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Socially Efficient Scheme to Protect Property Entitlements : Property Rules vs. Liability Rules

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Abstract

This paper studies socially optimal legal rules, property and liability rules, for protecting entitlements. We develop a simple three-stage game to model a nuisance situation in which a resident initially owns an entitlement and a polluter economically benefits from obtaining it. We find the following results. First, the resident and polluter fail to make voluntary bargaining as long as the bargaining cost is positive even without asymmetric information. The bargaining cost causes a hold-up problem and the polluter is not willing to come to the negotiation table. Second, the property rule does not enhance voluntary bargaining. These two results are inconsistent with the traditional view in the literature. Third, the liability rules achieve full efficiency with certainty. The result follows the literature.

1. Introduction

The legal entitlements are protected under two different rules: liability and property rules. If an entitlement is protected by liability rules, a potential buyer can take the entitlement without any permission from its holder. In this case, the buyer must compensate the holder by paying damages objectively determined by a court.

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(1) Calabresi and Melamed (1972) consider a property rule as a rule consisting of a procedure to choose who is endowed with an entitlement. In addition, they classify legal rules into four types according to (i) who is endowed with an entitlement, and (ii) what rule is employed to protect the entitlement. Suppose that a resident wants to enjoy clean air while a polluter wants to manage manufactures polluting air. Initially, the resident is endowed with a right to clean air, or the polluter is endowed with a right to pollution. In their term, *Rule 1* is a property rule protecting

The damages will often equate to a market price[1]. On the other hand, an entitlement is protected by property rules, nobody can remove the entitlement without a permission from its holder. However, the entitlement can be traded through voluntary bargaining if the holder and buyer reach an agreement. Thus, Calabresi and Melamed (1972) argue that property rules enhance voluntary bargaining if the bargaining cost is sufficiently small. In their context, the bargaining cost includes asymmetric information between the holder and buyer. Calabresi and Melamed (1972) conclude that, in terms of economic efficiency, when high transaction cost prevents parties from voluntarily bargaining over the price of an entitlement, the society needs liability rules. This is because the entitlement is never traded under property rules even though the initial allocation is inefficient. However, property rules are socially preferable to liability rules whenever transaction cost is sufficiently low and parties can bargain. This is because the society can save cost of setting damages and enforcing the compensation.

Many studies compare liability rules with property rules from a viewpoint of social efficiency. We briefly review existing studies that analyze the optimal legal rules by using bargaining models.

These studies often separately analyze several cases. Parties can come to the negotiating table if a transaction cost is small whereas bargaining is never available to parties in a case of a high transaction costs. In addition to obstacle to bargaining, information asymmetry may exist between the parties. The information asymmetry can prevent the parties from reaching agreement even though they start to bargain in a

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the resident's right to clean air, *Rule 2* is a liability rule protecting the resident's right to clean air, *Rule 3* is a property rule is a property rule protecting the polluter's right to pollution, and *Rule 4* is a liability rule protecting the polluter's right to pollution. Avraham (2004) notes that *Rule 4* was applied to the actual case, *Spur Industries v. Del Webb Development Co.,* 494 P.2d 700 (Ariz. 1972). He also notes that the Rule 2 has been interpreted as a *call option* held by a polluter. The polluter exercises a call option and buys the entitlement without any consensus from the resident if the exercise price is lower than the polluter's subjective value. Similarly, the Rule 4 gives a call option to a resident. The resident exercises a call option and enjoins the polluter to quit pollution without any consensus from the polluter if the exercise price is lower than the resident's subjective value.

case of low transaction cost[2]. The existing studies compare outcomes under property and liability rules in each case.

Kaplow and Shavell (1996) study property and liability rules in a situation where parties are involved in an ultimatum bargaining. They consider symmetric and asymmetric information about valuations for an entitlement between parties. They make the following findings. First, if the bargaining cost is high, both rules induce the same allocation of an entitlement with symmetric information whereas liability rules are superior to property rules with asymmetric information. Liability rules can use the non-owner's private information through his behavior of taking. The result is rather consistent with the one of Calabresi and Melamed (1972).

Kaplow and Shavell (1996) argue that liability rules work better than property rules even though damages do not equate to the entitlement holder's private value. The statement contradicts the traditional views in the literature that liability rules with *incorrect* damages lead to social inefficiency.

Second, if the bargaining cost is small, both rules yield the same allocation through voluntary bargaining with symmetric information whereas both rules cannot be ranked with asymmetric information. Both rules facilitate bargaining in different ways, but do not always induce an efficient allocation. This assertion is against the traditional view that property rules facilitate bargaining, reducing social costs, but liability rules burden courts because they have to correctly determine damages, increasing social costs (Calabresi and Melamed, 1972). However, perhaps property rules are socially preferable to liability rules in terms of "reciprocal takings".

