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Technology Adoption and Pro-social Preferences*

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Abstract. In this paper, I study the design of least cost technology adoption subsidy schemes when the individuals' decisions are affected by peer effects and pro-social motivations. Peers effects imply that the adoption decision of an agent influences the adoption decisions of the other agents. Moreover, the subsidy offered to an agent can directly encourage or discourage technology adoption by the other agents, a new effect that is due to pro-social preferences. I show that pro-social preferences lead to lower individual subsidies and to higher inequality among the agents. The model delivers empirical implications for intervention programs supporting the adoption of new technologies, both in contexts where peers have been shown to generate positive effects (as in the case of malaria prevention technologies and modern agricultural inputs) and in contexts where peers have been shown to generate negative effects (as in the case of deworming pills).

JEL classification: D91, D62, D86, 033

Keywords: incentives, externality, principal, agents, pro-social preferences.

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1 Introduction

Strong evidence supports the existence of peer effects in intervention programs aiming at increasing the adoption of new agricultural[1] or health technologies[2] in developing countries among neighbors, family members or friends,[3] that is individuals who care about each other.[4] While the body of evidence on these programs is growing, how they should be optimally designed is not theoretically well understood. How is it possible to induce individuals who care about each other to adopt a new technology? Is it less costly than for individuals who don't? Should intervention programs treat individuals equally? Should pro-social motivation lead to less or more inequality? These questions arise when designing an intervention program that aims to support the adoption of new technologies or more generally when a principal wants to induce successful coordination among individuals who care about each other.

In this paper, I study a situation in which a principal offers subsidies to the members of a group of agents who have pro-social preferences to induce them to adopt a technology. Each agent's decision to adopt the technology generates externalities for the other agents and the level of externality enjoyed by these agents depends on whether they also adopt the technology or not, which is the reason why there are peer effects in this setting. I assume that the individuals have quasi-maximin pro-social preferences (Charness and Rabin, 2002b), that is they give weight to their own payoff (as selfish motivation), to the sum of the payoffs (a collective motivation) and to the minimum payoff (a Rawlsian motivation). These social preferences generate a new phenomenon: the subsidy offered to an agent may directly favor or discourage technology adoption by the other agents (an "encouragement effect"). The principal designs the least-cost subsidy scheme such that the agents adopt the technology. Since intervention programs usually provide individual subsidies (e.g. individual vouchers, free distribution or price discount), I assume that the level of subsidy offered to one agent cannot depend on the other agents' decisions. The aim of the present paper is to analyze how pro-social preferences affect the optimal subsidy and the level of inequality.

The most interesting results are derived in the case of positive peer effects. I characterize the optimal subsidy scheme that implements technology adoption by all the agents as a unique Nash equilibrium ("unique implementation"). I show that pro-social preferences lead to lower individual subsidies. Moreover, the existence of pro-social preferences lead to an increase in objective inequality -the difference between individual material payoffs- while they lead to a decrease in subjective inequality -the difference between individual utility levels. However, in the specific case where the agents have a pure Rawlsian motivation, objective inequality is the same as with purely selfish agents while subjective inequality decreases.

I also analyze the implications of alternative assumptions and I provide several extensions.

[1] See Foster and Rosenzweig (1995); Munshi (2004); Bandiera and Rasul (2006); Conley and Udry (2010); Carter et al. (2019)

[2] See Kremer and Miguel (2007); Oster and Thornton (2012); Dupas (2014); Tarozzi et al. (2014); Adhvaryu (2014)

[3] The literature has also studied peer effects in contexts of participation decisions in labor markets (Munshi, 2003), education (Sacerdote, 2001; Angrist and Lang, 2004; Bayer et al., 2008), criminal networks (Glaeser et al., 1996; Bayer et al., 2009), financial decisions (Duflo and Saez, 2003; Banerjee et al., 2013), peer pressure in firms (Mas and Moretti, 2009), or fertility decisions (Munshi and Myaux, 2006).

[4] A strand of the experimental economics literature shows that pro-social motivations are prevalent, and even more salient than disadvantageous inequality aversion, see Charness and Rabin (2002a), Bellemare et al. (2008) or Gueye et al. (2020).

While the main results are derived in the case where the principal seeks to induce technology adoption by all the agents as a unique Nash equilibrium, the literature that deals with the optimal design of contracts with externalities among the agents has also considered the situation where the principal can coordinate the agents on his preferred equilibrium (as in Segal, 1999). I thus characterize the optimal contract that implements adoption of the technology by the agents of the group as one (of possibly many) Nash equilibrium ("partial implementation"). I show that in this case, homogeneous agents should get the same level of subsidy. I then extend the model to a situation where the agents are heterogeneous. I consider two types of heterogeneity: the agents either have heterogeneous costs and benefits (which is important to understand technology adoption, see Suri, 2011) or they have altruistic preferences (in the spirit of Bourlès et al., 2017), that is they may give different weights to the payoff of each other agent. I also extend the model to the case where non adopters benefit from positive externalities and show that the main results are not affected. I finally analyze the case where peer effects are negative, that is when adopters receive lower externalities than non adopters from adopters. I show that in this case, the (homogenous) agents all receive the same subsidy and then there is no inequality.

In the last part of the paper, I argue that the model can be used as an underlying theory for the empirical analysis of peer effects in the adoption of new health or agricultural technologies. Most of existing empirical studies in this literature provide evidence that individuals are more likely to adopt a new technology when the number of peers that decide to adopt the technology is larger (i.e. positive peer effects). This holds for a number of health (Oster and Thornton, 2012; Dupas, 2014; Adhvaryu, 2014) and agricultural technologies (Foster and Rosenzweig, 1995; Munshi, 2004; Conley and Udry, 2010; Carter et al., 2019). An exception is Kremer and Miguel (2007) who find negative peer effects in the case of a deworming program.[5] I first argue that the estimates of peer effects (and technology adoption decisions) are likely to be partly driven by the fact that the individuals in the samples are from the same family, network of friends or are neighbors, and that they care about each other. Moreover, I argue that my theoretical results suggest that the existence of pro-social preferences implies that peer effects estimates are biased. The model has also implications for the design of optimal subsidy (or free delivery) interventions. Each study in the literature focuses on one specific form of subsidy, such as subsidy vouchers (Dupas, 2014; Carter et al., 2019) or free delivery (Kremer and Miguel, 2007). There is however no study that compares the outcome of various forms of subsidies (e.g. uniform subsidy vouchers versus free delivery to a subset of the population). The present model may be used as the underlying theory of such comparative studies. My results combined with the results from the empirical literature suggest that uniform subsidies should perform better than free delivery (to a subset of the population) in the case of deworming programs, while free delivery (to a subset of the population) should perform better than uniform subsidies in the case of anti-malaria prevention technologies and agricultural inputs technologies.

This paper contributes to the literature on discriminatory incentives. Incentives are said to be (endogenously) discriminatory when they involve non symmetric rewards even when all the agents are identical, and the objective of the principal is to induce participation of all the agents. Optimal incentives can be discriminatory in various contexts, such as exclusionary contracts

[5] Another exception is Bandiera and Rasul (2006) who find evidence of an inverse U-shaped relationship between farmers' adoption of a new crop and the number of adopters.

(Rasmusen et al., 1991, Innes and Sexton, 1994), introductory prices by a monopolist in the presence of consumption externalities (Farrell and Saloner, 1985, Katz and Shapiro, 1986),[6] in general trade contracts (Segal, 2003), and in organizations (Winter, 2004). As in several papers in this literature, the optimal subsidy scheme derived in the present paper (when peer effects are positive) is characterized by a *divide and conquer property*: each agent gets a subsidy that would convince him to adopt the technology when all the agents who precede him in an arbitrary ranking also adopt the technology.[7] However, this literature has exclusively focused on agents with standard preferences. In many contexts, such as when designing an optimal intervention program supporting the adoption of new technology in developing countries, the principal has to consider the fact that the agents care about each other. This is the main purpose of the present paper.

This paper contributes to the literature on contracts with externalities. The seminal contribution by Segal (1999) shows that partial implementation contracts are inefficient in the presence of multilateral externalities (assuming standard, selfish preferences). In a setting where the agents make technology adoption decisions, I show that pro-social preferences affect the optimal partial implementation contract and that they decrease the implementation cost for the principal. Segal (2003) studies, in a general setting, the property of the optimal unique implementation contract and shows that forbidding the principal to propose discriminatory contracts aggravates inefficiencies when the agent's actions are strategic complements.[8] In the present paper, I extend this literature and study both the partial and the unique implementation contract when the agents have pro-social preferences in a situation where the agents make binary decisions (as in Winter, 2004) and their actions are either strategic complements (i.e. positive peer effects) or strategic substitutes (i.e. negative peer effects). This literature has exclusively focused on agents with standard preferences and has ignored the possibility that the contract offered to an agent directly affects the actions of the other agents (not only indirectly through peer effects), two related considerations which are the purpose of the present paper.

This paper also contributes to the growing literature on behavioral contract theory (see Koszegi, 2014 for a review). Indeed, the present paper consider a principal who contracts with multiple agents who have pro-social preferences, it is thus related to the contributions that have considered contracting with multiple agents. This literature has focused on the case of inequity-averse and/or status-seeking agents.[9] An exception is Dur and Sol (2010), who focus on (endogenous) altruism. My main focus is on the coordination problem and inequality, while the aforementioned contribution asks whether incentives can help to generate altruism. Another exception is Sarkisian (2017), who study the role of altruism and Kantian morality when a principal seeks to motivate a team of two agents. The present paper differs from this contribution because I focus on bilateral contracting (and not on team incentives) and also tackle the issues

[6] See also Bensaid and Lesne (1996) and Cabral et al. (1999).

[7] Segal (2003) and Bernstein and Winter (2012) find that the optimal contract has a similar structure in settings with standard preferences. Che and Yoo (2001) find that the optimal mechanism in a moral hazard in a team problem has also a similar structure.

