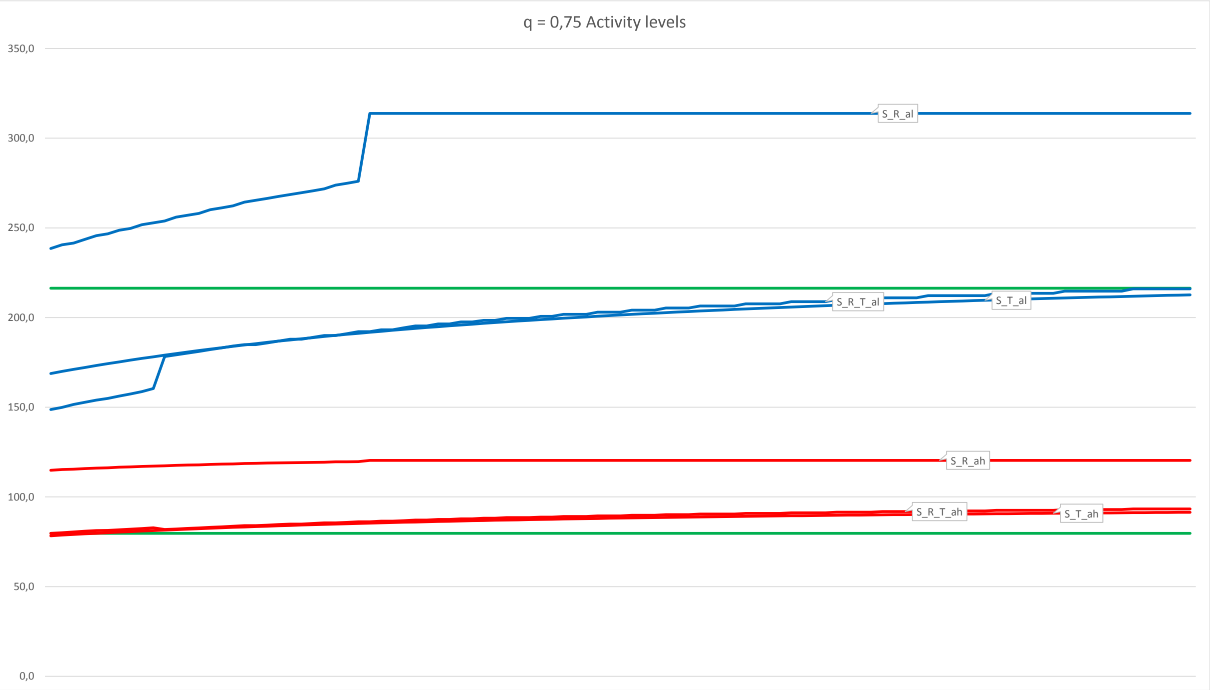

Figure 14: Activity level with q = 0,75 under different degrees of optimality

I stress that the relevance of these subtleties with kinks and great shifts in policy mix should not be exaggerated. It is a feature of the binary model. Although plausible applications could well be imagined. But just as the strength of a binary model is show the effects of a distribution of risks in clear and precise terms, features of the dynamics of the optimal policy mix is also effectively visualized. In a more general model with a continuous risk distribution the same effects could be traced, but one would be less likely to find kinks.

6.3 A Closer look at q = 1 ?

In this case every strict liability regime gives optimality throughout and irrespectively. Care levels and activity levels are constant and at their optimum. N_T will still suffer a utility loss from the activity level tradeoff. Administrative cost will be decisive.

6.4 Summary of Unilateral damage with flexible activity level

Policy packages where available instruments are utilized actively and balanced on the basis of good information on risks will generally perform well even under hard felt limits to liability and risks distributions. It seems most important to have a solid foundation of information in which to base policies on and to able to utilize instruments in harmonious combinations. The harder felt limits to liability the more important policy coordination becomes.

In the more subtle choice between policy packages consisting of strict liability on the one hand and negligence and taxation on the other, the balance hangs in a tradeoff between two problems. Negligence performs well in the face of limits to liability while strict liability performs well in the face of risk distributions and the following flexible adjustment of activity levels.