Ayres and Talley (1995) explicitly introduce a bargaining procedure under bilateral asymmetric information and show that liability rules are socially preferable to property rules even though parties cannot meet at bargaining. In their argument, liability rules

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(2) Information asymmetry can be a problem in a case of high transaction cost as well under liability rules. A court sets damages under liability rules, but the damages cannot equate to the entitlement holder's subjective value if the subjective value is the holder's private information.

give a divided entitlement to a non-owner whereas an entitlement holder keeps the entitlement under property rules. The non-owner can take the entitlement from the original owner without any consensuses under liability rules; thus, the non-owner holds an *option* to take the entitlement. This option can be considered as the divided entitlement. The main message is that liability rules weaken strategic behaviors, because each party becomes a seller decision and a buyer position at the same time; thus, each party cannot obtain a decisive bargaining power. As a consequence, liability rules lead to a consensual trade via bargaining.

Hylton (2006) develops a bargaining model with bilateral asymmetric information and studies property and liability rules. In his model, a court cannot use parties' private information to determine damages. He focuses on an entitlement holder's payoff and likelihood of bargaining failure.

First, if the bargaining cost is too high for the parties to meet at bargaining, liability rules are superior to property rules because the entitlement is never traded under property rules even though the holder values it lower. Second, if the bargaining cost is small, both rules yield the same outcomes. The entitlement is traded through voluntary bargaining under property rules whereas the non-owner takes and compensates the victim under liability rules. However, the compensation under liability rules may not be enough for the victim, i.e., liability rules can fail to protect the victim's subjective value. In addition, liability rules need *enforcement costs* which reduces social welfare whenever the non-owner takes the entitlement; thus, property rules are superior to liability rules even though both rules generate the same allocations [(3)]. His findings in cases with symmetric information mostly follow Calabresi and Melamed (1972). In cases with asymmetric information, Hylton argues that liability rules are sometimes preferable to

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(3) Hylton (2006), in addition, gave another reason that property rules are socially preferable to liability rules. Liability rules may cause the taking, resulting in demoralization. The potential victim may become careless to hold the entitlement whereas the potential taker may invest in technology for taking. Liability rules bear this kind of *denormalization costs*, reducing social welfare. However, the denormalization costs are outside the model.

property rules if the transaction costs are intermediate whereas the converse result is available if the costs are high.

Avraham (2004) considers a nuisance situation and suggests new liability rules that give *a put option* to either a resident or a polluter. Suppose that liability rules protecting a polluter give a put option to the polluter (referred to as *Rule 5*). The polluter can exercise the put option and sell his entitlement (right to pollution) to the resident without any consensus from the resident. In this case, the polluter stops polluting and earns money regardless of whether the resident wants clean air at the price. Suppose next that liability rules protecting a resident give a put option to the resident (referred to as *Rule 6*). The resident can exercise the put option and sell her entitlement (right to clean air) to the polluter without any consensus from the polluter. In this case, the resident forces the polluter to pollute air and earns money regardless of whether the polluter wants to pollute air to operate his factory at the price.

Avraham (2004) then argues that a *modular liability rule*, which combines the Rule 5 and the Rule 6, improves efficiency in terms of social welfare when there exists bilateral asymmetric information between the parties and bargaining is infeasible because of high transaction cost[(4)]. Under the modular liability rule, a court first sets the identical exercise price for both options, which is considered as damages. The resident then decides whether to exercise her option, and finally the polluter decides whether to exercise his option. Under an optimal exercise price, only the resident with a low subjective value exercises her option. The polluter then exercises his option if his subjective value is low, while he does not otherwise. The important point here is that the modular liability rule uses private information of *both* parties and achieves high performance in allocating the entitlement. However, (regular) liability rules use one party's private information[(5)].

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(4) Avraham (2004), in addition, assumed that bargaining is infeasible *after* a court sets damages.

(5) Suppose that the resident and polluter are involved in bilateral information asymmetry, and that the resident is endowed with right to clean air. Assume that the damage is set as the resident's expected value for her entitlement. The polluter takes the entitlement if and only if he evaluates

In line of intellectual property, Schankerman and Scotchmer (2001) compare property and liability rules from a viewpoint of patent holder's profits. They separately discuss ways to calculate damages under liability rules: one is damages based on lost profits and another is unjust enrichment. They pointed out that difference among the rules is a disagreement point in a bargain. The potential infringer either infringes the patent (taking the entitlement) or enters into a licensing agreement (getting a voluntary bargain) depending on the legal rules, generating the different profits to the patent holder. In their setting, the patent holder alone cannot benefit from its patent whereas the potential infringer can introduce new products and earn money by using the patent.

