Technology Adoption in Organizations: Use of Incentives and Standards for Control and Coordination

Rajiv Dewan Marshall Freimer Abraham Seidmann
William E. Simon Graduate School of Business Administration,
University of Rochester, Rochester, New York

Shankar Sundaresan
The Smeal College of Business Administration,
The Pennsylvania State University, University Park, Pennsylvania

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Abstract

Technology adoption has become an important management issue in today's decentralized organizations. Disparate systems and the attendant incompatibility costs between users and departments within an organization can create inefficiencies and reduce productivity. Fortunately, the managers of the organization have a rich tool-set — incentives and standards that they can use to manage technology adoption. We show that simple incentive plans, even ones that only provide bonuses for selection of standard technology or only provide penalties for non-standard selections suffice. Further, it is even possible to devise incentive plans which have zero expected costs to users and organizations and yet induce the users to pick common systems. We also examine technology adoption with communication between managers and users.

1 Introduction

Changes in information, manufacturing and other technology have increasingly led to decentralized systems. These decentralized systems take the form of end-user computing, departmental data servers, smaller single business units for manufacturing and smaller agile divisions of firms that are closer to customers. While there are clear benefits to decentralization of systems choices, some work flow, whether it is in the form of parts or data, occurs across the independent units. This work flow across independent units makes the benefits from technology to a unit depend on not only technology choice by it, but also by others. This joint dependency can create serious problems in organizations as the following quote from a *Fortune* article in August 1995 indicates:

> Boeing's quality and productivity problems stem directly from a World War II-era process that coordinates engineering and manufacturing. For years this vestigial way of work has been treated like a crazy uncle in the attic: Everybody knew it was a problem, but nobody wanted to deal with it. Because of inherent inefficiencies, it has driven up costs, lengthened production times, and created a sprawling bureaucracy–for Boeing and its customers. To give just one example of how out of control the process is, 800 different computer systems are required to manage it–and most of the computers don't communicate directly with each other.

Some firms have tried to solve the problem by mandating a single system for the whole organization. Enterprise Resource Planning Systems, exemplified by SAP, are one such class of systems. One can easily think of instances in which specific information arising from special knowledge or closeness to customers makes it beneficial to allow the users to pick their own systems. Indeed, trade press journals are replete with examples of failed enterprise-wide system implementations.

In this paper we carefully model the benefits of mandating a common system choice, delegating choices to users, or setting standards for systems choices to partly delegate systems choices. We also model the use of incentives as an additional mechanism to improve organizational efficiency.

Technology adoption in markets has been widely examined in economics literature. A survey of this literature is contained in [8]. Adoption of new technology over two periods by customers with or without perfect information is examined in [7]. They show that a bandwagon strategy, that is similar to our hurdle strategy in a one period game, is optimal. The impact of compatibility on market shares of products with different levels of compatibility is studied in [10]. The focus of their work is to determine the private and social incentives for network compatibility. They consider side-payments among firms for different compatibility arrangements. In our case, we take the technology offerings and their compatibility as a given and examine their adoption in an organizational setting where adoption incentives for users are possible. Delegated choice by consumers is also examined in [11] which focuses on effect of barriers to entry to produce goods of different technology.

Management of technology adoption in organizations is quite different from that in markets. Organizational architecture, including selecting rights to be delegated, monitoring, and setting appropriate incentives, offers a much richer tool set to a manager than is available to any one market participant. For instance, it is possible to offer users an incentive that is contingent on choices made by them and others. This is just not possible in most market situations. The richer tool set under the control of a firm's management allows for much finer control and coordination of technology adoption within the firm than is possible in the market place. This is the aspect of technology adoption that we model in this paper.

Management of technology adoption has received some attention. Selecting rights to delegate system choices, or equivalently the ones not to delegate, is commonly done in organizations. The system choice rights not delegated to user groups are called organizational standards in the context of technology management [1, 3]. Organizations have standards for programming, databases, personal computers, dataservers, communications, and other systems. For instance, some firms specify a specific brand of personal computer, operating system and application suite to be used by all.

Different mechanisms for managing technology choice are modeled and compared. We pose the problem as one of adoption of new technology. Different user groups have different evaluations of the new technology. We model the delegated choice of technology as a Bayesian game in which users do not know others' preferences. Instead, the prior distribution of others' preferences is common knowledge. In this case, we find that a Nash equilibrium exists and is characterized by a hurdle policy in which each user chooses a hurdle. If the privately known preference for the new system is greater than the hurdle then the user picks the new system. We show that if one user were to find the new technology more (less) preferable then all the users would adjust their hurdles to make the adoption of the new technology more (less) likely. This responsiveness to others' technology choices, which is driven by potential incompatibility costs, is often, however, not enough from an organizational standpoint.

To further improve technology adoption, the firm may judiciously use incentives. We model the impact of and choice of efficient incentives that are contingent on technology choice by all users. If a user is given an incentive to (not) adopt a particular technology then he moves his hurdle to make the choice more (less) likely. The problem of picking net value (net of incentives and incompatibility costs) maximizing incentives is modeled and analyzed. We find that it is important to be selective in offering incentives and not offer it identically to all users or in all circumstances. The effect of these incentives on users is to move the hurdles for adopting technologies. We show that optimal incentive plans need not be too complex. Even faced with an exponential variety of technology adoption patterns, there exist optimal incentive plans in which no user has non-zero incentives (which could be negative as is the case with penalties) for more than two patterns of technology adoption. Further, if only bonuses are permitted then there exist optimal incentive plans in which users may have bonuses only for choice of standard systems.

Next, we examine the use of standards for coordination of system choices across organizations. It is possible for the delegated game to have multiple equilibria, not all of which are equally favorable from a social or, in our case, organizational standpoint. These have been labelled *excess momentum* or (excess inertia) if the users do (not) adopt the new technology even when it is less (more) favorable. We show that incentives can be used for coordination purposes to make the organizationally more favorable equilibrium more likely.

Lastly, we consider technology adoption games with communication between the manager and the users. We find conditions, with and without incentives, under which the users truthfully report their preferences. These situations can be extended using the Revelation Principle to others where the users communicate privately and independently with the manager.

2 Delegated system adoption

Consider an organization with n users and a manager. All the users currently use the same system, indexed 0. Technology innovation takes place and a new system, indexed 1, becomes available. Not all users value the system identically. Indeed, some may prefer the old system to the new system. Let b^i be the benefit (potentially negative) to user i of using the new system over the old system.