7 Bilateral damage

The virtue of strict liability; adjusting care *and* activity level at the same time is a result of unconditional requirement for the actor to pay for damages caused. It is however also a result of the specific assumption of unilateral damage. In general it takes to parts create damages of any kind (besides damage inflicted upon oneself) one suffering the damage and one causing it. By assuming unilateral damage, one works with the assumption that the plaintiff could not do anything or adjust his own behavior in any way in order to escape damage. This is sometimes true. And it is sometimes so close to the truth that it might be best to design policy as if it was true. However sometimes it is not true at all and then policy must take into account victim's ability to prevent damage.

I will treat bilateral damage by first considering the situation of fixed activity level for both injurers and victims. Then I will move on to the most general case, bilateral damage with flexible activity level for injurer and victim. I shall however, not give a complete analysis of the general case. Here, I have found it better to analyze with reference to the case of unilateral damages and adjust the conclusions drawn in light of the features of bilateral care level, bilateral activity level or both. More specifically analyze the general case by first analyzing the situation where only the care level of the victim is flexible and then the situation in which only the activity level of the victim is flexible.

8 Bilateral Damage with Fixed activity level for injurers and victims

The natural extension of the model is to let the probability of accidents be a function not only of the specific actor's level of care, but also on other actors, that is, the potential victim's level of care. We thus include a new actor called victim or potential victim. The following values are used:

Care of victim: y

Marginal costs of care: $MC_{care} = 1$

Damages in the event of an accident: $d = 100$

Expected share of damages to be paid: $q = 0{,}75$

8.1 Optimality

Our working assumption will be that the potential victim does not know what type of actor he is facing when enduring an activity. The opposite, knowledge on the type of actor need not be unreasonable. For some applications this could be the correct way to model. I shall however stick to this assumption.

Besides introducing another actor in the game, all model assumptions and parameters remain unchanged accept for the probability of accidents which now depend on the care taken by the potential victim as well.

Probability of accident: $p(x^i, y) = \frac{1}{1+\sqrt{x^i}+\sqrt{y}}$

The function still has desired properties.

The minimization for society becomes:

$$\min_{x^L, x^H, y} T = \alpha^L p(x^L, y) d^L + \alpha^H p(x^H, y) d^H + \alpha^L x^L + \alpha^H x^H + y$$

And there are three first order conditions for minimum:

$$\frac{dT}{dx^L} = 0 \rightarrow -\frac{d^L}{2\left(1+\sqrt{x^L}+\sqrt{y}\right)^2 \cdot \sqrt{x^L}} = -1$$

$$\frac{dT}{dx^H} = 0 \rightarrow -\frac{d^H}{2\left(1+\sqrt{x^H}+\sqrt{y}\right)^2 \cdot \sqrt{x^H}} = -1$$

$$\frac{dT}{dy} = 0 \rightarrow -\frac{\alpha^L d^L}{2\left(1+\sqrt{x^L}+\sqrt{y}\right)^2 \cdot \sqrt{y}} - \frac{\alpha^H d^H}{2\left(1+\sqrt{x^H}+\sqrt{y}\right)^2 \cdot \sqrt{y}} = -1$$

With the probability of accidents depending both on care of the potential victim and the injurer, optimal care of one party depends on the actual care taken by the others. This is critical when assessing different tort regimes.

Solving for optimality with $\alpha^L = 0{,}5$ yields $x^L \approx 3{,}5, y \approx 5{,}3$ and $x^H \approx 7{,}5$.

It is interesting to note the difference between this model and one where the potential victim has knowledge of the type of actor he is facing. In such a situation there would not be one optimal victim's level of care based on expected damages but rather one optimal level in each case based on the specific actors involved in the situation. In the case of a potential victim facing a low risk actor the first order conditions would be:

$$\frac{dT}{dx^L} = 0 \rightarrow -\frac{d^L}{2\left(1+\sqrt{x^L}+\sqrt{y}\right)^2 \cdot \sqrt{x^L}} = -1$$

$$\frac{dT}{dy} = 0 \rightarrow -\frac{d^L}{2\left(1+\sqrt{x^H}+\sqrt{y}\right)^2 \cdot \sqrt{y}} = -1$$

In this case optimal care would be given by $x^L = y \approx 4$. It can be seen that in the case of the potential victim meeting a high risk actor the optimal solution is given by $x^H = y \approx 6{,}8$. Interestingly, the information problem yields an optimal solution that differs greatly from the situation with full information. Having to act on expected damages, instead of actual damages the victim should take a higher share of the care burden (with a share of 0.5 for each type the average care would be 5.4 with full information). The higher care taken by victim's means injurers should take less care.

