THE HUMAN SIDE OF MECHANISM DESIGN
A Tribute to Leo Hurwicz and Jean-Jacque Laffont

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ABSTRACT

This paper considers the human side of mechanism design, the behavior of economic agents in gathering and processing information. Economic juries charged with evaluating economic policy alternatives are the focus of this study. The selection and management of juries is a principle-agent problem involving the design of incentive mechanisms for participation and truthful revelation of values. This paper considers a simple general equilibrium economy in which juries of consumers are used to estimate the value of public projects. The impact of participation fees on jury selection and representativeness, and on statistical mitigation of response errors, is analyzed. Two incentive-compatible mechanisms for elicitation of public project preferences from juries, the Groves-Clarke mechanism in a version formulated by Green and Laffont, and a mechanism adapted by Palfrey and Rosenthal from the Becker-DeGroot-Marschak auction mechanism, are considered in the context of contingent valuation surveys. The paper concludes with an outline of some behavioral evidence on the performance of jury incentive mechanisms.

KEYWORDS: mechanism_design, principal-agent_problem, juries, welfare_theory

JEL CLASSIFICATION: D000, D600, D610, D710, D800, C420, C700

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1. Introduction

The study of mechanism design, the systematic analysis of resource allocation institutions and processes, has been the most fundamental development in economics in the last half-century, revealing the roles of information, incentives, and agent processing capacity in decentralized resource allocation, and allowing identification of sources of market failure. This paper is a tribute to Leo Hurwicz, who first recognized the core issue of mechanism design in resource allocation problems and formalized its theoretical foundations, and to Jean-Jacques Laffont, who was at the center of the translation of the foundational economic theory into the language and tools that today appear in game theory, in studies of the organization of firms and markets, and in the applied economics of regulation, taxation, and public good provision. Thinking about transactions among economic agents in terms of information and incentives now threads through and connects pure and applied research across economics. The discipline itself has been transformed, from observers and commentators on economic systems to architects who design incentives and engineer, implement, and test institutions.[2]

Figure 1 is a schematic outline of the economic topics that have developed from or been enriched by mechanism design theory. The first major branch is the study of information in resource allocation, emphasized in the seminal works of Ken Arrow and Jacob Marschak, with important applications to the behavior of markets with asymmetric information (George Akerlof, Mike Spence, Joe Stiglitz), to principal-agent problems and the design of efficient contracts (Peter Diamond, Oliver Hart, Jean-Jacques Laffont, Eric Maskin, Jim Mirrlees, Sherwin Rosen), to governance and the operation of teams (Oliver Williamson, Roy Radner), and to the pure theory of economic games (Robert Auman, Drew Fudenberg, Eric Maskin, Andy Postelwaite, Stan Reiter, Jean Tirole). The second major branch is the theory of incentives, emphasized in the work of Vickery, and applied to the

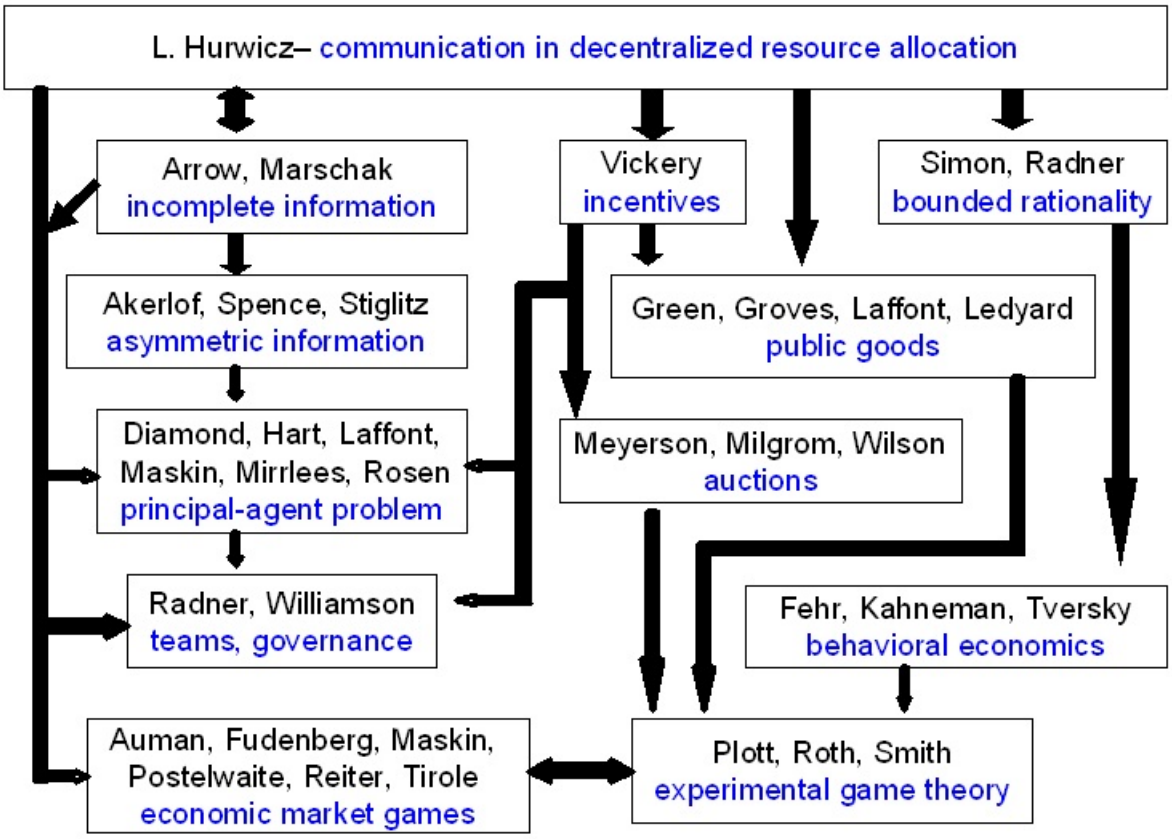
[2] Excellent general surveys of current issues in the theory of mechanism design can be found in Klemperer (2004), Krishna (2002), Maskin (2007), and Milgrom (2004).

problem of social decisions on public goods (Jerry Green, Ted Groves, Jean-Jacques Laffont, John Ledyard) and the design of auctions (Roger Meyerson, Paul Milgrom, Robert Wilson). The third major branch is the analysis of bounded rationality, the limited ability of economic agents to process information and consistently advance their self-interest. From the early study of bounded rationality by Herb Simon, the fields of behavioral economics (Ernst Fehr, Danny Kahneman, Amos Tversky) and experimental game theory (Vernon Smith, Charles Plott, Al Roth) have developed. There are important interconnections between the three major branches, with incentive theory playing a major role in principal-agent problems and in governance, and the reliability of information playing a major role in public goods decisions and economic games. Studies of auctions and of public good provision fueled the development of behavioral economics and experimental game theory. Particularly valuable contributions were made by Ken Arrow, Peter Diamond, Jean-Jacques Laffont, Eric Maskin, Roy Radner, and Jean Tirole, who recognized the span of mechanism design theory across the three major branches, and were instrumental in establishing interconnections and applications. Indicators of the impact of mechanism design on economics are the ten Nobel prizes awarded to names listed in Figure 1, and recognition that many other names in this figure are serious Nobel candidates.

The focus of the first formalization of mechanism design theory by Hurwicz (1960) was on the communication required to provide enough reliable information to each agent to achieve efficient one-time resource allocation. An elegant extension of the formal theory to incorporate stochastic and dynamic elements is accomplished by introducing information sets and state-dependent preferences; see Arrow (1953), Debreu (1959), Diamond (1967), Hurwicz, Reiter, and Radner (1975), and Radner (1972). This extension has produced important insights, but it left implicit the *process* that economic agents adopt to collect and draw inferences from statistical information. An alternative analysis starts with agents who face the *econometric* problem of collecting data from communications, distinguishing signal from noise, and learning about their environment. Modern communications technology illustrates the usefulness of this approach -- the bandwidth required to stream music or

images is greatly reduced because one need transmit only enough information to reconstruct *changes* with sufficient resolution. Mean information requirements determined by sequential error-correction are typically far less than worst case requirements. Analogously, the communication needed to support nearly efficient trade from a reference allocation may be substantially less than that required to determine an efficient allocation from scratch.

Figure 1. Mechanism Design: The Flow



A premise that pervades the theory of mechanism design is that economic agents act in their self interest. The binding constraint on efficient resource allocation is then the amount and reliability of the information agents receive on the nature of goods and the interests of other agents. This premise has two important implications. First, if mechanism design provides suitable institutions, communication channels, and incentives to ensure reliability, then agents will take care of the rest. Second, central planners lack the bandwidth, computational capacity, and incentives to achieve efficient resource allocation, but individual agents do have sufficient capacity to deal optimally with the more limited information relevant to them and decisions they face.

This paper reconsiders the premise that economic agents consistently recognize and advance their self-interest, and explores the opportunities for economic analysis afforded by treating economic agents as statisticians in a stochastic environment. Neither of these considerations is new. The processing limits of economic agents have been studied since the works of Simon, Kahneman, and Tversky, and figure regularly in behavioral economics. Bayesian learning models are prominent in experimental game theory. Nevertheless, there continue to be new findings on the nature of human decision-making, and opportunities for further research on designing mechanisms that are tolerant of human processing limits.

