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Working paper

Property Rights and the Efficiency of Bargaining

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August 14, 2012

1 Introduction

The problem of optimal allocation of property rights differs from the classical economic problem of optimal allocation of goods in an important way: while property rights may influence economic allocations, many of the details of the allocation are left for future specification by the agents, either unilaterally or by negotiation with each other. In this paper, we examine the effect of property rights on subsequent negotiations over economic allocations.

Here are just a few examples of how initial property rights should be set with the anticipation of subsequent bargaining. When designing an auction, the designer should consider not just the allocation determined in the auction but the possibility of resale. In designing the terms under which Google can digitize books, we should consider the possibility of Google's renegotiation of these terms with the books' publishers. In designing whether polluters have rights to impose externalities on other parties, and if so what compensation they should owe for the imposed damages, we should consider the possibility of the polluter renegotiating with the affected parties.

According to the famous "Coase Theorem" (Coase 1960), in the absence of "transaction costs," parties will reach Pareto efficient agreements regardless of initial property rights. In this paper, we examine settings in which this may not happen due to asymmetric information. As first shown by Myerson and Satterthwaite (1983), private information must generate inefficiency in bargaining between a buyer and a seller, for any possible bargaining mechanism they might use. Cramton, Gibbons, and Klemperer (1987) qualified the findings of Myerson and Satterthwaite, showing that for more evenly distributed (or randomized) property rights, efficient bargaining mechanisms do exist.

In addition to simple property rights of the sort considered by Myerson-Satterthwaite (1983) and Cramton et al. (1987), some legal and economic scholars have considered "liability rules," which give one party the right to choose an action that imposes externalities on other parties, while having to compensate them according to some pre-defined formula. Calabresi and Melamud (1972) considered such liability rules to be desirable only when bargaining is impractical, but subsequent work (Ayres-Talley (1994), Kaplow and Shavell (1995), Che (2006), Ayres (2005)) examined the possibility of bargaining in the shadow of liability rules.

This paper advances the literature in two ways. First, it identifies a wide class of economic settings and property rights (including both simple property rights and liability rules) in which efficient bargaining is impossible. Our result unifies a number of inefficiency results in the existing literature (Myerson and Satterthwaite 1983, Mailath and Postlewaite 1990, Williams 1999, Figueroa and Skreta 2008, Che 2006). In contrast to this earlier literature, our approach to establishing inefficiency does not require performing any computations. Instead, it only requires the verification of two simple conditions: (i) existence of "adverse opt-out types" and (ii) non-emptiness of the core and its multi-valuedness with a positive probability.[1]

We define an "opt-out type" as a type whose non-participation is consistent with efficiency (for any types of the other agents). In addition, for default property rights that induce externalities, such as liability rules, we define an "adverse type" as a type who, when he does not participate and behaves noncooperatively (e.g., chooses optimally whether to impose externalities on others under a liability rule), minimizes the total expected surplus of the other agents. (In settings with simple property rights and in which externalities are absent, any type is trivially an adverse type.) We focus on settings in which each agent has a type that is simultaneously an opt-out type and an adverse type. This assumption is clearly restrictive – for example, it is not satisfied by the kind of intermediate or randomized property rights considered by Cramton et al. and Segal and Whinston (2011). Nevertheless, we show that this assumption is satisfied in a number of settings involving

[1] Precursors to this approach can be found in Makowski and Ostroy (1989) and Segal and Whinston (2012).

simple property rights and liability rules. (We also allow this assumption to hold in an asymptotic form: e.g., an agent's type may become an "almost" adverse and opt-out type as it goes to $+\infty$.)

In contrast, the non-emptiness and multi-valuedness of the core is a typical feature of economic settings. For example, if, under appropriate definition of "goods," a price equilibrium exists (e.g., a Walrasian equilibrium, or a Lindahl equilibrium), then it will be in the core, and "generically" the core will be multi-valued (except for some limiting "competitive" cases with a large number of agents, where the core may converge to a unique Walrasian equilibrium).

Our inefficiency result has a simple logic to it: It is well known that in order to provide proper incentives to an agent in an efficient mechanism, he must be made a residual claimant of the total surplus, so the mechanism must look (in interim expectation) like a VCG mechanism. Furthermore, if the agent has an opt-out type, this type's participation constraint implies that the agent must receive at least his marginal contribution to the total surplus. But at any core allocation, the total surplus must be divided in such a way that no agent can receive *more* than his marginal contribution, since otherwise the allocation would be blocked by the coalition including all agents except this one. Furthermore, when the core is multi-valued, at least some agents must receive *less* than their marginal contributions. Hence, when the core is nonempty-valued, the sum of marginal contributions cannot fall short of the total available surplus, and it must exceed the total surplus whenever the core is multi-valued. Therefore, any efficient mechanism must run an expected deficit.

Our second contribution is to study optimal when the first best is not achievable. One corollary of our analysis is a simple formula for the minimal expected subsidy that an intermediary would have to pay in order to implement first-best efficiency in an incentive-compatible and individually rational mechanism. This formula implies easy comparative statics on different property rights that satisfy (i) and (ii). (For example, this includes simple property rights to "extreme" allocations as well as liability rules that let parties choose among such allocations.) Among such property rights, we can identify those that minimize the intermediary's expected deficit.

One interesting benchmark for comparison is property rights that maximize the expected surplus if renegotiation were impossible. With two agents and simple property rights that induce opt-out types, we show that the intermediary's expected first-best subsidy equals the expected renegotiation surplus, and therefore minimizing this expected subsidy is equivalent to maximizing the expected status quo surplus. (For example, in the buyer-seller model of Myerson and Satterthwaite (1983), if we can choose who should initially own the object, it is optimal to give it to the agent with the higher expected value for it.) However, this equivalence generally breaks down when there are more than two agents: in such cases, we instead want to raise the values of coalitions including all but one agent (reducing the "hold-out power" of individual agents).

For an illustration of these general ideas, we consider the setting of a liability rule with one polluter and many affected parties. The liability rule specifies the compensation the polluter must pay each affected party if he chooses to pollute. We show that this setting satisfies the adverse opt-out property, for any possible compensation levels. Since the core is easily seen to be multi-valued, this implies impossibility of efficient bargaining.

