Behavioral Mechanism Design*

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Abstract

This paper studies the mechanism design problem for the class of Bayesian environments where agents do care for the well-being of others. For these environments, we fully characterize interim efficient mechanisms and examine their properties. This set of mechanisms is compelling, since interim efficient mechanisms are the best in the sense that there is no other mechanism which generates unanimous improvement. For public good environments, we show that these mechanisms produce public goods closer to the efficient level of production as the degree of altruism in the preferences increases. For private good environments, we show that altruistic agents trade more often than selfish agents.

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Key Words: mechanism design, incentive compatibility, interdependent preferences, altruism, incentive efficiency.

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1 Introduction

A group of individuals must choose an alternative from the set of possible alternatives and must decide how to arrange monetary transfers. Initially, each agent has private information about each possible alternative. An agent's utility for a given alternative depends not only on her own material utility but also on the welfare of other agents. This implies agents are unselfish or altruistic. In this framework, we characterize the most efficient mechanisms within the mechanisms that satisfy incentive and feasibility constraints.

The assumption of self interest is problematic. Self interest hypothesis states that preferences among allocations depend only on an agent's own material well being. Experimental results suggest that people often do care for the well-being of others and have other regarding preferences. For example, there is more contribution to public goods than purely selfish maximization can lead us to expect. Moreover, people should not vote in elections, contribute to public television or share files in peer-to-peer networks if they are purely self interested. See Ledyard (1995) for a survey on public goods which documents several other anomalies. Similar anomalous results are also observed in private goods environments. For example, in games like the ultimatum game, the dictator game, and the gift exchange game, one player has a strictly dominant strategy if the player is self interested but he or she does not choose this selfish strategy. See also Fehr and Schmidt (2006) for more experimental evidence on unselfish preferences. Given these observations, I ask a basic question: How does the existence of agents exhibiting interdependent preferences change the mechanism design problem?

There exists an extensive literature on mechanism design. We refer the reader to Jackson (2003) for a survey on mechanism design literature. In previous studies the main focus is on either (the impossibility of) efficient or optimal mechanism design with selfish agents. In contrast to previous literature, we are interested in characterizing interim efficient mechanisms with unselfish agents. Interim is used to denote the informational time frame. We assume that all decisions, including whether to change the mechanism, are made at the interim stage. Interim efficiency is a natural extension of efficiency to incomplete information environments. If a mechanism is interim efficient, then it can never be common knowledge that there is another feasible mechanism which makes some types of agents better off without hurting other types of agents. This implies that any other mechanism would be unanimously rejected by all agents and should thus not be observed in practice. We show that these mechanisms correspond to decision rules based on *modified* virtual cost-benefit criterion, together with the appropriate incentive taxes. Moreover, we show that interim efficient decisions depend on the social concerns of the agents even though classical efficient decisions do not depend on the social concerns of the agents. There are a few papers that explore the properties of interim efficient allocation rules for standard mechanism design environments. See Wilson (1985) and Gresik (1991) for a characterization of ex ante efficient mechanisms for bilateral trade environments (double auctions), and Ledyard and Palfrey (2007) for a characterization of interim efficient mechanisms for public good environments.

We also provide applications for both public and private goods environments. In our applications, efficient decisions are independent of the social concerns of the agents. However, we show that interim efficient mechanisms produce public goods more often as the degree of altruism in the preferences goes up. That is, inefficiencies in public good provision decreases as the agents care more about the welfare of the other agents. For bilateral trade environments, we show that altruistic agents trade more often than selfish agents. This means that there are some information states of the economy where it is optimal to trade but selfish agents will not trade and altruistic agents will trade. Moreover, altruistic agents do not trade when it is not optimal to trade.

The remainder of the paper is organized as follows. In the next section, we describe the environment and introduce the basic notation. In Section 3 we formulate the set of constraints and provide necessary and sufficient conditions for incentive compatibility and individual rationality. The tools of mechanism design are used to provide these necessary and sufficient conditions. Then, we present the characterization results and proofs. Section 4 provides applications of our characterization for both public good and bilateral trade environments. Finally, we summarize the findings of the paper and make some concluding remarks in Section 5. The proofs are delegated to the Appendix.

2 The Model

Consider a Bayesian mechanism design framework with n agents. The set of agents is denoted by $N = \{1, ..., n\}$. Each agent has a type θ^i which is her private information. We assume that each agent knows her own type and does not know the types of the other agents. Each θ^i is independently drawn from cumulative distribution function $F^i(.)$ on $\Theta^i = [\underline{\theta}^i, \overline{\theta}^i]$ with $0 \leq \underline{\theta}^i \leq \overline{\theta}^i < \infty$. Types are drawn independently across agents; that is, the θ^is are independent random variables. We denote a generic profile of agent types by $\theta = (\theta^1, ..., \theta^n) \in \Theta \equiv \times_{i=1}^N \Theta^i$. For any $\theta \in \Theta$, we adopt the standard notation so that $\theta^{-i} = (\theta^1, ..., \theta^{i-1}, \theta^{i+1}, ..., \theta^n)$, and $\theta = (\theta^i, \theta^{-i})$ where $f(\theta) = \prod_{i=1}^N f^i(\theta^i)$. Let X be a finite set of possible nonmonetary decisions, or allocations (e.g., X could be a subset of an Euclidean space and represent the set of possible allocations of private and public goods).

Let $\Delta(X)$ be the set of probability distributions on X. A mechanism $\zeta = (y, t)$ consists of an allocation rule y and a payment rule t. Let $y^x(\theta)$ denote the probability of choosing $x \in X$, given the profile of types $\theta \in \Theta$. A feasible allocation rule (or social choice function) $y : \Theta \rightarrow \Delta(X)$ is a function from agents' reported types to a probability distribution over allocations such that $\sum_{x \in X} y^x(\theta) = 1$ and $y^x(\theta) \geq 0$ for all $\theta \in \Theta$. We allow allocation rules to randomize over feasible allocations. Let Y be the set of all possible allocation rules and $\Omega \subseteq Y$ be the set of all feasible allocation rules. The payment rule $t : \Theta \rightarrow \mathbb{R}^N$ is a map from the agents' reported types to monetary compensations where $\sum_{i=1}^N t^i(\theta) \geq 0$. This condition (ex-post budget balance) requires that there is no outside source to finance the compensations. Therefore, a mechanism cannot run a deficit.

The individual payoff function (or material utility) of an agent i given an allocation rule y, and her monetary payment t^i is

$$\Pi^i(y, t^i, \theta^i) = \sum_{x \in X} y^x(\theta) v^i(x, \theta^i) - t^i$$

where $v^i(x, \theta^i)$ is agent i's valuation of allocation x which depends on her private information. We assume that $v^i(x, \theta^i)$ is differentiable, monotone increasing, and convex in θ^i for all i and $x \in X$.

Beyond her individual payoff, agent i cares about the payoffs of others:

$$\begin{aligned} u^i(y, t, \theta) &= \rho^i \Pi^i + (1 - \rho^i)\overline{\Pi} \\ &= \sum_{x \in X} y^x(\theta) V^i(x, \theta, \rho^i) + \rho^i\left(\frac{\sum_{j \in N} t^j}{N} - t^i\right) - \frac{\sum_{j \in N} t^j}{N} \end{aligned}$$

where $\overline{\Pi} = \frac{\sum_{j \in N} \Pi^j}{N}$ is the average payoff in the population and $V^i(x, \theta, \rho^i) = \rho^i v^i(x, \theta^i) + (1 - \rho^i)\frac{\sum_{j \in N} v^j(x, \theta^j)}{N}$ is the total value of allocation x for agent i . The constant $\rho^i \in [0, 1]$ is an agent-specific weighting factor showing each agent's social concerns. If $\rho^i = 1$, the agent has selfish preferences which do not directly depend on the well being of others. If $\rho^i < 1$, the agent has altruistic preferences which are increasing in the well being of others. Note that as ρ^i increases the degree of altruism in preferences goes down and the agent gets a higher level of disutility from paying more than the average total payment. If all agents are identical in their social concerns ($\rho^i = \rho^j = \rho$), and $\rho = 0$, the model is a common value setting where full social preferences are in action and the society is homogeneous. If $\rho = 1$, the model is equivalent to the standard mechanism design environment with selfish agents. We assume that agents have identical social concerns to simplify the analysis for the rest of the paper ($\rho^i = \rho^j = \rho$ for all $i, j \in N$).[1]

We only consider direct mechanisms in which the set of reported types is equal to the set of possible types in the rest of the paper. By the revelation principle, any allocation rule that results from equilibrium in any mechanism is also an equilibrium allocation rule of an incentive compatible, direct mechanism. Therefore, there is no loss of generality in restricting our attention to these simple type of mechanisms.

Let $U^i(\zeta, \theta^i, s^i)$ be the interim expected utility of agent i when he reports $s^i \neq \theta^i$, assuming all other agents truthfully report their type. That is

$$U^i(\zeta, \theta^i, s^i) = E_{\theta^{-i}}[u^i(y(s^i, \theta^{-i}), t(s^i, \theta^{-i}), \theta)].$$

Denote $U^i(\zeta, \theta^i) \equiv U^i(\zeta, \theta^i, \theta^i)$. The ex-ante utility of agent i is

$$U^i(\zeta) = E_\theta[u^i(y(\theta), t(\theta), \theta)].$$

Define also the conditional expected payment function $a^i : \Theta^i \to \mathbb{R}$ such that

$$a^i(\theta^i) = E_{\theta^{-i}}[t^i(\theta)].$$

A mechanism is interim incentive compatible (IIC) if honest reporting of types defines a Bayesian-Nash equilibrium. That is ζ is IIC if and only if $U^i(\zeta, \theta^i) \geq U^i(\zeta, \theta^i, s^i)$ for all i, s^i, θ^i. We call a mechanism interim individual rational (IIR) if every agent wants to participate in the mechanism: $U^i(\zeta, \theta^i) \geq 0$ for all i, θ^i. A mechanism is ex ante budget balanced (EABB) if a mechanism designer does not

[1] The model can also be extended to environments where agents are spiteful ($\rho > 1$).

expect to pay subsidies to the agents, e.g., $E_\theta(\sum_{i=1}^N t^i(\theta)) \geq 0$. A mechanism is feasible if it satisfies IIC, IIR, and EABB.