A long list of papers have contributed to this issue. Some papers construct bargaining models to discuss the optimal legal rule to protect entitlements. In the literature, the existing studies mainly focus on a situation where there are two individuals: one is endowed with an initial entitlement and another wants to obtain the entitlement. Each individual values the entitlement differently. Both parties may know the valuation each other (*symmetric information*), or they privately know their own values (*asymmetric information*). In addition, a court, who determines damages under a liability rule, may or may not know the valuations. The individuals get a bargain if transaction cost is low, while they cannot if transaction cost is high.

However, those studies using the bargaining models may leave room to be filled with.

(1) The existing studies assume that parties surely bargain over the price whenever they can. However, parties may avoid a bargain with each other because at least one party wants to save the bargaining cost or expects that the bargain fails. Therefore, it seems natural to assume that both parties get a bargain when and

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the entitlement at a higher price than the damage. The liability rule can reach efficiency more than property rules because no trade takes place under property rules. The liability rule, however, leaves place to improve efficiency if the resident's subjective value is actually higher than the polluter's one. In this case, the polluter should not take the entitlement even if the polluter's value is greater than the resident's expected value. The modular liability rule serves for this purpose.

only when both of them want to bargain with each other.

(2) The existing studies often adopt an ultimatum bargaining as a bargaining procedure. However, a responder may usually have an opportunity to make a counteroffer. Therefore, it may be valuable to consider a sequential bargaining as well[(6)].

(3) The existing studies do not explicitly consider that a court bears the cost of setting damages under a liability rule. However, Calabresi and Melamed (1972) think that the cost plays important role in deciding the socially optimal legal rule.

This paper examines an optimal legal rule for protecting entitlements by using a bargaining model. We focus on a nuisance problem where a resident is initially endowed with a property entitlement to clean air and a polluter wants the entitlement in order to operate a factory. We assume that there is no information asymmetry between parties, because Calabresi and Melamed (1972) implicitly restrict their attention to a case where there is no asymmetric information between parties (but there is asymmetric information within a party), leading to a successful agreement if a bargain is possible[(7)]. A court has to set damages in case of infringement under liability rules. We assume that by bearing cost the court can correctly set damages equating to the resident's actual loss. The administrative cost is considered as social cost. The bargaining cost is not so expensive, and both parties can bargain over the price of the entitlement with each other if they want a bargain. We consider two bargaining procedures: an ultimatum bargaining where the resident makes a take-it-or-leave-it offer, and a sequential bargaining where the resident first makes an offer and the polluter then makes a counteroffer.

The organization of this paper is as follows. Section 2 describes a three-stage game

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(6) Actually, as we will see later, what legal rules should be employed depends on a bargaining procedure sensitively.

(7) Calabresi and Melamed (1972) discuss the optimal legal rule in an example of eminent domain. In their example, the society and parties understand that the park makes everyone happy, which means that there is no information asymmetry among the society and parties.

to model a nuisance situation under property and liability rules. Parties involving in this situation can bargain over a price of an entitlement if both of them wish to meet at bargaining. We employ an ultimatum bargaining as a bargaining procedure. The other bargaining procedure, a sequential bargaining, is discussed in appendices. Section 3 derives equilibria under property and liability rules, and then section 4 compares the equilibrium outcomes. Section 5 discusses limitation of the analysis and then concludes.

2. The model

We consider a nuisance situation in which a resident is initially endowed with the entitlement, a right to clean air. The resident values the entitlement at V_R whereas a polluter earns V_P by operating a factory with air pollution. We assume that the valuations are exogenous and a common knowledge.

We model the situation as a three-stage game. In a stage 1, both parties simultaneously decide whether to bargain (hereafter, B) or not (hereafter, NB). The game proceeds to a stage 2 if both of them choose B while a stage 3 otherwise. In the stage 2, they bargain over a price of the entitlement by incurring bargaining cost $c>0$. We employ an ultimatum bargaining as a bargaining procedure.

Under the ultimatum bargaining, the resident makes a take-it-or-leave-it offer P_R which is a price of the entitlement. If the polluter accepts the offer, then the entitlement is sold to the polluter at price P_R. On the other hand, if the polluter rejects the offer, the game proceeds to the stage 3.

In the stage 3, the polluter can solely choose an action depending on a rule. Under a property rule, the polluter has no choice, and the resident keeps holding the entitlement.

Under a liability rule, the polluter decides whether to take the entitlement (hereafter, T) or not (hereafter, NT). If the polluter chooses T, he then obtains the entitlement but has to compensate the resident; that is, he pays the resident's actual valuation V_R to the resident[8].

3. Equilibrium

In this section, we separately derive a subgame perfect equilibrium by backward induction in cases under the two rules.

3.1 Property rule

Stage 2. If the polluter accepts offer P_R, he then obtains payoff $V_P - P_R - c$. On the other hand, if he rejects the offer, he then obtains $-c$. Thus, the polluter optimally accepts the offer if and only if $V_P - P_R - c \geqq -c$, or equivalently $P_R \leqq V_P$. Here, we assume that the polluter accepts the offer when he is indifferent between accepting and rejecting.