[8] This model has been extended in several directions. See Bernstein and Winter (2012) and Sakovics and Steiner (2012) for contracting problems with heterogeneous externalities. See Bloch and Gomes (2006), Genicot and Ray (2006) and Galasso (2008) for dynamic models.

[9] See Itoh (2004), Demougin et al. (2006), Neilson and Stowe (2008), Bartling and von Siemens (2010), and Bartling (2011) for models with two inequity-averse or status-seeking agents. See Cabrales et al. (2008) for a dynamic model of the labor market.

of coordination and inequality.

The remainder of the paper is organized as follows. The model is introduced in Section 2. Section 3 provides a simple example that highlights the encouragement effect. Section 4 delivers the main results. In Section 5 I analyze alternative assumptions and I provide several extensions. Section 6 discusses policy implications. Finally, Section 7 concludes. All proofs are provided in an appendix.

2 The model

A principal offers individual subsidies (bilateral contracts) to several agents in an environment characterized by externalities between the agents. The timing is as follows: first, the principal proposes a publicly observable subsidy scheme to a set of agents; second, the agents observe the principal's proposition and simultaneously decide whether to adopt or not the technology at their individual subsidized price.

For the ease of presentation, I focus on positive peer effects in the main part of the paper, and I show how the results differ when considering negative peer effects in Section 5.4.

An agent who decides to adopt the new technology obtains a private benefit $\widehat{b}$ and generates a positive externality $w \geq 0$ for the other agents who also adopt the technology and no externality for the agents who do not adopt the technology.[10] An agent who decides not to adopt the technology receives an outside option $\widehat{c}$ (e.g. the profit of a farmer who does not use fertilizers). The principal aims to induce full technology adoption at the lowest possible cost. In order to reach this goal, she proposes a subsidy scheme $v = (v_1, v_2, ..., v_n)$ to the agents in the set of agents N, with $i = 1, 2, ..., n$, in order to provide them with incentives to adopt the technology. The subsidy is conditioned on the agent adopting the technology (i.e. agent i receives v_i from the principal if he adopts the technology and 0 otherwise). The subsidy scheme v is designed such that each agent receives a unique offer v_i, $i \in N$, that is to say that the principal is able to use individualized subsidies. The vector of agents' decisions is $x = (x_1, ..., x_n) \in \{0, 1\}^n$, where $x_i = 1$ means that agent i chooses to adopt the technology while $x_i = 0$ means that that agent decides not to adopt the technology.

When agent i adopts the new technology and m other agents also adopt this technology ($m + 1 = card\{j \in N : x_j = 1\}$), agent i's material payoff is:

$$\pi(x, v_i) = \widehat{b} + v_i + mw, \tag{1}$$

and,

$$\pi(x, v_i) = \widehat{c}, \tag{2}$$

if agent i does not adopt the technology ($x_i = 0$).

I assume that the agents have social preferences and that they give weight to their own payoff (a "selfish" motive) and to the payoffs of all the agents (a pro-social motive). Formally, the utility of agent i is:

$$U_i(x, v) = (1 - \theta)\pi(x, v_i) + \theta W(\boldsymbol{\pi}(x, v)), \tag{3}$$

[10] See Section 5.3 for an extension to the case where the non adopters benefit from a positive externality from adopters.

where $\boldsymbol{\pi}(x,v) = (\pi(x,v_1),...,\pi_n(x,v_n))$ is vector of the agents' payoffs, $1-\theta \in]0,1]$ is the weight that the agents give to their own payoff, and W is their pro-social motivation function. This pro-social motivation is a function of the vector of payoffs.

In the rest of the paper, I denote the (net) opportunity cost as:

$$c = \widehat{c} - \widehat{b} \tag{4}$$

In most of the paper, I will assume that the agents have quasi-maximin preferences (Charness and Rabin, 2002b), which is a commonly used functional form in the literature:[11]

Assumption QM (Quasi-maximin): *The pro-social motivation function is a weighted sum ($\eta \in [0,1]$) of the minimum payoff and of the sum of the payoffs,*

$$W(\boldsymbol{\pi}(x,v)) = \eta min\{\pi_1(x,v_1),...,\pi_n(x,v_n)\} + (1-\eta)\sum_{j\in N}\pi_j(x,v_j).$$

This pro-social motivation function gives weight η to the minimum payoff (a *Rawlsian motivation*) and $1-\eta$ to the sum of the payoffs (a *collective motivation*).

Using this specification, the utility of agent i can be rewritten as follows:

$$U_i(x,v) = (1-\theta)\pi_i(x,v_i) + \theta\eta\ min\{\pi_1(x,v),...,\pi_n(x,v)\} + \theta(1-\eta)\sum_{j\in N}\pi_j(x,v_j), \tag{5}$$

where $1-\theta$ is the weight of the *selfish motivation*, $\theta\eta$ is the weight of the *Rawlsian motivation* and $\theta(1-\eta)$ is the weight of the *collective motivation*.

In the following, I characterize the least cost contract that implements the adoption of the technology by all the agents as a unique Nash equilibrium of the adoption game (i.e. the optimal unique implementation contract).[12] For expositional convenience when dealing with indifferent agents, I require schemes to induce such a unique equilibrium only once the individual subsidies are increased by any positive amount. More precisely, I characterize the subsidy vector v^* that solves the following optimization problem:

$$Min_{v\in\Re^n}\ \sum_{j\in N} v_j \tag{6}$$

s.t. for all $x \in \Re^n$ and $x \neq \mathbf{1}^n$ and all $i \in N$,[13]

$$U_i(\mathbf{1}^n, t^*(\mathbf{1},v,\epsilon)) > U_i(x, t^*(x,v,\epsilon)), \tag{PC}$$

and, for all $\epsilon > 0$, for all $x \in \{0,1\}^n$ and $x \neq \mathbf{1}^n$, $\exists i \in N$ and $x' \in \{0,1\}^n$ such that

$$U_i(x', t^*(x',v,\epsilon)) > U_i(x, t^*(x,v,\epsilon)), \tag{UC}$$

[11] See Section 5 for extensions to situations where the agents give heterogeneous weights to the payoffs of the other agents.

[12] In Section 5.1 I investigate the case in which the principal is able to coordinate the agents on her preferred equilibrium (partial implementation) as in Segal (1999) for instance. More precisely, I characterize the optimal contract that implements full technology adoption as a Nash equilibrium (among possibly many).

[13] $\mathbf{1}^n$ denotes the vector composed of n ones.

where $t^*(x, v, \epsilon) = (t_1^*(x_1, v_1, \epsilon), ..., t_n^*(x_n, v_n, \epsilon))$ and $t_i^*(x_i, v_i, \epsilon) = x_i(v_i^* + \epsilon)$ for $i = 1, ..., n$.

Constraint (PC) ensures that full adoption is a Nash equilibrium of the adoption game and the set of constraints (UC) ensures that there is no other Nash equilibrium.

3 Simple example

In this section, I use a simple example to show that social preferences generate a new effect: the subsidies that the agents receive can directly affect the adoption decisions of the other agents. To see this, assume that there are two agents $i = 1, 2$ and that agent 1 adopts the technology. Agent 2 will also choose to adopt the technology if and only if

$$U_2(1, 1, v) \geq U_2(1, 0, v), \tag{7}$$

or,

$$(1-\theta)(v_2 + w) + \theta\eta \min\{v_1 + w, v_2 + w\} + \theta(1-\eta)(v_1 + w + v_2 + w) \geq \\ (1-\theta)c + \theta\eta \min\{v_1, c\} + \theta(1-\eta)(v_1 + c) \tag{8}$$

The decision of agent 2 thus depends on the comparison of the two agents' monetary payoffs when the two agents adopt the technology ($v_1 + w$ and $v_2 + w$, respectively), and the comparison of the two agents' monetary payoffs when agent 1 adopts the technology while agent 2 does not (v_1 and c, respectively). Thus, the subsidy received by agent 1, v_1, may affect the decision of agent 2 only if agent 2's decision changes the ranking between the two agents' payoffs, that is when $c \leq v_1 \leq v_2$ or when $v_2 \leq v_1 \leq c$. When $c \leq v_1 \leq v_2$, agent 2 has the largest payoff when the two agents exert effort, while he gets the lowest payoff when he does not exert effort. Thus, in this case, decreasing v_1 decreases agent 2's incentives to adopt the technology (a discouragement effect). Formally, we have that condition (8) is equivalent to $(1 - \theta\eta)(v_2 + w - c) + \theta(1-\eta)w \geq \theta\eta(c - w - v_1)$. When $v_2 \leq v_1 \leq c$, agent 2 has the smallest payoff when the two agents adopt the technology, while he gets the largest payoff when he is the only one who does not adopt the technology. Thus, in this case, decreasing v_1 increases agent 2's incentives to adopt the technology (an encouragement effect). Formally, we have that condition (8) is equivalent to $v_2 + w - c + \theta(1-\eta)w \geq \theta\eta(v_1 - c)$. Thus, when designing an optimal subsidy scheme, the principal has to consider that the decision of an agent is directly affected by the other agents' decisions and by the other agents' subsidy levels. The principal has to consider both the fact that an agent is more likely to adopt the technology when the other agents also adopt it and the fact that his incentives to exert effort can increase or decrease when the other agents' subsidy levels vary.

In terms of inequality, this example suggests that pro-social preferences lead to a decrease in the difference between the two agents' subsidy levels if the discouragement effect is present and to an increase in the difference between the two agents' subsidy levels if the encouragement effect is present.

Given that the principal's objective is to minimize the total subsidy (under the participation constraints (PC) and the uniqueness constraints (UC)), the situation in which $v_2 \leq v_1 \leq c$ is particularly attractive. Indeed, in this case, the levels of subsidies are low (below the opportu-

nity cost). In this case, there is an encouragement effect, which suggests that the participation constraints (PC) are more likely to hold. Thus the principal may be able to reduce the total subsidy.