A mechanism ζ is interim efficient (IE) if it is feasible and there is no other feasible mechanism $\widehat{\zeta}$ such that $U^i(\widehat{\zeta}, \theta^i) \geq U^i(\zeta, \theta^i)$ for all i, θ^i and $U^i(\widehat{\zeta}, \theta^i) > U^i(\zeta, \theta^i)$ for some i and for all $\theta^i \in \widetilde{\Theta}^i \subset \Theta^i$, where $\widetilde{\Theta}^i$ has strictly positive measure relative to Θ^i. IE is an extension of efficiency to the environments with private information. A mechanism is IE if there does not exist an alternative feasible mechanism that interim Pareto-dominates it. Note that the idea of Pareto-domination is applied to the expected utilities after the agents have learned their types. IE mechanisms can also be represented as the solutions to a set of maximization problems. A mechanism ζ is an IE mechanism if and only if there exists $\lambda = \{\lambda^i : \Theta^i \to \mathbb{R}^+\}_{i=1}^N$ with $\int_{\underline{\theta}^i}^{\overline{\theta}^i} \lambda^i(\theta^i) dF^i(\theta^i) > 0$ for some i, such that ζ maximizes $\sum_{i=1}^N \int_{\underline{\theta}^i}^{\overline{\theta}^i} \lambda^i(\theta^i) U^i(\zeta, \theta^i) dF^i(\theta^i)$ subject to ζ is feasible. Note that the weight attached to an agent i can vary with her type.[2] Thus, an IE mechanism maximizes weighted sum of agents' utilities subject to IIC, IIR, and EABB constraints.[3]

3 Results

Given welfare weights $\lambda > 0$, our main problem can now be stated as finding mechanisms that maximize

$$\sum_{i=1}^N \int_{\underline{\theta}^i}^{\overline{\theta}^i} \lambda^i(\theta^i) U^i(\zeta, \theta^i) dF^i(\theta^i)$$

subject to IIC, IIR, EABB, and obvious quantity constraints.

We now proceed to characterize the complete set of interim efficient mechanisms. We first start to reformulate the constraint set such that we can provide necessary and sufficient conditions for IIC and IIR. The second step in the characterization involves a general solution to the maximization problem with the constraints rewritten as described below. The constraints for IIC correspond to the first and second order conditions of an individual optimization problem. Following the same idea in Myerson (1981), we find the solution to the case where the second order IIC

[2]See Holmstrom and Myerson (1983).

[3]We could also use ex post budget balance condition. It turns out that EABB is equivalent to ex post budget balance condition in our setting.

condition is not binding (regular problems). Then, we provide a sufficient condition in which the solution to the regular problem coincides with the solution to the original problem. The standard tools of mechanism design are used to get the following preliminary results.

3.1 Preliminaries to the Main Results

IIC requires that it is a Bayesian equilibrium for each agent to report her type truthfully, i.e., none of the agents can obtain strictly higher payoffs by deviating individually. In our framework incentive compatibility can be characterized by means of an envelope and a monotonicity condition as in standard mechanism design problems. A similar result is also proved by Rochet (1987) for linear environments with selfish preferences.

Lemma 1 *A mechanism is IIC if and only if*

$$(s^i - \theta^i) \times (Q^i(s^i, \rho) - Q^i(\theta^i, \rho)) \geq 0 \quad for\ all\ s^i, \theta^i \in \Theta^i \tag{1}$$

$$U^i(\zeta, \theta^i) = U^i(\zeta, \underline{\theta}^i) + \int_{\underline{\theta}^i}^{\theta^i} Q^i(s, \rho) ds \tag{2}$$

where

$$Q^i(\theta^i, \rho) \equiv \int_{\Theta^{-i}} \sum_{x \in X} y^x(\theta) \frac{\partial V^i(x, \theta, \rho)}{\partial \theta^i} dF^{-i}(\theta^{-i}).$$

The first condition is the monotonicity condition which states that the expected marginal total value of agent i in her own type, $Q^i(\theta^i, \rho)$, should be monotone increasing in her own private information. This implies that $\frac{\partial Q^i(\theta^i,\rho)}{\partial \theta^i} \geq 0$. The second condition is the envelope condition. The monotonicity condition has implications only for allocation rules. Notice that the expected payment function a^i is completely determined by a constant $a^i(\underline{\theta}^i)$ and the allocation rule y. The constant of integration, $U^i(\zeta, \underline{\theta}^i)$ is uniquely determined by N constants $a(\underline{\theta})$ and y for all agents.

Now we can write expected budget surplus in an IIC mechanism using the result above.

$$B(\zeta) \equiv \sum_{i=1}^{N} \int_{\Theta} t^i(\theta) dF(\theta) = \sum_{i=1}^{N} \int_{\Theta} (\rho t^i(\theta) + (1-\rho) \frac{\sum_j t^j(\theta)}{N}) dF(\theta)$$

$$= \sum_{i=1}^{N} \left(\int_{\Theta} \sum_{x \in X} y^x(\theta) V^i(x, \theta, \rho) dF(\theta) - U^i(\zeta, \underline{\theta}^i) - \int_{\Theta^i} [\int_{\underline{\theta}^i}^{\theta^i} Q^i(s, \rho) ds] dF^i(\theta^i) \right)$$

Using integration by parts,

$$= \sum_{i=1}^{N} \int_{\Theta} \sum_{x \in X} y^x(\theta) \left(V^i(x,\theta,\rho) - \frac{\partial V^i(x,\theta,\rho)}{\partial \theta^i} \frac{1 - F^i(\theta^i)}{f^i(\theta^i)} \right) dF(\theta) - \sum_{i=1}^{N} U^i(\zeta, \underline{\theta}^i).$$

Let $\Phi(\zeta,\rho) \equiv \sum_{i=1}^{N} \int_{\Theta} \sum_{x \in X} y^x(\theta) \left(V^i(x,\theta,\rho) - \frac{\partial V^i(x,\theta,\rho)}{\partial \theta^i} \frac{1-F^i(\theta^i)}{f^i(\theta^i)} \right) dF(\theta)$. Notice that if ζ is EABB then $B(\zeta) \geq 0$. This also implies the mechanism designer does not expect to pay subsidies to the agents.

IIR requires that each type of each agent must be at least as well off by participating as they would be by not participating at the interim stage. We assume that outside options are exogenously given and without loss of generality normalized to zero. We next combine IIR and IIC to get a useful result for later.

Lemma 2 *An IIC mechanism ζ is IIR if and only if for all $i \in N$, $U^i(\zeta, \underline{\theta}^i) \geq 0$.*

3.2 Interim Efficient Mechanisms

Welfare weights play an important role in our analysis. Before stating the main characterization, the following definition will be useful in reformulating the original problem.

Definition 1 *If $\lambda^{0i} \equiv \int_{\underline{\theta}^i}^{\overline{\theta}^i} \lambda^i(\theta^i) dF^i(\theta^i) > 0$, let $\Lambda^i(\theta^i) = \frac{1}{\lambda^{0i}} \int_{\underline{\theta}^i}^{\theta^i} \lambda^i(s) dF^i(s)$. If $\lambda^{0i} = 0$, let $\Lambda^i(\theta^i) = 0$.*

λ^{0i} is agent i's ex ante welfare weight relative to other agents. $\Lambda^i(\theta^i)$ is a relative weight of agent i's lower types given her private information.

Now we can provide our first characterization. This result implies that the objective function can just be written as a function of utilities of the lowest types $U^i(\zeta, \underline{\theta}^i)$ and the allocation rule y. It does not depend on the transfers anymore.

Theorem 1 *A mechanism $\zeta = (y,a)$ is IE if and only if there exists non-negative type-dependent welfare weights, $\{\lambda^i\}_{i=1}^N$, where $\sum_{i \in N} \lambda^{0i} > 0$, and N constants, $\{c^i(\underline{\theta}^i)\}_{i=1}^N$, such that $(y, \{c^i(\underline{\theta}^i)\}_{i=1}^N)$ solves,*

$$max_{y \in \Omega} \sum_{i=1}^{N} \lambda^{0i} \left[U^i(\zeta, \underline{\theta}^i) + \int_{\underline{\theta}^i}^{\overline{\theta}^i} (\frac{1 - \Lambda^i(\theta^i)}{f^i(\theta^i)}) Q^i(\theta^i, \rho) dF^i(\theta^i) \right] \quad (3)$$

subject to

$$\Phi(\zeta,\rho) - \sum_{i=1}^{N} U^i(\zeta, \underline{\theta}^i) \geq 0 \quad (4)$$

$$U^i(\zeta, \underline{\theta}^i) = \int_{\Theta^{-i}} \sum_{x \in X} y^x(\underline{\theta}^i, \theta^{-i}) V^i(x, \underline{\theta}^i, \theta^{-i}, \rho) dF^{-i}(\theta^{-i}) - c^i(\underline{\theta}^i) \geq 0 \tag{5}$$

$$Q^i(\theta^i, \rho) \;\; \textit{monotone increasing for all } i, \theta^i. \tag{6}$$

Following the same idea in Myerson (1981) we characterize the solution to the problem in Theorem 1 for the case where monotonicity constraint is not binding. In this case solution can be obtained by pointwise maximizing the integrand in the objective function (3). Then we provide conditions under which the solutions to this reduced problem satisfies the monotonicity constraint. When solutions to the original problem and the reduced problem coincide, we refer to the problem as regular.