The first part of this paper applies mechanism design theory to the econometric problem of eliciting information from subjects in economic surveys and on economic juries, particularly direct revelation of truthful preferences for public projects. An issue in this application is that respondents may fail to recognize or act in their self-interest, making their rationality an issue in evaluating the incentive-compatibility of mechanisms. Attributes of human choice behavior are bounded attention, memory limits, reasoning limits, and sociality – the proclivity of humans to imitate others and to be guided by norms of reciprocity and altruism. These attributes can blur the links from incentives to individual decisions to social consequences that rational, individualistic preference maximizers should exhibit. The second part of the paper asks whether failures to respond to incentives

that often appear in laboratory experiments are significant in circumstances where incentives are large and consequences substantial.

2. Economic Juries

A *jury* is a group of experts utilized to reach a valuation, finding of fact, or verdict. Jury responses may fail to represent the public interest if selection makes a jury unrepresentative, or if jurors fail to receive, recognize, and respond rationally to incentives to provide accurate information. The selection and motivation of juries is a principal-agent problem. *Ex ante*, jurors may be given incentives for participation, effort, and truthful responses. Experimental treatments can be embedded in the incentive mechanisms to facilitate *ex post* statistical analysis to identify and mitigate response errors. Considering incentive mechanisms and statistical mitigation in tandem can improve the reliability of information collected from juries.

In this paper, I define economic juries expansively to include samples and participants in experiments whose responses influence economic policy, and concentrate on the direct elicitation of truthful preferences for public projects. Section 3 sets out a simple general equilibrium economy that is convenient for analyzing public projects, and describes the role that juries of consumers can play in public project decisions. Section 4 examines the impact of participation fees on jury selection and representativeness. Section 5 analyzes two incentive-compatible mechanisms for elicitation of public project preferences from juries, the Groves-Clarke mechanism in a form developed by Green and Laffont, and a mechanism adapted by Palfrey and Rosenthal from the Becker-DeGroot-Marschak auction mechanism. Section 6 considers the application of jury incentives in contingent valuation surveys for public good valuation, and concludes with an outline of some behavioral evidence on the performance of jury incentive mechanisms.

3. Optimal Provision of Public Projects

I adapt the framework of Green and Laffont (1977, 1979) to describe the public project decision problem; the following setup also draws upon Groves and Leob (1975), Groves and Ledyard (1977), Laffont and Martimort (2002), Maskin (2004), and McFadden (1999, 2004). Consider a simple general equilibrium model with consumers indexed n = 1,...,N who have risk-neutral indirect utility functions of Gorman polar form,

$$(1) \qquad u_n = V(y_n - t_n,p,x;\theta_n^*) \equiv [y_n - t_n - B(p,x,\theta_n^*)]/A(p) ,$$

where x is a vector contained in a compact set X that indexes public projects, with x = 0 denoting the status quo, p is a finite-dimensional vector of prices of private market goods, with p contained in a cone P whose interior is the positive orthant, y_n is consumer income, t_n is consumer tax earmarked to pay for x, θ_n^* is the consumer's type from a compact universe Θ, and A and B are continuous functions in their arguments that are conical, concave, closed, and non-decreasing in p.[3] Consumer income and tax may depend on p and x. The function $B(p,x,\theta_n^*)$ is committed expenditure, and the function A(p) is a price index. The preferences (1) are well-defined when consumer income net of tax is sufficient to cover committed expenditure. Beyond compactness, the set X is not restricted, so that it can index provision of discrete public projects, such as a decision to ban whale hunting, or continuous provision, such as the area of tropical forest protected from development. Mutually exclusive or linked public projects can be analyzed since X need not be convex. This model of the Gorman preference field can, by reinterpretation of x, also handle hedonic characteristics of public and private goods regulated by a social planner.

[3] I use the conventional terminology that a concave function A(p) is *conical* if it is homogeneous of degree one, and *closed* if its epigraph $\{(p,a)\in P\times\mathbb{R}|a\leq A(p)\}$ is a closed set. A closed concave function is continuous on the interior of P, and finite and upper semicontinuous on $P = \{p|A(p) > -\infty\}$. When income net of tax is sufficient to cover committed expenditure, the Gorman polar form is dual to the preferences $U(z,x,\theta_n) = \inf_{p\in P} V(p\cdot z,p,x;\theta_n) \equiv \inf_{p\in P} [p\cdot z - B(p,x,\theta_n)]/A(p)$.

Because A(p) is common to all consumer types, the Gorman indirect utilities (1) average to a utilitarian social per capita indirect utility function

$$(2) \qquad W(Y-T,p,x,\boldsymbol{\theta}^*) \equiv [Y-T-\textstyle\sum_{n=1}^{N} B(p,x,\theta_n^*)]/N\cdot A(p),$$

where Y is aggregate consumer income, T is aggregate tax, and $\boldsymbol{\theta} = (\theta_1,...,\theta_N)$. The welfare function (2) is the indirect utility of a representative consumer for the economy so that the economy has private good demands that satisfy Roy's identity applied to (2).[4] This "parallel Engle Curves" property makes (1) consistent with the quasi-linear utility assumption of Green and Laffont (1977). The private good demands are independent of the distribution of income as long as all incomes net of tax are sufficient to sustain committed expenditure. The Gorman preferences (1) give a simple, explicit characterization of private good equilibrium and optimal public project provision, but are less general than the treatment of public goods preferences by Groves and Ledyard (1979). Further discussion of the aggregation properties of Gorman preference fields is given in Chipman and Moore (1980, 1990) and McFadden (1999, 2004).

Assume that consumer income $y_n = f_n(p,x)$ is a convex, closed, conical function of p determined by the value of resource endowments, profit from the production of private goods, and incomes policy, that the consumer tax $t_n = g_n(p,x,\zeta)$ is a concave, closed, conical function of p, determined by the payment vehicle for x and a stochastic variable ζ

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[4] Roy's identity applied to (1) gives private good demands

$$z_n \in \nabla_p B(p,x,\theta_n) + (y_n - t_n - B(p,x,\theta_n))\nabla_p A(p)/A(p),$$

where "∇_p" denotes the subgradient correspondence, which always exists because A and B are concave, and is almost everywhere single-valued. Aggregating gives

$$Z \in \textstyle\sum_{n=1}^{N} \nabla_p B(p,x,\theta_n) + (Y - T - \sum_{n=1}^{N} B(p,x,\theta_n))\nabla_p A(p)/A(p),$$

which coincides with the result of applying Roy's identity to $W(Y-T,p,x,\boldsymbol{\theta})$.

that is known to the planner before x is determined and satisfies $g_n(p,0,\zeta) = 0$, and that f_n and g_n are continuous in their arguments. Then, aggregate consumer income and aggregate tax satisfy

$$(3) \qquad Y = F(p,x) \equiv \sum_{n=1}^{N} f_n(p,x) \quad \textit{and} \quad T = G(p,x,\zeta) \equiv \sum_{n=1}^{N} g_n(p,x,\zeta),$$

and $G(p,x,\zeta)$ is the cost of x. Assume that it is always feasible to provide each consumer with sufficient income net of taxes to cover committed expenditure.[5]

The private goods market clears when prices, given $\boldsymbol{\theta}$, x, ζ, and incomes policy, satisfy[6]

$$(4) \qquad p(\boldsymbol{\theta},x,\zeta) \in \operatorname{argmin}_{p\in P} W(F(p,x)-G(p,x,\zeta),p,x,\boldsymbol{\theta}).$$

Consumer n's real Willingness-to-Pay WTP(x,r) for public project x can be measured by the *compensating variation*, the net reduction in real income at x that leaves the consumer indifferent,

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[5] The assumption of sufficiency is satisfied, for example, if each consumer can subsist on her private endowment ω_n, or $p\cdot\omega_n > B(p,x,\theta_n^*)$, and there is a public endowment ω_0 sufficient to produce any public project vector in X. Sufficiency may also be achieved as a result of fiscal policy when $F(p,x) - G(p,x)$ exceeds $\sum_{n\le N} B(p,x,\theta_n^*)$ for all p, x. If the technology of the economy is compact, then F is finite for p in the non-negative unit simplex S and all $x \in X$. Shephard's identity gives private good supply net of inputs to public projects, $Q = \nabla_p F(p,x) - \nabla_p G(p,x,\zeta)$, where ∇_p denotes the subgradient correspondence, which always exists because of the convexity of F - G, and is almost everywhere single-valued.