In the following, a central issue will be to determine whether the principal can achieve unique implementation and use the encouragement effect to decrease the total subsidy. To reach this conclusion, I will show that the optimal unique implementation contract belongs to a set of contracts characterized by the *divide and conquer property* (DAC).[14] This set of contracts is such that the agents are ordered according to an arbitrary ranking and each agent prefers to adopt the technology when all the agents that precede him in the ranking adopt the technology and all the agents that follow him in the ranking do not. More precisely, I will show that the optimal contracts is characterized by the *decreasing divide and conquer property* (DDAC). This set of contracts is characterized by the DAC property and by the fact that the subsidies are decreasing according to the ranking of the agents: each agent receives a smaller subsidy than the agents that precede him and a larger subsidy than the agents that follow him in the ranking. As will be clear in the results, the DAC property is useful to characterize the optimal contract when the agents have collective motivations and the DDAC property is useful to characterize the optimal contract when the agents have a Rawlsian motivation.

I will also provide comparative statics results on the effect of a change in pro-social preferences (θ) on the differences between the agents' material payoffs (i.e. objective inequality) and on the differences between the agents' utility levels (i.e. subjective inequality). Notice that, as long as the agents are symmetric,[15] the difference in the material payoffs of two agents is equal to the difference in their subsidy levels when the optimal unique implementation contract is set in place: $\pi_i^* - \pi_j^* = v_i^* - v_j^*$.

4 Main Results

In order to disentangle the role of each component of the quasi-maximin preferences, I will first consider the simple case in which the agents' pro-social motivation is a pure collective motivation ($\eta = 0$), then I will focus on the case where their pro-social motivation is purely Rawlsian ($\eta = 1$) and finally I will consider the more general case in which they give weight to both ($0 \leq \eta \leq 1$).

4.1 Collective motivation ($\eta = 0$)

I assume here that the agents give no weight to the minimum payoff (i.e. $\eta = 0$). The utility of agent i is:

$$U_i(x, v) = \theta \pi_i(x, v_i) + (1 - \theta) \sum_{j \in N} \pi_j(x, v_j). \tag{9}$$

In this case, I show the following result:

Proposition 1: *If the agents' pro social motivation is purely a collective motivation ($\eta = 0$), the optimal subsidy scheme that implements full technology adoption as a unique Nash equilibrium of*

[14] Segal (2003), Winter (2004) and Bernstein and Winter (2012) also find optimal contracts that belong to this set in settings with standard (selfish) preferences.

[15] See Section 5 for extensions to the case of heterogeneous agents.

the adoption game is:

$$v_i^* = c - (i-1)w - \theta(i-1)w,$$

for $i = 1, ..., n$.

This result states that collective motivation affects the optimal subsidy scheme. The effect of collective motivation on the optimal contract is quite intuitive. As in the case with standard preferences (see Bernstein and Winter, 2012), the optimal contract is characterized by the divide-and-conquer property. An agent is indifferent between not adopting and adopting the technology when all the preceding agents in the arbitrary ranking adopt the technology and all the subsequent agents do not. Compared to the situation with standard preferences, the principal can decrease the transfer made to the agent by the agent's valuation of the externalities that agent generates for the preceding agents, in other words by $\theta(i-1)w$ for the agent ranked $i+1$ in the ranking.

Let us now focus on the implications in terms of objective and subjective inequality. The difference in the material payoffs of two subsequent agents is $\pi_i^* - \pi_{i+1}^* = v_i^* - v_{i+1}^* = (1+\theta)w$ and the corresponding difference in their utility levels is $U_i^* - U_{i+1}^* = (1-\theta)(\pi_i^* - \pi_{i+1}^*) = (1-\theta^2)w$. I can thus provide the following comparative static results:

Corollary 1: *If the agents' pro social motivation is purely collective* ($\eta = 0$)*, then pro-social preferences increase objective inequality while they decrease subjective inequality. Formally,*

$$\frac{\partial(\pi_i^* - \pi_{i+1}^*)}{\partial\theta} > 0 \text{ and } \frac{\partial(U_i^* - U_{i+1}^*)}{\partial\theta} < 0$$

Hence, when the agents have a collective motivation, the difference in the agents' material payoffs is larger. The intuition is that an agent's subsidy decreases when the weighted sum of externalities he generates for the preceding agents is larger. Hence, pro-social preferences lead to a larger decrease in the subsidy received by agent $i+1$ than in the subsidy received by agent i.

However, when the agents have a collective motivation, the difference in the agents' utility levels is smaller. The effect of the collective motivation on the utility levels differential is twofold. There is a direct effect that makes the utility levels less unequal ($-(\pi_i^* - \pi_{i+1}^*) = -(1+\theta)w < 0$) because the agents give less weight to their own payoff. There is also an indirect effect that goes through the effect on the difference in the agents' material payoffs and that makes the utility levels more unequal, $(1-\theta)\frac{\partial(\pi_i^* - \pi_{i+1}^*)}{\partial\theta} = (1-\theta)w$. The direct effect is stronger than the indirect effect because when the agents have pro-social preferences, they give less weight to their own payoff and they give a positive weight to the payoffs of the other agents. As a result, pro social motivations lead to lower subjective inequality.

4.2 Rawlsian motivation ($\eta = 1$)

I assume here that the agents give no weight to the sum of the payoffs ($\eta = 1$). The utility of agent i is then:

$$U_i(x, v) = (1-\theta)\pi_i(x, v_i) + \theta min\{\pi_1(x, v_1), ..., \pi_n(x, v_n)\}. \quad (10)$$

In this case, I can show the following result:

Proposition 2: *If the agents' pro social motivation is purely Rawlsian ($\eta = 1$), then the optimal subsidy scheme that implements full technology adoption as a unique Nash equilibrium of the adoption game is the same as if the agents were purely selfish:*

$$v_i^* = c - (i-1)w,$$

for $i = 1, ..., n$.

This neutrality result is quite surprising. When the agents give weight to the minimum payoff, the optimal subsidy scheme is not affected compared to the case in which they have standard preferences.[16] The logic behind this result can be illustrated by the following two agents example:

Example [two agents with Rawlsian motivations]: *Consider the case of two agents $i = 1, 2$ with pure Rawlsian motivations. The payoff of agent i is $\pi_i = \widehat{b} + w + v_i$ if he adopts the technology and agent $j \neq i$ also adopts the technology. His payoff is $\pi_i = \widehat{c}$ if he does not adopt the technology (whenever agent $j \neq i$ adopts it or not). The utility of agent $i = 1, 2$ is $U_i = (1-\theta)\pi_i + \theta min\{\pi_1, \pi_2\}$.*

In this example, the decreasing divide and conquer property (DDAC) holds when $v_1 \geq v_2$, and agent 1 prefers to adopt the technology when agent 2 does not adopt the technology,

$$(1-\theta)v_1 + \theta min\{v_1, c\} \geq (1-\theta)c + \theta c; \tag{11}$$

and agent 2 prefers to adopt the technology when agent 1 adopts the technology,

$$(1-\theta)(v_2 + w) + \theta min\{v_1 + w, v_2 + w\} \geq (1-\theta)c + \theta min\{v_1 + w, c\}. \tag{12}$$

Assume that the DDAC property holds. Since condition (11) is equivalent to $v_1 \geq c$, in other words the first agent cannot get a subsidy that is smaller than his net outside option. Using $v_1 \geq v_2$ and $v_1 \geq c$, we have that agent 2 obtains a payoff smaller than agent 1 whenever the former adopts the technology or not. Then condition (12) is equivalent to $v_2 + w - c \geq 0$. Hence, the least cost subsidy scheme which induces full technology adoption when the agents have pure Rawlsian motivations and such that the DDAC property holds is $v_1 = c$ and $v_2 = c - w$. This subsidy scheme is also the least cost scheme which induces full technology adoption when the agents have standard preferences.

The principal is not able to offer lower subsidies than in the case of standard preferences because the optimal subsidy scheme is characterized by the DDAC property. The optimal scheme is such that each agent receives the lowest payoff among the set of adopters when all preceding agents in the ranking are also adopters while all the subsequent agents are not. The first agent in the ranking receives a subsidy equal to the net opportunity cost c. Now consider the case of the agent ranked second in the ranking when the first agent adopts the technology. When the second

[16] This result is also in contrast with partial implementation because in this latter case, the principal is able to take advantage of Rawlsian motivations, even if the agents have no collective motivation. See Section 5.1.

agent does not adopt the technology, the two agents get c. When he adopts the technology, if that agent receives a subsidy that is lower than the subsidy he would get if he had standard preferences $(c - w)$, that agent's payoff is the minimum payoff $(c < c + w)$ and then his utility from adopting the technology is lower than his utility from not adopting the technology. The same logic applies for all subsequent agents.

The DDAC property implies that when all the previous agents in the ranking adopt the technology while all the subsequent agents do not, the agent is the one with the smallest payoff whenever she adopts the technology or not. Thus, the fact that he gives weight to both his own payoff and to the minimum payoff does not make a difference compared to the case where he only cares about his own payoff.

Notice that the subsidy received by an agent (v_i^*) decreases when his rank (i) increases, and then his material payoff (π_i^*) and his utility level (U_i^*) also decrease when his rank (i) increases. Thus, the first agent is at the top of the distribution of material payoffs and of utility levels. The difference in the material payoffs of two subsequent agents is $\pi_i^* - \pi_{i+1}^* = v_i^* - v_{i+1}^* = w$ and the corresponding difference in their utility levels is $U_i^* - U_{i+1}^* = (1-\theta)(\pi_i^* - \pi_{i+1}^*) = (1-\theta^2)w$. I can thus provide the following comparative static results:

Corollary 2: *If the agents' pro social motivation is purely Rawlsian ($\eta = 1$), then pro-social preferences do not affect objective inequality while they decrease subjective inequality:*

$$\frac{\partial(\pi_i^* - \pi_{i+1}^*)}{\partial\theta} = 0 \text{ and } \frac{\partial(U_i^* - U_{i+1}^*)}{\partial\theta} < 0$$

This result follows from the result of Proposition 2. Indeed, Proposition 2 states that the subsidies does not depend on pure Rawlsian motivations. As a consequence, the difference between two agents' payoffs does not depend either on pure Ralwsian motivations. Another consequence is that pure Rawlsian motivations have only a direct effect on the difference between two agents' utility levels and this direct effect is negative (because the agents give less weight to their own payoff). Hence, pure Rawlsian motivations lead to a decrease in subjective inequality.