The users communicate with each other, or send work to one another as part of their job at the organization. This work flow has the potential of exposing the users to incompatibility costs if their system choices are not identical. Let $\tau^{ij}_{x_i x_j}$ be the cost incurred by user i if he selects system x_i while user j selects system x_j with $x_i \neq x_j$. These incompatibility costs are affected by system choices, intensity of work flow between individuals and individual preferences. These costs need not be symmetric.

The system adoption problem has been examined in market [11] and in organizational [5] settings. In this paper we consider the case when the preferences are private. Hence, we assume that for each i, only user i knows his preference b^i that he has for the new system. Other participants, users and managers alike, have a common prior distribution $F^i(b^i)$. We assume that:

Assumption A1: The priors for each user are independent from one another.

Assumption A2: F^i is continuous for each user i.

Of these assumptions, assumption A1 seems more restrictive of the two. Do note that these priors are about the self-preference of each user for the new system. The dependence that comes from work flow is explicitly modeled as incompatibility costs. Essentially, we have separated the impact of system choice on a user into two components: one that is independent from other users, that we term as preference, and the other that arises from work flow and compatibility.

Theorem 1 *If assumptions A1 and A2 hold then there exists a Nash equilibrium in which each user selects a hurdle* $a^i \in [-\sum_{j\neq i} \tau_{01}^{ij}, \sum_{j\neq i} \tau_{10}^{ij}]$ *and picks the new system if his privately known preference for the new system* b^i *exceeds this hurdle.*

Proof: Each user conjectures what the other users might do and makes his decisions based on these conjectures. We consider equilibria in which these conjectures are fulfilled.

Consider user i who conjectures that user j will pick the new system if user j's privately observed preference exceeds a^j, for $j \neq i$. With these conjectures, if user i picks the new system, then his expected net value will be $b^i - \sum_{j\neq i} \tau_{10}^{ij} F^j(a^j)$. If he picks the old system then his expected net value will be $-\sum_{j\neq i} \tau_{01}^{ij}(1 - F^j(a^j))$. Putting these together, the hurdle for user i is:

$$a^i = \sum_{j\neq i} \tau_{10}^{ij} F^j(a^j) - \sum_{j\neq i} \tau_{01}^{ij}(1 - F^j(a^j)) \tag{1}$$

From this equation we see that $-\sum_{j\neq i} \tau_{01}^{ij} \leq a^i \leq \sum_{j\neq i} \tau_{10}^{ij}$ for each i. Let $A^i = [-\sum_{j\neq i} \tau_{01}^{ij}, \sum_{j\neq i} \tau_{10}^{ij}]$.

Hence the equations for each i, $i = 1, \ldots, n$, taken together represent a continuous reflexive mapping on the convex compact set $A^1 \times \cdots \times A^n$. By Brouwer's Fixed Point theorem we conclude that a fixed point exists. ♯

System choices in the two user case is illustrated below in Figure 1.

The choice of hurdles depends on the incompatibility costs and the prior distributions. These are common knowledge and hence the manager can

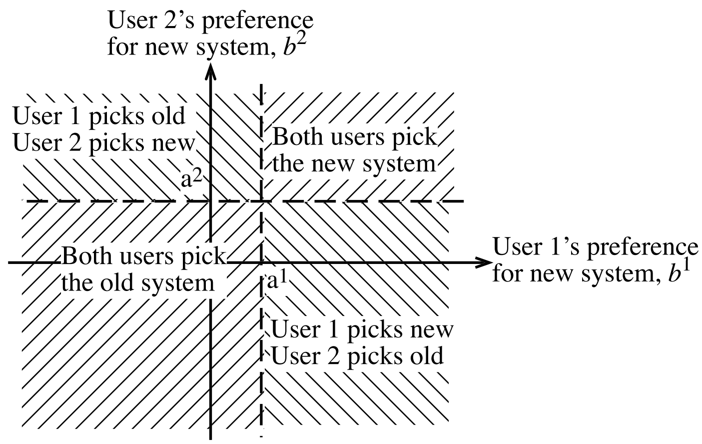


Figure 1: System choices when the choice is delegated to the users.

determine these hurdles and expect the users to behave in this fashion.

The total expected net benefit to the organization is:

$$V_{delegated} = \sum_{i=1}^{n} \Bigg(\int_{a^i}^{\infty} b \; \mathrm{d}F^i(b) - \sum_{j \neq i} \tau_{10}^{ij} F^j(a^j)(1 - F^i(a^i)) - \sum_{j \neq i} \tau_{01}^{ij} F^i(a^i)(1 - F^j(a^j)) \Bigg) \tag{2}$$

where a^i for $i = 1, \ldots, n$ are determined by equations (1).

Consider the situation if the manager tried to mandate a system choice rather than delegate it to the users. The manager would be maximizing net expected value. In the next example we show that in certain circumstances the manager may prefer to delegate rather than mandate system choices if he only knows the priors.

Example 1: Consider an example with two users. The preference of a new system over the old one for User1 is distributed uniformly in the interval

$[-1, \theta]$. The corresponding distribution for User2 is uniform in the interval $[-\theta, 1]$. Take $\theta > 1$ so that User1 prefers the new system on average and User2 prefers the old system on average. We will examine the impact of this difference of preference for systems.

If a user selects the new system while the other user stays with the old system then the user with new system incurs a backwards compatibility cost of $\tau_{10}^{12} = \tau_{10}^{21} = \tau$. The forward compatibility costs τ_{01}^{12} and τ_{01}^{21} are taken to be zero.

The choices that the manager has in mandating system choices, denoted by the pair of systems for user1 and user2, respectively, are:

(new, new): Expected value $(\theta - 1)/2 + (1 - \theta)/2 = 0$.

(old, old): Expected value 0.

(new, old): Expected value $(\theta - 1)/2 - \tau$.

(old, new): Expected value $-(\theta - 1)/2 - \tau$.

The manager will pick (new, new) with an expected value of 0 if $\theta < 1+2\tau$ and (new, old) otherwise.

For example, take $\theta = 1.5$ and $\tau = 0.4$. In this case the manager, if he mandates the system choice, will require both the users to pick the new system. The expected value for the organization in this case is 0.