[6] The assumptions on A, B, F, and G, and the sufficiency of income net of taxes, guarantee that the social indirect utility function $W(F(p,x)-G(p,x,\zeta),p,x,\boldsymbol{\theta})$ is non-negative, convex, closed, and homogeneous of degree zero in p on P, and is continuous on X. Hence the minimum of this function in p with $\|p\| = 1$ exists for each x and is continuous in x, and the minimand $p(\boldsymbol{\theta},x,\zeta)$ is a correspondence that is upper hemicontinuous on X. The net private good supply of the economy is contained in the scaled subgradient correspondence

$$A(p)\cdot\nabla_p W(F(p,x)-G(p,x,\zeta),p,x,\boldsymbol{\theta})$$
$$=\nabla_p F(p,x)-\nabla_p G(p,x,\zeta)-\sum_{n=1}^{N}\nabla_p B(p,x,\theta_n)+(F(p,x)-G(p,x,\zeta)-\sum_{n=1}^{N} B(p,x,\theta_n))\nabla_p A(p)/A(p);$$

then, the minimand $p(\boldsymbol{\theta},x,\zeta)$ achieves balance in private goods markets and defines a competitive equilibrium for each x,ζ and profile of consumer types $\boldsymbol{\theta}$.

$$\frac{f_n(p(\boldsymbol{\theta}^*,x,\zeta),x) - g_n(p(\boldsymbol{\theta}^*,x,\zeta),x,\zeta) - B(p(\boldsymbol{\theta}^*,x,\zeta),x,\theta_n^*)}{A(p(\boldsymbol{\theta}^*,x,\zeta))} - WTP_n(x,\zeta)$$

$$= \frac{f_n(p(\boldsymbol{\theta}^*,0,\zeta),0) - B(p(\boldsymbol{\theta}^*,0,\zeta),0,\theta_n^*)}{A(p(\boldsymbol{\theta}^*,0,\zeta))};$$

see McFadden (2004).

The socially optimal provision of public projects when consumer types $\boldsymbol{\theta}$ are known is

(5) $$x^*(\boldsymbol{\theta},\zeta) \in \operatorname{argmax}_{x\in X} W(F(p(\boldsymbol{\theta},x,\zeta),x,\zeta)-G(p(\boldsymbol{\theta},x,\zeta),x,\zeta),p(\boldsymbol{\theta},x,\zeta),x,\boldsymbol{\theta}) .$$

Combining (4) and (5), the competitive equilibrium in private goods and the optimal provision of public projects are determined by the saddle point

(6) $$\max_{x\in X} \min_{p\in P} W(F(p,x)-G(p,x,\zeta),p,x,\boldsymbol{\theta}).$$

Let $p^*(\boldsymbol{\theta},\zeta)$ denote the equilibrium private goods prices and $x^*(\boldsymbol{\theta},\zeta)$ denote the optimal public projects provision obtained from (6).[7] Note that $p^*(\boldsymbol{\theta},\zeta) = p(\boldsymbol{\theta},x^*(\boldsymbol{\theta},\zeta),\zeta)$, that $x^*(\boldsymbol{\theta},\zeta)$ is invariant under permutation of $\boldsymbol{\theta}$, let $\boldsymbol{\theta}_{-n}$ denote the vector of types of consumers other than n, and write $x^*(\theta_n,\boldsymbol{\theta}_{-n},\zeta)$ to isolate the effect of consumer n's type.

In many applications, X is a finite set, aggregate consumer income F(p) is independent of x, total project cost is specialized to $G(p,x,\zeta) = N\cdot A(p)\cdot r(x,\zeta)$, where $r(x,\zeta)$ is the real per

[7] Welfare $W(F(p(\boldsymbol{\theta},x,\zeta),x)-G(p(\boldsymbol{\theta},x,\zeta),x,\zeta),p(\boldsymbol{\theta},x,r),x,\boldsymbol{\theta})$ evaluated at private-market equilibrium prices $p(\boldsymbol{\theta},x,\zeta)$, is continuous on the compact domain X, so that $x^*(\boldsymbol{\theta},\zeta)$ and $p^*(\boldsymbol{\theta},\zeta) = p(\boldsymbol{\theta},x^*(\boldsymbol{\theta},\zeta),\zeta)$ exist. They are not necessarily unique. The vector $(x^*(\boldsymbol{\theta},\zeta),p^*(\boldsymbol{\theta},\zeta))$ defines an equilibrium when true consumer types are known, and consumers treat p^*, x^* and their income functions as given and not subject to strategic manipulation. The setup given here coincides with Green and Laffont (1977), with the minor exceptions that I allow the quasi-linear Gorman utility to be influenced by interactions between public projects and private goods, and include a public project cost factor ζ that may be unknown to consumers when they communicate with the planner.

capita cost of x, and indirect utility is $V_n(y_n,p,x;\theta_n) = [y_n - t_n - B_n(p)]/A(p) + v_n(x)$, with $v_n(0) = 0$ and $\theta_n = (v_n(\cdot),B_n(\cdot))$. Then, the social per capita indirect utility function specializes to

$$(7) \qquad W(F(p) - G(p,x,\zeta),p,x,\boldsymbol{\theta}^*) \equiv [F(p)- \textstyle\sum_{n\le N} B_n(p)]/N\cdot A(p) + v^{**}(x) - r(x,\zeta),$$

where $v^{**}(x) = \sum_{n\le N} v_n^*(x)/N$ is the true social value per capita of x, the market-clearing private good prices p* minimize $[F(p) - \sum_{n\le N} B_n(p)]/A(p)$ over $p \in P$ and are independent of r and v**, and the optimal $x^*(v^{**},\zeta)$ maximizes $v^{**}(x) - r(x,\zeta)$ over $x \in X$, independently of private good prices.[8] Then consumer n has $WTP_n(x,\zeta) = v_n^*(x) - r_n(x,\zeta)$, and $x^*(v^{**},\zeta)$ maximizes average WTP.

Now suppose that consumer types are not known to the social planning principal, and the value of public projects must instead be learned from consumers. I will assume that the principal selects a jury and elicits stated values from the jury members, using incentive mechanisms to minimize welfare losses from selection bias, reporting error due to strategic misrepresentation or carelessness, and statistical variation. The use of a jury for public projects decisions was first suggested by Green and Laffont (1979) in their analysis of the Groves-Clarke mechanism. The first reason to consider public project juries is that incentive mechanisms to induce truthful value reports from the whole population may require income transfers that are inconsistent with general equilibrium balance. This difficulty is eliminated if non-jurors are assigned residual income. Second, a population-wide elicitation will as a result of attrition lead to a *de facto* self-selected jury. It is statistically sounder to control jury selection through random sampling and fees for participation. Third, if juries are small and members are elicited independently, then there is less opportunity for formation of coalitions that can upset the incentive-compatibility of mechanisms. Fourth, the effectiveness of incentives for truthful reporting of values

[8] A further specialization is $v(x) = v_1x_1 + ... + v_Kx_K$ and $r(x) = r_1x_1 + ... + r_Kx_K$, where v_k and r_k are unit value and cost for public project k. For example, $X = \{(0,0),(1,0),(1,1)\}$ gives the case of a single public project available in 0,1, or 2 units, with a value v_1 for the first unit and a value $v_1 + v_2$ for both units.

requires respondents to recognize and respond rationally to the possibility that they will be pivotal. However, humans are inconsistent in their response to low probability events, and the possibility of being pivotal may be too remote to induce rational response in large juries.

In Section 4, I will assume that an elicitation mechanism is used that ensures that juror self-reports of values are truthful, and will examine participation selection bias and sampling variation in the jury selection mechanism. In Section 5, I will instead take the selected jury as given, and analyze incentive-compatible elicitation mechanisms.

4. Jury Selection and Participation Incentives

Agent participation in the case of a single agent has been studied by Grossman and Hart (1983), Jewitt (1988), and Laffont and Martimort (2002, Ch. 3,5). Philipson (1997, 1999, 2001) and Ryu, Couper, and Marans (2005) show that sample recruitment is a similar problem, except that rather than elicit the participation of a single agent, the principal now wants to control selection bias by recruiting as representative a jury of agents as possible. Factors entering this problem are the costs of contacting prospects and eliciting information from jurors, the effect of fees on participation, and the costs of a non-representative sample. An important feature of this problem is that participation fees, public projects presented, and incentives are treatments under the control of the planner that can be designed to identify and mitigate response errors.

I will analyze juror participation and response using a variant of the bivariate selection model originally introduced by Heckman (1974), and analyzed by Imbens and Newey (2002) and Chesher (2005). This model extends the univariate selection analysis of Philipson (1997), and is a special recursive case of systems of nonparametric simultaneous equations for which Matzkin (2006) has provided identification conditions and estimators.