4.3 Quasi-maximin preferences ($0 \leq \eta \leq 1$)

I now consider the more general case where the agents give weight to both the minimum payoff and to the sum of the payoffs. The utility of agent i is then:

$$U_i(x,v) = (1-\theta)\pi_i(x,v_i) + \theta\left(\eta min\{\pi_1(x,v_1),...,\pi_n(x,v_n)\} + (1-\eta)\sum_{j\in N}\pi_j(x,v_j)\right). \quad (13)$$

In this case, I provide the following characterization:

Proposition 3: *If the agents' pro social motivation is quasi-maximin ($0 \leq \eta \leq 1$), the optimal subsidy scheme that implements full technology adoption as a unique Nash equilibrium of the adoption game is such that $v_1^* = c$ and:*

$$v_i^* = c - (i-1)w\left(1 + \theta(1-\eta)\right) - \theta(1-\eta)w\sum_{t=1}^{i-1}(i-1-t)(\theta\eta)^t, \quad (14)$$

for all $2 \leq i \leq n$.

Notice that the payoffs of the two first agents do not depend on the Rawlsian component ($v_1^* = c$ and $v_2^* = c - (1+\theta)w$). The reason is that in the case of two agents, when the first agent adopts the technology, the second agent is the one with the minimum payoff whether he adopts the technology or not. The result of Proposition 3 can be better illustrated using a three agents example:

Example [three agents with a quasi-maximin motivation]: *Consider the case of three agents* $i = 1, 2, 3$. *The payoff of agent* i *is* $\pi_i = \widehat{b} + 2w + v_i$ *if the three agents adopt the technology,* $\pi_i = \widehat{b} + w + c$ *if agent* i *adopts the technology and only one of the two other agents also adopts the technology and* $\pi_i = \widehat{c}$ *if agent* i *does not adopt the technology (whenever the other two agents adopt the technology or not). The utility of agent* $i = 1, 2, 3$ *is* $U_i = (1-\theta)\pi_i + \theta\eta min\{\pi_1, \pi_2, \pi_3\} + \theta(1-\eta)(\pi_1 + \pi_2 + \pi_3)$.

In this example, the decreasing divide and conquer property (DDAC) holds when $v_1 \geq v_2 \geq v_3$, *and agent* 1 *prefers to adopt the technology when agent* 2 *adopts the technology,*

$$(1-\theta)v_1 + \theta\eta min\{v_1, c\} + \theta(1-\eta)(v_1 + 2c) \geq (1-\theta)c + \theta\eta c + \theta(1-\eta)(3c); \tag{15}$$

and agent 2 *prefers to adopt the technology when agent* 1 *adopts the technology,*

$$\begin{aligned}(1-\theta)(v_2 + w) + \theta\eta min\{v_1 + w, v_2 + w, c\} + \theta(1-\eta)(v_1 + v_2 + 2w + c) \\ \geq (1-\theta)c + \theta\eta min\{v_1 + w, c\} + \theta(1-\eta)(v_1 + 2c),\end{aligned} \tag{16}$$

and agent 3 *prefers to adopt the technology when agents* 1 *and* 2 *adopt the technology,*

$$\begin{aligned}(1-\theta)(v_3 + 2w) + \theta\eta min\{v_1 + 2w, v_2 + 2w, v_3 + 2w\} + \theta(1-\eta)(v_1 + v_2 + v_3 + 6w) \\ \geq (1-\theta)c + \theta\eta min\{v_1 + w, v_2 + w, c\} + \theta(1-\eta)(v_1 + v_2 + 2w + c),\end{aligned} \tag{17}$$

Assume that the DDAC property holds. Condition (15) *is equivalent to* $(1-\theta\eta)(v_1 - c) + \theta\eta min\{v_1 - c, 0\} \geq 0$ *and then to* $v_1 \geq c$, *in other words agent 1 cannot receive a subsidy which is lower than his net outside option. Thus, using* $v_1 \geq v_2$, *we have that condition* (16) *is equivalent to* $(1-\theta\eta)(v_2 + w - c) + \theta\eta min\{v_2 + w - c, 0\} \geq -\theta(1-\eta)w$. *Using* $v_1 \geq v_2 \geq v_3$, *I find that condition* (17) *is equivalent to* $v_3 + 2w - c + 2w\theta(1-\eta) \geq \theta\eta min\{v_2 + w - c, 0\}$. *Thus, as long as the agents have collective motivations (*$\theta(1-\eta) > 0$*), the subsidy that agent 2 receives can be such that he obtains a lower payoff when he adopts the technology than when he does not (*$v_2 + w < c$*). Thus, the least cost subsidy scheme such that the decreasing divide and conquer property holds is such that agent 1 receives a subsidy that is equal to his net outside option,* $v_1^* = c$. *Agent 2 receives the same subsidy as when the agents have a pure collective motivation,* $v_2^* = c - (1+\theta)w$. *Rawlsian motivations do not affect agent 2's subsidy because he receives the lowest payoff when he adopts the technology together with agent 1 and the lowest payoff (c) when he deviates. Agent 3 receives* $v_3^* = c - (1 + \theta(1-\eta))w + \theta\eta(v_2^* + 2w - c)$, *or* $v_3^* = c - 2(1 + \theta(1-\eta))w - \theta^2\eta(1-\eta)w$. *The subsidy received by agent 3 depends on his Rawlsian motivation parameter* η *because he his the agent with the lowest payoff when he adopts the technology together with agents 1 and 2 while*

agent 2 receives the lowest payoff when agent 3 deviates. These subsidies correspond to the optimal unique implementation subsidy scheme.

This result deserves several comments. First, the subsidy levels differ from the case in which the agents have a pure collective motivation, meaning that Rawlsian motivations affect the optimal subsidy scheme only if the agents have also a collective motivation. Second, compared to the case with a pure collective motivation, the agents obtain smaller subsidies, which means that the principal is able to take advantage of the presence of both types of pro-social motivations.

The optimal subsidy scheme is still characterized by the DDAC property. This enables the principal to decrease the subsidy given to each agent to make them indifferent between adopting and not adopting the technology when all the preceding agents in the ranking adopt the technology and all the subsequent agents in the ranking do not. The principal can do so because a decrease in the subsidy given to an agent (weakly) increases the incentive for the subsequent agents to adopt the technology. Indeed, a decrease in the subsidy given to an agent does not affect the minimum payoff when the following agent adopts the technology (because in this case, the following agent is the one who obtains the minimum payoff) while it weakly decreases the minimum payoff when the following agent does not adopt the technology.

The case with both collective and Rawlsian pro-social motivations differs from the case with purely Rawlsian pro-social motivations because collective motivations enable the principal to offer subsidies such that the agents' payoffs are lower than their net opportunity cost. As a consequence, when all the previous agents in the ranking adopt the technology while all the subsequent agents do not, the agent is the one with the smallest payoff when that agent adopts the technology but not when he does not adopt the technology. Thus, in this case, the fact that the agent gives weight to the minimum payoff makes a difference compared to the case where that agent only cares about his own payoff.

Let me now focus on the implications in terms of objective and subjective inequality. The difference in the material payoffs of two subsequent agents is given by:

$$\pi_i^* - \pi_{i+1}^* = v_i^* - v_{i+1}^* = w\left(1 + \theta(1-\eta)\right) + \theta(1-\eta)w\sum_{t=1}^{i-1}(\theta\eta)^t, \tag{18}$$

for all $2 \leq i \leq n$ and $\pi_1^* - \pi_2^* = v_1^* - v_2^* = w\left(1 + \theta(1-\eta)\right)$.

I can then prove the following result:

Corollary 3 : *If the agents have quasi-maximin pro-social motivations ($0 \leq \eta \leq 1$), then pro-social preferences lead to an increase in objective inequality and to a decrease in subjective inequality:*

$$\frac{\partial(\pi_i^* - \pi_{i+1}^*)}{\partial\theta} \geq 0 \text{ and } \frac{\partial(U_i^* - U_{i+1}^*)}{\partial\theta} < 0$$

This result generalizes the implications I have obtained in the case with pure collective motivations as it states that they are valid in the case where the agents have quasi-maximin preferences.

The intuition is similar to the intuition of the results obtained when the agents have pure collective motivations (see the discussion below Corollary 1).

5 Alternative assumptions and extensions

5.1 Partial Implementation

In the main part of the paper, I focus on the optimal full implementation subsidy scheme, that is the subsidy scheme that induces the agents to adopt the technology as a unique Nash equilibrium of the adoption game. In the literature, the case of partial implementation has also be considered (see Segal, 1999). Partial implementation refers to a situation where coordination is not an issue and the principal can choose his preferred Nash equilibrium of the technology adoption game. The optimal partial subsidy scheme is the least-cost subsidy scheme that induces all the agents to adopt the technology as a Nash equilibrium of the technology adoption game (among possibly many). It is characterized as follows.

Proposition 4: *If the agents' pro-social motivation is quasi-maximin, then the optimal partial implementation contract is such that:*

$$v_i^* = c - (n-1)w - S^P w,$$

where $S^P = \theta \frac{(n-1)(1-\eta)+\eta}{1-\theta\eta}$.