8.2 Tort regimes

While we up until now have considered only the negligence and strict liability it is now natural to include other types of rules as well. It is well known that having one party exempt from liability means that that party will not give any care. For instance strict liability for injurers with victims always receiving full compensation irrespective of own behavior gives a care level of victims of zero. Knowing that victims will not exert care, each actor will minimize costs with this in mind accordingly:

$$\frac{dT}{dx^L} = 0 \rightarrow -\frac{d^L}{2\left(1+\sqrt{x^L}\right)^2 \cdot \sqrt{x^L}} = -1$$

$$\frac{dT}{dx^H} = 0 \rightarrow -\frac{d^H}{2\left(1+\sqrt{x^H}\right)^2 \cdot \sqrt{x^H}} = -1$$

This will give the previously obtained results with $x^L \approx 9{,}3$ and $x^H \approx 16$. In this case this is inefficient because less effectual care by injurers is used instead of efficient care taken by potential victims (the marginal effect of care is declining in the care level of each injurer and victim). Reliving injurers from liability all in all would yield a similar situation with victims alone, taking care.

Shavell(1987) explores a set of different negligence rules under bilateral damage. He shows that fractional liability (each part bearing a fraction of costs irrespective of care) is inefficient, but that rules such as:

- Strict liability with defense of contributory negligence
- Strict liability with the defense of relative negligence
- Ordinary negligence
- Negligence rule with the defense of contributory negligence
- Comparative negligence

All can lead to optimal outcomes under different assumptions and circumstances. I will not dwell into the myriad of possible liability rules but stick to the basic regimes. Of course with limits to liability, rules based on strict liability without a mechanism like the defense of contributory negligence will not give optimal outcomes.

8.3 Rules based on strict liability

It is worth noting the duality between strict liability and no liability in the case of bilateral damage. No liability is in effect equal to strict liability for the victim, as when the injurer bears no costs of damages the victim on his side bears the full cost. This means that slack liability for injurers induces victims to take high care. An effect of this is that limited liability in a way resembles a situation of shared or fractional liability. A fraction of liability of 0.75 means that injurers bear 75 % of the costs of damages and that the victims bear the remaining 25 %. This is of course also true in the case of unilateral damage, but then it has no bearing on the behavior of victims and is thus of less interest.

If we compare the bilateral case of strict liability with the case of strict liability in the unilateral case, we find, interestingly that victims will take care, and that injurers as a result of this will take less care. For $q = 0{,}75$ it can be seen that the Nash equilibrium is

$y \approx 0.8$, $x^L \approx 4.9$ and $x^H \approx 9.4$. Here each actor fulfills their own first order conditions knowing the optimal response of the other actors:

$$\frac{dT}{dx^L} = 0 \rightarrow -\frac{d^L q}{2\left(1+\sqrt{x^L}\right)^2 \cdot \sqrt{x^L}} = -1$$

$$\frac{dT}{dx^H} = 0 \rightarrow -\frac{d^H q}{2\left(1+\sqrt{x^H}\right)^2 \cdot \sqrt{x^H}} = -1$$

$$\frac{dT}{dy} = 0 \rightarrow -\frac{\alpha^L d^L (1-q)}{2\left(1+\sqrt{x^L}+\sqrt{y}\right)^2 \cdot \sqrt{y}} - \frac{\alpha^H d^H (1-q)}{2\left(1+\sqrt{x^H}+\sqrt{y}\right)^2 \cdot \sqrt{y}} = -1$$

Victims require knowledge on the shares high and low risk actors but not on which type one faces in each singular case. The reason why victims take care is the fractional liability imposed on them by the limited liability for injurers.