An indicator for participation (d=1) or attrition (d= -1) is determined by

(8) $d = \text{sign}(g(z,m) - \eta)$

where η is a standard normal disturbance and g is a function that is increasing in the participation fee m and influenced by observed exogenous variables z. Then, the conditional probability for participation is $\text{Prob}(d|z,m) = \Phi(d \cdot g(z,m))$. Assume that m is drawn from a design distribution $F_M(m)$ chosen by the planner, and that the population density $f_Z(z)$ and the average participation rate p(m) are known or can be estimated consistently from population data and observations on attrition. Let $f_Z(z|m,d=1)$ denote the conditional density of z, given m, among participants. Then, Bayes' law implies

(9) $\text{Prob}(d=1|z,m) = \Phi(g(z,m)) = f_Z(z|m,d=1)p(m)/f_Z(z).$

The stated value $v \geq 0$ of a portfolio of public projects x is described by a model

(10) $\varepsilon = h(v,y,x,\eta),$

where ε is a standard normal disturbance that is independent of η, and h is increasing in v and is influenced by exogenous variables y that may overlap z. When the shapes of g and h are not restricted, there is no loss of generality in the assumption that η and ε are independent standard normal.[9] Eliciting stated values for alternative public project portfolios x corresponds to a system of equations (10), with v(x) and ε(x) indexed by x. Note that in general ε(x) will be correlated across x. Let $F_{V|y,x}(v) = \int_{-\infty}^{+\infty} \Phi(h(v,y,x,\eta))\varphi(\eta)d\eta$

[9] Statistical independence of η and ε is attained by construction, with all dependence of valuation on participation expressed through the η argument in h; see McFadden and Train (2000). Increasing transformations, absorbed into g and h, make η and ε standard normal. An implication of the transformation to normality is $\sup_v h(v,y,x,\eta) = +\infty$ and $h(0,y,x,\eta) = -\infty$.

denote the population CDF of v given y, x. The conditional CDF of v in the participating jury is

$$(11) \qquad F_{V|y,x,z,m,d=1}(v) = \int_{-\infty}^{g(z,m)} \Phi(h(v,y,x,\eta))\varphi(\eta)d\eta/\Phi(g(z,m)).$$

Following Manski (2005), $F_{V|y,x}(v)$ is bounded for given z,m by

$$(12) \qquad F_{V|y,x,z,m,d=1}(v)\Phi(g(z,m)) \le F_{V|y,x}(v) \le F_{V|y,x,z,m,d=1}(v)\Phi(g(z,m)) + \Phi(-g(z,m)).$$

When v satisfies $0 \le v \le v^{\#}$, with $v^{\#}$ a known upper bound, (12) implies

$$\Phi(g(z,m))\mu_k(y,x,z,m) \le \mathbf{E}_{V|y,x}(v^k) \le \Phi(g(z,m))\mu_k(y,x,z,m) + \Phi(-g(z,m))(v^{\#})^k$$

where

$$\mu_k(y,x,z,m) = \mathbf{E}_{V|y,x,z,m,d=1}(v^k) = \int_0^{v^{\#}} v^k F_{V|y,x,z,m,d=1}(dv)$$

is a juror's k-th moment of v. When h is non-increasing in η, the bounds (12) can be sharpened to

$$F_{V|y,x,z,m,d=1}(v)\Phi(g(z,m)) \le F_{V|y,x}(v) \le F_{V|y,x,z,m,d=1}(v)\Phi(g(z,m)) + \Phi(h(v,y,x,g(z,m)))\Phi(-g(z,m)),$$

and when h is non-decreasing in η, to

$$F_{V|y,x,z,m,d=1}(v)\Phi(g(z,m)) + \Phi(h(v,y,x,g(z,m)))\Phi(-g(z,m)) \le F_{V|y,x}(v) \le F_{V|y,x,z,m,d=1}(v)\Phi(g(z,m)) + \Phi(-g(z,m)).$$

Consider estimation of the model described by (8) to (11). First, $\Phi(g(z,m))$ can be estimated on the support of (z,m) by plugging in non-parametric estimates of the terms on the right-hand-side of (9). It may be useful to test if a semi-parametric structure, such as $g(z,m) = g_1(z) + g_2(z)\cdot m^{\gamma}$, adequately approximates the tail behavior of g(z,m). Alternately, if g(z,m) is parametric, then $\log \Phi(g(z,m))$ is the kernel of the log likelihood of z, given m and participation.

If attrition occurs "at random", then h(v,y,x) and $F_{V|y,x}(v) = \Phi(h(v,y,x))$ do not depend on η, and their estimation is not influenced by attrition. In this case, the primary purpose of participation fees is to minimize expected survey cost per completed interview. However, if h does depend on η, attritors have a different distribution of values than participants, and consistent estimation of the model must account for the effects of attrition. In either case, if attrition rates vary with z, it will be necessary in forming estimates of population means to weight jury observations by $\omega(z,m) = f_Z(z)/f_Z(z|m,d=1)$. The exogenous variables y in (10) satisfy $f_Y(y|z) = f_Y(y|z,m,d=1)$ by construction, since all exogenous variables that influence attrition are included in z. Thus, the weights ω(z,m) also apply to population means estimated from observations drawn from $F_{V|y,x,z,m,d=1}(v)$.

In case attrition is not "at random", differentiate (11) with respect to m,

$$\partial F_{V|y,x,z,m,d=1}(v)/\partial m = [\Phi(h(v,y,x,g(z,m))) - F_{V|y,x,z,m,d=1}(v)]g_m(z,m)\varphi(g(z,m))/\Phi(g(z,m)),$$

and invert to obtain

$$(13)\quad h(v,y,x,g(z,m)) = \Phi^{-1}(F_{V|y,x,z,m,d=1}(v) + [\Phi(g(z,m))/g_m(z,m)\varphi(g(z,m))]\cdot\partial F_{V|y,x,z,m,d=1}(v)/\partial m).$$

One can plug in estimates of g(z,m) and $F_{V|y,x,z,m,d=1}(v)$, and their derivatives with respect to m, to obtain an estimate of h(v,y,x,g(z,m)) on its support, and vary m to map out the function h(v,y,x,η). Note that in a fully nonparametric setup, the curse of dimensionality will

limit the accuracy with which g(z,m) and $F_{V|y,x,z,m,d=1}(v)$ can be estimated from juries of moderate size. For further analysis, I circumvent this problem by assuming that the number of configurations of (z,y,x) is finite, that p(m) = $\mathbf{E}_Z\Phi(g(z,m))$ is known, and that h is at least twice continuously differentiable in v and η with h_v bounded positive. Then, $F_{V|y,x,z,m,d=1}(v)$ and the moments $\mu_k(y,x,z,m)$ are estimable from J observations at a $J^{1/3}$ rate, and $\mathbf{E}_M\,\mu_k(y,x,z,m)$ is estimable at a $J^{½}$ rate. However, limiting large appearance fees to control costs will lead to less precise estimates of h at large η. If $g(z,m^*) < +\infty$, where m* is an upper bound on appearance fees, then h is unidentified for $\eta > g(z,m^*)$ and $F_{V|y,x}(v)$ is identified only up to the bounds (12). The method of Horowitz and Manski (1995), Manski (2005), and Imbens and Manski (2005) can be used to attach confidence intervals to the partially identified distribution $F_{V|y,x}(v)$ and its mean $\mathbf{E}_{V|y,x}(v)$. Alternately, in the semi-parametric case that η enters (11) additively, $h(v,y,x,\eta) = (1+\lambda^2)^{½}\,h^*(v,y,x) - \lambda\eta$, one has

$$(14) \qquad F_{V|y,x}(v) = \Phi(h^*(v,y,x))$$

with $\mathbf{E}_{V|y,x}(v^k) = k\int_0^\infty v^{k-1}\Phi(-h^*(v,y,x))dv$;

$$(1+\lambda^2)^{½}h^*(v,y,x) = \lambda g(z,m)) + \Phi^{-1}(F_{V|y,x,z,m,d=1}(v) + [\Phi(g(z,m))/g_m(z,m)\varphi(g(z,m))]\cdot\partial F_{V|y,x,z,m,d=1}(v)/\partial m);$$

$$f_{V|y,x}(v) = f_{V|y,x,z,m,d=1}(v)\Phi(g(z,m))/\Phi((1+\lambda^2)^{½}g(z,m) - \lambda h^*(v,y,x)).$$

The required invariance of these expressions in m can be used to estimate λ, test the consistency of the specification, and identify and estimate $F_{V|y,x}(v)$.

The mechanism design problem is to choose a jury size J and a distribution of participation fees $F_M(m)$ to minimize welfare loss due to inaccurate estimation of the social value of public projects. Assume that the social per capita welfare function is specialized to the form (7), that there is a single discrete public project, so that X = {0,1}, and that the

per capita cost r = r(1) of the public project has a positive density $f_R(r)$ over the relevant range. Recall that $p(m) = \mathbf{E}_Z \Phi(g(z,m))$ is the average participation rate. Then $p(m)f_M(m)/\int p(m')F_M(dm')$ is the density of fees paid to participants. Assume that there is a real cost c_1 of contacting a potential juror and a real cost c_2 of collecting a juror's information on values. Then the expected real cost per juror is

$$C = c_1 / \int_0^\infty p(m) F_M(dm) + c_2 + \int_0^\infty m p(m) F_M(dm) / \int_0^\infty p(m) F_M(dm). \tag{15}$$

In the U.S. in 2007, typical costs are c_1 = \$5 and c_2 = \$60 for a 30 minute telephone interview, and the probability of participation is roughly p(m) = (0.01+0.19 m)/(1 + 0.2 m). Then, if jury costs were the only consideration, they would be minimized by setting a single participation fee at about m = \$5, yielding an average participation rate of about 50 percent and an expected cost per juror of \$75. Alternately, the conventional standard of an 80 percent participation rate for a "representative" survey would require a participation fee of \$25 and a total cost of \$91 per juror.