The agents receive a subsidy that is equal to their net opportunity cost minus the sum of the externalities they receive from the other agents minus their valuation of the externalities they generate for the other agents ($(1-\eta)w$ for each of the $n-1$ other agents and ηw for the agent with the minimum payoff) normalized by the total weight they give to their own payoff $(1-\theta\eta)$. This result implies that, differently from the case where the principal wishes to induce technology adoption by all the agents as a unique Nash equilibrium, there is here no difference in the payoffs of the agents, and then inequality is not an issue.[17] Remember that, in order to design the unique implementation contract, the principal has to build a subsidy scheme such that, for each situation in which not all the agents adopt the technology, at least one agent has an incentive to deviate. The principal achieves this goal in choosing the least cost contract characterized by the DAC property. However, since the externalities are positive and the agents have pro-social preferences, eliminating all possible Nash equilibria that do not correspond to the outcome where all the agents adopt the technology is costly for the principal.

The main drawback of the optimal partial implementation contract is that the agents' technology adoption decision subgame may have multiple Nash equilibria. Here, there are at least two equilibria: the situation in which all the agents adopt the technology (by definition of partial implementation) and the situation in which none of the agents adopt the technology (this can be easily checked because $v_i^* \leq c$ for all i).

[17] Inequality is not an issue as long as the agents are homogenous. For a characterization of the optimal partial implementation contract with heterogeneous agents, see the proof of Proposition 5. The proof allows for the opportunity costs c and the preferences parameters θ and η to be heterogeneous.

Notice that I make here the assumption that the agents are homogenous for ease of comparison with the main results. In the proof of the Proposition provided in Appendix, I provide a more general characterization of the optimal partial implementation subsidy scheme and I allow opportunity costs and preferences to be heterogeneous.

5.2 Heterogeneity

I assume here that the agents may have heterogeneous costs and benefits and I denote c_i the net opportunity cost of agent i. I also allow the agents to have heterogeneous social preferences and that they may give heterogeneous weight to their own payoff and to the payoffs of all the agents. Formally, the utility of agent i is:

$$U_i(x, v) = (1 - \theta_i)\pi_i(x, v_i) + \theta_i W_i(\boldsymbol{\pi}(x, v)), \tag{19}$$

where $1-\theta_i \in]0, 1]$ is the weight that the agent i gives to her own payoff, and W_i is her pro-social motivation.

I allow the weights the agents give to each other agents to differ. This type of heterogeneity accounts for the possibility of altruistic agents:

Assumption (Altruism): *The agents have altruistic preferences if their pro-social motivation function is a weighted sum of the payoffs,* $W_i(\boldsymbol{\pi}(x, v)) = \sum_{j\in N} \gamma_{ij}\pi_j(x, v_j)$ *where* $\sum_{i\in N}\sum_{j\in N}\gamma_{ij} = N$ *and* $\gamma_{ij} = \gamma_{ji} \geq 0$ *for all* i, j.

Using this assumption, I show the following result:

Proposition 5: *If the agents have altruistic preferences, then the optimal unique implementation subsidy scheme is such that agent* i *is ranked before agent* $i+1$ *if and only if* $\lambda_i \leq \lambda_{i+1}$ *where* $\lambda_i \equiv \frac{\theta_i}{1-\theta_i+\theta_i\gamma_{ii}}$ *for all* i *and the optimal subsidies are:*

$$v_i^* = c_i - (i-1)w - \lambda_i \sum_{j<i} \gamma_{ij} w,$$

for all i.

This result states that when the agents are heterogeneous, the subsidy still has to compensate for their (heterogeneous) net opportunity costs, for the externalities they receive from the preceding agents and for the weighted sum of the externalities they generate for these agents. The weight of the externality generated for an agent is proportional to the weight given to the payoff of this agent γ_{ij} in the utility function. The proportional coefficient, λ_i, is an individual measure of the relative weight agent i gives to the payoff of the other agents (θ_i) and to the weight he gives to his own payoff ($1-\theta_i+\theta_i\gamma_{ii}$). Notice that the symmetric situation corresponds to $\gamma_{ii} = \gamma_{ij} = 1$ and $\theta_i = \theta$ for all i, j.

The ranking of the agents does not depend on their net opportunity cost because the principal has to compensate for these costs whatever the ranking. The agents ranked first are those who have the smallest pro-social preference parameters θ_i, they are thus advantaged compared to the

other agents.

5.3 Externalities for non adopters

In the main part of the paper, I make the simplifying assumption that the non adopters do not benefit from externalities from the agents who adopt the technology. In this section, I show that the main results hold when I relax this assumption, as long as peer effects remain positive.

I assume here that when agent i does not adopt the technology, he benefits from an externality $w_0 \geq 0$ when one agent adopt the technology. Formally, his material payoff is:

$$\pi_i(x, v_i) = \widehat{c} + mw_0, \tag{20}$$

if agent i does not adopt the technology ($x_i = 0$) while m other agents adopt it.

Using this assumption I show the following result:

Proposition 6: *If peer effects are positive ($\Delta = w - w_0 > 0$) the agents' pro social motivation is quasi-maximin ($0 \leq \eta \leq 1$), the optimal subsidy scheme that implements full technology adoption as a unique Nash equilibrium of the adoption game is such that $v_1^* = c - \theta(1-\eta)(n-1)w_0$ and:*

$$v_i^* = c - (i-1)\Delta\left(1 + \theta(1-\eta)\right) - \theta(1-\eta)\Delta\sum_{t=1}^{i-1}(i-1-t)(\theta\eta)^t \\ - \frac{\theta\eta - (\theta\eta)^i + \theta(1-\eta)(n-1)\left(1-(\theta\eta)^i\right)}{1-\theta\eta}w_0, \tag{21}$$

for all $2 \leq i \leq n$.

This result is an extension of Proposition 3. It characterizes the optimal subsidy scheme when the non adopters receive positive externalities from adopters and peer effects are positive ($\Delta = w - w_0 > 0$).

The effect of an increase of w_0 on the individual subsidy level v_i^* is ambiguous. On the one hand, if the agents have no pro-social preferences, an increase in w_0 leads to an increase in the individual subsidies. Indeed, when the agents have no pro-social preferences ($\theta = 0$), the subsidy received by agent i is simply given by $v_i^* = c-(i-1)\Delta = c-(i-1)(w-w_0)$, which increases when w_0 increases. The intuition is that, in order to induce agent i to adopt the technology when the agents that precede agent i adopt the technology while the subsequent agents do not, the principal has to compensate agent i for the externalities he receives if he chooses not to participate, that is $(i-1)w_0$. On the other hand, if the agents have sufficiently strong pro-social preferences ($\theta \to 1$) and pure collective motivations ($\eta = 0$), an increase in w_0 leads to a decrease in the subsidy level received by the first agents. Indeed, in this case, the subsidy level of agent i is given by $c - 2(i-1)w + (i-1-(n-i))\,w_0$, which decreases when w_0 increases if and only if $i < \frac{n+1}{2}$. The intuition is the following. An increase in w_0 has two effects on the subsidy level of the agents. The first effect is the same as in the case where the agents have no pro-social preferences. The second effect comes from the fact that, when the agents that precede agent i adopt the technology while the subsequent agents do not, if agent i adopts the technology, the principal can

decrease the subsidy level of agent i by agent i's valuation of the externalities i generates for non adopters, that is $(n-i)w_0$. This explains why the subsidy of agent i is augmented by the term $(i-1-(n-i))\,w_0$ here. The first effect prevails for the agents who are last in the ranking while the second effect prevails for the agents who are first in the ranking.

I can now show that the comparative statics results still hold:

Corollary 4: *If peer effects are positive ($\Delta = w - w_0 > 0$) and the agents have quasi-maximin pro-social motivations ($0 \leq \eta \leq 1$), then pro-social preferences lead to an increase in objective inequality and to a decrease in subjective inequality:*

$$\frac{\partial(\pi_i^* - \pi_{i+1}^*)}{\partial\theta} \geq 0 \text{ and } \frac{\partial(U_i^* - U_{i+1}^*)}{\partial\theta} < 0$$

for all $1 \leq i \leq n-1$.

This result is an extension of Corollary 3. It shows that even if non adopters receive positive externalities from non adopters, pro-social preferences lead to an increase in objective inequality and a decrease in subjective inequality as long as peer effects remain positive ($w \geq w_0$). I study the case of negative peer effects ($w < w_0$) in the next section.

5.4 Negative peer effects

Up to this point, I have assumed positive peer effects. I now consider the alternative situation where peer effects are negative. Negative peer effects mean that an agent has less incentives to adopt the technology when the number of other agents who adopt the technology increases. This arises in the present setting if adopters generate lower externalities for the other adopters than for the non adopters ($\Delta \equiv w - w_0 < 0$).[18]

I show that the optimal subsidy scheme is characterized as follows:

Proposition 7: *If peer effects are negative ($\Delta = w - w_0 < 0$) and the agents' pro social motivation is quasi-maximin ($0 \leq \eta \leq 1$), then the optimal subsidy scheme that implements full technology adoption as a unique Nash equilibrium of the adoption game is:*

$$v_i^* = c + (n-1)(w_0 - w) - S^P w, \tag{22}$$

where $S^P = \theta\frac{(n-1)(1-\eta)+\eta}{1-\theta\eta}$.

As in the case of positive peer effects, pro-social preferences lead to a decrease in individual subsidies. However, differently from the case where peer effects are positive, subsidies are not differentiated and all the agents obtain the same material payoff.

The intuition of this result is as follows. When peer effects are negative, an agent's material gain from technology adoption is lower when other agents adopt the technology. Moreover, when an agent adopts the technology, he generates less externalities for the other agents when they also adopt the technology. As a consequence, the least cost subsidy scheme has to make an agent

[18] In the terminology of Segal (2003), there are increasing externalities when $\Delta \geq 0$ and decreasing when $\Delta < 0$.

indifferent between adopting the technology and not adopting it when all the other agents adopt the technology. The optimal unique implementation subsidy scheme is thus the same as in the case of partial implementation (see Proposition 4), except that the outside option of the agent here is not c but $c + (n-1)w_0$ since the agent receives a total externality of $(n-1)w_0 \geq 0$ when he does not adopt the technology while the other agents adopt it.