Given the polluter's optimal decision, the resident's payoff is given by

$$\begin{cases} P_R - c \text{ if she offers } P_R \leqq V_P, \text{ and} \\ V_R - c \text{ otherwise.} \end{cases}$$

We have to separately consider two cases regarding a magnitude relation of the parties' valuations. First, suppose $V_R < V_P$. The resident should post offer $P_R^* = V_P$, followed by acceptance, because $P_R^* - c = V_P - c > V_R - c$. Therefore, if $V_R < V_P$, the parties immediately reach an agreement and the entitlement is traded through voluntary bargaining between them. The resident obtains payoff $V_P - c$ whereas the polluter obtains $V_P - P_R^* - c = -c$.

Second, suppose $V_R \geqq V_P$. The resident should post offer $P_R^* > V_P$, followed by rejection, because $P_R - c \geqq V_P - c$ holds for any offer P_R acceptable to the polluter. Therefore, if $V_R \geqq V_P$, the parties fail to make bargaining and thus the entitlement is not traded. The resident obtains payoff $V_P - c$ whereas the polluter obtains payoff $-c$.

Stage 1. We now consider the optimal decision in the stage 1 under the property rule. Given the decisions in the stage 2, the resident and polluter obtain payoffs $V_P - c$ and

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(8) We assume that trial automatically begins if the polluter infringes the resident's property. In addition, we assume that neither party incurs the trial cost, for the sake of simplicity.

$-c$ from bargaining, respectively. On the other hand, without bargaining, the resident obtains payoff V_P whereas the polluter gains nothing.

Consequently, the resident weakly prefers B to NB if $V_R<V_P$ while NB to B otherwise. On the other hand, the polluter weakly prefers NB to B in any cases.

Therefore, the parties get no bargaining. We summarize this result as the following lemma.

Lemma 1. Suppose that the parties choose a weakly dominant strategy. Under the property rule, there exists a unique subgame perfect equilibrium. In the equilibrium, the resident chooses B if $V_R<V_P$ while NB otherwise, whereas the polluter chooses NB.

They have no chance of voluntary bargaining and thus the resident keeps holding the entitlement. If $V_R<V_P$, the allocation is inefficient because the polluter values the entitlement higher than the resident. If $V_R\geqq V_P$, the allocation is efficient because the resident values the entitlement higher than the polluter.

The result contradicts to the traditional view that property rules enhance voluntary bargaining. The underlying reason is that the ultimatum bargaining brings zero payoff to the polluter. Thus, the polluter chooses not to bargain in order to save the bargaining cost as long as it is positive. Note that the result remains unchanged even if the polluter makes a take-it-or-leave-it offer. In addition, the result remains unchanged under a random proposer bargaining where a proposer is equally likely chosen from the resident and polluter.

3.2 Liability rule

Stage 3. There are two different paths making the stage 3 to emerge. First, we consider the case where the parties bargain over the price in the stage 2 but they do not reach any agreement. After the bargaining is over in the stage 2, the polluter decides to choose either T or NT. If the polluter chooses T, a court orders him to compensate and

to pay V_R to the resident. Thus, the resident obtains payoff $V_R - c$ whereas the polluter obtains payoff $V_P - V_R - c$. On the other hand, if the polluter chooses NT, the resident obtains payoff $V_R - c$ whereas the polluter obtains payoff $-c$.

Second, we consider the case where the parties fail to make bargaining in the stage 1. Similarly, if the polluter chooses T, the resident obtains payoff V_R whereas the polluter obtains payoff $V_P - V_R$. On the other hand, if the polluter chooses NT, the resident obtains payoff V_R whereas the polluter obtains zero payoff.

In the both cases, the polluter chooses T if and only if $V_P \geqq V_R$.

Stage 2. We have to separately consider two cases. First, suppose $V_R < V_P$. If the polluter accepts offer P_R, he then obtains payoff $V_P - P_R - c$. On the other hand, if he rejects the offer, the polluter will choose T in the stage 3 and thus obtains $V_P - V_R - c$. Thus, the polluter optimally accepts the offer if and only if $V_P - P_R - c \geqq V_P - V_R - c$, or equivalently $P_R \leqq V_P$.

Given the polluter's optimal decision, the resident's payoff is given by

$$\begin{cases} P_R - c \text{ if she offers } P_R \leqq V_P, \text{ and} \\ V_R - c \text{ otherwise.} \end{cases}$$

The resident should post offer $P_R^* = V_R$, followed by acceptance, because $P_R^* - c = V_R - c$. Therefore, if $V_R < V_P$, the parties immediately reach an agreement and the entitlement is traded through voluntary bargaining between them. The resident obtains payoff $P_R^* - c = V_R - c$ whereas the polluter obtains $V_P - P_R^* - c = V_P - V_R - c$.