The expected per capita welfare loss from providing the public project is obtained by comparing per capita welfare (7) when types are known and public project supply is optimal with per capita welfare when the cost of a jury of size J is subtracted from aggregate income and the public project is provided when a value $v' = v(1)$, determined from the self-reported values of jurors, exceeds r. Letting $v^{**} = \mathbf{E}_Y \mathbf{E}_{V|y,x}(v)$ denote the true population per capita value of the public project, and f_R the density of $r(1,\zeta)$ induced by ζ, the difference is

(16) $$\text{Loss} = CJ/N + E_{V'}\left|\int_{v^{**}}^{v'} |v^{**}-r| f_R(r)dr\right|$$

$$= CJ/N + \int_0^{v^{**}} (v^{**}-r)G_V(r)f_R(r)dr + \int_{v^{**}}^{\infty} (r-v^{**})(1-G_V(r))f_R(r)dr$$

$$= CJ/N + \int_0^{\infty} (r-v^{**})[1-G_V(r)]f_R(r)dr + \int_0^{v^{**}} (v^{**}-r)f_R(r)dr,$$

where $G_{V'}$ denotes the distribution function of the jury threshold value.

A full minimization of the loss (16) through choice of the design distribution $F_M(m)$ and the jury size J requires quantification of the impact of attrition and jury size on $G_{V'}$, and more critically, prior information on the structure of welfare that is most consistently handled in a Bayesian decision framework. However, simplifying approximations give some indication of the nature of the solution. Letting $v^{\%}$ and σ^2/J denote the mean and variance of the jury threshold value, the loss (16) for juries of moderate size in which the jury threshold value is concentrated near its mean is approximately

(17) $$\text{Loss} \approx CJ/N + f_R(v^{\%})[\sigma^2/2J + (v^{\%} - v^{**})^2/2].$$

The optimal jury size minimizing this approximate loss is $J = (Nf_R(v^{\%})\sigma^2/2C)^{½}$. In most cases, f_R will be inversely proportional, and σ will be proportional, to the value of the project. Then, the optimal jury size will rise with the square root of the population and the project value, and fall with the square root of the expected cost of a juror. For example, if f_R and $f_{V|y,x=1}$ are uniform on $[0,v^{\#}]$, then the numerical values C = \$75, $v^{\#}$ = 100, and N = 240,000 give J = 115.

The approximate loss (17) at the optimal jury size is

(18) $$\text{Loss} \approx [2f_R(v^{\%})\sigma^2C/N]^{½} + f_R(v^{\%})(v^{\%} - v^{**})^2/2.$$

Consider a situation where the planner knows only the bound (12) on the distribution of values and its moments. To simplify, assume the exogenous variables z and y are absent, so that $p(m) = \Phi(g(m))$ is the participation probability for consumers facing fee m. Suppose the planner chooses a single value of m and takes the jury threshold to be

$$v' = p(m))\mu'(x,m) + \tfrac{1}{2}(1 - p(m))v^{\#},$$

where $\mu'(x,m)$ is the estimate of $\mu(x,m)$ from jury self-reports and the mid-point of the range of values $[0,v^{\#}]$ is imputed to attritors. Then, $C = c_1/p(m) + c_2 + m$ is the expected cost per juror and $v^{\%} - v^{**} = (\tfrac{1}{2} - \gamma)(1 - p(m))v^{\#}$ is the expected systematic error arising from attrition. The maximum possible loss, occurring when $\gamma = 0$, is

$$\text{Loss} \approx [2f_R(v^{\%})\sigma^2 C/N]^{1/2} + f_R(v^{\%})(1 - p(m))^2(v^{\#})^2/8$$

.

This expression can be minimized numerically in m. In the example with f_R and $f_{V|y,x=1}$ uniform on $[0,v^{\#}]$, $v^{\#} = 100$, N = 240,000, $p(m) = (0.01+0.19\ m)/(1 + 0.2\ m)$, $c_1 = \$5$, and $c_2 = \$60$, the optimal fee is m = \$170 which induces a participation rate of 92.5%, the optimal jury size is J = 65, the cost per juror is \$235, and the expected loss per capita is \$0.20, or about 1.6 percent of the expected increase in welfare from optimal provision of the public project. Thus, a jury of modest size and cost, although with participation fees substantially higher than are considered the norm in survey research, ensures a relatively negligible welfare loss arising from the need to estimate the true value of the public project.

Additional prior information on the structure of the response model, or less weight on the worst case, will reduce the loss associated with attrition, reducing the need to attain very high participation rates, and leading to lower participation fees and larger jury sizes. For example, the semi-parametric specification (14) allows an unbiased estimate of v^{**} using a two-point design distribution $F_M(m)$ located near the jury cost-minimizing level. For the previous numerical example, one can use a design with participation fees of \$4 and \$6

with equal probability and a jury of size J = 115, and achieve an expected loss per capita of about $0.07, or 0.6 percent of the expected welfare gain from the public project.

The approximate calculations above omit two important factors, the contribution to the dispersion of the distribution of jury thresholds from imprecision in the estimation of structural functions and parameters, which will tend to make J larger, and declining effectiveness of incentives for truthful response with jury size, which will tend to make J smaller. The calculations also leave unexplored the possibility that more sophisticated econometric mitigation of attrition bias in the design of the jury threshold estimator, and use of experimental treatments in jury selection to enhance the effectiveness of mitigation, could reduce further the expected welfare loss from using a jury estimate of value to determine the provision of public projects.

5. Incentive-Compatible Elicitation Mechanisms

Consider the planner's problem of eliciting unknown juror valuations of public projects. The economic consequences of a juror's stated value can create incentives to be truthful, or to respond strategically and "free ride". This section will focus on economic incentive mechanisms designed to induce truthful stated values. There are other factors that influence juror behavior, and may be as important as economic incentives, such as the degree to which interpreting questions and forming responses requires cognitive effort, including the recall of facts and experiences from memory, reconstruction of imperfect memories, and construction of previously unexpressed preferences, and non-economic incentives for strategic misrepresentation, including the influence of norms for "socially responsible" behavior. There may be substantial heterogeneity in juror behavior, including differences in the construal of questions and in approaches to problem-solving. Consideration of these non-economic factors will be postponed to the next section.

The history of direct elicitation of preferences dates to a 1932 paper written by the psychologist Leon Thurstone at the instigation of the economist Henry Schultz. Thurstone's direct elicitation approach was rejected by leading economists of that day, including Frisch, Hotelling, and Friedman. The concerns of these critics were that subjects freed of the discipline of completing market transactions would fail to take measured account of prices and budget, and would use their responses to posture, or to express attitudes and opinions, making the stated preferences unreliable for predicting market behavior. There was little further development in stated preference methods until the mid-1960's, when this approach, renamed *conjoint analysis*, began to be explored as an applied tool in psychometrics, market research, and transportation research. These developments emphasized construction of preference maps through presentation of multiple choices set by experimental design. For private goods that are familiar, or given sufficiently rich description, conjoint analysis with embedded incentives has proven to be a reliable tool for predicting market demand, and it is widely used in the design of new products.

A largely independent development of stated preference methods, called *contingent valuation* (CV) and focused on eliciting preferences for public goods, occurred in resource economics (Davis, 1963; Randall, Ives, and Eastman, 1974). The method has been promoted and used somewhat uncritically as a tool for valuing resource damage, and there is a large and contentious literature on its validity, but methodologically it is simply a form of conjoint analysis with a truncated design for the experimental presentation of alternatives. Hence, the concerns of its critics are those for stated preference methods in general, with added concerns about consumers' ability to generate preferences for unfamiliar public goods, respond consistently in hypothetical versus real choice settings, and respond predictably to hypothetically incentive-compatible framing of survey tasks.

Three distinct aspects of direct elicitation of preferences are (1) the *elicitation frame*, or context and format of the question and requested response, (2) the *implementation frame*, or link between jury responses and the (subjective) probability that a policy will be

implemented, and (3) the *payment vehicle*, specifying the tax a juror would bear for implemented projects. Aspects of the elicitation frame are whether the juror is trained or experienced in making jury judgments, whether open-ended or referendum (yes/no) responses are called for, and whether the context encourages or discourages altruistic behavior. The implementation frame is *consequential* if there is a positive (subjective) probability that a juror's stated value will be *pivotal* in determining whether a project is supplied, and *hypothetical* if there is no direct link between jury response and the eventual decision on project supply. The payment vehicle imposes taxes earmarked to cover the cost of implemented projects, and the tax imposed on jurors may be *coupled* to their stated values, or *decoupled*.

Consider the public project decision problem within the setup given in Section 2, specialized so that X is a finite set, aggregate consumer income F(p) is independent of x, total project cost is $G(p,x,\zeta) = N\cdot A(p)\cdot r(x,\zeta)$, where $r(x,\zeta)$ is the real per capita cost of x, and indirect utility is $V_n(y_n,p,x;\theta_n) = [y_n - t_n - B_n(p)]/A(p) + v_n(x)$, with balance requiring that

$$F(p) = \sum_{n=1}^{N} y_n \quad \text{and} \quad N\cdot r(x,\zeta) = \sum_{n=1}^{N} t_n.$$

The elicitation of stated values is a game of incomplete information played by the planner and jurors j = 1,...,J, with each juror having private information on her true values, and the planner having private information on the cost of projects. I consider two implementation frames and payment vehicles that will induce truthful valuations, provided jurors understand and respond to the mechanism incentives; this analysis is drawn in part from Green *et al* (1998).