6 Policy implications

The model analyzed in this paper covers situations in which there are technological externalities,[19] or social learning externalities.[20]

Health technology adoption is a first field of application of the model (see Dupas, 2011 for a review). Field experiments on the effect of anti-malaria technologies find strong positive peer effects in the case of bed-nets interventions, such as Dupas (2014) who finds positive peer effects when individuals receive insecticide-treated bed nets subsidy vouchers in networks of neighbors (in Kenya). In contrast, in a field experiment on deworming pills adoption, Kremer and Miguel (2007) found negative peer effects when deworming drugs are given for free to some individuals in networks of friends, relative and neighbors (also in Kenya).

Agricultural technology adoption is another field of application of the model (see Foster and Rosenzweig, 2010).[21] Foster and Rosenzweig (1995), Conley and Udry (2010) and Munshi (2004) provide evidence that farmers learn how to optimally use inputs when cultivating a new crop from the choices of peers within their village cultivating the same crop. Bandiera and Rasul (2006) report evidence of an inverse U-shaped relationship between farmers' adoption of a new crop and the number of adopters within their network of family and friends, which suggests that in this application peer effects are first positive and then negative. Carter et al. (2019) provide field experimental evidence that Mozambican farmers who belong to the network of peers of farmers who are eligible for subsidized input prices are more likely to adopt the same inputs.

In light of these empirical results, my model provides several practical implications. First, the results of the present paper show that pro-social preferences lead to lower individual subsidies, because they facilitate technology adoption, whenever peer effects are positive or negative. In the empirical literature mentioned above, peer effects are estimates of the effect of providing a subsidy to an individual on the adoption decision of another individual. In the present paper (see Section 3), I argue that providing a subsidy to an individual A has two effects on the adoption decision of another individual B, an indirect (peer) effect and a direct effect. The peer effect is such that an increase in agent's A subsidy increases the likelihood that A adopts the technology, which in turn increases (decreases) the likelihood that agent B adopts the technology if peer effects are positive (negative). The direct effect is such that an increase in agent's A subsidy affects the adoption decision of agent B through pro-social preferences. Moreover, this effect is

[19] Foster and Rosenzweig (2010) state that positive (negative) technological externalities arise when the benefits to an individual of adopting a technology are increasing when others also use this technology.

[20] Social learning arises if early adopters provide (voluntarily or not) late adopters with new information or knowledge about the technology. Social learning can operate through providing more accurate information about the private returns from adopting the technology or through directly affecting the returns. Situations in which individuals initially underestimate the private returns of technology adoption or situation in which early adopters learn to others how to use the technology are specific cases of increasing externalities.

[21] The literature has focused on inputs (new crop, fertilizer and improved seeds) for which peer effects can be explained by social learning or social norms, but hardly by technological externalities.

not a peer effect, as it is not caused by the adoption decisions of the other agents. It can be negative or positive: if the optimal subsidy scheme is implemented (and then $v_2^* < v_1^* \leq c$), the direct effect is negative, that is an increase in agent's A subsidy decreases agent's B incentives to adopt the technology. Hence, pro-social preferences lead to downward biased estimates of peer effects. If a non optimal subsidy scheme is implemented (and such that $v_2^* \geq v_1^* \geq c$), the direct effect is positive, that is an increase in agent's A subsidy increases agent's B incentives to adopt the technology. In this case, pro-social preferences lead to upward biased estimates of peer effects.

Second, the theoretical characterization of the optimal subsidy scheme enables to compute the subsidy intervention that ensures adoption by all the members of a group of individuals at least cost. In order to compute optimal individual subsidies, one can use estimates of the net opportunity cost, of externalities, and of pro-social preferences (which can be measured using lab experimental games, see Engelmann and Strobel, 2004). The optimal intervention could be implemented in the form of vouchers of different values.

Third, the present model may be used as the underlying theory of empirical studies aiming at comparing the effectiveness of various forms of subsidy schemes. Up to now, each study in the empirical literature focuses on one specific form of subsidy, such as subsidy vouchers (Dupas, 2014; Carter et al., 2019) or free delivery (Kremer and Miguel, 2007). My results combined with the results from this literature provide testable implications. Indeed, they suggest that uniform subsidies should perform better than free delivery to a subset of individuals in the case of deworming programs, while free delivery to a subset of the population should perform better than uniform subsidies in the case of anti-malaria prevention technologies and agricultural inputs technologies.

In practice, differentiated subsidies are not always politically accepted. Indeed, the fact that pro-social preferences should lead to more differentiated subsidies and then to more objective inequality is not appealing for a public authority. However, I have shown that pro-social preferences may lead to lower subjective inequality even if objective inequality increases. Hence, as a result, acceptability of differentiated subsidies may not be an issue when the individuals care about each other.

7 Conclusion

In this paper, I have studied the role of pro-social preferences on the relationship between incentives and inequality in a model in which a principal proposes individualized subsidies (bilateral contracts) to a group of agents in order to induce technology adoption. I have shown that agents' pro-social preferences lead to a decrease in the implementation cost for the principal, a decrease in the payoff of each agent, an increase in objective inequality and a decrease in subjective inequality.

The model can help to design an optimal intervention aiming at providing incentives for the adoption of a new technology in developing countries. The results of the paper suggest that pro-social preferences increase the estimates of peer effects and the likelihood of adoption. The model also implies that the optimal intervention should provide differentiated subsidized prices or differentiated access to the technology when there are positive peer effects, and this is especially true when the individuals belong to the same family or network of friends. The results also suggest that the acceptability of differentiated subsidies may not be a crucial issue since pro-

social motivations may lead to a decrease in subjective inequality even though they lead to an increase in objective inequality.

8 Appendix

Proof of Proposition 1: See the Proof of Proposition 6 with $w_0 = 0$ and $\eta = 0$.

Proof of Proposition 2: See the Proof of Proposition 6 with $w_0 = 0$ and $\eta = 1$.

Proof of Proposition 3: See the Proof of Proposition 6 with $w_0 = 0$.

Proof of Corollary 1: See the proof of Corollary 3 with $\eta = 0$.

Proof of Corollary 2: See the proof of Corollary 3 with $\eta = 1$.

Proof of Corollary 3: The difference between the subsidies received by two successive agents i and $i+1$ is given by: The difference in the utility levels of two subsequent agents can be written as follows:

$$U_i^* - U_{i+1}^* = (1-\theta)w + (1-\theta)\theta(1-\eta)w\frac{1-(\theta\eta)^i}{1-\theta\eta}. \tag{23}$$

Differentiating this expression with respect to θ, I obtain:

$$\frac{(1-\theta\eta)^2}{w}\frac{\partial(U_i^* - U_{i+1}^*)}{\partial\theta} = (1-\theta)(1-\eta) - (1-\theta\eta)^2 - (\theta\eta)^i(1-\theta)(1-\eta)\left(1+i(1-\theta\eta)\right) - \left(1-(\theta\eta)^i\right)\theta(1-\eta)(1-\theta\eta) < 0. \tag{24}$$

Proof of Proposition 4: The situation in which all the agents adopt the technology is a Nash equilibrium if and only if each agent i prefers to adopt the technology when all the other agents adopt the technology:

$$(1-\theta_i)\left(v_i + (n-1)w\right) + \theta_i\eta_i min_j\{v_j + (n-1)w\} + \theta_i(1-\eta_i)\left(\sum_j v_j + n(n-1)w\right)$$
$$\geq (1-\theta_i)c + \theta_i\eta_i min\{min_{j\neq i}\{v_j + (n-2)w\}, c\} + \theta_i(1-\eta_i)\left[\sum_{j\neq i} v_j + (n-1)(n-2)w + c\right],$$

or,

$$\left[1-\theta_i+\theta_i(1-\eta_i)\right]\left(v_i + (n-1)w - c\right)$$
$$+\theta_i\eta_i\left[min_j\{v_j + (n-1)w\} - min\{min_{j\neq i}\{v_j + (n-2)w\}, c\}\right] + \theta_i(1-\eta_i)(n-1)w \geq 0. \tag{25}$$

There are four cases to consider for each agent i: he gets more than the minimum payoff, whether he adopts the technology or not, $min_{j\neq i}v_j \leq v_i$ and $min_{j\neq i}v_j + (n-2)w < c$; he gets the minimum payoff when he adopts the technology while he does not when he deviates, $v_i < min_{j\neq i}v_j \leq c-(n-2)w$; he does not get the minimum payoff when he adopts the technology while he does when he deviates, $c-(n-2)w \leq min_{j\neq i}v_j \leq v_i$; he gets the minimum payoff, whether

he deviates or not, $c-(n-2)w < min_{j\neq i}v_j$ and $v_i < min_{j\neq i}v_j$. The principal will not choose a vector of subsidy such that one of the two latter cases arises, if there exist other feasible vectors of subsidy. I will show such vectors do exist.

In order to minimize costs, the principal has thus two options. First, he may choose a vector of subsidy v^* such that $min_{j\neq i}v_j \leq v_i$ and $min_{j\neq i}v_j + (n-2)w < c$ for all i. Assuming that the principal (re)order the agents as described in the statement of the Proposition, he will choose $v_i^* = c-(n-1)w - \frac{(n-1)\theta_i(1-\eta_i)+\theta_i\eta_i}{1-\eta_i\theta_i}w$ for all $i \neq n$ and $v_n^* = v_{n-1}^*$.