With our assumptions it would be better if the victims actually take significant care, even though it will slacken the care of injurers under strict limited liability, this is again because the first units of care is very cost efficient.

8.4 Variations of strict liability and regulation

It is an option to use regulation in combination with strict liability. If the tort regime is strict liability for injurers and there are limits to liability, there is however not possible to overcome this and achieve optimality so long as there is also a distribution of the riskiness of potential injurers and not a single risk level that could be regulated to the one correct level.

Strict liability with defense of contributory negligence could also be combined with regulation of the care level for injurers. Clearly it would then be best to set the level of regulation at the optimal level for low risk injurers so long as the share of high risk injurers is not very large.

8.5 Negligence rules

As known, negligence has an advantage in offsetting limits in liability that is not too large. Optimality can be achieved in the bilateral case with different schemes. One option is the plain negligence rule, meaning that injurers do not pay damages unless care is found to be below due care. Injurers will thus choose to exert due care, and knowing this victims will also take optimal care. This is because victims realize that injurers take due care and that victims must take the cost of eventual accidents. In a way victims are given strict liability for damages so long as injurers show due care. A rule of negligence with the defense of contributory negligence will also give optimality, both parties will find it best to exert due care.

All in all bilateral damage supplies us with an extra argument in favor of negligence when there are limits to liability.

9 Bilateral damage with flexible activity level

As mentioned, this last setup of the standard liability analysis matrix is also the most complicated. Modeling bilateral damage could be straight forward in the abstract. The approach was shown in the basic theory chapter. It is a property of the bilateral damage situation however that the probability of corner solutions, as explained, is imminent. Another feature is that interior solutions are less stable; small changes in the settings may drastically alter the nature of the optimal solution. A typical pattern is an interior solution with a very small activity level and high care level for one part and vice versa for the other. A change in settings may quickly alter the solution to the opposite, with the other side having to take high care and exert a low level of activity.

Injurers and victims alike enjoy a utility from engaging in a potentially dangerous activity. As in the basic theory, we shall assume, as is reasonable, that the total damage from the activity is the product of victim activity level and injurer activity level. The social goal in this case is to maximize the following:

$$\max_{x^L, x^H, y, s^L, s^H, s^V} T = u(s^V) + \alpha^L u(s^L) + (1-\alpha^L)u(s^H) - \alpha^L s^L s^V p(x^L, y) d^L$$
$$- (1-\alpha^L) s^H s^V p(x^H, y) d^H - s^L \alpha^L x^L - s^H (1-\alpha^L) x^H - s^V y$$

That is the total utility of the activity for injurers and victim, minus total accident costs, minus total care costs. With the same utility functions and probability functions as before the expression is:

$$\max_{x^L, x^H, y, s^L, s^H, s^V} T = A\sqrt{s^V} + \alpha^L A\sqrt{s^L} + (1-\alpha^L)A\sqrt{s^H} - \frac{\alpha^L s^L s^V d^L}{1+\sqrt{x^L}+\sqrt{y}} - \frac{(1-\alpha^L) s^H s^V d^H}{1+\sqrt{x^H}+\sqrt{y}}$$
$$- s^L \alpha^L x^L - s^H (1-\alpha^L) x^H - s^V y$$

For simplicity we use the same utility function for injurers and victims. From this we derive six first order conditions:

$$\frac{dT}{dx^L} = 0 \rightarrow -\frac{s^V d^L}{2\left(1+\sqrt{x^L}+\sqrt{y}\right)^2 \cdot \sqrt{x^L}} = -1$$

$$\frac{dT}{dx^H} = 0 \rightarrow -\frac{s^V d^H}{2\left(1+\sqrt{x^H}+\sqrt{y}\right)^2 \cdot \sqrt{x^H}} = -1$$

$$\frac{dT}{dy} = 0 \rightarrow -\frac{\alpha^L s^L d^L}{2\left(1+\sqrt{x^L}+\sqrt{y}\right)^2 \cdot \sqrt{y}} - \frac{(1-\alpha^L) s^H d^H}{2\left(1+\sqrt{x^H}+\sqrt{y}\right)^2 \cdot \sqrt{y}} = -1$$