Second, suppose $V_R \geqq V_P$. If the polluter accepts offer P_R, he then obtains payoff $V_P - P_R - c$. On the other hand, if he rejects the offer, the polluter will choose NT in the stage 3 and thus obtains $-c$. Thus, the polluter optimally accepts the offer if and only if $V_P - P_R - c \geqq -c$, or equivalently $P_R \leqq V_P$.

Given the polluter's optimal decision, the resident's payoff is given by

$$\begin{cases} P_R - c \text{ if she offers } P_R \leqq V_P, \text{and} \\ V_R - c \text{ otherwise.} \end{cases}$$

The resident should post offer $P_R^* > V_P$, followed by rejection, because $P_R - c \leqq V_R - c$ holds for any offer P_R acceptable to the polluter. Therefore, if $V_P \geqq V_P$, the parties fail to make bargaining and thus the entitlement is not traded. The resident obtains payoff $V_R - c$ whereas the polluter obtains payoff $-c$.

Stage 1. We now consider the optimal decision in the stage 1 under the property rule. Given the decisions in the stage 2, the payoffs of the resident and polluter are given as follows. First, if $V_R < V_P$, the resident and polluter obtain payoffs $V_R - c$ and $V_P - V_R - c$ from bargaining, respectively. On the other hand, without bargaining, the resident and polluter obtain payoffs V_R and $V_P - V_R$, respectively. Second, if $V_R \geqq V_P$, the resident and polluter obtain payoffs $V_R - c$ and $-c$ from bargaining, respectively. On the other hand, without bargaining, the resident obtains payoff V_R whereas the polluter gains nothing.

Consequently, in any cases, the both parties weakly prefers NB to B. We summarize this result as the following lemma.

Lemma 2. Suppose that both parties choose a weakly dominant strategy. Under the liability rule, there exists a unique subgame perfect equilibrium, where both parties choose NB in the stage 1 and thus they have no chance of voluntary bargaining. If $V_R < V_P$, the polluter chooses T and pays V_R to the resident. The allocation is efficient because the polluter values the entitlement higher than the resident. If $V_R \geqq V_P$, the polluter chooses NT and thus the resident keeps holding the entitlement. The allocation is efficient because the resident values the entitlement higher than the polluter.

The result stated in the lemma 2 seems consistent with a traditional view. The damages determined under the liability rule serve as a "market price" of the entitlement and thus yield the efficient allocation even without voluntary bargaining. Note that the

result relies on the assumption of symmetric information.

4. Analysis

This section compares the outcomes realized under the property and liability rules. First, we observe no bargaining in all cases. Especially, they fail to bargain even when the polluter values the entitlement higher than the resident. In this case, there exists a positive trading rent as long as the bargaining cost is small, and thus the resident actually wishes to come to the negotiating table under the property rule. The polluter, however, chooses not to bargain because he faces a hold-up problem in that he incurs all the bargaining cost once they come to the negotiating table. Therefore, as the following proposition states, the positive bargaining cost diminishes a chance of voluntary bargaining even though it is very small.

Proposition 1. The resident and polluter get no chance of bargaining regardless of valuation for the entitlement and protection rule as long as the bargaining cost is positive.

The following corollary immediately comes from the proposition 1.

Corollary 1. Property rules do not enhance voluntary bargaining.

It is worth noting here that these results are inconsistent with the traditional views in the literature. The literature suggests that property rules enhance voluntary bargaining if the bargaining cost is sufficiently small, but it might not be the case. A hold-up problem emerges from the positive cost. One may think that the ultimatum bargaining indeed causes the hold-up problem, and that other bargaining procedure, a sequential bargaining, for example, can solve the problem. Unfortunately, it is not the truth. As the following proposition states, the hold-up problem remains even though the polluter has a chance to make a counteroffer.

Proposition 2. Suppose that the bargaining procedure is a sequential bargaining. With a sequential bargaining, the resident and polluter get no chance of bargaining regardless of valuation for the entitlement and protection rule as long as the bargaining cost is positive.

Proof. See the appendices. *Q.E.D.*

As we saw above, trading through voluntary bargaining does not occur even though the polluter, a non-owner of the entitlement, values it higher. However, in such a case, the entitlement is traded through the polluter's taking action under the liability rule. Therefore, as the following proposition states, the liability rule achieves an efficient allocation, which is not available under the property rule. The result seems consistent to the literature. The result is not surprising because of the assumption of symmetric information between the parties and of the ability of the court to set the damages at the resident's subjective valuation.

Proposition 3. The liability rule yields an efficient allocation through the polluter's taking action when the polluter values the entitlement higher than the resident. The efficient allocation cannot be achieved by the property rule.