Second, the principal may choose a vector of subsidy $\widetilde{v}$ such that one agent (denoted s) gets a strictly smaller payment than the other agents. The subsidy offered to agent s has to be such that $v_s < min_{j\neq s}v_j \leq c-(n-2)w$ and the subsidy offered to any other agent i has to be such that $min_{j\neq i}v_j \leq v_i$ and $min_{j\neq i}v_j + (n-2)w < c$. The principal will thus set $\widetilde{v}_i = v_i^*$ for all $i \neq s$. Letting $k(s)$ be an agent such that $min_{j\neq s}\widetilde{v}_j = \widetilde{v}_{k(s)}$, according to the description of case (ii) above, the subsidy $\widetilde{v}_s$ must be such that $c-(n-1)w(1+\theta_s(1-\eta_s)) - \theta_s\eta_s\left[1+\frac{(n-1)\theta_{k(s)}(1-\eta_{k(s)})+\theta_{k(s)}\eta_{k(s)}}{1-\theta_{k(s)}\eta_{k(s)}}\right]w \leq \widetilde{v}_s < min_{j\neq s}v_j^* = v_{k(s)}^*$. This inequality characterizes a non empty set of subsidies $\widetilde{v}_s$ only if $\frac{(n-1)\theta_{k(s)}(1-\eta_{k(s)})+\theta_{k(s)}\eta_{k(s)}}{1-\eta_{k(s)}\theta_{k(s)}} < \frac{(n-1)\theta_s(1-\eta_s)+\theta_s\eta_s}{1-\eta_s\theta_s}$.

Hence, the vector of subsidy $\widetilde{v}$ with $s=n$ minimizes the cost of the principal as long as $S_n \neq S_{n-1}$ while it is the vector of subsidy v^* when $S_n = S_{n-1}$. The statement of Proposition 1 can be easily derived from this conclusion. □

Proof of Proposition 5: Assume that there are $q-1$ agents ($2 \leq q \leq n$) who adopt the technology and the other agents do not. Let $P(i)$ denote the set of the $q-1$ agents who adopt the technology. Agent $i \in N \setminus P(i)$ has an incentive to adopt the technology if and only if:

$$\begin{aligned}(1-\theta_i)\left(v_i+(q-1)w\right)+\theta_i\left[\sum_{j\in P(i)\cup\{i\}}\gamma_{ij}\left(v_j+(q-1)w\right)+\sum_{j\notin P(i)\cup\{i\}}\gamma_{ij}c_j\right]\\ \geq (1-\theta_i)c_i+\theta_i\left[\sum_{j\in P(i)}\gamma_{ij}\left(v_j+(q-2)w\right)+\sum_{j\notin P(i)}\gamma_{ij}c_j\right],\end{aligned} \tag{26}$$

or,

$$v_i \geq c_i-(q-1)w-\frac{\theta_i\sum_{j\in P(i)}\gamma_{ij}}{1-\theta_i+\theta_i\gamma_{ii}}w. \tag{27}$$

Assume that full technology adoption is a Nash equilibrium. In order to eliminate all the other outcomes as Nash equilibria and minimize his cost, the principal has to use a divide and conquer scheme. The agents are thus ranked and condition (27) is binding and it can be written as follows:

$$v_i^* = c_i-(i-1)w-\lambda_i\sum_{j<i}\gamma_{ij}w, \tag{28}$$

where $\lambda_i = \frac{\theta_i}{1-\theta_i+\theta_i\gamma_{ii}}$. Now I characterize the optimal ranking. Assume that the agents are ranked such that agent 1 is ranked first, agent 2 ranked second, etc. If the principal decides to permute two subsequent agents k and $k+1$, then the sum of the subsidies increases by $\gamma_{kk+1}\left(\lambda_{k+1}-\lambda_k\right)w$. Hence, the ranking that minimizes the implementation cost is such that agent i is ranked before agent $i+1$ only if $\lambda_i \leq \lambda_{i+1}$. To check that full technology adoption is a Nash equilibrium, notice that condition (27) holds when v_i is replaced by v_i^*, q by n and $P(i)$ by $N \setminus i$.□

Proof of Proposition 6: Here the utility function of agent i is given by:

$$U_i = (1-\theta)\pi_i + \theta\left(\eta\ min\{\pi_1, ..., \pi_n\} + (1-\eta)\sum_{j\in N}\pi_j\right). \tag{29}$$

Assume that the incentive scheme has the divide and conquer property: the agents are ordered such that i_{j+1} is the agent that has an incentive to adopt the technology when the first j agents adopt the technology and the remaining agents do not. The corresponding formal condition for agent i_1 is:

$$(1-\theta)v_{i_1} + \theta\eta min\{v_{i_1}, c+w_0\} + \theta(1-\eta)\left(v_{i_1} + (n-1)c + (n-1)w_0\right) \geq (1-\theta)c + \theta\eta c + \theta(1-\eta)nc, \tag{30}$$

or,

$$(1-\theta)(v_{i_1} - c) + \theta\eta min\{v_{i_1} - c, w_0\} + \theta(1-\eta)\left(v_{i_1} - c + (n-1)w_0\right) \geq 0. \tag{31}$$

For agent i_{j+1} with $2 \leq j+1 \leq n-1$ the corresponding formal condition can be written as follows:

$$\begin{aligned}(1-\theta)(v_{i_{j+1}} + jw) + \theta\eta min\{v_{i_{p(j+1)}} + jw, c + (j+1)w_0\} \\ + \theta(1-\eta)\sum_{k\leq j+1}(v_k + jw) + \theta(1-\eta)\sum_{j+2\leq k\leq n}(c + (j+1)w_0) \\ \geq (1-\theta)(c + jw_0) + \theta\eta min\{v_{i_{p(j)}} + (j-1)w, c + jw_0\} \\ + \theta(1-\eta)\sum_{k\leq j}(v_k + (j-1)w) + \theta(1-\eta)\sum_{j+1\leq k\leq n}(c + jw_0)\end{aligned} \tag{32}$$

where $i_{p(j+1)}$ is the agent such that $min_{l\leq j+1}\{v_l\} = v_{i_{p(j+1)}}$.

Condition (32) is equivalent to:

$$\begin{aligned}(1-\theta\eta)(v_{i_{j+1}} + j\Delta - c) + \theta(1-\eta)\left((n-1)w_0 + j\Delta\right) \geq \\ \theta\eta\left(min\{v_{i_{p(j)}} + (j-1)w, c + jw_0\} - min\{v_{i_{p(j+1)}} + jw, c + (j+1)w_0\}\right),\end{aligned} \tag{33}$$

and for agent i_n, the condition is:

$$\begin{aligned}(1-\theta\eta)(v_{i_n} + (n-1)\Delta - c) + \theta(1-\eta)(n-1)w \geq \\ \theta\eta\left(min\{v_{i_{p(n-1)}} + (n-2)w, c + (n-1)w_0\} - \left(v_{i_{p(n)}} + (n-1)w\right)\right),\end{aligned} \tag{34}$$

Step 1: I show that any contract that is characterized by the divide and conquer property and that minimizes the implementation cost is such that each agent is indifferent between adopting and not adopting the technology when all the preceding agents in the ranking adopt the technology while all the subsequent agents in the ranking do not.

In other words, I show in this Step 1 that the least cost contract such condition (31), condition (33) for $j+1 = 2, ..., n-1$ and condition (34) hold is such that all these inequalities are binding.

Let first show that the claim holds for $1 \leq k+1 \leq n-1$. Notice that condition (31) is more likely to be binding when v_{i_1} decreases and that condition (33) for $j+1 = k+1$ is more likely to be binding when $v_{i_{k+1}}$ decreases. A sufficient condition for the principal to choose to bind condition (31) or (33) for $j+1 = k+1$ is thus that a decrease in $v_{i_{k+1}}$ does not make any other constraint less likely to hold. Let me first focus on condition (33) for $l+1 \leq n-1$. Let me show that $\Omega_{l+1} \equiv min\{v_{i_{p(l)}} + (l-1)w, c + lw_0\} - min\{v_{i_{p(l+1)}} + lw, c + (l+1)w_0\}$ for $l+1 \leq n-1$ and $l+1 \neq k+1$ does not increase when $v_{i_{k+1}}$ decreases. First assume that $l+1 \leq k$. In this case, Ω_{l+1} does not depend on $v_{i_{k+1}}$. Second, assume that $k+2 \leq l+1 \leq n-1$. If $i_{p(l)} \neq i_{k+1}$ then $i_{p(l+1)} \neq i_{k+1}$ and then Ω_{l+1} does not depend on $v_{i_{k+1}}$. If $i_{p(l+1)} = i_{k+1}$ then $i_{p(l)} = i_{k+1}$ and $\Omega_{l+1} = min\{v_{i_{k+1}} + (l-1)w, c + lw_0\} - min\{v_{i_{k+1}} + lw, c + (l+1)w_0\}$. Notice that if $min\{v_{i_{k+1}} + lw, c + (l+1)w_0\} = v_{i_{k+1}} + lw$ then $min\{v_{i_{k+1}} + (l-1)w, c + lw_0\} = v_{i_{k+1}} + (l-1)w$. Thus Ω_{l+1} cannot increase when $v_{i_{k+1}}$ decreases. If $i_{p(l)} = i_{k+1}$ and $i_{p(l+1)} \neq i_{k+1}$, then Ω_{l+1} does not increase when $v_{i_{k+1}}$ decreases. Let me now consider condition (34). If $i_{p(n-1)} \neq i_{k+1}$ then $i_{p(n)} \neq i_{k+1}$ and then condition (34) does not depend on $v_{i_{k+1}}$. If $i_{p(n-1)} = i_{k+1}$ and $i_{p(n)} \neq i_{k+1}$, then condition (34) is more likely to hold when $v_{i_{k+1}}$ decreases. If $i_{p(n)} = i_{k+1}$ then $i_{p(n-1)} = i_{k+1}$ and condition (34) becomes:

$$\begin{aligned}(1-\theta\eta)(v_{i_n} + (n-1)\Delta - c) \geq \\ -\theta\eta\left(v_{i_{k+1}} + (n-1)w - min\{v_{i_{k+1}} + (n-2)w, c + (n-1)w_0\}\right) - \theta\left(1-\eta\right)(n-1)w, \quad (35)\end{aligned}$$

If $v_{i_{k+1}} + (n-2)w \leq c + (n-1)w_0$, then condition (35) does not depend on $v_{i_{k+1}}$. If $v_{i_{k+1}} + (n-2)w > c + (n-1)w_0$, condition (35) becomes:

$$(1-\theta\eta)(v_{i_n} + (n-1)\Delta - c) \geq -\theta\eta\left(v_{i_{k+1}} + (n-1)\Delta - c\right) - \theta(1-\eta)(n-1)w. \quad (36)$$

Condition (36) can be rewritten as follows:

$$(1-\theta\eta)(v_{i_n} - v_{i_{k+1}}) \geq -\left(v_{i_{k+1}} + (n-1)\Delta - c\right) - \theta(1-\eta)(n-1)w. \quad (37)$$

The right hand side in (37) is negative because $v_{i_{k+1}} + (n-2)w > c + (n-1)w_0$ and the left hand side is positive because $i_{p(n)} = i_{k+1}$. I conclude that, in this case, condition (34) always holds. Hence, the principal chooses $v_{i_{k+1}}$ such that condition (33) for $j+1 = k+1$ is binding if $k+1 < n$ and such that condition (34) is binding if $k+1 = n$.