$$\frac{dT}{ds^L} = 0 \rightarrow \frac{A}{2\sqrt{s^L}} = \frac{s^V d^L}{1+\sqrt{x^L}+\sqrt{y}} + x^L$$

$$\frac{dT}{ds^H} = 0 \rightarrow \frac{A}{2\sqrt{s^H}} = \frac{s^V d^H}{1+\sqrt{x^H}+\sqrt{y}} + x^H$$

$$\frac{dT}{ds^V} = 0 \rightarrow \frac{A}{2\sqrt{s^V}} = \frac{(1-\alpha^L) s^H d^H}{1+\sqrt{x^H}+\sqrt{y}} + \frac{\alpha^L s^L d^L}{1+\sqrt{x^L}+\sqrt{y}} + y$$

The first three state that there should be cost-efficiency in production for both injurers and victim. The marginal cost of care should equal the marginal benefit in terms of a reduction in the probability of accidents, the three latter shows that the activity level of both victim and injurers should be optimally adjusted with the marginal utility of activity equal to the marginal damage and care costs.

While solving the first three equations for care level is analytically infeasible, we can solve for the optimal adjustment of activity level of the parties:

$$For\ i = L, H\ s^i = \left[\frac{A/2}{p(x^i, y) S^V d^i + x^i}\right]^2$$

$$s^V = \left[\frac{A/2}{(1-\alpha^L) p(x^H, y) S^H d^H + \alpha^L p(x^L, y) S^L d^L + y}\right]^2$$

With bilateral damage, limited liability and unequal risk we have three problems to cope with in search of optimality. It was not possible to achieve optimality with two of these problems in the case of unilateral damage. There we found that negligence must be combined with taxation in order to make the injurers adjust their activity level. Taxation however must be at a single level and optimality is impossible with a distributed riskiness of the injurers. Using strict liability partially solves the activity level problem, and more efficiently so when combined with a tax to pick up the slack in liability. But still, the limits to liability cannot make both types of actor take optimal care, even though regulations may abate the problem, optimality was not possible.

So with bilateral damage we should not expect optimality either. And so I shall not search for it but rather analyze features of the best possible policy mix. This will be discussed in relation to the case of unilateral damage. One could expect the third problem introduced by bilateral damage to fundamentally alter the discrepancy between optimal outcome and possible outcome, but this is not the case. The reason is the flexibility of the liability rules when applied to two parties of an accident. Dual mechanisms like defense of contributory negligence can be adapted to the new situation. As dual liability rules will dominate over singular ones I will only assess dual rules in this part, although one could imagine singular liability being preferred on the ground of administrative costs. Note however that simple negligence is a dual liability rule in this case as it is in effect strict liability with the defense of contributory negligence for the victim side.

The following rules will be assessed:

1) Strict liability with the defense of contributory negligence
2) Negligence

Under both these regimes injurers and victims will take optimal care if not for the possibility of limited liability. Under (1) Injurers face strict liability and will take less than optimal care if there are limits to liability. Under negligence both side will take optimal care irrespectively as there naturally are no limits to liability for the suffered damages of victims.

As it is our working assumption that the activity level of victims cannot be taxed, it would be tempting to conclude that the tax should be laid on the side of injurers, as is also touched upon in the basic theory, making (2) a dominating strategy compared to (1) as strict liability will adjust victim's activity level and taxation could be used on the injurer's side. However it is also on the injurer's side that we find the distribution of risk, a problem which is also moderated by strict liability. We thus have an intricate tradeoff – Is it most important to limit the activity level of the victim, or to lay strict liability on injurers in order to alleviate the activity level tradeoff in the face of distributed risk? We now have two forces pulling for a negligence based rule; limited liability and victims' activity level. Still, the activity level tradeoff on the injurers' side pulls in favor of policies based on strict liability.

With our assumptions it would be no point in introducing regulations on the victim's side. As we have no distribution of risk amongst them and as contributory negligence (or in effect strict liability) will induce optimal care for this side in any way.