The values for the delegated decision and for mandated with priors are shown in Figure 2. Examining Figure 2 we see that when the preferences are private to the users, then delegating the choice to users may increase the

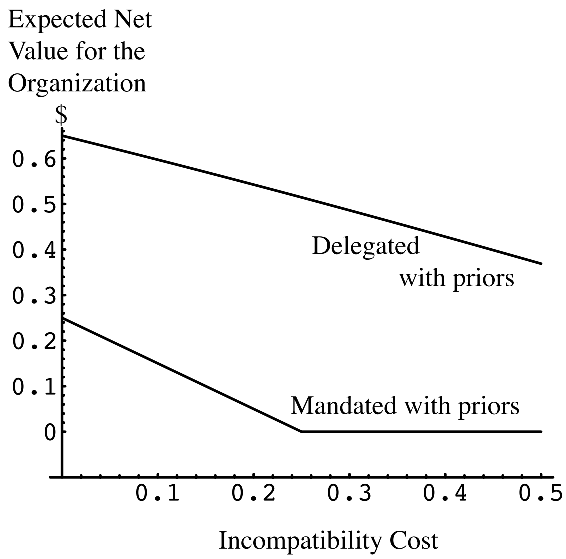


Figure 2: Expected value for the organization for the delegated policy may be greater than that from mandating without full information. ($\theta = 1.5$)

expected net value for the organization. $\sharp$

We next examine the impact of changing preferences on the outcome of the delegated system adoption game.

A Nash equilibrium is called *locally stable* if there exists a neighborhood of the equilibrium such that every tantonnement process starting with a point in the neighborhood converges to the equilibrium point. Stable and unstable fixed points in the context of the delegated game are illustrated in Figure 3. It is well known that if the Jacobian of the reaction functions has a spectral radius of less than one then the equilibrium point is locally stable [14]. In the next theorem we show that such equilibrium points of the delegated adoption game reflect the responsiveness of a user to preferences of others.

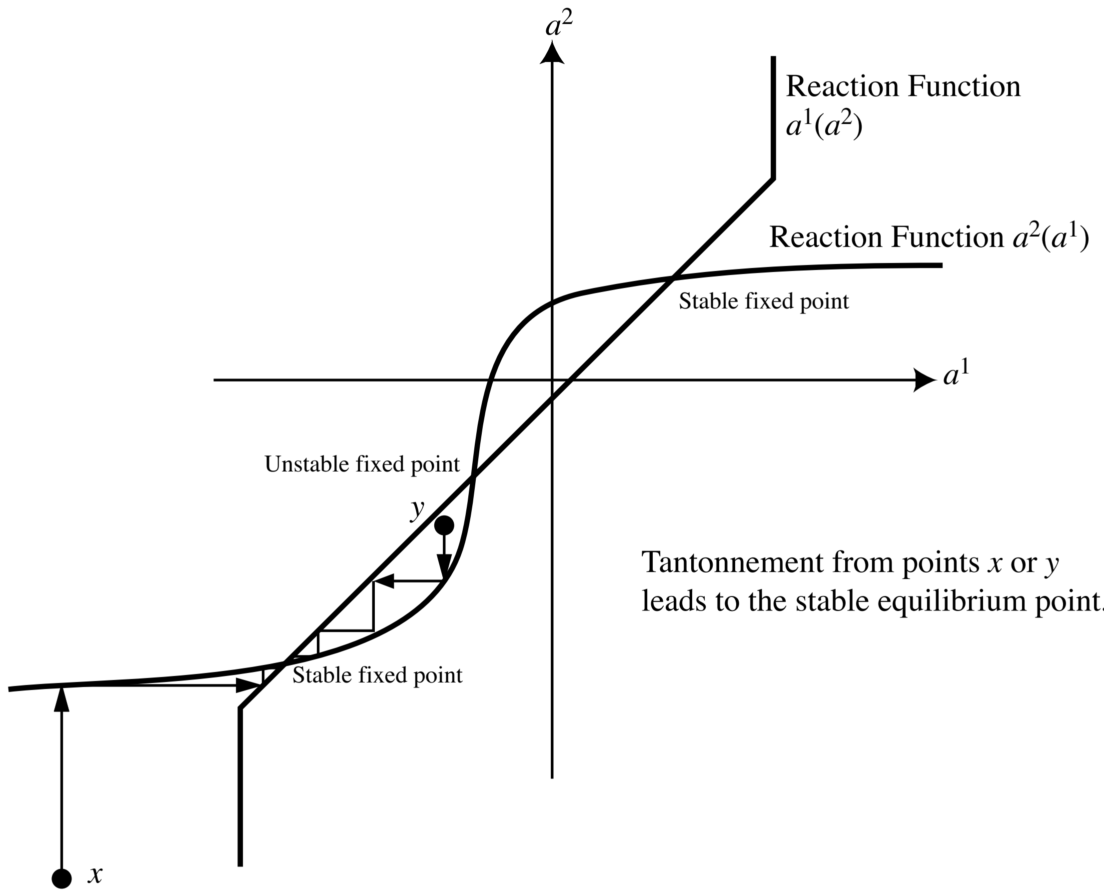


Figure 3: Stable and unstable Nash equilibria

Theorem 2 *If a^* is an equilibrium point such that the Jacobian of the reaction functions of users has a spectral radius of less than one then an increase in preference for a system by one user will lead to an adjustment of a^* such that the technology preferred by one user is more likely to be adopted by all users.*

Proof: Without loss of generality, let user 1 increase his preference for the new technology. To formalize this, let the prior over preference by user 1 for new technology be parameterized by λ, i.e, $F^1(b;\lambda)$ with $\partial F^1/\partial\lambda < 0$. Hence a prior with higher λ stochastically dominates one with lower λ. In other words, user 1 is more likely to prefer the new system if λ increases. Let the starting value of λ be zero.

Re-write the reaction functions (1) in vector notation as $a(\lambda) = R(a;\lambda)$. In this notation, we compute the Jacobian of the reaction function $R'(a^*, 0) = ((\frac{\partial R^i}{\partial a^j}))$ where:

$$\frac{\partial R^i}{\partial a^j} = \begin{cases} 0 & \text{if } j = i, \\ (\tau_{01}^{ij} + \tau_{10}^{ij})F^j(a^j) \geq 0 & \text{if } j \neq i. \end{cases}$$

This Jacobian has all non-negative elements, and by the hypothesis of the theorem, it has a spectral radius of less than one. Consider the identity

$$a - R(a, \lambda) = 0$$

that is satisfied at the fixed point a^* for $\lambda = 0$. The Jacobian of the left-hand side of this equation is

$$I - R'(a^*, 0)$$

By Theorem 4.C.6 on inverses of dominant diagonal matrices in [15], the Jacobian is non-singular and the inverse has all non-negative elements. Hence by the Implicit Function Theorem, we obtain $a'(\lambda)$ in the neighborhood of $\lambda = 0$:

$$a'(0) = [I - R'(a^*)]^{-1} \frac{\partial R(a^*, \lambda)}{\partial \lambda}|_{\lambda=0}$$

where

$$\frac{\partial R(a^*, \lambda)}{\partial \lambda}|_{\lambda=0} = \begin{bmatrix} 0 \\ \tau_{01}^{21} + \tau_{10}^{21} \\ \vdots \\ \tau_{01}^{n1} + \tau_{10}^{n1} \end{bmatrix} \frac{\partial F^1(a^*, \lambda)}{\partial \lambda}|_{\lambda=0}$$