Next, we examine the compensation levels that minimize the expected first-best subsidy. We find that it is optimal to set the total compensation paid by the polluter equal to the sum of affected parties' expected damages. Interestingly, this is also true if we want to maximize the expected surplus in the absence of any bargaining. Even though the setting has more than two agents, this conclusion carries over. However, what is different from the two-agent model is the question of how the total compensation should be allocated among consumers. If there were no bargaining, this allocation would be a matter of indifference, since it is only the total compensation that affects the polluter's decision. However, for the problem of minimizing the expected subsidy for first-best bargaining, the allocation of total compensation matters. Specifically, we show that this allocation must maximize the sum of the values of coalitions consisting of the polluter and all but one of the affected parties. The first-order condition for this maximization requires equalizing the probabilities of pollution that would be chosen by all such coalitions. In general, the optimal compensations do *not* pay each affected party its expected damages, even though this equality is true in total. On the other hand, we show that if one party has a higher distribution of damages than another party in the sense of first-order stochastic dominance, the former party should be awarded larger compensation than the latter.

Evaluating property rights by their effects on the expected subsidy required for first-best bargaining may not be the right thing to do, since in most cases a benevolent mediator willing to subsidize bargaining is not available. One alternative approach is to consider the maximal ("second-best") expected surplus that could be achieved in budget-balanced bargaining. It is therefore interesting to compare the rankings of property rights obtained under the first-best and second-best approaches.[2]

Unfortunately, we are unable to solve for the second-best bargaining procedure at a comparable level of generality to our first-best subsidy calculation. For this reason, we focus on the simple case of a liability rule with just two agents – one polluter and one affected party – whose values are drawn from a uniform distribution on an interval, normalized to be $[0, 1]$. For this case, we solve for the second-best bargaining mechanism and the resulting expected surplus as it depends on the compensation level. We find that the second-best expected surplus is maximized by setting compensation equal to the expected value of the affected party, which is $1/2$ under our normalization. Thus, the optimal compensation under second-best bargaining is the same as that minimizing the expected first-best subsidy, which is in turn the same as the optimal compensation in the absence of bargaining. However, we also find a qualitative difference between the comparative statics of compensation on the second-best expected surplus and on the expected first-best subsidy. Namely, while the expected first-best subsidy is always lower the closer the compensation is to $1/2$, the same is not always true for the second-best expected surplus. Instead, we find that setting compensation close to 0 or to 1 yields a lower expected second-best surplus than setting it at exactly 0 or 1 (which corresponds to giving one of the agents a simple property right to the object). We show that the same conclusion extends to *all* distributions of the two agents' valuations (not just uniform). Thus, evaluating property rules and liability rules by their effects on second-best expected bargaining surplus yields some unexpected results: in particular, contrary to the intuition of Ayres (2005), a liability rule may sometimes reduce the efficiency of second-best bargaining relative to a simple property rule.

We also examine the "dual-chooser" liability rules (Ayres 2005), which stipulate that trade happens if and only if both sides agree to it at a posted price. In the absence of renegotiation, such rules unambiguously improve

[2] The second-best approach can also be criticized on the grounds that there may not exist an agent who is interested in or capable of enforcing the second-best bargaining procedure. Yet another approach is to assume a specific bargaining procedure. For example, Mylovanov and Troger (2012) consider the effect of property rights on two-agent bargaining where one agent has the power to make a take-it-or-leave-it offer to the other agent. While instructive, their results leave it unclear to what extent they are robust to the assumed bargaining game.

upon simple property rules. For example, when both parties' valuations are drawn from the uniform distribution on [0,1], it is optimal to post a price of 1/2, which is strictly better than a simple property right (corresponding to price equal to 0 or 1). However, in the presence of bargaining, dual-chooser rules lose their advantage. For example, we find that the expected first-best deficit under any posted price is the same as under a simple property rule. Furthermore, we find that the expected second-best surplus under a posted price is generically lower, and never higher, than under a simple property rule.

2 Setup

We consider a general model with N agents, who bargain over a nonmonetary decision $x \in X$, as well as a vector $t \in \mathbb{R}^N$ of monetary transfers. Each agent i privately observes a type $\theta_i \in \Theta_i$, and his resulting payoff is $v_i(x, \theta_i) + t_i$. We assume that the types $(\tilde{\theta}_1, \ldots, \tilde{\theta}_N) \in \Theta_1 \times \ldots \times \Theta_N$ are *independent* random variables.

Appealing to the Revelation Principle, we focus on direct revelation mechanisms $\langle \chi, \tau \rangle$, where $\chi : \Theta \to X$ is the decision rule, and $\tau : \Theta \to \mathbb{R}^N$ is transfer rule. In particular, we often be interested in implementing an *efficient* decision rule χ^*, which solves:

$$\chi^*(\theta) \in \arg\max_{x \in X} \sum_i v_i(x, \theta_i) \text{ for all } \theta \in \Theta.$$

We let $V(\theta) = \sum_i v_i(\chi^*(\theta), \theta_i)$ be the maximum total surplus achievable in state θ.

When considering direct revelation mechanisms that correspond to bargaining mechanisms, we restrict them to satisfy *budget balance*:

$$\sum_i \tau_i(\theta) = 0 \text{ for all } \theta \in \Theta.$$

and *(Bayesian) Incentive Compatibility*:

$$\begin{aligned} & \mathbb{E}[v_i(\chi(\theta_i, \widetilde{\theta}_{-i}), \theta_i) + \tau_i(\theta_i, \widetilde{\theta}_{-i})] \\ \geq \; & \mathbb{E}[v_i(\chi(\theta_i', \widetilde{\theta}_{-i}), \theta_i) + \tau_i(\theta_i', \widetilde{\theta}_{-i})] \text{ for all } i, \theta_i, \theta_i' \in \Theta_i \end{aligned}$$

Next we proceed to describing participation constraints. For this purpose, we need to describe what outcome each agent i expects when he refuses to participate in the bargaining mechanism. In general, this outcome will depend on the types of the other agents. For example, the other agents may make some noncooperative choices under a liability rule, and these choices may depend on their types. Alternatively, the other agents may be able to bargain with each other over some parts of the outcome without the participation of agent i, and this bargaining may have externalities on agent i. It is also possible that if agent i refuses to participate, the default will involve a noncooperative game among agents, and the outcome of this game will depend on all the agents' types.

To incorporate all these possibilities, we assume that if agent i refuses to participate and the state of the world is θ, the nonmonetary decision is $\hat{x}_{-i}(\theta)$, and agent i receives a transfer $\hat{\tau}_{-i}(\theta)$ (it does not matter for our purposes what transfers are received by the other agents). The resulting reservation utility of agent i is

$$V_i(\theta) = v_i(\hat{x}_{-i}(\theta), \theta_i) + \hat{\tau}_{-i}(\theta)$$

For example, in the simple special case of a fixed status quo $(\hat{x}, \hat{\tau})$ that either cannot be renegotiated at all without all agents' participation or whose renegotiation by a subset of agents does not affect nonparticipating agents (e.g. because renegotiation can only involve exchange of private goods), the reservation utility would take the form $V_i(\theta) = v_i(\hat{x}, \theta_i) + \hat{\tau}_i$. In general, the functions $\hat{x}_{-i}(\theta)$ and $\hat{\tau}_{-i}(\theta)$ depend on both the property rights and the assumptions about bargaining, but for most of the analysis we will take these functions as given.