Given non-negative type-dependent welfare weights, $\{\lambda^i\}_{i=1}^N$, we can define the Lagrangian function as

$$\mathcal{L}(y, (c^i(\underline{\theta}^i))_{i=1}^N, \gamma, (\mu^i)_{i=1}^N) = \sum_{i=1}^N \lambda^{0i} \left[U^i(\zeta, \underline{\theta}^i) + \int_{\underline{\theta}^i}^{\overline{\theta}^i} \left(\frac{1 - \Lambda^i(\theta^i)}{f^i(\theta^i)}\right) Q^i(\theta^i, \rho) dF^i(\theta^i) \right]$$

$$+ \gamma \left[\Phi(\zeta, \rho) - \sum_{i=1}^N U^i(\zeta, \underline{\theta}^i) \right]$$

$$+ \sum_{i=1}^N \mu^i \left(\int_{\Theta^{-i}} \sum_{x \in X} y^x(\underline{\theta}^i, \theta^{-i}) V^i(x, \underline{\theta}^i, \theta^{-i}, \rho) dF^{-i}(\theta^{-i}) - c^i(\underline{\theta}^i) \right).$$

The first-order conditions with respect to γ (EABB multiplier) and with respect to μ^i (IIR multiplier) imply that

$$\gamma \geq 0, B(\zeta) \geq 0 \;\; \textit{and} \;\; \gamma B(\zeta) = 0,$$

$$\mu^i \geq 0, U^i(\zeta, \underline{\theta}^i) \geq 0 \;\; \textit{and} \;\; \mu^i U^i(\zeta, \underline{\theta}^i) = 0 \;\; \textit{for all } i \in N.$$

The first order condition with respect to $a^i(\underline{\theta}^i)$ yields $-\lambda^{0i} + \gamma - \mu^i = 0$. Then $\gamma \geq \lambda^{0i}$ for all $i \in N$. This implies the EABB constraint is always binding ($\gamma > 0$) since there is $i \in N$ such that $\lambda^{0i} > 0$ and $\mu^i \succeq 0$ for all $i \in N$. The intuition of this result is the following. We assumed that contributions in excess are not socially valued. If the EABB is not binding, a redistribution of budget surplus to the agents would result in an interim Pareto improvement. If IIR constraints for the lowest types of agents with non maximal expected welfare weight is not binding, redistribution of wealth to agents with maximal expected welfare weight would increase the weighted welfare function. The following lemma summarizes the discussion above.

Lemma 3

$$\sum_{i=1}^{N} \lambda^{0i} U^i(\zeta, \underline{\theta}^i) = \gamma \sum_{i=1}^{N} U^i(\zeta, \underline{\theta}^i)$$
$$= \gamma \Phi(\zeta, \rho).$$

Using the above result, the objective function (3) can be written as follows

$$\sum_{i=1}^{N} \left[\int_{\Theta} \sum_{x \in X} y^x(\theta) \left(V^i(x,\theta,\rho) - \frac{\partial V^i(x,\theta,\rho)}{\partial \theta^i} \frac{1 - F^i(\theta^i)}{f^i(\theta^i)} \right) dF(\theta) + \frac{\lambda^{0i}}{\gamma} \int_{\Theta^i} (\frac{1 - \Lambda^i(\theta^i)}{f^i(\theta^i)}) Q^i(\theta^i, \rho) dF^i(\theta^i) \right] =$$

$$\sum_{i=1}^{N} \int_{\Theta} \sum_{x \in X} y^x(\theta) \left[V^i(x,\theta,\rho) + \frac{\partial V^i(x,\theta,\rho)}{\partial \theta^i} \left(\frac{F^i(\theta^i) - 1}{f^i(\theta^i)} + \frac{\lambda^{0i}}{\gamma} \frac{1 - \Lambda^i(\theta^i)}{f^i(\theta^i)} \right) \right] dF(\theta).$$

When we substitute and rearrange terms, we get the following result. This result is simplified reformulation of Theorem 1 for regular problems. The utilities of lowest types $U^i(\zeta, \underline{\theta}^i)$ are explicitly entered into the objective function and the constraints of the maximization problem reduce to two constraints representing the EABB constraint.

Theorem 2 *For regular problems, there is a payment rule* $\{a^i\}_{i=1}^N$ *such that* $\zeta = (y, a)$ *is IE if and only if there exists non-negative type-dependent welfare weights,* $\{\lambda^i\}_{i=1}^N$ *with* $\sum_{i \in N} \lambda^{0i} > 0$*, and* $\gamma \geq \overline{\lambda}$ *such that* $y \in \Delta(X)$ *simultaneously solves the following inequalities*

$$\max_{y \in \Omega} \sum_{i=1}^{N} \int_{\Theta} \sum_{x \in X} y^x(\theta) \Big[V^i(x,\theta,\rho) + \frac{\partial V^i(x,\theta,\rho)}{\partial \theta^i} \left(\frac{F^i(\theta^i) - 1}{f^i(\theta^i)} + \frac{\lambda^{0i}}{\gamma} \frac{1 - \Lambda^i(\theta^i)}{f^i(\theta^i)} \right) \Big] dF(\theta) \quad (7)$$

$$0 \leq \Phi(\zeta, \rho) \quad (8)$$

$$0 = (\gamma - \overline{\lambda}) \Phi(\zeta, \rho). \quad (9)$$

3.3 Modified Virtual Valuations

In this section we show the effects of interdependent preferences in our setting. Let

$$W^i(x,\theta,\rho,\lambda^i) = V^i(x,\theta,\rho) + \frac{\partial V^i(x,\theta,\rho)}{\partial \theta^i} \left(\frac{F^i(\theta^i) - 1}{f^i(\theta^i)} + \frac{\lambda^{0i}}{\gamma} \frac{1 - \Lambda^i(\theta^i)}{f^i(\theta^i)} \right). \quad (10)$$

We call $W^i(x,\theta,\rho,\lambda^i)$ as the (modified) virtual valuation of agent i for allocation x following Myerson (1981). Rather than directly working with total valuations, interim efficient mechanisms use the agents' total valuations suitably adjusted. The virtual valuation for a given allocation is equal to the agent's total valuation for the allocation, $V^i(x,\theta,\rho)$, with two adjustments that depend on the distribution of types, welfare weights, and social concerns of the agents. The first one, $\frac{\partial V^i(x,\theta,\rho)}{\partial \theta^i}\frac{F^i(\theta^i)-1}{f^i(\theta^i)}$, is due to the informational rent to be given for truthful revelation of the agent's private information. The second one is due to distortions arising from redistribution of income $(\frac{\partial V^i(x,\theta,\rho)}{\partial \theta^i}\frac{\lambda^{0i}}{\gamma}\frac{1-\Lambda^i(\theta^i)}{f^i(\theta^i)})$. Note that these adjustments are weighted with the marginal total valuation of agent i for a given allocation and hence virtual valuations also depend on the allocation.

3.4 A Sufficient Condition for Regularity

In this section we provide sufficient conditions under which the solution to the regular problem coincide with the solution to the original problem in Theorem 1.

Substituting (10) into (7) gives us:

$$\max_{y\in F}\sum_{i=1}^{N}\int_{\Theta}\sum_{x\in X}y^x(\theta)W^i(x,\theta,\rho,\lambda^i)dF(\theta). \tag{11}$$

The regular problem to find IE mechanisms can now be stated as (y,a) is an interim efficient mechanism if and only if the allocation rule $y\in\Delta(X)$ simultaneously solves (11), (8), and (9). Note that the payment rule is fully specified by the allocation rule and exogenous constants.

The problem stated above has a simple solution defined by[4]

$$y^x(\theta,\lambda)=\begin{cases}1 & \text{if } x = argmax_{m\in X}\sum_{i=1}^{N}W^i(m,\theta,\rho,\lambda^i)\\ 0 & \text{otherwise.}\end{cases} \tag{12}$$

This implies an IE mechanism assigns probability one to an allocation with the highest sum of modified virtual valuations. Note that to find the interim efficient mechanism we use the minimum possible $\gamma\geq\bar{\lambda}$ such that (8) and (9) are satisfied.

This solution also provides an algorithm to find the interim efficient mechanisms. Firstly, given welfare weights, set $\gamma=\bar{\lambda}$ and find the allocation rule $y^x(\theta,\lambda)$ for

[4]For simplicity, we assume that there are no allocations $x,y,x\neq y$ such that $\sum_{i=1}^{N}W^i(x,\theta,\rho,\lambda^i)=\sum_{i=1}^{N}W^i(y,\theta,\rho,\lambda^i)$. We can also use a random tie-breaking rule.

each $\theta \in \Theta$. If this solution satisfies (8) and (9) then the expected transfer functions $a(\theta)$ are calculated using the formula in the proof of Theorem 2. Then, (y, a) is the solution. If the solution does not satisfy the constraints, then for each $\gamma > \bar{\lambda}$ find the allocation rule. Then, find the minimum value of γ such that the allocation rule y_γ satisfies the constraints. Given the allocation rule, calculate the expected transfer functions a_γ as before. Then, (y_γ, a_γ) is the solution.