9.1 Analysis when only the care level of the victim is flexible

Sometimes it is only reasonable to expect victim's level of care to be flexible. For instance, the degree of damages from noise or smoke pollution may be a consequence of the care and activity level of the polluter, but also of measures taken by the victim that are best described as care- measures, such as sound proofing. Although activity level is relevant (the amount of time spent at home or outside) it is best left out of the liability question and the analysis.

We can now reformulate the objective function as follows:

$$\max_{x^L,x^H,y,s^L,s^H,s^V} T = \alpha^L A\sqrt{s^L} + (1-\alpha^L)A\sqrt{s^H} - \frac{\alpha^L s^L d^L}{1+\sqrt{x^L}+\sqrt{y}} - \frac{(1-\alpha^L)s^H d^H}{1+\sqrt{x^H}+\sqrt{y}} - s^L\alpha^L x^L - s^H(1-\alpha^L)x^H$$

And we obtain five first order conditions for optimality:

$$\frac{dT}{dx^L} = 0 \rightarrow -\frac{d^L}{2\left(1+\sqrt{x^L}+\sqrt{y}\right)^2\cdot\sqrt{x^L}} = -1$$

$$\frac{dT}{dx^H} = 0 \rightarrow -\frac{d^H}{2\left(1+\sqrt{x^H}+\sqrt{y}\right)^2\cdot\sqrt{x^H}} = -1$$

$$\frac{dT}{dy} = 0 \rightarrow -\frac{\alpha^L s^L d^L}{2\left(1+\sqrt{x^L}+\sqrt{y}\right)^2\cdot\sqrt{y}} - \frac{(1-\alpha^L)s^H d^H}{2\left(1+\sqrt{x^H}+\sqrt{y}\right)^2\cdot\sqrt{y}} = -1$$

$$\frac{dT}{ds^L} = 0 \rightarrow \frac{A}{2\sqrt{s^L}} = \frac{d^L}{1+\sqrt{x^L}+\sqrt{y}} + x^L$$

$$\frac{dT}{ds^H} = 0 \rightarrow \frac{A}{2\sqrt{s^H}} = \frac{s^V d^H}{1+\sqrt{x^H}+\sqrt{y}} + x^H$$

The first three gives optimal care levels for all actors involved while the last two gives optimal levels of activity for the two types of injurer.

The choice of negligence rule is now of less importance, as both strict liability with the defense of contributory negligence and negligence will induce victims to take optimal care. The tradeoff should thus be of the same nature as under unilateral damage. The possibility of victims taking care should of course be taken into account when forming the optimal policy.

In any way if the activity level of the victim can be considered fixed bilateral damage will give weight to a negligence rule according to the tradeoff found in the above chapter.

9.2 Analysis when only the activity level of the victim is flexible

When it is the activity level of the victim that is flexible, things are somewhat more complicated. We can now reformulate the objective function as follows:

$$\max_{x^L,x^H,s^L,s^H,s^V} T = u(s^V) + \alpha^L u(s^L) + (1-\alpha^L)u(s^H) - \alpha^L s^L s^V p(x^L) d^L$$
$$- (1-\alpha^L)s^H s^V p(x^H) d^H - s^L \alpha^L x^L - s^H (1-\alpha^L) x^H$$

And there are five first order conditions for optimality

$$\frac{dT}{dx^L} = 0 \rightarrow -\frac{s^V d^L}{2\left(1+\sqrt{x^L}\right)^2 \cdot \sqrt{x^L}} = -1$$

$$\frac{dT}{dx^H} = 0 \rightarrow -\frac{s^V d^H}{2\left(1+\sqrt{x^H}\right)^2 \cdot \sqrt{x^H}} = -1$$

$$\frac{dT}{ds^L} = 0 \rightarrow \frac{A}{2\sqrt{s^L}} = \frac{s^V d^L}{1+\sqrt{x^L}+\sqrt{y}} + x^L$$

$$\frac{dT}{ds^H} = 0 \rightarrow \frac{A}{2\sqrt{s^H}} = \frac{s^V d^H}{1+\sqrt{x^H}+\sqrt{y}} + x^H$$

$$\frac{dT}{ds^V} = 0 \rightarrow \frac{A}{2\sqrt{s^V}} = \frac{(1-\alpha^L)s^H d^H}{1+\sqrt{x^H}} + \frac{\alpha^L s^L d^L}{1+\sqrt{x^L}}$$

The first two gives optimal care levels for both injurers while the last three gives optimal activity levels for injurers and victim. The interesting point to notice is that the optimal activity level of the victim will depend on the actual activity level of injurers.