5. Conclusion

The literature since Carabresi and Melamed (1972) implicitly assumes that voluntary bargaining occurs between parties as long as the bargaining cost is sufficiently small, and then suggests that property rules are mostly preferable to liability rules in the sense that the former enhances voluntary bargaining than the latter. Especially, the bargaining costs include asymmetric information between parties. However, we point that the traditional view is not always true.

This paper introduces a simple bargaining model to examine socially optimal regal

rules for protecting entitlements in a nuisance situation. We assume no asymmetric information between a resident, an owner of an entitlement, and a polluter. Moreover, we assume that a court can perfectly set damages as the resident's subject value to the entitlement under a liability rule if the polluter infringes the resident. We make the following findings. First, the resident and polluter get no chance of bargaining regardless of valuation for the entitlement and protection rule as long as the bargaining cost is positive. Second, in addition, the property rule does not enhance voluntary bargaining. These two results contradict the traditional view in the literature. The underlying reason is that a hold-up problem emerges from the positive cost. Note that the hold-up problem remains even if the polluter can make a counteroffer to the resident in the bargaining. Third, consistent to the traditional view, the liability rule yields an efficient allocation through the polluter's taking action when the polluter values the entitlement higher than the resident.

We close this paper by noting the direction of future researches. First, one can consider cases with asymmetric information between parties and court. Our motivation in this paper is to show that voluntary bargaining does not occur even without asymmetric information, but situations with asymmetric information seem more realistic. The difficulty of analyzing cases with asymmetric information includes a strategic behavior by parties with private information that offers in bargaining convey some private information to their opponent. As a result, parties may no longer reach any agreements (Fudenberg and Tirole, 1983; Chatterjee and Samuelson, 1983, 1987, 1988; Cramton, 1984) or an agreement may be delayed (Cramton, 1992). Moreover, one should consider transaction costs under liability rules because a court has to determine damages.

Second, this paper ignores an issue of who should be initially endowed the entitlement. As Carabresi and Meramed (1972) consider, what rules should be optimal to protect entitlements depends upon the initial allocation of them. Moreover, the effect of more complicated rules such as the rules 5 or 6 argued in Avraham (2004) might be sensitive

in the initial allocation. With regard to these issues, we await the complete answer to come from future research.

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Appendix A

In Appendix A, we employ a sequential bargaining as the bargaining procedure in the stage 2. Under the sequential bargaining, the resident first posts a take-it-or-leave-it offer P_R as a price of the entitlement. If the polluter accepts the offer, then the entitlement is sold to the polluter at price P_R. On the other hand, if the polluter rejects the offer, he then offers counteroffer P_P. If the resident accepts the offer, then the entitlement is sold to the polluter at price P_P. On the other hand, if the resident rejects the offer, the game proceeds to the stage 3. We assume that the payoff yielded through a counteroffer is discounted by a common discounting factor $\delta \in (0,1)$, which is the cost of delay.

Appendix B

B.1 Property rule

Stage 2. If the resident accepts counteroffer P_P, she then obtains payoff $\delta P_P - c$. Note that the benefit from bargaining is discounted but the bargaining cost is not because the parties immediately incur the bargaining cost at the negotiating table. On the other hand, if she rejects the counteroffer, she then obtains $V_R - c$. Note that in the case of

rejection, the resident's payoff is not discounted because her initial position remains unchanged. Thus, the resident optimally accepts the counteroffer if and only if $\delta P_P - c \geqq V_R - c$, or equivalently $P_P \geqq V_R/\delta$. Here, we assume that the resident accepts the offer when she is indifferent between accepting and rejecting.

Given the resident's optimal decision, the polluter's payoff is given by

$$\begin{cases} \delta(V_P - P_P) - c \text{ if he offers } P_P \geqq V_R/\delta, \text{and} \\ -c \text{ otherwise.} \end{cases}$$

Thus, the polluter's decision depends upon a magnitude relation of valuations. We have to separately consider three cases.

(i) If $V_P > V_R/\delta$, the polluter optimally chooses counteroffer $P_P^* = V_R/\delta$, followed by acceptance, because $\delta (V_P - P_P^*) - c = \delta V_P - V_R - c \geqq -c$. Given the polluter's decision, the resident optimally chooses offer P_R. If the polluter accepts the offer, the resident and polluter obtain payoffs $P_R - c$ and $V_P - P_R - c$, respectively. On the other hand, rejection by the polluter yields payoffs $\delta P_P^* - c = V_R - c$ and $\delta (V_P - P_P^*) - c = \delta V_P - V_R - c$ to the resident and polluter, respectively. Therefore, the polluter accepts the offer P_R if and only if $V_P - P_R - c \geqq \delta V_P - V_R - c$, or equivalently $P_R \leqq (1-\delta) V_P + V_R$. Given the polluter's decision described above, the resident's payoff is given by

$$\begin{cases} P_R - c \text{ if she offers } P_R \leqq (1-\delta)V_P + V_R, \text{and} \\ V_R - c \text{ otherwise.} \end{cases}$$

Thus, the resident optimally chooses offer $P_R^* = (1-\delta) V_P + V_R$ to be accepted because $P_R^* - c = (1-\delta) V_P + V_R - c > V_R - c$.