We now provide a condition under which the solution (12) and the condition imply that the monotonicity constraint is satisfied.

Assumption 1 *(a) $W^i(x, \theta, \rho, \lambda^i)$ is non decreasing in θ^i for all $i \in N$, $x \in X$ and all $\theta \in \Theta$, and (b) $\frac{\partial V^i(x,\theta,\rho)}{\partial \theta^i}$ is non decreasing in x for all $i \in N$, all $\theta \in \Theta$, and all $x \in X$.*

Note that we did not make any assumption about how the total valuations depend on the allocation up to now. Assumption 1 basically restricts the set of admissible valuation functions and welfare weights such that the solution to the reduced problem satisfies the monotonicity condition (1). Assumption 1(a) reduces to a joint condition on priors F^i, welfare weights and the curvature of the total valuation functions. We already know by the initial assumption that $\frac{\partial V^i(x,\theta^i,\rho)}{\partial \theta^i}$ increases (decreases) when θ^i increases (decreases). However, the allocation might also change as a result of increase in an agent's signal. Note that the allocation can not decrease due to Assumption 1(a). Assumption 1(b) guarantees that the derivative of the total valuation functions $\frac{\partial V^i(x,\theta,\rho)}{\partial \theta^i}$ are also non decreasing in x. For example, if priors are uniform on $[0, 1]$, $V^i(x, \theta, \rho) = x(\rho\theta^i + (1-\rho)\frac{\sum_{j \in N} \theta^j}{N})$, and $\rho = 0$ then

$$W^i(.) = \frac{\sum_{j \in N} \theta^j}{N} + \frac{1}{N}(\theta^i - 1 + \frac{\lambda^{0i}}{\gamma}(1 - \Lambda^i(\theta^i)).$$

So Assumption 1(a) requires $\frac{\partial W^i}{\partial \theta^i} \geq 0$. This is true if and only if $\lambda^i(\theta^i) \leq 2\gamma$ for all $i \in N$ and all $\theta^i \in \Theta^i$. We know that $\gamma \geq \overline{\lambda}$ and welfare weights are always non-negative. Therefore, this condition is satisfied for all possible welfare weights. For general priors and social concerns, this assumption requires

$$\gamma \geq \frac{\lambda^i(\theta^i)}{2f^i(\theta^i) - \frac{\frac{\partial f^i(\theta^i)}{\partial \theta^i}(F^i(\theta^i) - \Lambda^i(\theta^i))}{f^i(\theta^i)}}.$$

This implies Assumption 1(a) may not be satisfied for all welfare weights with arbitrary priors. We showed that with uniform priors the assumption can be satisfied for all welfare weights and thus it is satisfied by all incentive efficient mechanisms. Note also that the total valuation function satisfies Assumption 1(b).

Theorem 3 *If each* $W^i(.)$ *and* $V^i(.)$ *satisfies Assumption* 1*, then the solution* (12) *satisfies all constraints in Theorem* 1*.*

4 Applications

Our characterization is general and can be applied to different economic settings. In this section, we present the main intuition of the characterization by providing simplified applications for both public and private goods environments.

4.1 Public Goods

There are N people who must decide on the level of a public good which is produced according to constant returns to scale. In addition, they must decide how to distribute the production costs. Let $X = \{0, 1\}$ denote the possible values of the public good. The cost of producing the public good is equal to K. In our main model, we assumed that social allocation is costless but it is easy to incorporate the cost of social allocation to our model.

For this application we assume that the total valuation functions have the following form:

$$V^i(x, \theta, \rho) = x\left(\rho\theta^i + (1-\rho)\frac{\sum_{j\in N}\theta^j}{N}\right). \tag{13}$$

This implies the utility function of agent i is

$$u^i(y, t, \theta) = \sum_{x\in X} y^x(\theta)V^i(x, \theta, \rho) + \rho\left(\frac{\sum_{j\in N} t^j}{N} - t^i\right) - \frac{\sum_{j\in N} t^j}{N}, \tag{14}$$

where $\rho \in [0, 1]$ is the measure of social concerns. If $\rho = 1$, the model is equivalent to the standard public good environment where agents are selfish. If $\rho = 0$, the model is a common values setting where full social preferences are in action and the society is homogeneous (every agent has the same valuation for the public good). If $1 > \rho \geq 0$, agents have interdependent preferences. Note that as ρ decreases the degree of altruism in preferences goes up and the model converges to the full social preferences setting.

For the regular case, given welfare weights $\lambda^i : \Theta^i \to \mathbb{R}^+$, an IE mechanism satisfies:

$$\max_{y \in \Omega} \sum_{i=1}^{N} \int_{\Theta} \left(\sum_{x \in X} y^x(\theta)(W^i(x, \theta, \rho, \lambda^i) - \frac{K}{N} x) \right) dF(\theta) \tag{15}$$

$$0 \leq \Phi(\zeta, \rho) - \int_{\Theta} K \sum_{x \in X} y^x(\theta) x dF(\theta) \tag{16}$$

$$0 = (\gamma - \overline{\lambda}) \left[\Phi(\zeta, \rho) - \int_{\Theta} K \sum_{x \in X} y^x(\theta) x dF(\theta) \right]. \tag{17}$$

Suppose IIR was not required. It is much easier to solve the problem without IIR constraints. First-order conditions imply $\lambda^{0i} = \gamma = \overline{\lambda}$ for all $i \in N$. Hence the ex-ante welfare weights must all be equal. Otherwise, the solution does not exist, since it is always possible to improve welfare by making arbitrarily large transfers between agents with different welfare weights. The problem stated above has a simple solution:

$$y^x(\theta, \lambda) = \begin{cases} 1 & \text{if } x = argmax_{m \in X} \sum_{i=1}^{N} W^i(m, \theta, \rho, \lambda^i) - Km \\ 0 & \text{otherwise,} \end{cases} \tag{18}$$

and the payment functions can be found using the formula in the proof of Theorem 2 after subtracting the expected cost of the public good from the constraint on the sum of the expected payment of the lowest types of each agent.

The public good is produced if

$$\sum_{i=1}^{N} \theta^i + (\rho + \frac{1-\rho}{N}) \sum_{i=1}^{N} \frac{F^i(\theta^i) - \Lambda^i(\theta^i)}{f^i(\theta^i)} \geq K.$$

The first best decision is to produce the public good when $\sum_{i=1}^{N} V^i(1, \theta, \rho) = \sum_{i=1}^{N} V^i(1, \theta, \rho = 1) = \sum_{i=1}^{N} v^i(1, \theta) = \sum_{i=1}^{N} \theta^i \geq K$. Let $\Theta^e = \{\theta | \sum_{i=1}^{N} \theta^i \geq K\}$ and $\Theta^\rho = \{\theta | \sum_{i=1}^{N} W^i(.) \geq K\}$. Efficiency dictates that the public good provision does not depend on social concerns of the agents, ρ. In interim efficient mechanisms, there are distortions from the first best due to informational rents, the type-dependent welfare weights and the measure of social concerns. Note that even though the sum of the valuations for the public good is independent of social concerns of agents, interim efficient production decisions depend on the interdependence among preferences.

Suppose $\lambda^i(\theta^i)$ is decreasing for all i and θ^i (lower types are weighted more heavily). This implies the aim of the planner is that agents valuing the public good more should bear a larger share of the costs. Then, $\sum_{i=1}^{N} \frac{F^i(\theta^i)-\Lambda^i(\theta^i)}{f^i(\theta^i)} < 0$. This implies there is less production than the ex post efficient mechanisms for all ρ since sum of the modified virtual valuations is less than the sum of the valuations. Moreover, as ρ decreases, or the degree of altruism in the preferences goes up, the public good is produced more often. That is, when higher types are less heavily weighted than lower types, underproduction is a more efficient way to relax incentive compatibility constraints than transfers. However, incentive compatibility constraints are less binding as we converge to the full social preferences environment (ρ decreases) and there is no need to relax the incentive compatibility constraints. This leads to a relative increase in the production of the public good.

Now, suppose $\lambda^i(\theta^i)$ is increasing for all i and θ^i (higher types are weighted more heavily). Then, $\sum_{i=1}^{N} \frac{F^i(\theta^i)-\Lambda^i(\theta^i)}{f^i(\theta^i)} > 0$. This implies there is more production than the ex post efficient mechanisms for all ρ since sum of the modified virtual valuations is more than the sum of the valuations. Moreover, as ρ decreases, the public good is produced less often. It is also easy to see that if $\lambda^i(\theta^i) = c \in \mathbb{R}_+$ for all i and θ^i, ex ante efficient production decision which are also interim efficient correspond to the classical first best decision (or ex-post efficient allocation). The following comparative statistics result directly follows from the above discussion.