Given these functions and the resulting reservation utility, the (interim) individual rationality constraints of agent i can be written:

$$\mathbb{E}[v_i(\chi(\theta_i, \tilde{\theta}_{-i}), \theta_i) + \tau_i(\theta_i, \tilde{\theta}_{-i})] \geq \mathbb{E}[V_i(\theta_i, \tilde{\theta}_{-i})] \text{ for all } \theta_i.$$

We will say that property rights $(\hat{x}, \hat{\tau})$ *permit efficient bargaining* if there exists a budget-balanced, incentive-compatible, and individually rational mechanism implementing an efficient decision rule χ^*

3 An Inefficiency Theorem

3.1 Characterization of Intermediary Profits

It will prove convenient to focus on mechanisms with payments of the following form:

$$\begin{aligned} \tau_i(\theta|\hat{\theta}_i) &= \sum_{j \neq i} v_j\left(\chi^*\left(\theta\right), \theta_j\right) - K_i(\hat{\theta}_i) & (1) \\ \text{where } K_i(\hat{\theta}_i) &= \mathbb{E}[V(\hat{\theta}_i, \tilde{\theta}_{-i}) - V_i(\hat{\theta}_i, \tilde{\theta}_{-i})]. & (2) \end{aligned}$$

Note that these payments describe a Vickey-Clarke-Groves ("VCG") mechanism [see Mas-Colell, Whinston, and Green (1995), Chapter 23]. The variable portion of the payment, $\sum_{j \neq i} v_j\left(\chi^*\left(\theta\right), \theta_j\right)$, causes each agent i to fully internalize his effect on aggregate surplus, thereby inducing him to announce his true type and implementing the efficient allocation rule $x^*(\cdot)$. The fixed participation fee K_i, on the other hand, equals type $\hat{\theta}_i$'s expected gain from participating in the mechanism absent the fixed charge, so it causes that type's IR constraint to hold with equality. If we imagine that there is an intermediary in charge of this trading process, its expected profit with this mechanism is given by

$$\begin{aligned} \pi(\hat{\theta}) &= \mathbb{E}\left[\sum_i \tau_i(\tilde{\theta}|\hat{\theta}_i)\right] \\ &= \sum_i \mathbb{E}[V(\hat{\theta}_i, \tilde{\theta}_{-i}) - V_i(\hat{\theta}_i, \tilde{\theta}_{-i})] - (N-1)\,\mathbb{E}[V(\tilde{\theta})]. & (3) \end{aligned}$$

To ensure that all types participate, the participation fee for each agent i can be at most $\inf_{\hat{\theta}_i \in \Theta} K_i(\hat{\theta}_i)$, resulting in an expected profit for the intermediary of

$$\overline{\pi} \equiv \inf_{\hat{\theta} \in \Theta} \pi(\hat{\theta}). \qquad (4)$$

If there exists a type $\hat{\theta}_i$ achieving the infimum, i.e.,

$$\hat{\theta}_i \in \arg\min_{\theta_i \in \Theta_i} \mathbb{E}\left[V(\theta_i, \tilde{\theta}_{-i}) - V_i(\theta_i, \tilde{\theta}_{-i})\right],$$

it will be called agent i's *critical type*. This is a type that has the lowest net expected participation surplus in the mechanism.

The sign of the expected profit (4) determines whether property rights permit efficient bargaining:[3]

Lemma 1 *(i) Any property rights at which* $\overline{\pi} \geq 0$ *permit efficient bargaining. (ii) If, moreover, for each agent* i*,* Θ_i *is a smoothly connected subset of a Euclidean space, and* $u_i(x, \theta_i)$ *is differentiable in* θ_i *with a bounded gradient on* $X \times \Theta$*, then property rights permit efficient bargaining only if* $\overline{\pi} \geq 0$.

3.1.1 Adverse Opt-Out Types

For each agent i, let

$$V_{-i}(\theta) = \sum_{j \neq i} v_j(\hat{x}_{-i}(\theta), \theta_j) - \hat{\tau}_{-i}(\theta)$$

be the joint payoff of the other agents when i does not participate. Observe that by construction we have superadditivity:

$$V_i(\theta) + V_{-i}(\theta) = \sum_j v_j(\hat{x}_{-i}(\theta), \theta_j) \leq \sum_j v_j(\chi^*(\theta), \theta_j) = V(\theta) \text{ for all } \theta \in \Theta.$$

Definition 2 *Given property rights, type* θ_i *of agent* i *is an* ***opt-out type*** *if* $\hat{x}_{-i}(\theta_i, \theta_{-i}) = \chi^*(\theta_i, \theta_{-i})$ *for all* θ_{-i}.

Note that if θ_i is an opt-out type, then $V(\theta_i, \theta_{-i}) = V_i(\theta_i, \theta_{-i}) + V_{-i}(\theta_i, \theta_{-i})$ for all θ_{-i}. That is, there are never any gains from bargaining between type θ_i and the other agents, regardless of their types.

Definition 3 *Given property rights, type* θ_i *of agent* i *is an* ***adverse type*** *if it minimizes* $\mathbb{E}[V_{-i}\left(\theta_i, \tilde{\theta}_{-i}\right)]$.

Note, in particular, that when agent i imposes no externalities on others, it is natural for $\hat{x}_{-i}(\theta)$ and $\tau_{-i}(\theta)$, and therefore $V_{-i}(\theta)$, to be independent of θ_i, and in this case any type is trivially adverse.

The significance of these definitions for our results stems from the following observation:

[3] Versions of this result appear, for example, in Makowski and Mezzetti (1994), Krishna and Perry (1998), Neeman (1999), Williams (1999), Schweizer (2006), Figueroa and Skreta (2008), and Segal and Whinston (2011). Part (i) of the Lemma can be proven by building a budget-balanced mechanism as suggested by Arrow (1979) and d'Aspremont and Gérard-Varet (1979), and satisfying all agents' participation constraints with appropriate lump-sum transfers. Part (ii) follows from the classical Revenue Equivalence Theorem.