Under negligence with taxation, optimal care will be taken by injurers. When it comes to activity levels, first order conditions for the actors are as follows: Each type of injurer will maximize utility of production minus care costs and taxation:

$$For\ i = L, H\ \max_{S^i} A\sqrt{S^i} - S^i(x^i + t)$$

With the resulting activity level of

$$For\ i = L, H\ s^i = \left[\frac{A/2}{x^i + t}\right]^2$$

This is the same as for unilateral damage. Victims face strict liability and will adapt their activity level according to:

$$\max_{S^V} A\sqrt{S^V} - \alpha^L s^V s^L p(x^L) d^L - \alpha^H s^V s^H p(x^H) d^H$$

Solving the first order condition gives:

$$s^V = \left[\frac{A/2}{\alpha^L s^L p(x^L) d^L + \alpha^H s^H p(x^H) d^H}\right]^2$$

As the activity level of the victims depend on that of the injurers, also victims will change behavior when the tax rate is altered, making their activity level not necessarily optimal, but rather privately optimal when the activity level of the injurers is taken into account. Besides this curiosity, negligence has the advantage of optimal care levels, but the disadvantage of having to face the activity level tradeoff with taxation and the situation is thus quite similar to unilateral damage.

If we turn to strict liability instead, the maximization functions for the parties become:

$$For\ i = L, H\ \max_{S^i} A\sqrt{S^i} - S^i(x^i + s^V p(x^i) d^i q + t)$$

That is, the utility of activity minus care and liability costs and an eventual tax. Solving the first order condition gives the following activity level:

$$For\ i = L, H\ s^i = \left[\frac{A/2}{x^i + s^V p(x^i) d^i q + t}\right]^2$$

In this situation however the victims will not have proper incentive to alter their activity level optimally, as they receive compensation for damages by a fraction of q:

$$\max_{s^V} A\sqrt{S^V} - \alpha^L s^V s^L p(x^L) d^L(1-q) - \alpha^H s^V s^H p(x^H)\, d^H(1-q)$$

$$s^V = \left[\frac{A/2}{\alpha^L s^V s^L p(x^L) d^L(1-q) + \alpha^H s^V s^H p(x^H) d^H(1-q)}\right]^2$$

This gives to high an activity level for victims. Victims will take optimal care so long as the strict liability is combined with the defense of contributory negligence.

First of all it is evident that a pure taxation and regulation regime could be preferable over a liability regime as this will not make the victim overdo the activity in question because of compensation from the injured. A tax regime however will give us the activity level tradeoff on the injurer's side.

Summed up we have roughly the following situation:

Policy	**Problems**
Negligence and taxation	- Activity level tradeoff on injurer side
Strict liability with defense of contributory negligence (with taxation and regulation)	- Activity level tradeoff not completely dealt with by liability (limited liability) - To high activity level of victims
Taxation and regulation	- Care level tradeoff for injurers - Activity level tradeoff on injurers side

Table 5: Summary of main results from bilateral damage

This is again a matter of the distribution of riskiness on the injurer's side versus the importance of having victims adjust their activity level. It is thus also a matter of determining how flexible one should consider the activity level of injurers to be.

9.3 Summary of Bilateral damage

The model of unilateral damage is a useful reference point for the considerations of the optimal policy mix. First of all one should consider to what degrees the activity level and care level of victims can be considered to be flexible. Sometimes it is the case that damages will occur regardless of victims care level. And sometimes activity level can for a large part be considered to be fixed. When the care level of victims is flexible, a dual negligence rule can be relied upon to make victims take optimal care and the tradeoff should be in the same nature as under unilateral damage. With flexible activity level we remember that for unilateral damage, the tradeoff involved when choosing between N_T and policies based on strict liability consisted mainly of the activity level tradeoff on the injurer's side, versus the care level tradeoff on the injurer's side. This was again affected by on the one side the limits to liability and on the other side the distributions of risk on the injurer's side. In the case of bilateral damage, especially two things happen. First an extra burden is cast to the use of strict liability, namely the following lack of adjustments of activity level on the victim's side. Secondly a third option now looks more promising, namely a pure tax and regulations regime.