Proposition 1 *If the welfare weights are decreasing in type, the public good is produced more often as the degree of altruism in preferences goes up.*

Now suppose that IIR constraints are required. The main question is then whether the individual rationality constraint will be binding or not for the agent who is assigned the highest welfare weight. We know that individual rationality constraints will be binding for all other agents since $\gamma \geq \bar{\lambda}$. Note that γ is found using the algorithm in Section 3.4. Suppose $\gamma > \bar{\lambda}$. This implies individual rationality constraints are binding for all agents. For this case, virtual valuations are equivalent to

$$W^i(\theta, \rho, \lambda^i) = \left(\rho\theta^i + (1-\rho)\frac{\sum_{j\in N} \theta^j}{N} + (\rho + \frac{1-\rho}{N}) \left(\frac{F^i(\theta^i) - 1}{f^i(\theta^i)} + \frac{\lambda^{0i}}{\gamma} \frac{1-\Lambda^i(\theta^i)}{f^i(\theta^i)} \right) \right). \tag{19}$$

The public good is produced if

$$\sum_{i=1}^{N} \theta^i + (\rho + \frac{1-\rho}{N}) \left(\sum_{i=1}^{N} \frac{F^i(\theta^i) - 1}{f^i(\theta^i)} + \frac{\lambda^{0i}}{\gamma} \frac{1-\Lambda^i(\theta^i)}{f^i(\theta^i)} \right) \geq K. \tag{20}$$

With IIR constraints, virtual valuations are lower for all agents. Hence the frequency of interim efficient public good production is always lower with the constraints than without. This implies that in some cases it might be efficient to produce the public good but there might not be enough surplus to cover the incentive costs without violating individual rationality constraints. Note that the adjustment term, $(\rho + \frac{1-\rho}{N})\left(\sum_{i=1}^{N} \frac{F^i(\theta^i)-1}{f^i(\theta^i)} + \frac{\lambda^{0i}}{\gamma}\frac{1-\Lambda^i(\theta^i)}{f^i(\theta^i)}\right)$, is always negative. If interim efficient production occurs, then $\sum_{i=1}^{N} \theta^i > K$. IE mechanisms do not produce the public good when it is not optimal to produce the public good and these mechanisms may not produce the public good when it is optimal to produce. However, the adjustment term becomes smaller as the degree of altruism in the preferences goes up. This implies agents earn less informational rents, the budget balance constraint is relaxed and the constrained optimum is getting more efficient. Because it is easier to satisfy individual rationality constraints with relatively more unselfish agents. That is, public good provision increases as ρ decreases, and there will be fewer information states of the economy in which it is optimal to produce the public good but the public good is not produced. Formally, $\Theta^e \supseteq \Theta^{\rho'} \supseteq \Theta^{\rho}$ for all $\rho, \rho' \in [0,1]$ such that $\rho > \rho'$. Note that, inefficiency in public good production is the smallest when full social preferences are in action. These observations lead to the following result.

Proposition 2 *Interim efficient public good provision increases with the degree of altruism in preferences.*

4.2 Bargaining: One Buyer and One Seller

There is a risk-neutral seller who wants to sell an indivisible object that she owns and a risk-neutral buyer who wants to buy the object. The seller's type is $\theta^s \in [\underline{\theta}^s, \overline{\theta}^s]$, and the buyer's type is $\theta^b \in [\underline{\theta}^b, \overline{\theta}^b]$. We assume that $[\underline{\theta}^s, \overline{\theta}^s] \cap [\underline{\theta}^b, \overline{\theta}^b] \neq \emptyset$. That is, there are gains from trade for some information states of the economy. A nonmonetary decision may be represented by a vector $x = (x^s, x^b)$, where $x^s = 1$ if the seller keeps the good, $x^s = 0$ if the seller sells the good, $x^b = 1$ if the buyer gets the good, and $x^b = 0$ if the buyer does not get the good. The set of possible allocations is then $X = \{(1,0),(0,1)\}$. Agent i's individual payoff depends on the decision rule y, her private information θ^i and her monetary transfer t^i,

$$\Pi^i(y, t^i, \theta^i) = \sum_{x \in X} y^x(\theta) v^i(x^i, \theta^i) - t^i.$$

Beyond her individual payoff, agent $i \in \{b, s\}$ cares about the payoff of the other agent,

$$u^i(y,t,\theta) = \sum_{x \in X} y^x(\theta) V^i(x,\theta,\rho) - \rho t^i - (1-\rho)\frac{t^s + t^b}{2}.$$

For this application we assume that total valuation functions have the following form:[5]

$$V^i(x,\theta,\rho) = \left(\rho x^i \theta^i + (1-\rho)\frac{x^s\theta^s + x^b\theta^b}{2}\right).$$

If the parties do not reach an agreement, they get their outside options. The seller's outside option is $U^{0s}(\theta^s) = \frac{1+\rho}{2}\theta^s$ and $U^{0b}(\theta^b) = \int_{\Theta^s} \frac{1-\rho}{2}\theta^s dF^s(\theta^s)$ for the buyer, the buyer's expected value when he does not make any payments to the seller and the seller keeps the good. Note that the interpretation of outside options is not standard in our model. We could also set $U^{0s}(\theta^s) = \theta^s$ and $U^{0b}(\theta^b) = 0$. This would imply interdependence between preferences are not observed if there is no trade.

IIR requires an agent's net utility given incentive taxes to be non-negative for all of that agent's types:

$$U^i(\zeta,\theta^i) - U^{0i}(\theta^i) = U^i(\zeta,\underline{\theta}^i) + \int_{\underline{\theta}^i}^{\theta^i} Q^i(s,\rho)ds - U^{0i}(\theta^i) \geq 0 \;\; for\ all\ i \in M, \theta^i \in \Theta^i.$$

This is only true if

$$U^i(\zeta,\underline{\theta}^i) + min_{\theta^i}\left[\int_{\underline{\theta}^i}^{\theta^i} Q^i(s)ds - U^{0i}(\theta^i)\right] \geq 0.$$

It is easy to see that IIR constraint is binding for the lowest possible type of the buyer and for the highest possible type of the seller. Note that for the buyer individual rationality is satisfied if and only if $U^b(\zeta,\underline{\theta}^b) \geq \int_{\Theta^s} \frac{1-\rho}{2}\theta^s dF^s(\theta^s)$. For the seller, individual rationality requires $U^s(\zeta,\underline{\theta}^s) - \int_{\underline{\theta}^s}^{\overline{\theta}^s} Q^s(a,\rho)da - \frac{1+\rho}{2}\overline{\theta}^s \geq 0$. The expected surplus using our formulation in the paper can be written as

$$B(\zeta) \equiv \sum_{i \in \{b,s\}} \int_{\Theta} \sum_{x \in X} y^x(\theta)\left(V^i(x,\theta,\rho) - \frac{\partial V^i(x,\theta,\rho)}{\partial \theta^i}\frac{1-F^i(\theta^i)}{f^i(\theta^i)}\right) dF(\theta) +$$

$$-U^b(\zeta,\underline{\theta}^b) - U^s(\zeta,\underline{\theta}^s).$$

[5]If $\rho = 1$, the model is equivalent to the original Myerson and Satterthwaite (1983) bargaining problem with selfish agents.

Repeating the same arguments, an interim efficient mechanism maximizes

$$\max_{y\in\Omega} \sum_{i\in\{b,s\}} \int_\Theta \left[\sum_{x\in X} y^x(\theta)(V^i(x,\theta,\rho) + \frac{\partial V^i(x,\theta,\rho)}{\partial\theta^i}\left(\frac{F^i(\theta^i)-1}{f^i(\theta^i)} + \right.\right. \tag{21}$$

$$\left.\left.\frac{\lambda^{0i}}{\gamma}\frac{1-\Lambda^i(\theta^i)}{f^i(\theta^i)} + (1-\frac{\lambda^{0i}}{\gamma})\frac{I^i(\theta^i)}{f^i(\theta^i)}\right)\right] dF(\theta)$$

$$0 \le \Psi(\zeta,\rho) \tag{22}$$

$$0 \le \gamma - \overline{\lambda} \tag{23}$$

$$0 = (\gamma - \overline{\lambda})\Psi(\zeta,\rho) \tag{24}$$

where

$$I^i(\theta^i) = \begin{cases} 1 & \text{if } \theta^i < argmin_{\theta^i}\left[U^i(\zeta,\underline{\theta}^i) + \int_{\underline{\theta}^i}^{\theta^i} Q^i(s,\rho)ds - U^{0i}(\theta^i)\right]; \\ 0 & \text{if } \theta^i \ge argmin_{\theta^i}\left[U^i(\zeta,\underline{\theta}^i) + \int_{\underline{\theta}^i}^{\theta^i} Q^i(s,\rho)ds - U^{0i}(\theta^i)\right] \end{cases}$$

and

$$\Psi(\zeta,\rho) = \sum_{i\in\{b,s\}} \left[\int_\Theta \sum_{x\in X} y^x(\theta)\left(V^i(x,\theta,\rho) + \frac{\partial V^i(x,\theta,\rho)}{\partial\theta^i}\ \frac{F^i(\theta^i)-1}{f^i(\theta^i)}\right) dF(\theta) + \right.$$

$$\left.\min_{\theta^i}\left(\int_{\underline{\theta}^i}^{\theta^i} Q^i(s,\rho)ds - U^{0i}(\theta^i)\right)\right]$$

$$= \int_\Theta y^{(0,1)}(\theta)\left[\theta^b - \theta^s + \frac{1+\rho}{2}\left(\frac{F^b(\theta^b)-1}{f^b(\theta^b)} - \frac{F^s(\theta^s)}{f^s(\theta^s)}\right)\right] dF(\theta). \tag{25}$$

The modified virtual valuation of the buyer is:

$$W^b(x,\theta,\rho,\lambda^b) = V^b(x,\theta,\rho) + \frac{\partial V^b(x,\theta,\rho)}{\partial\theta^b}\left(\frac{F^b(\theta^b)-1}{f^b(\theta^b)} + \frac{\lambda^{0b}}{\gamma}\frac{1-\Lambda^b(\theta^b)}{f^b(\theta^b)}\right),$$

and the modified virtual valuation of the seller is

$$W^s(x,\theta,\rho,\lambda^s) = V^s(x,\theta,\rho) + \frac{\partial V^s(x,\theta,\rho)}{\partial\theta^s}\left(\frac{F^s(\theta^s)}{f^s(\theta^s)} - \frac{\lambda^{0s}}{\gamma}\frac{\Lambda^s(\theta^s)}{f^s(\theta^s)}\right).$$