Lemma 4 *When agent i has a type θ_i° that is both an adverse type and an opt-out type,it is a critical type.*

Proof. We can then write for all $\theta_i \in \Theta_i$,

$$\begin{aligned}
\mathbb{E}\left[V(\theta_i^\circ,\tilde{\theta}_{-i}) - V_i(\theta_i^\circ,\tilde{\theta}_{-i})\right] &= \mathbb{E}\left[V_{-i}(\theta_i^\circ,\tilde{\theta}_{-i})\right] \\
&\leq \mathbb{E}\left[V_{-i}(\theta_i,\tilde{\theta}_{-i})\right] \\
&\leq \mathbb{E}\left[V(\theta_i,\tilde{\theta}_{-i}) - V_i(\theta_i,\tilde{\theta}_{-i})\right]
\end{aligned}$$

where the equality is because θ_i° is an opt-out type, the first inequality is because θ_i° is an adverse type, and the second inequality is by superadditivity. ■

Our results will apply not only to settings in which adverse opt-out types exist, but also to settings in which the existence is only of the following asymptotic form:

Definition 5 *The* adverse opt-out property *holds for agent i if there exists a sequence $\left(\theta_i^k\right)_{k=1}^{\infty}$ in Θ_i such that as $k \to \infty$,*

$$\mathbb{E}\left[V\left(\theta_i^k,\tilde{\theta}_{-i}\right) - V_i\left(\theta_i^k,\tilde{\theta}_{-i}\right) - V_{-i}\left(\theta_i^k,\tilde{\theta}_{-i}\right)\right] \to 0$$

and

$$\mathbb{E}\left[V_{-i}\left(\theta_i^k,\tilde{\theta}_{-i}\right)\right] \to \inf_{\hat{\theta}_i} \mathbb{E}\left[V_{-i}(\hat{\theta}_i,\tilde{\theta}_{-i})\right].$$

Note that this property holds whenever agent i has an adverse opt-out type θ_i° (in which case we can let $\theta_i^k = \theta_i^\circ$ for all k), but it may also hold in other cases – e.g., sometimes we may need to take a sequence with $\theta_i^k \to +\infty$ (in which case we may say informally that $\theta_i = +\infty$ is an adverse opt-out type).

While the adverse opt-out property will hold in the several settings we consider, it is a restrictive property. Next we introduce the following weak notion of the core:

Definition 6 *$w \in \mathbb{R}^N$ is a* marginal core payoff vector *in state θ if*

(i) *$\sum_{j\neq i} w_j \geq V_{-i}(\theta)$ for all i, and*

(ii) $\sum_i w_i = V(\theta)$.

Condition (i) simply says that the coalition consisting of all agents except agent i does not block, while condition (ii) says that the maximal total surplus is achieved. Using (ii), condition (i) can be rewritten as $w_i \leq V(\theta) - V_{-i}(\theta)$, i.e., no agent i can receive more than his marginal contribution to the total surplus.

Theorem 7 *Suppose that the assumptions of Lemma 1(ii) hold, the adverse opt-out property holds for each agent, and the marginal core is non-empty in all states and multi-valued with a positive probability. Then efficient bargaining is impossible.*

Proof. The adverse opt-out property implies that

$$
\begin{aligned}
\overline{\pi} &= \sum_i \inf_{\hat{\theta}_i \in \Theta_i} \mathbb{E}[V(\hat{\theta}_i, \tilde{\theta}_{-i}) - V_i(\hat{\theta}_i, \tilde{\theta}_{-i})] - (N-1)\,\mathbb{E}[V(\tilde{\theta})] \\
&= \sum_i \inf_{\hat{\theta}_i \in \Theta_i} \mathbb{E}[V(\hat{\theta}_i, \tilde{\theta}_{-i}) - V_i(\hat{\theta}_i, \tilde{\theta}_{-i}) - V_{-i}(\hat{\theta}_i, \tilde{\theta}_{-i}) + V_{-i}(\hat{\theta}_i, \tilde{\theta}_{-i})] - (N-1)\,\mathbb{E}[V(\tilde{\theta})] \\
&= \sum_i \inf_{\hat{\theta}_i \in \Theta_i} \mathbb{E}[V_{-i}(\hat{\theta}_i, \tilde{\theta}_{-i})] - (N-1)\,\mathbb{E}[V(\tilde{\theta})] \qquad (5) \\
&\leq \sum_i \mathbb{E}[V_{-i}(\tilde{\theta})] - (N-1)\,\mathbb{E}[V(\tilde{\theta})] \\
&= \mathbb{E}\left[V(\tilde{\theta}) - \sum_i [V(\tilde{\theta}) - V_{-i}(\tilde{\theta})]\right] \qquad (6)
\end{aligned}
$$

Now, in a marginal core payoff vector w, we have

$$w_i \leq V(\theta) - V_{-i}(\theta) \qquad (7)$$

for each i, so

$$V(\theta) = \sum_i w_i \leq \sum_i [V(\theta) - V_{-i}(\theta)]. \qquad (8)$$

This inequality must hold in all states. Furthermore, in any state θ in which the marginal core is multi-valued, there exists a payoff vector w with inequality (7) being strict for at least one agent i, and so inequality (8) must be strict as well. Since this must happen with a positive probability, while the weak inequality (8) must hold with probability 1, the bound (6) implies that $\overline{\pi} < 0$, and so impossibility of efficient bargaining is implied by Lemma 1(ii). ∎

3.1.2 Some Applications

The assumptions of Theorem 7 cover many classical economic settings. For one example, consider the double-auction setting of Williams (1999), in which there are N_s sellers with values drawn from a distribution on $[\underline{\theta}_s, \overline{\theta}_s]$ and N_b buyers with values drawn from a distribution on $[\underline{\theta}_b, \overline{\theta}_b]$ with $(\underline{\theta}_b, \overline{\theta}_b) \cap (\underline{\theta}_s, \overline{\theta}_s) \neq \varnothing$. Since this is a setting without externalities, all types are trivially opt-out types. Note that (i) a buyer of type $\underline{\theta}_b$ is an opt-out type if either $\underline{\theta}_b \leq \underline{\theta}_s$ or $N_b > N_s$, and (ii) a seller of type $\overline{\theta}_s$ is an opt-out type if either $\overline{\theta}_s \geq \overline{\theta}_b$ or $N_s > N_b$. Moreover, a competitive equilibrium exists in every state and is not unique with a positive probability. Since a competitive equilibrium is always in the core, Theorem 7 applies when both (i) and (ii) hold.[4]

Theorem 7also applies to the public good setting of Mailaith and Postlewaite (1990), in which each of N consumers' values is drawn from a distribution on $[0, \overline{\theta}]$, the cost of provision is $c > 0$, and the status quo property right is no provision ($\hat{x}_i = 0$ for all i). Letting $x_i \in \{0, 1\}$ denote whether agent i is given access to the public good, and assuming a default of equal cost-sharing among the agents who have access to it, we have $u_i\,(x, \theta_i) = \theta_i - c/\sum_j x_j$ if $x_i = 1$ and $= 0$ otherwise. Thus, when $\hat{x} = 0$ we have no externalities and each agent's type 0 is an opt-out type. Note that a Lindahl equilibrium exists in every state and is not unique with a positive probability. Since a Lindahl equilibrium is in the core, Theorem 7 applies.[5]

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[4] The argument can also be extended to show impossibility whenever $N_b = N_s$. In this case, note that in an efficient allocation any agent of type below $\underline{\theta} \equiv \max\{\underline{\theta}_s, \underline{\theta}_b\}$ receives an object with probability zero, so is therefore indistinguishable from type $\underline{\theta}$, and any agent of type above $\overline{\theta} \equiv \min\left\{\overline{\theta}_s, \overline{\theta}_b\right\}$ receives an object with probability one, so is therefore indistinguishable from type $\overline{\theta}$. Therefore, the profit in the mechanism must be the same as if all agents' types were instead distributed on the same interval $\left[\underline{\theta}, \overline{\theta}\right]$ (with possible atoms at its endpoints), in which case efficient bargaining is impossible by the argument in the text.