10 Other factors

We have seen that in many situations different policy packages comes out fairly equal. This section takes up two momentums that could tip the balance besides administrative costs.

Up until now we have treated care as uniform size to be adjusted in order to limit damages of a unit of activity, this for analytical clarity. However in reality, care is multidimensional, with many different acts that together form the carefulness of a party (Shavell 1987). For instance, while driving it is cautious to keep the speed limit, but also to check the mirror and to keep distance etc. (this is the example in Shavell(1987)). The importance of this is that some factors of care are visible, or verifiable, and can then be included in a negligence assessment, while others are less verifiable and can perhaps only be expected to be taken into account under strict liability.

Another momentum that could matter is to consider whether the implied liability of victims actually is limited in some way, this could happen by the welfare state or by damages being inflicted on other persons as well. For instance becoming unfit for work as a consequence of damages of some sort is economically more severe for society than what is felt for the victim. This is a consequence of taxation as well as welfare transfers or social insurance programs. This could also tip the balance.

11 Conclusions

Legal, financial and other measures to regulate harmful activates is best understood in combination. Seen in isolation the optimal use of one single instrument depends on the practical use of other instruments. I have shown that the choice between negligence and strict liability depends on the use of other instruments, and in many thinkable circumstances crucially so. It is also evident that the optimal pigouvian tax hinges on the liability regime and regulatory measures taken. Details aside, policies where available instruments are used in harmonious combination on the basis of good information can be expected to perform well in many, or most circumstances. This may demand coordination amongst the legislative, executive and judicial powers.

I have utilized a simple two actor model in order to shed light on the use of the use of different instruments. The model is simplistic in nature when compared to the realities of the problems at hand. And the assumptions made in order to achieve a certain degree of analytical rigor are restrictive and limiting on the robustness of the conclusions that can be drawn. However I hope that the analysis have given some added insight into the most important tradeoffs and moments to consider when establishing policies for the regulation of potentially harmful activities.

The most important tradeoff when it comes to the choice between negligence based rules and rules based on strict liability, has in our setting been the one between the distribution of risk leading to the activity level tradeoff on the one hand and the limited liability potentially leading to lower care taken as well as an above optimal activity level on the other. With a distribution of risk amongst actors they will induce different external effects on society from their activity, and there is an external effect even when the care level is optimal. As such, different actors should face costs adjusted to their damages, exactly what the strict liability policy achieves. With limited liability however levels of care will be to low and activity to high. The negligence policy can achieve optimal care levels but then taxation must be used to adjust the activity level according to externalities created which leads to an inefficiency in the chosen activity levels of different actors. It must thus be assessed whether it is the differences in risk momentum or the limited liability momentum that add the most weight to the burden.

In the case of bilateral damages where only the care level of both parties is flexible it is shown that negligence does very well as expected because there are no longer any activity level tradeoff. When the activity level is flexible negligence also looks more promising as this can give optimal adjustment of activity level on the victim’s side, but it is by no means sure that this policy is preferable over strict liability as the activity level tradeoff on the injurers side is still there.

So it is shown that Negligence and taxation has the upper hand on the care level tradeoff while policies based on strict liability has the upper hand when it comes to the activity level tradeoff. Flexible activity level on the victim’s side for bilateral accidents will likely more often than not tip the balance in favor of negligence and taxation based policy. With bilateral damages a non-tort regime with only taxation and regulation becomes more attractive, this is due to the problem that damages paid from one party is a gain to the other party, with the incentive problems that this gives rise to. Other factors not directly considered in the core model can of course also tip the balance.

I have focused on the economic consequences of different policies. However, just as legal instruments have economic impacts, the use of taxation or regulations can have important legal consequences as explained. Full liability for damages that are sought alleviated by the legislator through taxation could place an unfair double burden on some actors in the economy. This will off course also give rise to economic inefficiencies.

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