An IE mechanism gives the good to the agent with the highest positive modified virtual valuations. Trade will take place whenever the seller's modified virtual valuation is below the buyer's modified virtual valuation. This implies trade occurs if

$$\theta^b - \theta^s + \frac{1+\rho}{2}\left(\frac{F^b(\theta^b)-1}{f^b(\theta^b)} + \frac{\lambda^{0b}}{\gamma}\frac{1-\Lambda^b(\theta^b)}{f^b(\theta^b)} - \frac{F^s(\theta^s)}{f^s(\theta^s)} + \frac{\lambda^{0s}}{\gamma}\frac{\Lambda^s(\theta^s)}{f^s(\theta^s)}\right) \ge 0.$$

The first best decision is to trade the good when $\theta \in \Theta^e = \{\theta | \theta^b \geq \theta^s\}$. Efficient trade cannot occur with probability one in interim efficient mechanisms. There are distortions from the first best due to informational rents, redistribution of income, and our behavioral assumption. Note that efficient trade decisions do not depend on the degree of altruism in preferences. However, interim efficient trade depends on the interdependence between preferences.

With IIR constraints, modified virtual valuation of the buyer is lower and modified virtual valuation of the seller is higher than the case without IIR constraints. Hence interim efficient trade occurs less often with the constraints than without. It might be efficient to trade in some cases but there might not be enough surplus to cover incentive costs without violating individual rationality constraints.

Suppose the priors are uniform on $[0, 1]$. Then trade occurs if and only if

$$\theta^b - \theta^s \geq \frac{1+\rho}{3+\rho}\left(1 - \frac{\lambda^{0b}}{\gamma}(1 - \Lambda^b(\theta^b)) - \frac{\lambda^{0s}}{\gamma}\Lambda^s(\theta^s)\right).$$

In the ex ante efficient mechanism, which is also interim efficient, $\lambda^s = \lambda^b = 1$, trade occurs if and only if

$$\theta^b - \theta^s \geq \frac{(1+\rho)(\gamma-1)}{(3+\rho)\gamma - (1+\rho)}.$$

The probability of trade in an interim efficient mechanism can be higher or lower than the ex ante efficient mechanism depending on welfare weights. Note that the set of ex ante efficient mechanisms is a subset of the set of interim efficient mechanisms. In the ex ante efficient mechanism the seller adjusts her total valuation upward and the buyer adjusts her total valuation downward. They are willing not to trade even if trade is beneficial to both parties to get more favorable total payoffs. This may not be the case in interim efficient mechanisms depending on welfare weights.

If we apply our algorithm from Section 3.4, we see that γ is positively correlated with ρ. The following table, Table 1, summarizes the relationship among the resource feasibility Lagrangian multiplier (γ), the degree of altruism ρ, and information state of the economy $\theta = (\theta^b, \theta^s)$ for which trade occurs.

Note that the probability of ex ante efficient trade is equal to the probability of efficient trade when $\rho = 0$. In this case agents only care about the total valuations but do not care about the transfers, so the problem is equivalent to finding efficient

ρ	γ	$\theta^b - \theta^s \geq$
0	1	0
0.3	1.15	0.08
0.6	1.3	0.17
1	1.45	0.25

Table 1: Relationship between ex ante efficient trade and the degree of altruism in preferences.

mechanisms. This will not be true for all interim efficient mechanisms since welfare weights might be type dependent. We can conclude from the table that the probability of trade decreases as ρ increases since there will be less (θ^s, θ^b) for which trade occurs as ρ increases. This implies altruistic agents trade more often than selfish agents. Moreover, selfish agents are more willing to risk losing beneficial trades to get a more favorable payment than unselfish agents. The following result states that this observation can easily be extended to all interim efficient mechanisms.

Proposition 3 *Trade occurs more often as the degree of altruism in preferences goes up.*

The above result implies that there will be more information states of the economy ($\theta \in \Theta$) where it is interim efficient to trade as ρ decreases. Moreover, agents do not trade when it is not optimal to trade ($\theta^b - \theta^s < 0$) and they may not trade when it is optimal to trade ($\theta^b - \theta^s \geq 0$). However, there will be fewer information states of the economy where trade does not occur but trade is optimal as the degree of altruism in the preferences increases. That is, $\Theta^e \supseteq \Theta^{\rho'} \supseteq \Theta^{\rho}$ for all $\rho, \rho' \in [0, 1]$ such that $\rho > \rho'$.

5 Concluding Remarks

In this paper, we have characterized interim efficient mechanisms for Bayesian environments with interdependent preferences. We mostly concentrated on regular problems where we assumed that monotonicity constraint is not binding and provided a sufficient condition for regular problems. The extension of characterization to irregular problems remains open. We also provided applications that show the properties of these mechanisms for both public and private goods environments.

Our initial intention was to extend our analysis to the case where the individuals share prior claims to the objects (dissolving a partnership). In that case individual rationality constraints are type specific and the determination of buyers and sellers is endogenous. Moreover, individual rationality constraints bind in the interior and this interior point (or region) is also endogenous. This creates difficulties in separating virtual valuations from the allocation rule, and hence virtual valuations are also endogenous. Then, our formulation does not work for this case. Our conjecture is that the set of initial shares for which efficient dissolution is possible extends as the degree of altruism in preferences goes up. Extending the formulation to this problem is an open question. We did not have this problem in our formulation because individual rationality constraints are binding for the lowest or highest types of agents for all incentive compatible mechanisms.

One possibility for future research is to consider a model where the social concerns of agents are also private information. Then, types are multidimensional. This extension appears to be a difficult open question since the problems with multidimensional analysis are well known in mechanism design literature. Another possibility for future research is to consider a mechanism design problem with Fehr and Schmidt (1999) type of preferences where individuals are inequity averse. This complicates the mechanism design problem since this type of preferences introduces discontinuities.

The extension of our characterization to the Bayesian environments with private social concerns will be a subject of our future research.

6 Appendix

Proof of Lemma 1. ($\Rightarrow$) Let $s^i > \theta^i$. IIC implies $U^i(\zeta, \theta^i) \geq U^i(\zeta, \theta^i, s^i)$ and $U^i(\zeta, s^i) \geq U^i(\zeta, s^i, \theta^i)$ where

$$U^i(\zeta, \theta^i, s^i) = U^i(\zeta, s^i) - \int_{\Theta^{-i}} \sum_{x \in X} y^x(s^i, \theta^{-i}) V^i(x(s^i, \theta^{-i}), s^i, \theta^{-i}, \rho) dF^{-i}(\theta^{-i})$$

$$+ \int_{\Theta^{-i}} \sum_{x \in X} y^x(s^i, \theta^{-i}) V^i(x(s^i, \theta^{-i}), \theta, \rho) dF^{-i}(\theta^{-i})$$

and

$$U^i(\zeta, s^i, \theta^i) = U^i(\zeta, \theta^i) - \int_{\Theta^{-i}} \sum_{x \in X} y^x(\theta) V^i(x(\theta), \theta, \rho) dF^{-i}(\theta^{-i})$$

$$+ \int_{\Theta^{-i}} \sum_{x \in X} y^x(\theta) V^i(x(\theta), s^i, \theta^{-i}, \rho) dF^{-i}(\theta^{-i}).$$

This implies $Q^i(s^i, \rho) \geq \frac{U^i(\zeta, s^i) - U^i(\zeta, \theta^i)}{s^i - \theta^i} \geq Q^i(\theta^i, \rho)$ and hence $Q^i(\theta^i, \rho)$ is nondecreasing. Letting $s^i \to \theta^i$ implies $\frac{\partial U^i(\zeta, \theta^i)}{\partial \theta^i} = Q^i(\theta^i, \rho)$. Then $U^i(\zeta, \theta^i) = U^i(\zeta, \underline{\theta}^i) + \int_{\underline{\theta}^i}^{\theta^i} Q^i(s, \rho) ds$.

($\Leftarrow$) Now suppose 1 and 2 hold. Then $U^i(\zeta, s^i) - U^i(\zeta, \theta^i) = \int_{\theta^i}^{s^i} Q^i(s, \rho) ds \geq (s^i - \theta^i) Q^i(\theta^i, \rho)$. This implies, repeating the construction backwardly in the necessary part, $U^i(\zeta, \theta^i) \geq U^i(\zeta, \theta^i, s^i)$ and $U^i(\zeta, s^i) \geq U^i(\zeta, s^i, \theta^i)$. $\square$

Proof of Lemma 2. IIR is satisfied if and only if $U^i(\zeta, \theta^i) \geq 0$ for all i, θ^i. By IIC

$$U^i(\zeta, \theta^i) = U^i(\zeta, \underline{\theta}^i) + \int_{\underline{\theta}^i}^{\theta^i} Q^i(s, \rho) ds \geq 0 \quad for\ all\ i \in N, \theta^i \in \Theta^i.$$

That is, it requires

$$min_{\theta^i \in \Theta^i} \left[U^i(\zeta, \underline{\theta}^i) + \int_{\underline{\theta}^i}^{\theta^i} Q^i(s, \rho) ds \right] \geq 0,$$

$$\Leftrightarrow$$

$$U^i(\zeta, \underline{\theta}^i) + min_{\theta^i \in \Theta^i} \left[\int_{\underline{\theta}^i}^{\theta^i} Q^i(s, \rho) ds \right] \geq 0 \Leftrightarrow U^i(\zeta, \underline{\theta}^i) \geq 0 \quad for\ all\ i \in N.$$

The other direction is trivial since $V^i(x, \theta^i)$ is monotone increasing in θ^i. $\square$

I first note the following result that will be used later.