Hence the sign of $a'(0)$ is determined by that of $\partial F^1 / \partial \lambda$. ♯

Example 2: As an example to illustrate the theorem, consider a variant of Example 1. User2's prior distribution of preferences, F^2, is $U[-1.5, 1]$ and so user2 does not like the new system. User1's prior distribution, F^1, is $U[-1, \theta]$ with θ varying from 2 to 5. Note that $U[-1, \theta]$ stochastically dominates $U[-1, \theta']$ iff $\theta \geq \theta'$. So as θ increases, user1 increasingly prefers the new system. In response to increasing preference for the new system, user1 lowers his hurdle and, consequently, raises his probability of selecting the new system. Interestingly, user2, whose priors do not change at all, also responds to changes in user1's preferences and lowers his hurdle and consequently, increases his probability of selecting the new system. This is shown in Figure 4. In this example $\tau_{10}^{12} = \tau_{10}^{21} = 0.4$. ♯

We next turn to incentives to improve system adoption by users.

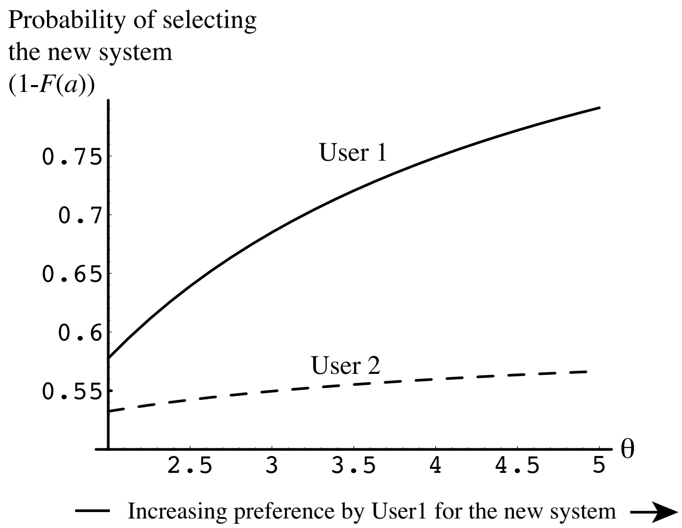


Figure 4: Both users respond to one user's increasing preference for the new system; $F^1 = U[-1, \theta]$, $F^2 = U[-1.5, 1]$, $(\tau_{10} = 0.4)$

3 Incentivized technology adoption

The manager would like to improve the expected net value to the organization beyond what is attainable using purely delegated decision making by the users. To this end, he offers system choice contingent incentives to users.

Let the n-element vector x denote the system choice with element i being 1 if user i selects the new system and 0 otherwise. For notational convenience, given a choice vector x, define x_i, x_{-i}, to be a choice vector where user i picks system x_i and all others pick systems according to elements of the $n-1$ vector x_{-i} which has all but the i^{th} element of x. Let s^i_x denote the incentive offered to user i if the system choice vector is x. With this notation, the payoff for user i if he picks the new system is $b^i + s^i_{1,x_{-i}} - \sum_{\substack{j \neq i \\ j:x_j=0}} \tau^{ij}_{10}$. The payoff if he picks the old system is $s^i_{0,x_{-i}} - \sum_{\substack{j \neq i \\ j: x_j = 1}} \tau^{ij}_{01}$.

Each user forms conjectures on choices made by others. Suppose that user i conjectures that user j will choose the old system if the preference for the the new system b^j is less than some hurdle a^j and user j will pick the new system otherwise. With these conjectures, the expected value for user i if he selects the new system is:

$$b^i + \sum_{x_{-i}} s^i_{1,x_{-i}} P_{x_{-i}}(a) - \sum_{j \neq i} \tau^{ij}_{10} F(a^j)$$

where:

$$P_{x_{-i}}(a) = \Pi_{\substack{j \neq i \\ x_j = 1}} (1 - F(a^j)) \Pi_{\substack{j \neq i \\ x_j = 0}} F(a^j)$$

The expected value if he selects the old is:

$$\sum_{x-i} s^i_{0,x_{-i}} P_{x_{-i}}(a) - \sum_{j \neq i} \tau^{ij}_{01} (1 - F(a^j))$$

Consequently, if user i were to select a hurdle it would be:

$$\begin{aligned} a^i = & - \sum_{x_{-i}} s^i_{1,x_{-i}} P_{x_{-i}}(a) + \sum_{j \neq i} \tau^{ij}_{10} F(a^j) \\ & + \sum_{x_{-i}} s^i_{0,x_{-i}} P_{x_{-i}}(a) - \sum_{j \neq i} \tau^{ij}_{01} (1 - F(a^j)) \end{aligned} \quad (3)$$

The next theorem shows that there exists a fulfilled expectations Nash equilibrium in which each of the users uses a hurdle policy to pick his system.

Theorem 3 *If assumptions A1 and A2 hold then there exists a Nash equilibrium in which each user selects a hurdle a^i and picks the new system if his privately known preference for the new system b^i exceeds this hurdle.*

The proof of this theorem is similar to that of Theorem 1 and is omitted here.

Define the following terms:

Expected system benefit net of incompatibility costs for user i:

$$EB^i = \int_{a^i}^{\infty} b \, \mathrm{d}F^i(b) - (1 - F^i(a^i)) \sum_{j \neq i} \tau_{10}^{ij} F(a^j) - F^i(a^i) \sum_{j \neq i} \tau_{01}^{ij} (1 - F(a^j))$$

Expected compensation for user i:

$$EC^i = \sum_{x_{-i}} ((1 - F^i(a^i)) s^i_{1,x_{-i}} + F^i(a^i) s^i_{0,x_{-i}}) P_{x_{-i}}(a)$$

The sign of the incentives is not restricted and so they may be penalties or bonuses contingent on system choices. If we use penalties, then we need individual rationality constraints to ensure that the users get at least their reservation utilities.

$$EB^i + EC^i \geq \bar{U}^i \tag{4}$$

The expected value for the organization is:

$$\sum_{i=1}^{n} (EB^i - EC^i) \tag{5}$$

The manager's goal is to pick incentives for each allocation vector and user so as to maximize the expected net value for the organization while meeting constraints of hurdle choice and individual rationality. We show in the next example that it is possible to do strictly better with incentives than without.