[5] Theorem 7 does not address the extent of bargaining inefficiencies or the form they take. These questions have been studied in a number of papers. Myerson and Satterthwaite (1983) and McKelvey and Page (2002) find that in certain settings the inefficiencies exhibit a "status-quo bias": the final allocation lies between the initial and efficient allocations. Other papers examine the dependence of inefficiency on the number of agents. In the double-auction setting, Gresik and Satterthwaite (1989) find that the inefficiency in an ex ante optimal mechanism shrinks to zero as $N_b, N_s \to \infty$. Intuitively, this relates to the fact that the core converges (in probability) to the unique competitive equilibrium of the continuous limit economy, hence in the limit the agents can fully appropriate their

These examples assume simple property rights without externalities. In Section 5 below we will also consider an application to settings with liability rules.

4 Expected First-Best Subsidy

Assume that we have fixed status quo $\hat{x} \in \hat{X}$ (or no externalities), and $N = 2$, with both agents having opt-out types. Then

$$\begin{aligned} V_{-1}(\theta) &= V_2(\theta) = v_2(\hat{x}, \theta_2), \\ V_{-2}(\theta) &= V_1(\theta) = v_1(\hat{x}, \theta_1). \end{aligned}$$

Thus,

$$\begin{aligned} \overline{\pi}(\hat{x}) &= \mathbb{E}\left[V(\tilde{\theta}) - \left(V(\tilde{\theta}) - V_1(\tilde{\theta})\right)) - (V(\tilde{\theta}) - V_2(\tilde{\theta}))\right] \\ &= \mathbb{E}\left[v_2(\hat{x}, \tilde{\theta}_2) + v_1(\hat{x}, \tilde{\theta}_1) - S(\tilde{\theta})\right] < 0. \end{aligned}$$

In words, a mediator who implements the first best must subsidize the entire renegotiation surplus. Thus, the status quo $\hat{x}$ that minimizes the expected subsidy (within a class of those that have opt-out types) must maximize the expected status quo surplus $\mathbb{E}[v_1(\hat{x}, \tilde{\theta}_1) + v_2(\hat{x}, \tilde{\theta}_2)]$. For example, in the setting of Myerson and Satterthwaite (1983), if we can choose the initial owner of the object, we should choose the agent with the higher expected value.

With $N > 2$ agents, this is no longer true: it is optimal to maximize $\mathbb{E}[\sum_i V_{-i}(\tilde{\theta}_{-i})]$, which differs from maximizing than $\mathbb{E}[\sum_i V_i(\tilde{\theta}_i)]$. The idea is that it is optimal to minimize the "hold-out power" of individual agents – their marginal contributions.

5 Application: Liability Rule for Pollution

Consider a setting in which agent 0 (the "firm") chooses whether to pollute, labeled by $x \in \{0, 1\}$. The firm's utility is $v_0(x, \theta_0) = \theta_0 x$, where θ_0 denotes

marginal contributions [as in Makowski and Ostroy (1989, 1995, 2001)]. In contrast, in the public good setting of Mailaith and Postlewaite (1990), the core grows in relative size as $N \to \infty$, and inefficiency is exacerbated (in fact, the probability of providing the public good in any mechanism goes to zero).

its value for polluting. Agents $i = 1, ..., N$ are consumers, whose utilities are given by $v_i(x, \theta_i) = (1 - x)\theta_i$. Efficient pollution is therefore given by

$$\chi^*(\theta) = 1 \text{ if and only if } \theta_0 \geq \sum_{i \geq 1} \theta_i.$$

We assume that for all i, $\tilde{\theta}_i$ has a full-support absolutely continuous distribution on $\Theta_i = [0, +\infty)$.

The property rights are given by the liability rule: the firm can choose to pollute, in which case it must pay pre-specified compensation $p_i \geq 0$ to each consumer $i \geq 1$. Thus, if the firm does not participate in bargaining, it optimally chooses $\hat{x}_{-0}(\theta) = \chi^*(\theta_0, p)$, and its transfer is given by $\hat{\tau}_{-0}(\theta) = -\left(\sum_i p_i\right)\hat{x}_{-0}(\theta)$.

We must also specify what happens if agent $i \geq 1$ does not participate. To obtain the results in the simplest possible way, we assume that all the other agents then bargain efficiently among each other, given that agent i must be paid compensation p_i if pollution is chosen. Thus, they optimally choose pollution $\hat{x}_{-i}(\theta) = \chi^*(p_i, \theta_{-i})$, and agent i's compensation is $\hat{\tau}_{-i}(\theta) = p_i \hat{x}_{-i}(\theta)$. (This assumption is natural when we have an intermediary interested in enforcing first-best bargaining. Below we remark that this assumption does not affect the inefficiency conclusion, and actually minimizes the expected subsidy requires for implementing first-best bargaining.)

Given these assumptions, it is easy to see that each agent $i \geq 1$ has an opt-out type $\theta_i^\circ = p_i$. This type is also trivially adverse, since the agent imposes no externalities on the others. Hence, by Lemma 4, it is agent i's critical type.

Now, the firm has two opt-out types: $\theta_0 = 0$ (which never pollutes in the mechanism and does not pollute when it does not participate) and $\theta_0 = +\infty$ (which always pollutes in the mechanism and pollutes when it does not participate). Furthermore, $\theta_0 = 0$ is an adverse type if $\sum_{i \geq 1} p_i \geq \mathbb{E}[\sum_{i \geq 1} \tilde{\theta}_i]$ while $\theta_0 = +\infty$ is an adverse type if the inequality is reversed. (Of course, formally speaking $\theta_0 = +\infty$ is not a "type," but taking a sequence $\theta_0^k \to +\infty$ shows that the firm does satisfy the adverse opt-out property.)