Groves-Clarke-Green-Laffont (GCGL) Mechanism: Originating in the works of Groves and Loeb (1975) and Clarke (1971), and stated for juries by Green and Laffont (1978), this mechanism requires that the planner announce a real tax $r_j(x,\zeta)$ for juror j that depends on the project x and on a factor ζ that determines its cost, and each juror report a stated real value $v_j^{\%}(x,\zeta)$ to the planner that can depend on the factor ζ. The project implemented

maximizes (7) with the unknown true social value per capita v**(x) replaced by its jury estimate, so that

(19) $$x^{\%}(\zeta) = \text{argmax}_{x\in X}\left(\sum_{j=1}^{J} v_j^{\%}(x,\zeta)/J \; - \; r(x,\zeta)\right).$$

The net benefit of x to juror n, taking into account the tax, is $v_n^*(x) - r_n(x,\zeta)$. This juror will report the strategic value

(20) $$v_n^{\%}(x,\zeta) = v_n^*(x) - r_n(x,\zeta) + Jr(x,\zeta) - \sum_{j\le J \& j\neq n} v_j^{\%}(x,\zeta),$$

so that (19) becomes $x^{\%}(\zeta) = \text{argmax}_{x\in X}\,(v_n^*(x) - r_n(x,\zeta))$, aligning the social choice criterion with this juror's utility. If the tax the planner imposes on n is

$$r_n(x,\zeta) = Jr(x,\zeta) - \sum_{j\le J \& j\neq n} v_j^{\%}(x,\zeta),$$

the result in (20) is that $v_n^{\%}(x,\zeta) = v_n^*(x)$, so that it is a dominant strategy, independent of the behavior of other jurors, for juror n to report her true value. In this setup, non-jurors will be taxed for the residual necessary to cover the cost of implemented projects,

$$\sum_{n=J+1}^{N} r_n(x,\zeta) \;=\; (N-J^2)r(x,\zeta) \;+(J-1)\sum_{j=1}^{J} v_j^{\%}(x,\zeta),$$

It may be necessary in this mechanism to use additional lump-sum transfers, which can depend on ζ but not on x, to ensure that jurors and non-jurors all have net incomes sufficient to cover committed expenditures. For juries of modest size in large populations, sufficiency for jurors will be the primary concern, as the average impact on non-jurors will be close to the per capita real cost of the project r(x,ζ), which by the definition of X was

generally affordable. Lump-sum transfers to jurors then may have the dual purpose of minimizing juror attrition and ensuring that the incentive-compatible mechanism is feasible.

The GCGL mechanism is a *provision point mechanism* that ties implementation to an average value that exceeds a specific cost threshold. If each juror believes there is a positive probability that an implementation decision will be made, that if it is made it will maximize the average jury net payoff, and there is a positive probability of a configuration of reports of others and costs that would make her response pivotal, then the argument above verifies that it is an undominated Bayes-Nash strategy for each jury member to report her true value, so the mechanism is strongly individually incentive-compatible; see Palfrey and Srivastava (1991). Note that if subjects believe and understand the implementation frame and tax function in the GCGL jury mechanism, then features of the elicitation frame, such as whether values are reported as functions of x and ζ, as open-ended responses to elicitations at specific x,ζ values, or as yes/no responses to threshold questions, does not matter. The mechanism will lead to efficient provision of public projects, up to the modest loss of accuracy arising from jury sampling noise and selection, as discussed in Section 3.

Becker-DeGroot-Marschak-Palfrey-Rosenthal (BDMPR) Mechanism: A second incentive-compatible mechanism that is natural for referendum elicitations is an adaptation of the Becker-DeGroot-Marschak auction mechanism that has been used in public goods games by Palfrey and Rosenthal (1990, 1994), and tacitly by Hoehn and Randall (1987). Suppose there is a single project, so X = {0,1}. Suppose each juror understands that her tax if project 1 is implemented is the per capita real cost $r(1,\zeta)$, and believes an implementation frame stating that her valuation can alter the probability of implementation, making her pivotal. This belief may be induced by language such as "when the cost per person of providing 1 is finally determined, then the probability of implementation increases with the plurality in this jury who favor the project at this cost". Let $v_n^{\%}(1)$ denote the cost threshold at which juror n would vote to support 1, so that $\mathbf{1}(v_n^{\%}(1) - r(1,\zeta) > 0)$ indicates

approval of project 1 at realized cost r(1,ζ). Juror n's subjective probability of implementation is

(21) $$\mathbf{E}_{-n}\Psi\left(\sum_{j=1}^{J}\left[\mathbf{1}(v_j^{\%}(1)-r(1,\zeta)>0)\right]/J\right),$$

where Ψ is a non-decreasing function, and $\mathbf{E}_{-n}$ is the juror's subjective expectation regarding the thresholds of other jurors. Juror n is pivotal if either Ψ is a strictly increasing function, or if Ψ is non-decreasing and non-constant, and its expectation with respect to the reports of others is strictly increasing. The last possibility includes conventional voting rules such as majority rule, provided each consumer's subjective beliefs about others is sufficiently diffuse so that she believes her vote might be critical. Juror n's expected utility is then

(22) $$\boldsymbol{E}_{\zeta}(v_n^{*}(1)-r(1,\zeta))\cdot\boldsymbol{E}_{-n}\Psi\left(\frac{\mathbf{1}(v_n^{\%}(1)-r(1,\zeta))\ +\ \sum_{j\neq n\&j\leq J}\mathbf{1}(v_j^{\%}(1)-r(1,\zeta))}{J}\right).$$

Make the critical assumption that $v_n^*(1)$ is in the interior of the support of the random per capita cost r(1,ζ) induced by the cost factor ζ unknown to the jurors. Then, any report $v_n^{\%}(1) < v_n^*(1)$ lowers the probability of implementation for some events that are desirable, and any report $v_n^{\%}(1) > v_n^*(1)$ raises the probability of implementation for some events that are undesirable. Then, truth-telling in the referendum vote is an undominated Bayes-Nash strategy. The difference between this setup and the GCGL one is that in this case, the effect of being pivotal operates through the probability of provision rather than through the payoff conditioned on achieving a provision point. Again, elicitation format does not matter – asking directly for the subject's threshold $v_n^{\%}(1)$ or obtaining it indirectly in various referendum setups should lead to the same answer. It is important that a juror's required payment given implementation is independent of the stated threshold. If, alternately, the payment is coupled to $v_n^{\%}(1)$ through a payment function $q(r(1,\zeta),v_n^{\%}(1))$ that is increasing in $v_n^{\%}(1)$, then the subject has an incentive to "free ride" by under-reporting $v_n^{\%}(1)$.

The BDMPR mechanism can be extended to multiple alternatives if the planner conducts a series of independent elicitations that compare each possible project portfolio with the baseline alternative x = 0, and if the juror responds to each elicitation myopically, overlooking the strategic possibility that understating values on less preferred alternatives may increase the probability that more preferred alternatives are implemented. However, if jurors are not myopic, then this mechanism encounters the usual difficulties of strategic manipulation in sequential voting.

While the BDMPR mechanism is incentive-compatible, it is not efficient, as there is no guarantee that project x will be implemented if, and only if, $v^{**}(x) - r(x,\zeta) > 0$. Specifically, the referendum vote used in the mechanism cannot recognize when a few jurors with thresholds far above cost should in the utilitarian calculus outweigh a larger number of jurors with thresholds just below cost.

Other Mechanisms: A number of alternative mechanisms are available for making public project decisions that vary in the conditions under which they are (approximately) incentive-compatible, and in the (approximate) efficiency of their implementation rules. A benchmark that is not incentive-compatible and suffers from free-riding is the voluntary contribution mechanism. Morgan (2000) proposes a variant in which tickets in a large-payoff lottery are tied to voluntary contributions, and provide an incentive that mitigates free-riding; see Pecorino and Temimi (2007). More generally, interweaving portfolios of private goods and public projects, and designing elicitations of stated values with stochastic implementation of some (private good) components, may present jurors with a problem that is easy to solve consistently only by being truthful. It is also possible to vary the strength of incentives by rewarding consistency across jurors, as in the powerful provision point mechanism of Groves and Ledyard (1977), which can be adapted to jury-based valuation under more general preferences than Gorman preferences.

Two critical requirements in the public projects provision mechanisms just described are that each juror recognize and act upon her ability to directly influence her net income and the supply of public projects through her self-reported values, and that she *not*

recognize and act upon the strategic opportunities her report offers for the indirect determination of her income function and private goods prices via the influence of her reported values on the social planner's calculations to set lump sum net taxes and achieve income balance. In both the GCGL and BDMPR mechanisms, the probability that an individual juror is pivotal falls with jury size. If jurors display the common behavioral pattern of sometimes ignoring low-probability events, then compliance with these mechanisms will fall as jury size increases. Gibbard (1973) and Satterthwaite (1975) show that in general no non-dictatorial balanced mechanism in an economy with a finite number of consumers can be strategy-proof, so the restrictions on juror beliefs and behavior necessary to assure that a mechanism is strongly individually incentive compatible require something less than total rationality and understanding. In particular, the mechanisms will perform poorly if jurors act strategically to influence private goods prices, or alternately fail to recognize they may be pivotal, fail to recognize the consequences of their actions when they are pivotal, or allow non-economic incentives to override economic ones.