Example 3: Continuing with Example 1, we consider the effect of incentivizing the users. We consider two cases: one with $\theta = 1.1$ and another with $\theta = 2$. Variable θ, the support of opposite ends of the support for the two users, is a measure of disparity of preferences. The expected value to the organization net of incentives paid is plotted against the incentive in Figure 5. In each case we either incentivize user2 alone ($s^2_{1,1} = s$, $s^2_{0,1} = -s$) or user1 and user2 ($s^1_{1,1} = s^2_{1,1} = s$, $s^1_{0,1} = s^2_{0,1} = -s$). From the diagram we see that we are better off incentivizing both users when the disparity is low. On the other hand, we need incentivize only one user when the disparity is higher.

Picking the users to incentivize and the magnitude of the incentives depends on the problem parameters and are not easy to determine on an ad-hoc basis. $\sharp$

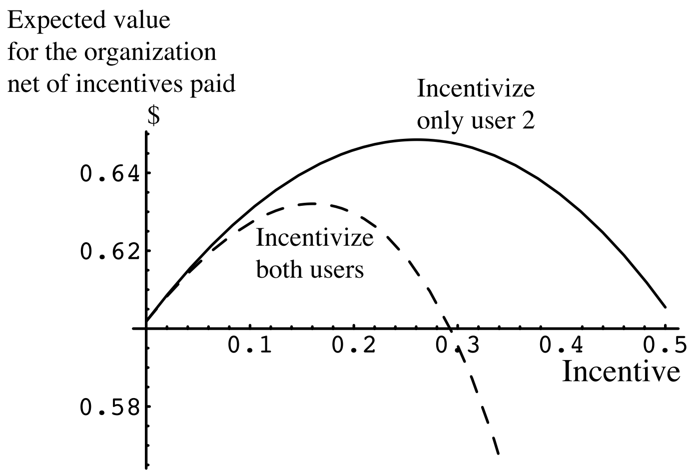
Next, we examine an incentive scheme designed to internalize the incompatibility costs.

3.1 Incentives to internalize incompatibility costs

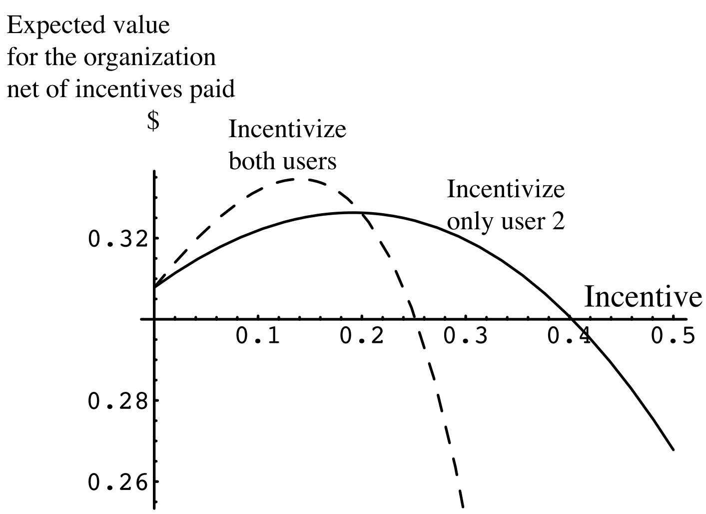
Consider a situation in which the manager can pick the hurdles for the users. What hurdles would the manager pick? He would pick the hurdles to maximize $\sum_i EB^i$. Setting the derivative with respect to a^i equal to zero, we get:

$$a^i_m = \sum_{j \neq i} (\tau^{ij}_{10} + \tau^{ji}_{01}) F^j(a^j_m) - \sum_{j \neq i} (\tau^{ij}_{01} + \tau^{ji}_{10})(1 - F^j(a^j_m)) \quad \text{for each } i \tag{6}$$

For this derivation we have assumed that the prior distributions have a non-zero density throughout. In addition, if we make assumptions A1 and A2 as before, then we can show that these equations have a solution.



Case A: Higher disparity in preferences (θ = 2.0)



Case B: Lower disparity in preferences (θ = 1.1)

Figure 5: Which users to incentivize?

Comparing equations (6) and the hurdle equations for the delegated case, equations (1), we see that the essential differences between these is that user i, for each i, ignores incompatibility costs that he himself does not incur, i.e., costs τ_{01}^{ji} and τ_{10}^{ji} for each $j \neq i$.

The manager would like each user i to use the hurdle a_m^i for picking his system. It is important to note that the manager can compute the hurdle for each user from publicly available information. What the manager cannot do, however, is verify that users follow this hurdle. This is because the preference information is only privately known to the users. So what is the manager to do? To solve this problem we turn to a scheme that is often discussed in information management literature: set the incentives to exactly account for this externality [12]. If we can set these incentives then we can expect the user to select the hurdles that the manager might mandate. We next show that not only can we do this but we can also set it so that the ex-ante expected compensation for each user (and hence for the organization as well) is zero.

We first derive the appropriate incentives and then discuss the issues such as individual rationality, i.e., satisfying constraints in equations (4).

We illustrate the incompatibility internalizing incentives for the case of two users. Rewrite equation (3) for two users:

$$\begin{aligned} a^1 &= (s_{0,0}^1 - s_{1,0}^1 + \tau_{10}^{12})F^2(a^2) + (s_{0,1}^1 - s_{1,1}^1 - \tau_{01}^{12})(1 - F^2(a^2)) \\ a^2 &= (s_{0,0}^2 - s_{1,0}^2 + \tau_{10}^{21})F^1(a^1) + (s_{0,1}^2 - s_{1,1}^2 - \tau_{01}^{21})(1 - F^1(a^1)) \end{aligned} \quad (7)$$

Comparing this with equation (6) for two users, we see that the following incentives will result in the users selecting the hurdles that the manager wants:

$$\begin{aligned} s^1_{0,0} - s^1_{1,0} &= \tau^{21}_{01} \\ s^1_{1,1} - s^1_{0,1} &= \tau^{21}_{10} \end{aligned} \tag{8}$$

The incentives for user2 are set similarly. Further, we can set the expected compensation to zero by picking incentives such that:

$$\begin{aligned} F^1(a^1_m)s^1_{0,0} + (1 - F^1(a^1_m))s^1_{1,0} &= 0 \\ F^1(a^1_m)s^1_{0,1} + (1 - F^1(a^1_m))s^1_{1,1} &= 0 \end{aligned} \tag{9}$$

Again, the equations for user2 are similar. Equations (8) and (9) can be solved to obtain the needed incentives:

$$\begin{aligned} s^1_{0,0} &= (1 - F^1(a^1_m))\tau^{21}_{01} & s^1_{1,0} &= -F^1(a^1_m)\tau^{21}_{01} \\ s^1_{1,1} &= F^1(a^1_m))\tau^{21}_{10} & s^1_{0,1} &= -(1 - F^1(a^1_m))\tau^{21}_{10} \\ s^2_{0,0} &= (1 - F^2(a^2_m))\tau^{12}_{01} & s^2_{1,0} &= -F^2(a^2_m)\tau^{12}_{01} \\ s^2_{1,1} &= F^2(a^2_m))\tau^{12}_{10} & s^2_{0,1} &= -(1 - F^2(a^2_m))\tau^{12}_{10} \end{aligned}$$

To illustrate the use of these incentives, consider the following example.