Finally, it is easy to see that the core is nonempty-valued and multi-valued with a positive probability. Hence, Theorem 7 implies that efficient bargaining is impossible.

Remark 8 *We now observe that the inefficiency conclusion would not be affected if consumer $i \geq 1$ expected a different outcome $\hat{x}_{-i}(\theta)$ from non-*

participation, while still being compensated $\hat{\tau}_{-i}(\theta) = p_i \hat{x}_{-i}(\theta)$ according to the liability rule. Indeed, note that given the compensation, the reservation utility of type $\theta_i = p_i$ is zero regardless of $\hat{x}_{-i}(\theta)$. Hence, just by looking at the participation constraints of this type, which do not depend on $\hat{x}_{-i}(\theta)$, will imply that efficient bargaining is impossible.

Furthermore, we can argue that if an intermediary can choose $\hat{x}_{-i}(\theta)$ following nonparticipation of consumer $i \geq 1$ to minimize the expected first-best subsidy, then it can do no better than setting $\hat{x}_{-i}(\theta) = \chi^*(p_i, \theta_{-i})$. Indeed, the choice of $\hat{x}_{-i}(\theta)$ does not affect the participation constraint of consumer i's type $\theta_i = p_i$, but by choosing $\hat{x}_{-i}(\theta) = \chi^*(p_i, \theta_{-i})$ the intermediary makes this type a critical type, therefore making all the other consumer types' participation constraints redundant. Therefore, the following analysis of optimal damages p applies to the situation where the intermediary can choose optimal $\hat{x}_{-i}(\theta)$ following nonparticipation by individual consumers.

We now solve for the vector of damages $p = p_1, .., p_N$ that minimizes the expected first-best deficit. Using expression (5) for the expected mediator profit, the optimization problem can be written as

$$\max_{p_1,..,p_N \geq 0} \sum_{i=0}^{N} \mathbb{E}\left[V_{-i}(\theta_i^\circ, \tilde{\theta}_{-i})\right], \text{ where}$$

$$\begin{aligned}
\mathbb{E}\left[V_{-0}(\theta_0^\circ, \tilde{\theta}_{-0})\right] &= \min\left\{\sum_{i\geq 1} \mathbb{E}\left[\tilde{\theta}_i\right], \sum_{i\geq 1} p_i\right\} \text{ and} \\
\mathbb{E}\left[V_{-i}(\theta_i^\circ, \tilde{\theta}_{-i})\right] &= \mathbb{E}\left[\max\left\{\tilde{\theta}_0 - p_i, \sum_{j\neq i,\, j\geq 1} \tilde{\theta}_j\right\}\right] \text{ for } i \geq 1.
\end{aligned}$$

Note that using the Envelope Theorem, for $i \geq 1$,

$$\partial \mathbb{E}\left[V_{-i}(\theta_i^\circ, \tilde{\theta}_{-i})\right] / \partial p_i = -\Pr\left\{\tilde{\theta}_0 - p_i > \sum_{j\neq i,\, j\geq 1} \tilde{\theta}_j\right\} \in (-1, 0), \tag{9}$$

while

$$\begin{aligned}
\partial \mathbb{E}\left[V_{-0}(\theta_0^\circ, \tilde{\theta}_{-0})\right] / \partial p_i &= 1 \text{ if } \sum_{i\geq 1} \mathbb{E}\left[\tilde{\theta}_i\right] > \sum_{i\geq 1} p_i \text{ and} \\
&= 0 \text{ if the inequality is reversed.}
\end{aligned}$$

Therefore, at the optimum we must have $\sum_{i\geq 1} p_i = \sum_{i\geq 1} \mathbb{E}\left[\tilde{\theta}_i\right]$, i.e., the total damages paid by the firm should equal the total expectation damages for the affected parties. This would also be optimal in a setting where bargaining is impossible.

However, in contrast to the setting without bargaining, it now matters how the damages are allocated among consumers. The problem of optimal allocation of damages can be formulated as

$$\max_{p_1,..,p_N \geq 0} \sum_{i\geq 1} \mathbb{E}\left[V_{-i}\left(p_i, \tilde{\theta}_{-i}\right)\right] \text{ s.t. } \sum_{i\geq 1} p_i = \sum_{i\geq 1} \mathbb{E}\left[\tilde{\theta}_i\right].$$

The first-order condition for this constrained maximization problem equalizes the derivatives $\partial \mathbb{E}\left[V_{-i}(\theta_i^{\circ}, \tilde{\theta}_{-i})\right]/\partial p_i$ across $i = 1, ..., N$. Using (9), this means equalizing the probabilities $\Pr\left\{\tilde{\theta}_0 - p_i > \sum_{j\neq i,\ j\geq 1} \tilde{\theta}_j\right\}$ of pollution chosen by coalitions containing all agents except for consumer i. (Note that the first-order condition is sufficient for optimality, since the expressions for the derivatives are decreasing in p_i.) This equalization implicitly defines the optimal allocation of the total damages $\sum_{i\geq 1} \mathbb{E}\left[\tilde{\theta}_i\right]$ among consumers.

Observe that in general it is not optimal to compensate to each consumer i according to its expectation damages (i.e., set $p_i = \mathbb{E}\left[\tilde{\theta}_i\right]$). Instead, the optimal compensation depend on more subtle properties of the distributions of damages. However, we can say that if $\tilde{\theta}_i$ is strictly higher than $\tilde{\theta}_j$ in the sense of First-Order Stochastic Dominance, then the optimal damages have $p_i > p_j$. (Indeed, if the inequality were reversed, then coalition $N \backslash \{i\}$ would have a strictly higher probability of pollution than coalition $N \backslash \{j\}$.)

6 Optimal Property Rights with Second-Best Bargaining

In many circumstances, there isn't a planner available to subsidize trade. In that case, a more appropriate approach to determining optimal property rights involves looking at second-best mechanisms that maximize expected surplus subject to a budget balance constraint. Analyzing that problem, however, is complicated by the interplay between the mechanism chosen and the agents' critical types: those critical types depend on the mechanism being employed, but the best mechanism depends on the agent's critical types (because they determine which IR constraints bind). In this section, we analyze this problem. As this is a much harder problem than the first-best problem studied earlier, we restrict attention to a case with two agents trading a single indivisible good and, through much of the analysis, we assume their values θ_1 and θ_2 are both drawn from the uniform distribution on $[0, 1]$.