6. Consumer Response to Incentives

There is a large empirical literature on consumer behavior in various economic environments in the laboratory and in the field. I am going to give a very selective review of findings that shed some light on the ability of consumers to recognize and exploit choice opportunities in their own self-interest, in the presence of the incentives that naturally appear in markets, and in laboratory settings where incentives can be designed that should lead to specific behaviors if consumers can process information and choose rationally.

Behavior in Public Good Games: Mechanisms of the GCGL or BDMPR type are effective in obtaining truthful information if consumers recognize the opportunities provided by the choice alternatives they are offered, and seek to maximize (risk-neutral, Gorman polar, parallel Engle curve) self-interest, unconstrained by social norms and objectives. The behavioral question is whether consumers meet this standard. Some of the most striking evidence comes from voluntary contribution systems for public goods, the ultimatum and trust games, and auctions. An early paper of Bohm (1972) found that "free riding" was uncommon even in circumstances where the incentive structure invited it. Shafir & Tversky (1992) found that the dominated strategy of cooperation is often played in the prisoner's dilemma game, apparently induced by superstitious beliefs. Fehr and Schmidt (1999), Fehr and Falk (2002), Fehr and Fischbacher (2002, 2004), Fehr and Gachter (2004), and others have found that in the ultimatum and trust games, many participants are motivated by social norms to play dominated strategies. These results suggest broadly that in circumstances where there is a perceived mutual benefit from cooperation, consumers have altruistic motives, superstitious beliefs, and social norms for reciprocity and fairness that may override pure self-interest. On the other hand, there is considerable evidence that in the purely competitive circumstances of second-price auctions, where the compatibility of the incentives in the auction with truth-telling are transparent, consumers tend to bid their true values; see Harstad (1990), Friedman and Rust (1993), Garratt, Walker, and Wooders (2004). Studies of behavioral response to the GCGL mechanism find that it does not induce wide-spread truth-telling in small untrained juries, but compliance increases sharply when subjects are trained and given detailed information on the payoff structure. There is also an indication that compliance falls in larger juries where the pivotal income adjustment does not loom as large and the advantages of the dominant strategy are obscured; see Attiyeh, Franchosi, and Issac (2000) and Kawagoe and Mori (2001). Chen and Plott (1996) find that compliance in the related Groves-Ledyard mechanism depends significantly on the penalty parameter in that mechanism, indicating that the magnitude of the incentive matters. Palfrey and Rosenthal

(1990) find that with training, small juries show good compliance when the public goods game is played in referendum voting form.

Contrasting these results, there appear to be three main factors that determine whether consumers will comply with individual incentives: (1) whether the game is purely competitive, versus one in which benefits of cooperation are recognized and lead to responses influenced by social norms; (2) whether the mechanism is substantially individualistic and transparent, or is obscured by the operations of other players or institutions; and (3) whether or not the penalties to deviating from a compliant response are strong and obvious. Thus, second-price auctions are generally sufficiently competitive and the incentives for truth-telling are sufficiently individualistic and transparent, to induce compliance. By contrast, public goods games require considerable training and clear information on payoffs to avoid erratic, non-compliant responses. In this respect, the BDMPR mechanism, or the Groves-Ledyard mechanism with a substantial penalty, appear to have some transparency advantage over the GCGL mechanism. These factors imply for survey research applications, where it is difficult to provide strong incentives and training, that compliance with the incentives of strategy-proof mechanisms is problematic, and except for purely individualistic decisions such as private good choices, responses are likely to be influenced by social norms. Consequently, it is unclear that one can obtain more reliable information in surveys using weakly incentive-compatible mechanisms than using a hypothetical framework that evokes social norms for honesty and reciprocity.

Evidence on the Reliability of Contingent Valuation (CV) Responses: Elicitation of stated preferences, and particularly the CV method, have been the focus of most of the concentrated attention in economic survey research on the reliability of responses and the effect of hypothetical versus real incentives. The primary concerns have been the issue of "hypothetical bias", and survey methods that minimize this bias, and the incentive compatibility properties of alternative elicitation formats.

The reliability of stated preferences and their predictive power has been studied in market research, and applied areas such as transportation research; see McFadden

(1980), Ben-Akiva and Morikawa (1990), Louviere, Hensher, and Swait (1999, 2000), Shen (2005), and Train and Wilson (2005). In most cases, preferences for private goods such as new consumer products are examined. Questions have centered on the format of the elicitations, particularly the "richness" of the description of choice alternatives, the form of response (e.g., choice, ranking, rating, referendum WTP, open-ended WTP), the design of multiple elicitations, and cross-analysis of revealed preferences. Methods for studying these questions include study of the internal consistency of multiple stated preferences (e.g., transitivity, monotonicity, diminishing returns), consistency between stated and revealed preferences, and predictability of real choices from stated preferences, either to subsequent offerings within the survey or to subsequent market experience.

A very broad summary of the findings are that stated preferences for private goods in a well-designed conjoint analysis are generally consistent with revealed preferences, or can be made so by calibration. The incentives provided by a positive probability of a follow-up transaction may increase compliance, but compliance without incentives is not bad, and compliance with incentives is not perfect. Stated preferences can be influenced by the framing and presentation of attributes. For example, Tversky, Sattath, & Slovic (1988) show that the decision format can change the *prominence* given to different attributes of alternatives. In choice among products, price is given more weight in a direct choice task than it is when consumers are asked to specify an attribute level that makes two alternatives indifferent. Further, price is often given more prominence in stated preferences than it is in revealed preferences, probably because it provides a common and familiar quantitative low-effort standard for comparison. There is a strong *status quo* or *endowment* effect in stated preferences, sometimes termed the WTP/WTA gap, and while this also appears in revealed preferences, its importance may vary. When goods in a stated choice experiment are unfamiliar or sparsely described, the expressed preferences are more erratic. An overall conclusion is that stated preferences for private goods collected within an experimental design that provides a good sense of verisimilitude are generally consistent with and predictive for revealed preferences, even without positive

incentives for truth-telling. However, stated preferences for unfamiliar goods are erratic, partly because of the difficulty of providing sufficiently cogent descriptions of these products to make the choice problem realistic and induce the effort needed to approximate real market behavior, and partly because consumer preferences among unfamiliar objects are a construction project, poorly formed and unstable until contextual cues, experience, and perceptions come together to fix their form.

For the public goods that are commonly the target of CV surveys, such as recreational facilities, uncontaminated groundwater, and seabirds, most studies suggest that hypothetical bias is significant; see List and Gallet (2001), Venkatachalam (2004). The methods used for this assessment include internal consistency of WTP elicitations that vary by extent, adding up, and context, but most importantly the relationship between stated willingness to contribute and actual contributions. Elicitation format influences responses, and it is possible that subjects are influenced by the nominal incentive compatibility of some hypothetical formats. However, altruism, social norms, and perceptual anomalies are more likely explanations for the observed patterns; see Kahneman, Ritov, and Schkade (1999). Authors finding substantial hypothetical bias include Azevedo, Herriges, and Kling (2003), Bennet, Provencher, and Bishop (2004), Champ and Bishop (2001), Cummings, Elliott, Harrison, and Murphy (1997), Diamond and Hausman (1994), Johannesson, Liljas, and Johansson (1998), Loomis, Brown, Lucero, and Peterson (1996, 1997), and McFadden (1994). Authors finding limited hypothetical bias include Carlsson and Martinsson (2001), Carson, Flores, and Meade (2001), Haab, Huang, and Whitehead (1999), Whitehead (2002), and Willis and Powe (1998). An overall assessment is that studies finding the least bias focus on private goods, and that proponents of CV find fewer problems with hypothetical bias than do critics.

A significant issue in CV elicitation for public goods, and a possible factor in hypothetical bias, is that respondents construe hypothetical tasks as asking for “socially responsible” values that reflect an altruistic attribution of the benefit of a public project to others in addition to the individual’s personal value, whereas consequential tasks calling

for payment focus attention on individualistic value. Such behavior is consistent with statements from consumers that voluntary contributions and other altruistic acts provide a "warm glow" that justifies this behavior. Put another way, altruistic motives may be overwhelmed when private incentives are strong, but may reassert themselves when private incentives are weak or context encourages attention to the advantages of cooperation and reciprocity.