(ii) If $V_R < V_P \leqq V_R/\delta$, the polluter optimally chooses counteroffer $P_P^* < V_R/\delta$ to be rejected. If the polluter accepts the offer, the resident and polluter obtain payoffs $P_R - c$ and $V_P - P_R - c$, respectively. On the other hand, rejection by the polluter induces rejection to the counteroffer by the resident and yields payoffs $V_R - c$ and $-c$ to the resident and polluter, respectively. Therefore, the polluter accepts the offer P_R if and only if $V_P - P_R - c \geqq -c$, or equivalently $P_R \leqq V_P$. Given the polluter's decision described above, the resident's payoff is given by

$$\begin{cases} P_R - c \text{ if she offers } P_R \leqq V_P, \text{and} \\ V_R - c \text{ otherwise.} \end{cases}$$

Thus, the resident optimally chooses offer $P_R^*=V_P$ to be accepted because $P_R^*-c=V_P-c>V_R-c$.

(iii) If $V_R \geqq V_P$, the polluter optimally chooses counteroffer $P_P^*<V_R/\delta$ to be rejected. Following the same logic discussed above in the case (ii), the resident's payoff is given by

$$\begin{cases} P_R - c \text{ if she offers } P_R \leqq V_P, \text{and} \\ V_R - c \text{ otherwise.} \end{cases}$$

However, in this case, the resident optimally chooses offer $P_R^*>V_P$ to be rejected because $P_R-c \leqq V_R-c$ for any $P_R \leqq V_P$.

Stage 1. We now consider the optimal decision in the stage 1 under the property rule.

The previous discussion shows the payoffs of the resident and polluter from bargaining:

(1) If $V_P>V_R/\delta$, the resident and polluter obtain payoffs $(1-\delta)V_P+V_R-c$ and $\delta V_P - V_R - c$, respectively;

(2) If $V_R<V_P \leqq V_R/\delta$, the resident and polluter obtain payoffs V_P-c and $-c$, respectively; and

(3) If $V_R \geqq V_P$, the resident and polluter obtain payoffs V_P-c and $-c$, respectively.

On the other hand, the entitlement is not traded without bargaining, and then the resident and polluter obtain payoffs V_P and 0, respectively.

In the case (i), the resident weakly prefers NB to B, whereas the polluter weakly prefers B to NB as long as the bargaining cost is negligible (i.e., c → 0). In the cases (ii) and (iii), both parties prefer NB to B. The following lemma describes a subgame perfect equilibrium under the property rule.

Lemma 3. Suppose that the parties choose a weakly dominant strategy. Under the property rule, there exists a unique subgame perfect equilibrium. In the equilibrium,

the polluter chooses B if $V_P > V_R/\delta$ while NB otherwise, whereas the resident chooses NB. They have no chance of voluntary bargaining and thus the resident keeps holding the entitlement. If $V_R < V_P$, the allocation is inefficient because the polluter values the entitlement higher than the resident. If $V_R \geqq V_P$, the allocation is efficient because the resident values the entitlement higher than the polluter.

B.2 Liability rule

Stage 3. As previously, there are two different paths for the stage 3 to emerge. First, we consider the case where the parties bargain over the price in the stage 2 but they do not reach any agreement. After the bargaining is over in the stage 2, the polluter decides to choose either T or NT. If the polluter chooses T, a court orders him to compensate and to pay V_R to the resident. Thus, the resident obtains payoff $\delta V_R - c$ whereas the polluter obtains payoff $\delta (V_P - V_R) - c$. Note that the payoffs are discounted due to the cost of delay. On the other hand, if the polluter chooses NT, the resident obtains payoff $V_R - c$ whereas the polluter obtains payoff $-c$.

Second, we consider the case where the parties fail to meet at bargaining in the stage 1. Similarly, if the polluter chooses T, the resident obtains payoff V_R whereas the polluter obtains payoff $V_P - V_R$. Note that the payoff is not discounted without bargaining. On the other hand, if the polluter optimally chooses NT, the resident obtains payoff V_R whereas the polluter obtains zero payoff.

In the both cases, the polluter chooses T if and only if $V_P \geqq V_R$.

Stage 2. We have to separately consider two cases. First, suppose $V_R < V_P$. If the resident accepts counteroffer P_R, she obtains payoff $\delta P_P - c$. If she rejects it, she obtains $\delta V_R - c$ because the polluter will choose T in the stage 3. Thus, the resident optimally accepts the counter offer if and only if $\delta P_P - c \geqq \delta V_R - c$, or equivalently $P_P \geqq V_R$. Given the resident's optimal decision, the polluter's payoff is given by

$$\begin{cases}\delta(V_P - P_P) - c \text{ if she offers } P_P \geqq V_R, \text{and} \\ \delta(V_P - V_R) - c \text{ otherwise.}\end{cases}$$

The polluter should offer $P_P^*=V_R$ to be accepted because $\delta\ (V_P-P_P^*)-c=\ \delta\ (V_P-V_R)-c$. Here, we assume that the polluter wishes his offer to be accepted if he is indifferent between acceptance and rejection.