Myerson and Satterthwaite (1983) characterized the optimal second-best mechanism for the case of simple property rights, where one agent is a seller (the initial owner) and the other agent is the buyer. The optimal mechanism is shown in Figure 1 (labeling the seller as agent 1 and the buyer as agent 2), which leads to a surplus loss of 7/64 (from the first-best surplus of 3/4).[6] It involves a trading "gap" $l = 1/4$, which represents the amount that the buyer's value must exceed the seller's value for trade to occur. Here we will investigate what can be achieved with a liability rule in which one agent (or firm) is given the option to own the good (or pollute) in return for paying p to the other agent. Without loss of generality, we will take the agent who has this option to be agent 1. Note that if $p = 0$ then agent 1 will always exercise his option in the default, so it is equivalent to agent 1 being the owner with a simple property right. If, instead, $p = 1$, then agent 1 will never exercise his option, so it is equivalent to agent 2 being the owner with a simple property right. Hence, the *optimal* liability rule cannot be worse than the optimal simple property right. However, we will see that there are always some liability rules that are worse than the best simple property right.

Our analysis hinges on identifying "critical types," i.e., those types whose participation constraints bind. For the passive agent 2, it is easy to see that one critical type must be $\hat{\theta}_2 = p$, since this type has a zero net expected participation surplus in the mechanism. For the active agent 1, matters are a bit more complicated. We observe, first, that this agent's critical types always include either $\hat{\theta}_1 = 0$, or $\hat{\theta}_1 = 1$, or both. To see this, observe that in the default outcome, this agent's payoff is $V_1(\theta_1) = \max\{\theta_1 - p, 0\}$, which is a convex function whose derivative is 0 below p and 1 above p. This agent's expected payoff $U_1(\theta_1)$ in any mechanism, on the other hand, has a derivative $U_1'(\theta_1)$ at each θ_1 that equals that type's expected probability of receiving

[6] Cramton, Gibbons, and Klemperer (1987) showed that the first best is achievable for the convex set of intermediate property rights if randomized property rights are possible [see also Segal and Whinston (2011)].

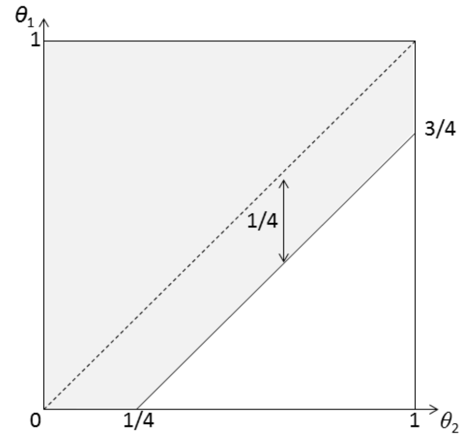

Figure 1: Second-Best in the Myerson-Satterthwaite Model

the good in the mechanism, so $U_1'(\theta_1) \in [0, 1]$ for all θ_1.

For any given critical types, we can solve for the mechanism that maximizes expected surplus subject to budget balance and satisfaction of the critical types' IR constraints. The solution is obtained by maximizing the "virtual surplus" in every state, with some "ironing" involved to ensure monotonicity of the solution. We then check that given the derived mechanism we have the right critical types. The solution is summarized in the following proposition:

Proposition 9 *Given a liability rule in which agent 1 has the option to own in return for a payment of $p \in [0, 1]$, the optimal second-best allocation rule take the following forms, for some function $l(p)$:*[7]

- ***For*** $p < 3/8$***:*** $x_1(\theta_1, \theta_2) = 1$ *if and only if either (i)* $\theta_2 \leq \theta_1 \leq p$ *or (ii)* $\theta_1 \geq p$ *and* $\theta_1 \geq \theta_2 - l(p)$;
- ***For*** $p \in [3/8, 5/8]$***:*** $x_1(\theta_1, \theta_2) = 1$ *if and only if either (i)* $\theta_2 + p - 3/8 \leq \theta_1 \leq p$ *or (ii)* $\theta_1 \geq p$ *and* $\theta_1 \geq \theta_2 + p - 5/8$*;*
- ***For*** $p > 5/8$***:*** $x_1(\theta_1, \theta_2) = 1$ *if and only if either (i)* $\theta_2 + l(p) \leq \theta_1 \leq p$ *or (ii)* $\theta_1 \geq p$ *and or* $\theta_1 \geq \theta_2$*.*

[7] The optimal payments are derived in the usual way given these allocation rules.

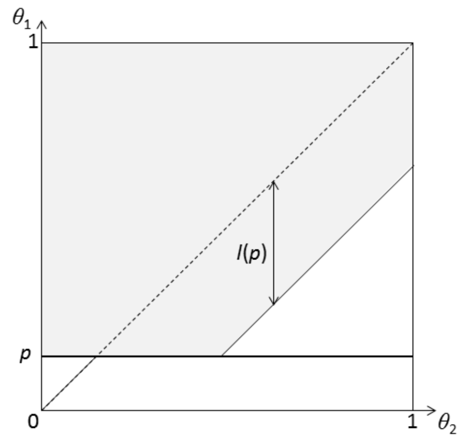

Figure 2: Second-Best for p < 3/8

Proof. In the Appendix. ■

Figures 2-4 show the sets of types for which agent 1 receives the good for the three cases identified in Proposition 9. The three cases correspond to situations in which agent 1's critical type is $\hat{\theta}_1 = 1$ (for $p < 3/8$), $\hat{\theta}_1 = 0$ (for $p > 5/8$), and both types 0 and 1 are critical types (for $p \in [3/8, 5/8]$). [Note that the critical type is 1 (resp. 0) for low (resp. high) p, which are cases where the property right is relatively close to agent 1 (resp. 2) having a simple ownership right.] The function $l(p)$ in Figures 2 and 4 is similar to the Myerson-Satterthwaite gap seen in Figure 1, and like that gap its size is set to achieve budget balance. As for the case depicted in Figure 3, it exhibits two gaps: one agent 1 consumes less than efficiently when $\theta_1 \leq p$, and more than efficiently when $\theta_1 \geq p$. The two gaps are related to each other by the condition that the probability of trade in the mechanism is exactly p, which ensures that the participation constraints of agent 1's types $\hat{\theta}_1 = 0$ and $\hat{\theta}_1 = 1$ can bind at the same time. The size of the gaps is again determined by the requirement of expected budget balance.