Example 4: We continue with the example with uniform priors uniform over $[-1, 5]$ for user1 and over $[-1.5, 1]$ for user2. We take $\tau^{12}_{10} = 0.4$ and $\tau^{12}_{01} = \tau^{21}_{10} = \tau^{21}_{01} = 0.1$. With these parameters, user1 greatly prefers the new system but has high backward compatibility costs. Other incompatibility costs are moderate.

The hurdles and probability of picking the new system for the two users are shown in Table 1. The first panel describes the situation when no incentives are used. The incentives are set to internalize incompatibility cost and yet have zero expected cost in the next panel. Note the manager prefers to incentivize the users to make them both more likely to pick the new system. This results in 1% improvement in net value for the organization for a 12% drop in user2's net value. ♯

Incentive Policy		**Incentives** $s_{0,0}$	$s_{1,1}$	$s_{1,0}$	$s_{0,1}$	**Hurdle**	**P[New]**	**User's** **EB**	**EC**	**Total**	**Org. Net**
Delegated	U1					0.187	0.802	1.887	0.0	1.887	
	U2					-0.060	0.424	0.145	0.0	0.145	2.032
Incentives	U1	0.081	0.186	-0.081	-0.019	0.116	0.814	1.925	0.0	1.925	
to internalize	U2	0.055	0.181	-0.219	-0.045	-0.370	0.548	0.126	0.0	0.126	2.050
Simplified	U1		.0033		-.0142	0.116	0.814	1.925	0.0	1.925	
Thm. 4	U2		.1705		-.2066	-0.370	0.548	0.126	0.0	0.126	2.050
Bonus for	U1	0.1	0.1			0.116	0.814	1.925	0.053	1.978	
Standard	U2	0.1	0.4			-0.370	0.548	0.126	0.187	0.313	1.811
Penalties for	U1			-0.1	-0.1	0.116	0.814	1.925	-0.048	1.877	
Non-Standard	U2			-0.1	-0.4	-0.370	0.548	0.126	-0.157	-0.032	2.255

Table 1: Impact of different incentive policies on technology adoption and net value.

The potential for decrease in some users' utilities can cause the individual rationality constraint, (4), to be violated. In this case, the mandated hurdles are not feasible and the constrained problem in equations (3)–(5) has to be solved. The complexity of this problem depends on the priors distributions. For uniformly distributed priors, this problem is an easily solvable quadratic program.

If the incentive compatibility constraints are satisfied by the mandated hurdles chosen by the manager, then the manager's constrained problem is trivially solved: select the mandated hurdles and set the incentives as in the equations above. For all users whose individual rationality constraint is not binding, reduce the incentive in all states by the slack in the constraint. This will maintain feasibility and maximize the value to the organization.

In the next two subsections we discuss simplifications of the incentive plans.

3.2 Simplified incentive plans

Next, let us examine the incentive plans more carefully. There are 2^n possible allocation vectors and so the manager has to potentially pick $n2^n$ incentives. In the next theorem we show that there exist optimal incentive plans with at most $2n$ non-zero incentives.

Theorem 4 *If the manager's problem has a solution then there exist optimal incentive plans in which each user has non-zero incentives for at most two choice vectors.*

Proof: Let s^* solve the problem and let a^* be the hurdles obtained for these incentives using equation (3). Consider a new problem of picking incentives s to maximize the objective function (5) subject to keeping the hurdles at a^*. The objective function (5), hurdle constraint (3), and individual rationality constraint (4), all are all linear in s. Further, the linear program is separable for each user i. Each subprogram is linear with two constraints. The basis is a 2×2 matrix and hence we can obtain an optimal solution with non-zero incentives for at most two choice vectors. ♯

Example 4 Continued: Now consider applying Theorem 4 to the example we have been discussing. We can replace the incentives for the eight choice vectors by just four shown in the table. The probabilities of picking the new system by each of the users, and all the payoffs remain the same. Do note that each user has a penalty and a bonus associated with different choices. In many organizations, we have noted that managers use only penalties or bonuses but not both. To illustrate these schemes, we have added two panels to Table 1.

Only bonuses for standard choices: In this we can get the users to pick the new system with the probabilities determined above, but the bonuses reduce the net value to the organization. The user net values are higher with the bonuses.

Only penalties for non-standard choices: Again we can get the users to use the same hurdles but there is a wealth transfer from the users to the organization. This may violate individual rationality (participation constraints expressed in equation (4)) for users.

The last two sets of incentives are examined in greater detail in the next subsection. ♯

3.3 Incentives for Standards

An alternative formulation of the incentivized problem is to replace the individual rationality constraints by constraints that restrict the incentives to be non-negative, i.e., only permit bonuses. This presents an interesting subcase to analyze. In this case we can show that each user will have a non-zero incentive for at most one choice vector.

We make an additional assumption:

Assumption A3: $F^i(-\sum_{j\neq i}\tau_{01}^{ij}) > 0$, and $F^i(\sum_{j\neq i}\tau_{10}^{ij}) < 1$ for each user i.

Theorem 5 *If assumption A3 holds and the manager's problem has a solution with only bonuses permitted then there exist optimal incentive plans in which each user has non-zero incentive for at most one choice vector. Further, these incentives can be chosen such that only standard choices have non-zero incentives.*

Proof: The proof of the first part is very similar to that of Theorem 4 with individual rationality constraint replaced by non-negativity constraints. For the second part, consider the subproblem for any user i:

$$\min_s F(a^{i*})s_0^i + (1 - F(a^{i*}))s_1^i$$

Subject to

$$s_0^i - s_1^i = k^i$$

$$s_0^i,\ s_1^i \geq 0$$

where:

$$
\begin{aligned}
s_0^i &= \sum_{x_{-i}} s_{0,x_{-i}}^i P_{x_{-i}}(a^*) \\
s_1^i &= \sum_{x_{-i}} s_{1,x_{-i}}^i P_{x_{-i}}(a^*) \\
k^i &= a^{i*} + \sum_{j \neq i} \tau_{01}^{ij}(1 - F(a^{j*})) - \sum_{j \neq i} \tau_{10}^{ij} F(a^{j*})
\end{aligned}
$$

This linear program can be solved by inspection.