Next, we consider the resident's decision. If the polluter accepts offer P_R, he obtains payoff V_P-P_R-c. If he rejects it, he obtains $\delta(V_P-V_R)-c$ as we saw above. Thus, the polluter optimally accepts the offer if and only if $V_P-P_R-c \geqq \delta(V_P-V_R)-c$, or equivalently $P_R \leqq (1-\delta)\ V_P+\delta\ V_R$. Given the polluter's decision, the resident's payoff is given by

$$\begin{cases}P_R - c \text{ if she offers } P_R \leqq (1-\delta)V_P + \delta V_R, \text{and} \\ V_R - c \text{ otherwise.}\end{cases}$$

The resident should optimally choose $P_R^*=(1-\delta)\ V_P+\delta\ V_P$ to be accepted because $P_R^*-c=(1-\delta)\ V_P+\delta\ V_R\ -c>V_R-c$. Therefore, if $V_R<V_P$, the parties immediately reach an agreement through voluntary bargaining. The resident and polluter obtain payoffs $(1-\delta)\ V_P+\delta\ V_R-c$ and $\delta(V_P-V_R)-c$, respectively.

Second, suppose $V_R \geqq V_P$. If the resident accepts counteroffer P_P, she obtains δP_P-c. If she rejects if, she obtains V_R-c because the polluter will choose NT in the stage 3. Thus, the resident optimally accepts the counter offer if and only if $\delta P_P-c \geqq V_R-c$, or equivalently $P_P \geqq V_R/\delta$. Given the resident's optimal decision, the polluter's payoff is given by

$$\begin{cases}\delta(V_P - V_R) - c \text{ if she offers } P_P \geqq V_R/\delta, \text{and} \\ -c \text{ otherwise.}\end{cases}$$

The polluter should offer $P_P^*=V_R$ to be rejected because $\delta\ (V_P-V_R)-c<-c$ for any $P_P \geqq V_R/\delta$.

Next, we consider the resident's decision. If the polluter accepts offer P_R, he obtains payoff V_P-P_R-c. If he rejects it, he obtains $-c$ as we saw above. Thus, the polluter optimally accepts the offer if and only if $V_P-P_R-c \geqq -c$, or equivalently $P_R \leqq V_P$. Given

the polluter's decision, the resident's payoff is given by

$$\begin{cases} P_R - c \text{ if she offers } P_R \leqq V_P, \text{and} \\ V_R - c \text{ otherwise.} \end{cases}$$

The resident should optimally choose $P_R^* > V_P$ to be rejected because $P_R - c \leqq V_R - c$ for any $P_R \leqq V_P$. Therefore, if $V_R \geqq V_P$, the parties never reach an agreement. The resident and polluter obtain payoffs $V_R - c$ and $-c$, respectively.

Stage 1. We now consider the optimal decision in the stage 1 under the property rule. Given the decisions in the stage 2, the payoffs of the resident and polluter are given as follows. First, if $V_R < V_P$, the resident and polluter obtain payoffs $(1-\delta)\, V_P + \delta\, V_R - c$ and $\delta\,(V_P - V_R) - c$ from bargaining, respectively. On the other hand, without bargaining, the resident and polluter obtain payoffs V_R and $V_P - V_R$, respectively. Second, if $V_R \geqq V_P$, the resident and polluter obtain payoffs $V_R - c$ and $-c$ from bargaining, respectively. On the other hand, without bargaining, the resident obtains payoff V_R whereas the polluter gains nothing.

Consequently, the resident prefers B to NB if $V_R < V_P$ while NB to B otherwise. The polluter prefers NB to B in any cases. We summarize this result as the following lemma.

Lemma 4. Suppose that both parties choose a weakly dominant strategy. Under the liability rule, there exists a unique subgame perfect equilibrium. In the equilibrium, if $V_R < V_P$, the resident chooses B whereas the polluter chooses NB. If $V_R \geqq V_P$, both parties choose NB in the stage 1. If $V_R < V_P$, the polluter chooses T and pays V_R to the resident. The allocation is efficient because the polluter values the entitlement higher than the resident. If $V_R < V_P$, the polluter chooses NT and thus the resident keeps holding the entitlement. The allocation is efficient because the resident values the entitlement higher than the polluter.

Appendix C

Proof of Proposition 2.

Proof. It is immediate from the lemmas 3 and 4 in the appendix B. *Q.E.D.*