Figure 5 graphs the resulting inefficiency – the loss in expected surplus from the first best level – as a function of p (the solid black curve) . For comparison, the figure also shows the inefficiency with no bargaining (the dotted blue curve) and the deficit for a planner who would subsidize trade to

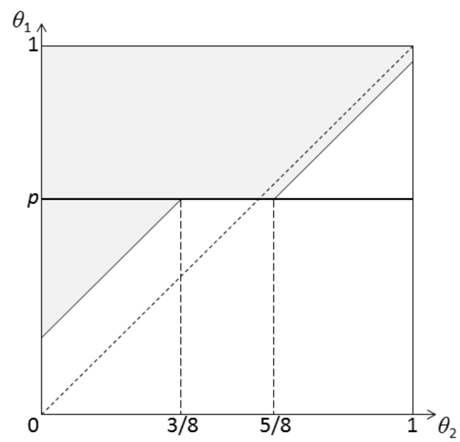

Figure 3: Second-Best for $3/8 < \text{p} < 5/8$

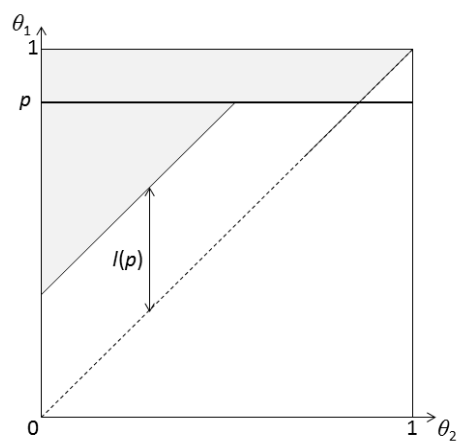

Figure 4: Second-Best for $\text{p} > 5/8$

achieve the first best (the dashed red curve). As can be seen in the figure, the optimal property right has $p = 1/2$ in all three cases. Perhaps surprisingly, however, the surplus achievable with a liability rule is not monotone increasing as p moves toward $1/2$, and is in fact lower for p close to 0 (resp. 1) than at $p = 0$ (resp. 1). That is, a slightly interior p is worse than the simple property right it is near.

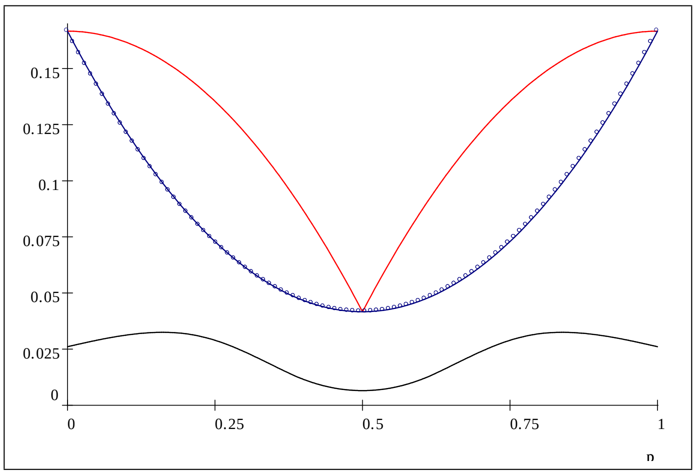

Figure 5

The fact that a liability rules which induce default allocations close to but different from a simple property right are worse than that simple property right does not depend on our assumption of a uniform distribution. As the following Proposition shows, it is true for *any* distributions of values for the two agents:

Proposition 10 *For any distributions F_1 and F_2 on $[0,1]$, there exists a $\delta > 0$ such that any liability rule with $p \in [1, 1-\delta]$ [resp, $p \in [0, \delta]$ has lower second-best expected surplus than $p = 1$ (resp. $p = 0$), which is equivalent to simple ownership by agent 2 (resp. agent 1).*

Proof. In the Appendix. ■

7 Dual-Chooser Rule

For another application, we consider a "dual-chooser" rule with two agents as described by Ayres (2005): agent 2 is the initial owner of the good, but agent 1 can get it if both agents agree to this at a pre-specified price p. We assume that both agents' values for the good are drawn from the same interval, which we normalize to be $[0, 1]$. Our first observation is that with this rule, agent 2's type $\hat{\theta}_2 = 1$ is an adverse opt-out type, while agent 1's type $\hat{\theta}_1 = 0$ is an adverse opt-out type (these types never trade, either in the default mechanism or in the efficient mechanism). Since these types have the same reservation utilities as in the standard Myerson-Satterthwaite setting in which agent 2 is the owner, we obtain that the expected first-best subsidy is the same as in the Myerson-Satterthwaite setting, regardless of p.

As for the second-best expected surplus, we observe that for any posted price p it cannot exceed that in the Myerson-Satterthwaite setting where agent 2 has a simple property right. Indeed, the participation constraints of agent 2's type $\hat{\theta}_2 = 1$ and agent 1's type $\hat{\theta}_1 = 0$, which are the critical types in the Myerson-Satterthwaite setting, must still be satisfied, and these types' reservation utilities are the same as in the Myerson-Satterthwaite setting regardless of p. In fact, we can show that the second-best expected surplus is typically *strictly lower* than in the Myerson-Satterthwaite setting, focusing for simplicity on the case where both agents' values are drawn from a uniform distribution on $[0, 1]$. Indeed, in this case, for any posted price $p \leq 1/2$, the posted-price mechanism is a profit-maximizing mechanism for a buyer of type $\theta_1 = 2p$, while in the Myerson-Satterthwaite second-best mechanism, with this type of buyer, the seller is faced with the price $\max\{2p - 1/4, 0\} \neq p$ when $p \notin \{0, 1/4\}$. Hence, for a posted price $p \in (0, 1/4) \cup (1/4, 1/2]$, a second-best mechanism in the Myerson-Satterthwaite setting would violate the participation constraint of a buyer of type $\theta_1 = 2p$ in the dual-chooser setting, and so the second-best dual-chooser solution will be inferior. Symmetrically, we can show that for a posted price $p \in [1/2, 3/4) \cup (3/4, 1)$, a second-best mechanism in the Myerson-Satterthwaite setting would violate the participation constraint of a seller of type $\theta_2 = 2p - 1$ in the dual-chooser setting, and so the second-best dual-chooser solution will be inferior.

We can summarize these observations as follows:

Proposition 11 *In the default given by a posted price p, when both parties' values are distributed on the same interval,*

(i) the expected first-best subsidy is the same as under a simple property right by agent 2,

(ii) the expected second-best surplus cannot exceed that under simple property right by agent 2,

(iii) if both agents' values are distributed uniformly on $[0,1]$*, the expected second-best surplus is strictly lower than under simple property rights for any* $p \in (0,1/4) \cup (1/4,3/4) \cup (3/4,1)$.

In contrast, with uniformly distributed values on $[0,1]$, the expected default surplus in the posted-price mechanism is strictly concave in p and maximized at $p = 1/2$.

8 Conclusion

We have found that the notions of opt-out types and marginal contributions are useful for establishing inefficiency results for bargaining under various property rights regimes. Furthermore, we used these notions to have a simple calculation for the expected subsidy needed for first-best bargaining under those regimes. This offers one simple way to examine the comparative statics of property rights. We have compared this to other benchmarks, such as the expected surplus at the default, and the second-best expected bargaining surplus. As applications, we considered simple property rules, liability rules and "dual-chooser" (posted-price) rules.

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