Incentive compatibility of CV elicitations of value, and the role of elicitation format, has been a continuing concern of environmental economists; see Randall, Ives, and Eastman, 1974), Randall, Hoehn, and Brookshire (1983), Hoehn and Randall (1987), and Carson and Groves (2007). Careless treatment of incentive issues, particularly failure to distinguish clearly between circumstances where incentives are hypothetical or real, and to distinguish between the theoretical incentive compatibility of mechanisms and behavioral compliance, have led to confusion in the resource economics literature regarding the influence of elicitation formats, and the relevance of private good choice behavior to public good choice behavior; e.g., the claim by Hoehn and Randall (1987), Carson and Groves (1999), and Loomis, Brown, Lucero, and Peterson (1996) that only a referendum format can potentially elicit incentive-compatible responses. The discussion of incentive compatibility given in the Section 5 of this paper shows that when a CV elicitation is presented within a consequential implementation frame that has a credible possibility that the respondent is pivotal, then both the GCGL or BDMPR jury mechanisms are incentive-compatible. While there are issues with the transparency of the mechanisms, which could interact with elicitation format, and with the training needed for subjects to be aware of their payoffs, there are no first-order differences in incentive-compatibility between elicitation formats that employ the same payment vehicle.

The most relevant experimental tests of incentive-compatibility for public goods have been conducted in laboratory or quasi-laboratory settings where small juries have used alternative mechanisms to determine provision and cost-sharing. Results are mixed, with many studies finding significant hypothetical bias. Champ, Flores, Brown, and Chivers

(2002) find that payment vehicle (e.g., referendum on mandatory tax, unspecified voluntary donation, and voluntary contribution with provision-point mechanism for implementation) matters in a hypothetical, but perhaps taken as realistic, elicitation of WTP for acquisition of park land in Boulder, Colorado. Cummings, Harrison, and Rutstrom (1995) and Cummings, Elliott, Harrison, and Murphy (1997) find in a laboratory CV experiment conducted under hypothetical and real conditions that subjects are not usually truthful in referendum responses. Lusk and Schroeder (2004) find significant hypothetical bias in WTP for beef steaks. Loomis, Brown, Lucero, and Peterson (1996, 1997) find strong hypothetical bias in experiments comparing hypothetical CV and real second-price auctions. However, Frykblom (2000) does not find significant hypothetical bias in another comparison of referendum and second-price auction mechanisms. A number of authors have suggested variations on the CV method that appear to have less hypothetical bias, or provide a better basis for calibration to remove this bias. List (2002) investigates choice experiments for a private good and a public good contribution, This method fits within the general methods of conjoint analysis used in market research. The findings that private good choices conform to truth-telling is then not surprising, but the carry-over to the voluntary contribution task is, and the details of List's mechanism may prove instructive to designers of WTP elicitations. Rondeau, Schulze, and Poe (1999) and Poe, Clark, Rondeau, and Schulze (2002) compare hypothetical referendum WTP with that obtained from a provision point mechanism, and find a smaller gap than in experimental comparisons with a voluntary contribution mechanism. However, calibration is an imperfect method for overcoming hypothetical bias, because it must rely on comparison commodities that may not be good proxies for the target good. For example, Fox, Shogren, Hayes, and Kliebenstein (1998) find that calibration factors are commodity-specific.

Consumer Response to Large Incentives: At a basic level, the fact that humans can function and survive in market economies indicates that they recognize and act upon the economic incentives they face. However, there is a long-standing question in economics as to whether this comes from conscious, relentless preference maximization, or from less

coherent and organized use of heuristics that give satisfactory results in most circumstances. In familiar settings, these alternatives models of behavior may be largely indistinguishable, but in an unfamiliar setting such as play of a public goods game or making a choice among new products and services, heuristics may be incompatible with rational response to the incentives in the situation. Then, it is useful to look for designed or natural experiments where consumers are confronted with novel decisions and their responses can be assessed against rational standards. The answers can help to guide mechanism design – can it rely on economic incentives alone, or is a degree of paternalism needed to inform, train, and coax consumers to act in their self-interest?

There is considerable evidence that in familiar decision-making circumstances where self-interest really matters, consumers are approximately rational. Studies of choice among lotteries with large payoffs by Binswanger (1980) and by Attanasio, Barr, and Cardenas (2006) have been found to conform closely to postulates of rational decision-making under uncertainty. List (2003) and Garratt, Walker, and Wooders (2004) find that experienced market decision-makers show few behavioral anomalies.

Winter, Heiss, and McFadden (2006) and Heiss, McFadden, and Winter (2007) study the opening of a new subsidized prescription drug insurance program for the elderly in the U.S. This program works through voluntary enrollment in one of a menu of private plans. Immediately prior to the start of the program in 2006, the study surveyed consumers and asked their enrollment intentions. That survey also collected data on prescription drug use, which determines whether the program would be immediately beneficial to a risk-neutral consumer. Immediately after the open enrollment period ended, we surveyed these consumers again and asked their enrollment choices. The program was new and complex, and the consequences of choices ambiguous, so that consumers were at risk of procrastinating past the enrollment period, or of making poor decisions. The table below summarizes the findings from this study on enrollment behavior among those who had to make an active enrollment decision. The table is weighted to correct for attrition; see McFadden, Heiss, Jun, and Winter (2006).

Medicare Part D Prescription Drug Insurance Enrollment Behavior								
2005 Drug Bill	Enrollment Choice	Total	2006 Net Benefit		Expected Present Value		Irrational	
			Negative	Positive	Negative	Positive	Min	Max
$0	No	36.3%	32.3%	4.0%	5.8%	30.5%		
	Yes	63.7%	56.9%	6.8%	10.9%	52.9%		
	Total	14.1%	89.1%	10.9%	16.6%	83.4%	4.0%	41.3%
(0,$1250]	No	19.4%	3.9%	15.5%	0.0%	19.4%		
	Yes	80.6%	12.8%	67.9%	0.1%	80.5%		
	Total	22.2%	16.7%	83.3%	0.1%	99.9%	15.5%	19.5%
($1250,∞)	No	5.7%	0.0%	5.7%	0.0%	5.7%		
	Yes	94.3%	0.2%	94.2%	0.0%	94.3%		
	Total	63.7%	0.2%	99.8%	0.0%	100.0%	5.7%	5.7%
All	No	13.0%	5.4%	7.6%	0.8%	12.2%		
	Yes	87.0%	11.0%	76.0%	1.6%	85.4%		
	Total	N = 721	16.4%	83.6%	2.4%	97.6%	7.6%	13.8%

In this table, active deciders are classified by their annual pharmacy bills in 2005. Within each pharmacy bill category, the percentages enrolling are given in the third column, with the "Total" rows giving the percentage of the sample in each category. Columns 4 and 5 break the sample down by whether, given their 2005 age, health status, and pharmacy bills, enrollment is expected to have an immediate positive expected net benefit in 2006. Consumers who fail to enroll in the face of an immediate expected net benefit are fairly clearly irrational. Columns 6 and 7 break the sample down by whether a dynamic stochastic program gives a net positive expected present value for immediate enrollment, taking into account the consumer's expected health and mortality, and the penalties for delayed enrollment. This program uses health status and prescription drug use transitions estimated from the Medicare Current Beneficiary Study, a rotating panel of 40,000 consumers enrolled in Medicare. Consumers who fail to enroll when this expected present value is positive, or enroll when this expected present value is negative, are probably irrational, although it is

possible that some of these classifications are due to subjective beliefs, discount rates, or private information that are not reflected in the dynamic stochastic program. In principle, risk aversion would induce higher enrollment rates than the maximization of expected present value would predict. However, the predicted enrollment rates are sufficiently high to make the possible impact of risk aversion very small. Columns 8 and 9 give lower and upper bounds on the percentage of consumers making irrational choices. The overall conclusion of the study is that only a small minority of consumers, between 7.6 and 13.8 percent, made enrollment decisions that were clearly contrary to their self-interest. Further, many of these were consumers with low or zero prescription drug use in 2005 for whom the consequences of a non-optimal choice were small in expected present value terms. There is however, a hard core of about 7.2 percent of consumers who failed to enroll in the face of substantial immediate incentives to do so. These results are consistent with the proposition that most, but not all, consumers faced with substantial incentives respond rationally, but there is a fringe who without assistance will fail to achieve their self-interest.

Conclusions: In overview, I conclude that when incentives are large, consumer behavior shows little deviation from rationality, not only in familiar choice settings, but surprisingly even in complex, unfamiliar ones. There are exceptions. The quality of decision-making is heterogeneous, and there will usually be a fringe of consumers who are unable to get it right. When choices involve remote future consequences, uncertainty, or affect, this fringe grows. However, when incentives are small or unclear, less effort goes into determining best choices, and irrelevant factors play a larger role. Consumers are surprisingly truthful in circumstances where they don't need to be, but they may not supply the concentration and effort required to be accurate. Unfortunately, most economic surveys fit the case of small or unclear incentives, with little built-in control of effort and accuracy. The use of incentive theory, for example the Philipson (1999) suggestion to reward responses that are validated, is a promising avenue for bringing economic consumers up to the task of providing the information needed to implement the broad program of mechanism design set out by Leo Hurwicz, Jean-Jacques Laffont, and others for organization of resource allocation for public

projects and private goods in a world of imperfect information. However, inconsistency in consumer response to incentives, particularly when their consequences are perceived as small or ambiguous, appears to be a problem that needs to be taken into account in drawing policy conclusions from principal-agent theory.

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