If k^i is zero then set all s_x^i for all x to zero.

If k^i is positive then set $s_0^i = k^i$. Then pick any one $s_{0,x_{-i}}^i$ with non-zero coefficient and set that appropriately. Existence of at least one is guaranteed by the hypothesis. The choice of the individual incentive picked does not matter as it contributes the same expected amount, k^i to the objective function. In particular, if assumption A3 holds then the coefficient for $s_{0,0\ldots0}^i$ is positive and this incentive for picking the old system as standard can be set to be positive.

The k^i negative case is similar, except that $s_{1,1\ldots1}^i$ is positive. $\sharp$

Continuing with the previous example, we can set $s_{1,1}^2 = 0.4$ and get the same hurdles.

If the individual rationality constraints are not binding and the manager is interested in system adoption and not interested in using penalties for wealth transfer from users to the organization, then there exist incentive plans with only penalties for situations when users choose dissimilar or non-standard systems.

3.4 Using standards for coordination

In this subsection, we consider the case with n users who have identical priors and incompatibility costs. Even with users ex-ante identical there is an important issue of coordinating system choices among multiple users. In such circumstances, coordination could help in selecting among multiple equilibria or account for ex-post (after users know their preferences) differences. The former role of standards has been well recognized. Farrel and Saloner describe cases in which users faced with choice among multiple equilibrium and incompatibility costs may stay with an inferior choice (excess inertia) or move to an inferior choice (excess momentum) [7]. Consider the following example to illustrate the use of incentives to coordinate choices among users:

Example 6: Suppose that the preferences are private and the prior distributions are uniform over the intervals $[-1, 1.1]$ and $[-1.1, 1]$ for users 1 and 2, respectively. The incompatibility costs are $\tau_{10}^{12} = \tau_{10}^{21} = 0.4$. With these costs, the delegated hurdles chosen by user1 and user2 are 0.26 and 0.24, respectively. The expected net value to user1, user2 and organization are 0.170, 0.138, and 0.308, respectively. If the manager sets the incentives to pick the hurdles then the hurdles chosen are 0.01 and -0.01 for user1 and user2, respectively. In other words, the manager would like the users to pick the new system with much greater likelihood than they would in a delegated setting. With these new hurdles, the net value of user1, user2 and the organization are 0.181, 0.144, and 0.326, respectively. This strictly Pareto dominates the delegated setting. Every one is better off. Essentially, the manager has used incentives to coordinate the choice of systems. ♯

Coming back to the case of ex-ante identical users, consider the case when the manager decides to incentivize m of the n users. The remaining $n-m$ users are un-incentivized. Since we are considering groups of users, we simplify the notation. The incompatibility costs are shown in the Table 2:

		User 2	
		Old System (0)	New System (1)
User 1	Old System (0)	0,0	τ_f, τ_b
	New System (1)	τ_b, τ_f	0, 0

Table 2: Incompatibility costs

Backward incompatibility cost, τ_b is the cost incurred by a new system user when he interacts with an old system user. Forward incompatibility cost, τ_f is the opposite.

Theorem 3 applies to this case as it did earlier. Hence, there exist hurdle policies that are in Nash equilibrium. Let a_i and a_u be the hurdle used by incentivized and un-incentivized users, respectively. In other words, an (non-incentivized) incentivized user picks the new system if his revealed preference for the new system exceeds a_i (a_u).

Without loss of generality, consider the case when the new system is better than the old for the organization, i.e, if the manager could mandate a choice, he would pick the new system with greater likelihood than the users left to their own devices.

The incentive compatibility conditions for choice of hurdles by users when m users are incentivized with s when they pick the new system are:

$$\begin{aligned} a_i &= -s + [(m-1)F(a_i) + (n-m)F(a_u)]\tau_b \\ &- [(m-1)(1-F(a_i)) + (n-m)(1-F(a_u))]\tau_f \\ a_u &= [mF(a_i) + (n-m-1)F(a_u)]\tau_b \\ &- [m(1-F(a_i)) + (n-m-1)(1-F(a_u))]\tau_f \end{aligned} \tag{10}$$

Again, from Theorem 3, we can deduce that if the independent priors F are continuous and the support properly contains the interval $[-(n-1)\tau_f, (n-1)\tau_b]$ then there exist proper solutions to these simultaneous equations.

With these hurdles, the expected incompatibility cost for an incentivized user is:

$$\begin{aligned} \tau_i(a_i, a_u) &= [(m-1)F(a_i) + (n-m)F(a_u)](1-F(a_i))\tau_b \\ &+ [(m-1)(1-F(a_i)) + (n-m)(1-F(a_u))]F(a_i)\tau_f \end{aligned}$$

The expected incompatibility cost to a non-incentivized user is:

$$\begin{aligned} \tau_u(a_i, a_u) &= [mF(a_i) + (n-m-1)F(a_u)](1-F(a_u))\tau_b \\ &+ [m(1-F(a_i)) + (n-m-1)(1-F(a_u))]F(a_u)\tau_f \end{aligned}$$

The organization's expected net benefit is:

$$m\int_{a_i}^{\infty}(b-s)\mathrm{d}F(b) + (n-m)\int_{a_u}^{\infty} b\mathrm{d}F(b) - m\tau_i(a_i, a_u) - (n-m)\tau_n(a_i, a_u) \tag{11}$$

The manager sets incentive s for the m users to maximize the net benefit to the organization, (11), subject to hurdle choice constraints, (10), and non-negativity of s.

A *bandwagon effect,* in which all users switch to the new system if a critical number of users decide to switch, has been reported in technology adoption literature. This relies on the forward incompatibility cost, τ_f, the cost faced by users of the old system who interact with users of the old system, to coerce them to switch. In the absence of these costs, incentives can be used to achieve the same effect. This is shown in the next theorem for uniformly distributed priors.

Theorem 6 *If the prior distributions are uniform over the interval* $[l, r]$ *with with* $l < 0$, $-l < r$, *the forward compatibility costs are zero and the backward compatibility costs are such that* $4/3(n-1)\tau_b < r - l < 2(n-1)\tau_b$ *and* $r > (n-1)\tau_b$, *then the manager prefers to incentivize all users.*

Proof: We eliminate the hurdles a_i and a_n from the objective function (11) using equations (10). The resulting function is quadratic and and convex in s. The first order condition provides:

$$s = \frac{-n(l - r + 2(n-1)\tau_b)(r - (n-1)\tau_b)}{(r - l - (n-1)\tau_b)^2 \left(\frac{m(-3(r-l)+4(n-1)\tau_b)}{(r-l-(n-1)\tau_b)^2} + \frac{(n-m)(-3(r-l)-4\tau_b)}{(r-l+\tau_b)^2}\right)}$$

With the hypothesis, the numerator is negative. The denominator is negative too. This implies that $s > 0$.