Lemma 4

$$\int_{\underline{\theta}^i}^{\overline{\theta}^i} \lambda^i(\theta^i)\left(U^i(\zeta,\underline{\theta}^i)+\int_{\underline{\theta}^i}^{\theta^i} Q^i(s,\rho)ds\right)dF^i(\theta^i)$$

$$=$$

$$\lambda^{0i}\left[U^i(\zeta,\underline{\theta}^i)+\int_{\underline{\theta}^i}^{\overline{\theta}^i}(\frac{1-\Lambda^i(\theta^i)}{f^i(\theta^i)})Q^i(\theta^i,\rho)dF^i(\theta^i)\right].$$

Proof of Lemma 4. By changing the order of integration we get:

$$\begin{aligned}
LHS &= \lambda^{0i}U^i(\zeta,\underline{\theta}^i)+\int_{\underline{\theta}^i}^{\overline{\theta}^i} Q^i(s,\rho)\left[\int_s^{\overline{\theta}^i}\lambda^i(\theta^i)dF^i(\theta^i)\right]ds \\
&= \lambda^{0i}\left[U^i(\zeta,\underline{\theta}^i)+\int_{\underline{\theta}^i}^{\overline{\theta}^i} Q^i(s,\rho)(1-\Lambda^i(s))ds\right] \\
&= \lambda^{0i}\left[U^i(\zeta,\underline{\theta}^i)+\int_{\underline{\theta}^i}^{\overline{\theta}^i}(\frac{1-\Lambda^i(\theta^i)}{f^i(\theta^i)})Q^i(\theta^i,\rho)dF^i(\theta^i)\right].
\end{aligned}$$

□

Proof of Theorem 1. Directly follows from Lemmas 1, 2, and 4. (4) is EABB, (5) is IIR, and (6) is the first part of IIC. □

Proof of Lemma 3. Let $\overline{\lambda} = max_{i\in N}\{\lambda^{0i}\}$. Define also $K = \{k \mid \overline{\lambda} = \lambda^{0k},\ \forall\ k \in N\}$, the set of agents who have the highest ex ante welfare weight, and $M = \{m \mid \overline{\lambda} > \lambda^{0m},\ \forall\ m \in N\}$, the set of agents whose welfare weights are lower than the highest ex ante welfare weight, where $N = K \cup M$. There are two possible cases:

Case 1: $\gamma > \overline{\lambda}$. This implies for all $i \in N$, $\mu^i > 0 \Rightarrow U^i(\zeta,\underline{\theta}^i) = 0 \Rightarrow$ IIR constraints are binding for all agents' lowest types.

Case 2: $\gamma = \overline{\lambda}$. This implies for each $k \in K$, $\gamma = \overline{\lambda} = \lambda^{0k} \Rightarrow \mu^k = 0 \Rightarrow U^k(\zeta,\underline{\theta}^k) \geq 0$ and for each $m \in M$, $\gamma = \overline{\lambda} > \lambda^{0m} \Rightarrow \mu^m > 0 \Rightarrow U^m(\zeta,\underline{\theta}^m) = 0 \Rightarrow$ IIR constraints are binding for all agents' lowest types in M and the constraints are not binding for all agents in K.

From Case 1 and 2, if $U^i(\zeta,\underline{\theta}^i) \neq 0$ for some $i \in M \subseteq N$ then for all $i \in M$ ex ante welfare weights are equal to $\gamma = \overline{\lambda} = \lambda^{0i}$. This implies $\sum_{i=1}^N \lambda^{0i}U^i(\zeta,\underline{\theta}^i) =$

$\gamma \sum_{i=1}^{N} U^i(\zeta, \underline{\theta}^i) = \gamma \Phi(\zeta, \rho)$. The second equality follows by EABB constraint which is always binding. $\square$

Proof of Theorem 2. It follows from Lemma 3 and the discussion for Case 1 and 2 as stated above. Suppose the type-dependent welfare weights are such that $\lambda^{0i} = \overline{\lambda} > \lambda^{0j}$ for all $j \in N\backslash\{i\}$ and $\gamma \geq \overline{\lambda}$. The payment function (if $\rho \neq 0$) is given by[6]:

$$\forall\, j \neq i, \quad a^j(\theta^j) = \frac{\int_{\Theta^{-j}} \sum_{x \in X} y^x(\theta) V^j(x, \theta, \rho) dF^{-j}(\theta^{-j}) - \int_{\underline{\theta}^j}^{\theta^j} Q^j(s, \rho) ds}{\rho}\ , \tag{26}$$

$$a^i(\theta^i) = \frac{\int_{\Theta^{-i}} \sum_{x \in X} y^x(\theta) V^i(x, \theta, \rho) dF^{-i}(\theta^{-i}) - \Phi(\zeta, \rho) - \int_{\underline{\theta}^i}^{\theta^i} Q^i(s, \rho) ds}{\rho}. \tag{27}$$

We know that IIR constraint is binding for the lowest types of all $-i$. This implies $\sum_{l \in N} U^l(\zeta, \underline{\theta}^l) = U^i(\zeta, \underline{\theta}^i) = \Phi(\zeta, \rho)$ since EABB is always binding. Then, $\rho a^i(\theta^i) = \int_{\Theta^{-i}} \sum_{x \in X} y^x(\theta) V^i(x, \theta, \rho) dF^{-i}(\theta^{-i}) - U^i(\zeta, \theta^i)$. By using the envelope condition, we get the payment function of the agent with maximal welfare weight. This implies agent i is the residual claimant. For other possible welfare weights, we will need additional constants to find the payment rule. Suppose we are in Case 1. This implies, $\Phi(\zeta, \rho) = 0$ from EABB and $\int_{\Theta^{-i}} \sum_{x \in X} y^x(\underline{\theta}^i, \theta^{-i}) V^i(x, \underline{\theta}^i, \theta^{-i}, \rho) dF^{-i}(\theta^{-i}) = c^i(\underline{\theta}^i) = \rho a^i(\underline{\theta}^i)$ from IIR. Therefore, we can uniquely solve for the set of expected payments of all agents' minimum types. Suppose now we are in Case 2. The argument for each $i \in M$ is similar to Case 1. On the other hand, for each $i \in K$ the IIR constraint may not be binding. Therefore, we need $|K|$ constants to solve for the payment function. Note that the agents with the maximal expected welfare weight share the remaining surplus (or cost) to make the EABB constraint binding. This implies agents in set K will be residual claimants. $\square$

Proof of Theorem 3. The solution is constructed such that all constraints other than monotonicity are satisfied. We only need to show that the solution satisfies the monotonicity constraint. Suppose $\theta^i \geq s^i$, $x = argmax_{m \in X} \sum_{i=1}^{N} W^i(m, \theta, \rho, \lambda^i)$ and $y = argmax_{m \in X} \sum_{i=1}^{N} W^i(m, s^i, \theta^{-i}, \rho, \lambda^i)$. This implies $x \geq y$ by Assumption

[6]If $\rho = 0$, any appropriate incentive taxes that add up to zero will work since in this case agents only care about the average payment and we know that budget is always balanced.

1(a). By Assumption 1(b),

$$Q^i(\theta^i,\rho) = \int_{\Theta^{-i}} \sum_{x\in X} y^x(\theta^i,\theta^{-i}) \frac{\partial V^i(x,\theta,\rho)}{\partial\theta^i} dF^{-i}(\theta^{-i}) = \int_{\Theta^{-i}} \frac{\partial V^i(x,\theta,\rho)}{\partial\theta^i} dF^{-i}(\theta^{-i})$$

$$\geq Q^i(s^i,\rho) = \int_{\Theta^{-i}} \frac{\partial V^i(y,s^i,\theta^{-i},\rho)}{\partial s^i} dF^{-i}(\theta^{-i}).$$

This implies $Q^i(\theta^i,\rho)$ is monotone increasing. Note that if $x = y$, $Q^i(\theta^i,\rho)$ is obviously monotone increasing since we initially assumed that the valuation functions are monotone increasing in type for all agents. Therefore, the solution (12) satisfies all constraints in Theorem 1. □