We substitute the optimal s into the objective function and take its derivative with respect to m to obtain a rational function with a squared denominator and the following numerator:

$$2(-3l + 3r + 4\tau_b)(-l + r + \tau_b)^2(l - r + 2(n-1)\tau_b)^2(r + \tau_b - n\tau_b)^2$$

This is also positive given the hypothesis of the theorem. Further it is independent of m and hence, the objective function improves linearly with m. Consequently, if the manager chooses to incentivize one user, he will incentivize all users. ♯

4 System Adoption with Communication

Communication between the users and the manager is considered in this section. We consider a simple communication system in which each user simultaneously and privately communicates with the manager.

On the time line of this new game with communication, first, the manager announces a system choice rule (a mapping from reports to system choices for each user) and choice contingent incentives. Next, each user reports his private preferences. Finally, the system choice is made based on the announced rules and the reports. This problem of picking the rules and incentives is very similar to the "incentive problem in a conglomerate" game modeled by Groves in [9].

Let $x(r) = ((x_i(r) \in 0, 1))_{i=1,\ldots,n}$ be the vector of systems choices based on reports r where $r = (r_1, \ldots, r_n)$.

Based on the announced rules and incentives, each user picks a report r^i that maximizes his expected utility:

$$\begin{aligned}\max_{r^i} \quad & E_{r_{-i}}\,[\; b^i x^i(r) + s^i_{x(r)} \\ + \quad & \sum_{j\neq i} \tau^{ij}_{01} x_j(r)(1 - x_i(r)) + \sum_{j\neq i} \tau^{ij}_{10}(1 - x_j(r))x_i(r) \;]\end{aligned}$$

First consider the case when the manager does not offer any incentives but in other respects the game is identical to the one described above. We make one additional assumption.

Assumption A4: The user tells the truth if the user is indifferent between telling the truth or not.

Theorem 7 *If the manager announces that he will use a hurdle policy for picking systems and uses the same hurdles as in the delegated game with no communication then the users will report truthfully.*

Proof: The hurdles for the delegated game with no communication, a^i_d, for each i, are defined in equation (1).

First consider the case when $b^i < a^i_d$. If the user reports truthfully that his preference is below the hurdle then his expected payoff is:

$$\begin{aligned} - \quad & \sum_{j\neq i} \tau^{ij}_{01}(1 - F^j(a^j_d)) \\ = \quad & a^i_d - \sum_{j\neq i} \tau^{ij}_{10} F^j(a^j_d) \\ > \quad & b^i - \sum_{j\neq i} \tau^{ij}_{10} F^j(a^j_d) \end{aligned}$$

The last term is the expected payoff to user i if he reports that his preference exceeds the hurdle. Hence in this case the user prefers to report the truth.

The proof for the opposite case of $b^i > a_d^i$ is similar. When $b^i = a_d^i$ then the user is indifferent between telling the truth or not and by assumption A4, he reports the truth. ♯

This theorem is more widely applicable than the hypothesis seems to indicate. By the Revelation Principle [13] the truth-telling game described above is revenue equivalent to other more general communication games as long as each user communicates independently and confidentially with the manager and the manager is committed to his announced policy. Further, all the analysis of the delegated game with no communication that is exhibited in section 2 applies to this game too.

Now consider the communication game with incentives.

Theorem 8 *If the manager announces that he will provide incentives to internalize the incompatibility externality, use a hurdle policy for picking systems and use the hurdles a_m^i for each i, then the users will report truthfully.*

Proof: The hurdles are defined in equation (6) and the incentives are exhibited in section 3.1.

First consider the case when $b^i < a_m^i$. If the user reports truthfully that his preference is below the hurdle then his expected payoff is:

$$- \sum_{j \neq i} \tau_{01}^{ij}(1 - F^j(a_m^j)) + \sum_{x_{-i}} s_{0,x_{-i}}^i P_{x_{-i}}$$

$$
\begin{aligned}
&= a^i_m - \sum_{j \neq i}(\tau^{ij}_{10} + \tau^{ji}_{01})F^j(a^j_m) + \sum_{j \neq i}\tau^{ji}_{10}(1 - F^j(a^j_m)) + \sum_{x_{-i}} s^i_{0,x_{-i}}P_{x_{-i}} \\
&= a^i_m - \sum_{j \neq i}\tau^{ij}_{10}F^j(a^j_m) + \sum_{x_{-i}} s^i_{1,x_{-i}}P_{x_{-i}} \\
&> b^i - \sum_{j \neq i}\tau^{ij}_{10}F^j(a^j_m) + \sum_{x_{-i}} s^i_{1,x_{-i}}P_{x_{-i}}
\end{aligned}
$$

The last term is the expected payoff to user i if he reports that his preference exceeds the hurdle. Hence in this case the user prefers to report the truth.

The proof for the opposite case of $b^i > a^i_m$ is similar. When $b^i = a^i_m$ then the user is indifferent between telling the truth or not and by assumption A4, he reports the truth. ♯

Again, by the Revelation Principle, this theorem is more widely applicable than the hypothesis seems to indicate. Further, all the analysis of the game with no communication that is exhibited in section 3.1 applies to this game too.

5 Conclusions

In this paper we have considered a number of different mechanisms to coordinate and control technology adoption in organizations. The users of systems, being closer to the functions performed, may have specific knowledge about the usefullness of different technologies. The organization can take advantage of this information by delegating the system choice to the users. This often results in higher expected value for the organization than when a manager, who does not have the specific information, mandates the choices.

The organization can do even better by judiciously using incentives for technology adoption. We derive optimal incentive plans for technology adoption that consider individual rationalty and incentive compatibility on the part of the users. We derive a number of simplifications of the incentive plans. These incentive plans need not be too complex — there exist optimal plans in which users have non-zero incentives only for standard choices. There also exist incentive plans in which there are only penalties for non-standard choices.

We show that if we pick incentives that internalize the incompatibility externality for each user then the users will adopt technologies that are best for the organization. This is similar to the incentive scheme exhibited by Mendelson in [12] in which incentives are used to control the utilization of a common congested system. Further, this incentive plan also fits the Clarke-Groves mechanism [4, 9]. These plans, however, are a simplification of the general problem explored in this paper as they ignore the cost of incentives themselves.

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