Proof of Proposition 1. Suppose the welfare weights are decreasing in type. This implies $\sum_{i=1}^N \frac{F^i(\theta^i)-\Lambda^i(\theta^i)}{f^i(\theta^i)} < 0$. We know that the probability of public good production (the ratio of type profiles in which public good is produced) is equal to $Prob(y_\rho^{x=1} > 0) = Prob(\theta|\sum_{i=1}^N \theta^i + (\rho + \frac{1-\rho}{N})\sum_{i=1}^N \frac{F^i(\theta^i)-\Lambda^i(\theta^i)}{f^i(\theta^i)} \geq K)$. Now consider $\hat{\rho} > \rho$ and θ where $y^{x=1}(\rho,\theta) = 1$. It is easy to see that $Prob(y_\rho^{x=1} > 0) \geq Prob(y_{\hat{\rho}}^{x=1} > 0)$ since there is $\hat{\rho}$ such that $\sum_{i=1}^N \theta^i + (\rho + \frac{1-\rho}{N})\sum_{i=1}^N \frac{F^i(\theta^i)-\Lambda^i(\theta^i)}{f^i(\theta^i)} \geq K \geq \sum_{i=1}^N \theta^i + (\hat{\rho} + \frac{1-\hat{\rho}}{N})\sum_{i=1}^N \frac{F^i(\theta^i)-\Lambda^i(\theta^i)}{f^i(\theta^i)}$. Note also that if $y^{x=1}(\rho,\theta) = 0$ then $y^{x=1}(\hat{\rho},\theta) = 0$. Next consider $\rho > \tilde{\rho}$ and θ where $y^{x=1}(\rho,\theta) = 0$. Then $Prob(y_{\tilde{\rho}}^{x=1} > 0) \geq Prob(y_\rho^{x=1} > 0)$ since there is $\tilde{\rho}$ such that $\sum_{i=1}^N \theta^i + (\tilde{\rho} + \frac{1-\tilde{\rho}}{N})\sum_{i=1}^N \frac{F^i(\theta^i)-\Lambda^i(\theta^i)}{f^i(\theta^i)} \geq K \geq \sum_{i=1}^N \theta^i + (\rho + \frac{1-\rho}{N})\sum_{i=1}^N \frac{F^i(\theta^i)-\Lambda^i(\theta^i)}{f^i(\theta^i)}$. Note also that if $y^{x=1}(\rho,\theta) = 1$ then $y^{x=1}(\tilde{\rho},\theta) = 1$. The proof for the case of increasing welfare weights is also similar. □

Proof of Proposition 2. Given welfare weights and priors, let $\Theta^\rho = \{\theta|\sum_j W^j(\theta,\rho,\lambda^i) \geq K\}$ be the set of types where public good is produced by an IE mechanism ζ, given (ρ,γ). Let $\Theta^{\rho'} = \{\theta|\sum_j W^j(\theta,\rho',\lambda^i) \geq K\}$ be the set of types where public good is produced by ζ given (ρ',γ'). Note that for all $\rho^* \in [0,1]$ and all $\theta \in \Theta^{\rho^*}$, $\sum_{i=1}^N \theta^i \geq K$ since efficiency, interim incentive compatibility, and interim individual rationality are incompatible. This implies the adjustment term in modified virtual valuations is always negative. Suppose without loss of generality $\rho' < \rho$. We want to show that there are more information states of the economy where the public good is produced as the degree of altruism in preferences goes up, $\Theta^{\rho'} \supseteq \Theta^\rho$. Suppose on the contrary there is θ such that $\theta \in \Theta^\rho$ and $\theta \notin \Theta^{\rho'}$. Then

$$\sum_{i=1}^N \theta^i + (\rho + \frac{1-\rho}{N}) \left(\sum_{i=1}^N \frac{F^i(\theta^i) - 1}{f^i(\theta^i)} + \frac{\lambda^{0i}}{\gamma} \frac{1-\Lambda^i(\theta^i)}{f^i(\theta^i)} \right) \geq K$$

and

$$\sum_{i=1}^{N}\theta^i + (\rho' + \frac{1-\rho'}{N})\left(\sum_{i=1}^{N}\frac{F^i(\theta^i)-1}{f^i(\theta^i)} + \frac{\lambda^{0i}}{\gamma'}\frac{1-\Lambda^i(\theta^i)}{f^i(\theta^i)}\right) < K.$$

This is only possible if $\gamma' > \gamma$. We also know that $\gamma \geq \overline{\lambda}$ from first-order conditions. This implies

$$\Psi(\zeta,\rho) - \int_{\Theta^\rho} K dF(\theta) \geq \Psi(\zeta,\rho') - \int_{\Theta^{\rho'}} K dF(\theta) = 0$$

where

$$\Psi(\zeta,\rho') = \int_{\Theta^{\rho'}}\left(\sum_{i=1}^{N}\theta^i + (\rho' + \frac{1-\rho'}{N})\sum_{i=1}^{N}\frac{F^i(\theta^i)-1}{f^i(\theta^i)}\right) dF(\theta).$$

Let, without loss of generality, $\Theta^\rho = \{\theta | \sum_j \theta^j > A(\theta,K)\}$ and $\Theta^{\rho'} = \{\theta | \sum_j \theta^j > B(\theta,K)\}$. Since $(\rho' + \frac{1-\rho'}{N})\sum_{i=1}^{N}\frac{F^i(\theta^i)-1}{f^i(\theta^i)} > (\rho + \frac{1-\rho}{N})\sum_{i=1}^{N}\frac{F^i(\theta^i)-1}{f^i(\theta^i)}$ for all $\theta \in \Theta$, $B(\theta,K) > A(\theta,K)$. This implies if $\theta \in \Theta^\rho$ then $\theta \in \Theta^{\rho'}$, contradicting our initial assumption. $\square$

Proof of Proposition 3. Given welfare weights and priors, let Θ^ρ be the set of types where trade occurs given (ρ,γ) and $\Theta^{\rho'}$ be the set of types where trade occurs given (ρ',γ'). Let, without loss of generality, $\rho' < \rho$ (altruism in the preferences increases). We want to show that $\Theta^{\rho'} \supseteq \Theta^\rho$. Suppose on the contrary there exists θ such that $\theta \in \Theta^\rho$ but $\theta \notin \Theta^{\rho'}$. (We know that either $\Theta^{\rho'} \supseteq \Theta^\rho$ or $\Theta^{\rho'} \subseteq \Theta^\rho$.) This implies

$$\theta^b - \theta^s + \frac{1+\rho}{2}\left(\frac{F^b(\theta^b)-1}{f^b(\theta^b)} + \frac{\lambda^{0b}}{\gamma}\frac{1-\Lambda^b(\theta^b)}{f^b(\theta^b)} - \frac{F^s(\theta^s)}{f^s(\theta^s)} + \frac{\lambda^{0s}}{\gamma}\frac{\Lambda^s(\theta^s)}{f^s(\theta^s)}\right) \geq 0$$

and

$$\theta^b - \theta^s + \frac{1+\rho'}{2}\left(\frac{F^b(\theta^b)-1}{f^b(\theta^b)} + \frac{\lambda^{0b}}{\gamma'}\frac{1-\Lambda^b(\theta^b)}{f^b(\theta^b)} - \frac{F^s(\theta^s)}{f^s(\theta^s)} + \frac{\lambda^{0s}}{\gamma'}\frac{\Lambda^s(\theta^s)}{f^s(\theta^s)}\right) \leq 0.$$

This is only possible if $\gamma' > \gamma \geq \overline{\lambda}$. This implies $\Psi(\zeta,\rho') = 0$. Since $\rho > \rho'$ and trade does not occur in ρ', we have

$$\theta^b - \theta^s + \frac{1+\rho}{2}(\frac{F^b(\theta^b)-1}{f^b(\theta^b)} - \frac{F^s(\theta^s)}{f^s(\theta^s)}) \leq \theta^b - \theta^s + \frac{1+\rho'}{2}(\frac{F^b(\theta^b)-1}{f^b(\theta^b)} - \frac{F^s(\theta^s)}{f^s(\theta^s)}) \leq 0.$$

We know that trade occurs for θ in ρ. Hence,

$$\Psi(\zeta,\rho) = \int_{\Theta^\rho}\left[\theta^b - \theta^s + \frac{1+\rho}{2}\left(\frac{F^b(\theta^b)-1}{f^b(\theta^b)} - \frac{F^s(\theta^s)}{f^s(\theta^s)}\right)\right] dF(\theta) \leq \Psi(\zeta,\rho') = 0.$$

This is a contradiction since γ is chosen by the algorithm such that $\Psi(\zeta,\rho) \geq 0$. $\square$

References

[1] Fehr, E. and K. Schmidt (1999): "A Theory of Fairness, Competition and Cooperation," *Quarterly Journal of Economics*, 114, 817–868.

[2] Fehr, E. and K. Schmidt (2006): "The Economics of Fairness, Reciprocity and Altruism Experimental Evidence and New Theories", in S. Kolm, J.M. Ythier, eds., Handbook of the Economics of Giving, Altruism and Reciprocity, Volume 1, Foundations, 615–691.

[3] Gresik, T. (1991): "Ex Ante Incentive Efficient Trading Mechanisms without the Private Valuation Restriction," *Journal of Economic Theory*, 55, 41–63.

[4] Holmstrom, B. and R.B. Myerson (1983): "Efficient and Durable Decision Rules with Incomplete Information," *Econometrica*, 51, 1799–1819.

[5] Jackson, M (2003): "Mechanism Theory", The Encyclopedia of Life Support Systems , EOLSS Publishers Co. Ltd, United Kingdom.

[6] Ledyard, J.O. (1995): "Public Goods: A Survey of Experimental Research," in John Kagel and Alvin Roth, eds., Handbook of Experimental Economics. Princeton, NJ: Princeton University Press, pp. 111-194.

[7] Ledyard, J.O. and T.R. Palfrey (2007): "A General Characterization of Interim Efficient Mechanisms for Independent Linear Environments," *Journal of Economic Theory*, 133, 441–466.

[8] Myerson R. (1981): "Optimal Auction Design," *Mathematics of Operations Research*, 6, 58–73.

[9] Myerson R. and M. Satterthwaite (1983): "Efficient Mechanisms for Bilateral Trading," *Journal of Economic Theory*, 28, 265–281.

[10] Rochet, J.C. (1987): "A Necessary and Sufficient Condition for Rationalizability in a Quasi-Linear Context," *Journal of Mathematical Economics*, 16, 191–200.

[11] Wilson, R. (1985): "Incentive Efficiency of Double Auctions," *Econometrica*, 53, 1101–1116.