To conclude Step 1, it remains to show that the claim also holds for agent i_n. It is sufficient to observe that condition (34) is more likely to hold when v_{i_n} increases and that all the other constraints do not depend on v_{i_n}.

It is easy to show that when condition (31) is binding, the least cost contract is such that $v_{i_1} = c - \theta\left((1-\eta)(n-1) + \eta\right)w_0$.

Step 2: Let me show that the least cost contract characterized by the divide and conquer property is such that the payoff of an agent who adopts the technology -when all the preceding agents also do so and the remaining agents do not- is lower than the payoff of the agents who do not adopt the technology, that is to say $v_{i_j} + (j-1)w \leq c + jw_0$ for all $j \leq n-1$.

We know from Step 1 that the least cost contract which has the divide and conquer property

is such that $v_{i_1} = c - \theta\left((1-\eta)(n-1)+\eta\right)w_0$, thus the claim holds in this case.

For all $2 \leq j+1 \leq n-1$, we have:

$$(1-\theta\eta)(v_{i_{j+1}} + j\Delta - c) + \theta(1-\eta)\left((n-1)w_0 + j\Delta\right) \\ = \theta\eta\left(min\{v_{i_{p(j)}} + (j-1)w, c + jw_0\} - min\{v_{i_{p(j+1)}} + jw, c + (j+1)w_0\}\right). \quad (38)$$

Notice that the definition of $p()$ implies that $v_{i_{p(j+1)}} \leq v_{i_{p(j)}}$. There are two sub-cases to consider.

First, if $v_{i_{p(j+1)}} + w \geq v_{i_{p(j)}}$, the right hand side in condition (38) is negative, and then a simple inspection of condition (38) leads to conclude that $v_{i_{j+1}} + jw \leq c + (j+1)w_0$.

Second, if $v_{i_{p(j+1)}} + w < v_{i_{p(j)}}$, then we must have $v_{i_{p(j+1)}} = v_{i_{j+1}}$. There are two sub-sub-cases to consider. First, if $v_{i_{p(j)}} + (j-1)w \geq c + jw_0$, condition (38) can be rewritten as follows:

$$(1-\theta\eta)(v_{i_{j+1}} + jw - c - (j+1)w_0) + \theta\eta min\{v_{i_{j+1}} + jw - c - (j+1)w_0, 0\} \\ = -\theta(1-\eta)\left((n-1)w_0 + j\Delta\right) - w_0, \quad (39)$$

and then $v_{i_{j+1}} + jw - c \leq c + (j+1)w_0$. Second, if $v_{i_{p(j)}} + (j-1)w < c + jw_0$, condition (38) becomes:

$$(1-\theta\eta)(v_{i_{j+1}} + j\Delta - c) + \theta(1-\eta)\left((n-1)w_0 + j\Delta\right) \\ = \theta\eta\left(v_{i_{p(j)}} + (j-1)w - min\{v_{i_{j+1}} + jw, c + (j+1)w_0\}\right). \quad (40)$$

Assume that $v_{i_{j+1}} + jw > c + (j+1)w_0$. Hence, condition (40) becomes

$$(1-\theta\eta)(v_{i_{j+1}} + j\Delta - c) + \theta(1-\eta)\left((n-1)w_0 + j\Delta\right) \\ = \theta\eta\left(v_{i_{p(j)}} + (j-1)w - c - (j+1)w_0\right). \quad (41)$$

In this case, the right hand side of condition (41) is negative and then $v_{i_{j+1}} + jw \leq c + (j+1)w_0$, which is a contradiction. We thus must have $v_{i_{j+1}} + jw \leq c + (j+1)w_0$.

An implication of Step 1 and Step 2 is that the least cost contract that respects the divide and conquer property is such that $v_{i_1} = c - \theta(1-\eta)(n-1)w_0$ and,

$$(1-\theta\eta)(v_{i_{j+1}} + j\Delta - c) + \theta\eta\left(v_{i_{p(j+1)}} + j\Delta - c\right) \\ = \theta\eta\left(v_{i_{p(j)}} + (j-1)\Delta - c\right) - \theta(1-\eta)\left((n-1)w_0 + j\Delta\right) - \theta\eta w_0, \quad (42)$$

for all $2 \leq j+1 \leq n$.

Step 3: Let me show that the least cost contract characterized by the divide and conquer property is such that the higher the rank of an agent in the given order, the lower his subsidy level: $v_{i_{j+1}} < v_{i_j}$ for all j.

Since the choice of the subsidy offered to an agent does not depend on the choice of the subsidies offered to the subsequent agents (see condition (42)), the principal has an incentive to choose $v_{i_{j+1}} \leq v_{i_j}$ for all j. I assume this is true and I will check that the solution respects this

condition. We thus have $v_{i_{p(j+1)}} = v_{i_{j+1}}$ for all j. In this case, the least cost contract that respects the necessary condition is characterized by $v_{i_1} = c - \theta(1-\eta)(n-1)w_0$ and the following recursive formula:

$$v_{i_{j+1}} + j\Delta - c = \theta\eta(v_{i_j} + (j-1)\Delta - c) - \theta(1-\eta)j\Delta - (\theta(1-\eta)(n-1) + \theta\eta)\, w_0, \quad (43)$$

for all $j = 1, ..., n-1$. Solving for the recursive formula, I find that:

$$v_{i_{j+1}} = c - j\Delta\,(1 + \theta(1-\eta)) - \theta(1-\eta)\Delta\sum_{t=1}^{j}(j-t)(\theta\eta)^t - \frac{\theta\,(\eta + (1-\eta)(n-1)) - (1+\theta(1-\eta)(n-1))\,(\theta\eta)^{j+1}}{1-\theta\eta}w_0, \quad (44)$$

for all $2 \leq j+1 \leq n$. The difference between two subsequent terms is then:

$$v_{i_j} - v_{i_{j+1}} = \Delta + \theta(1-\eta)\Delta\frac{1-(\theta\eta)^j}{1-\theta\eta} + (1+\theta(1-\eta)(n-1))\,(\theta\eta)^j w_0 > 0. \quad (45)$$

Step 4: I show that the least cost contract characterized by the divide and conquer property is such that any situation in which $m < n$ agents adopt the technology is not a Nash equilibrium of the technology adoption game.

It is sufficient to show that the least cost contract characterized by the divide and conquer property is such that agent i_{j+1} with $j+1 \leq n-1$ prefers to adopt the technology to adopt it when any other j agents adopt the technology. First notice that the claim holds for agent i_1, since this agent has an incentive to adopt the technology when no other agent adopts the technology. Let me now show that the claim also holds for any agent $2 \leq j \leq n-1$. We know from the definition of the divide and conquer property that agent $j+1$ adopts the technology when the j first agents also do so. Now assume that j agents adopt the technology and that at least one of these agents k is such that $k > j+1$. Using the results from Steps 2 and 3, we know that the last agent in the ranking who adopts the technology is the one who obtains the lowest payoff among all the agents, whenever agent $j+1$ adopts the technology or not. Hence, using condition (33), we have that agent i_{j+1} with $2 \leq j+1 \leq n-1$ adopts the technology when j other agents also do so if and only if:

$$(1-\theta\eta)(v_{i_{j+1}} + j\Delta - c) \geq -\theta\eta w - \theta(1-\eta)j\Delta - \theta(1-\eta)(n-1)w_0. \quad (46)$$

Condition (43) can be written as follows:

$$(1-\theta\eta)(v_{i_{j+1}} + j\Delta - c) = \theta\eta\left(v_{i_j} - v_{i_{j+1}} - \Delta\right) - \theta(1-\eta)j\Delta - \theta(1-\eta)(n-1)w_0. \quad (47)$$

Substituting condition (47) into condition (46), we have that condition (46) is equivalent to $v_{i_j} - v_{i_{j+1}} \geq -w_0$, which is true according the result from Step 3.

Step 5: I now show that the least cost contract characterized by the divide and conquer property is such that the situation in which all the agents adopt the technology is a Nash equilibrium.

This is indeed a Nash equilibrium if and only if each agent i prefers to adopt the technology

when all the other agents adopt it. We know from previous Steps that this claim holds for agent i_n. It remains to show that the claim holds for the other agents. An agent i_j such that $j < n$ prefers to adopt the technology when all other agents do if and only if:

$$(1-\theta)\left(v_{i_j}+(n-1)w\right)+\theta\eta\left(v_{i_n}+(n-1)w\right)+\theta(1-\eta)\left(\sum_k v_{i_k}+n(n-1)w\right)$$
$$\geq (1-\theta)\left(c+(n-1)w_0\right)+\theta\eta\left(v_{i_n}+(n-2)w\right)$$
$$+\theta(1-\eta)\left[\sum_{k\neq i_j} v_{i_k}+(n-1)(n-2)w+c+(n-1)w_0\right],$$

or,

$$(1-\theta\eta)\left(v_{i_j}+(n-1)\Delta-c\right)\geq -\theta\eta w-\theta(1-\eta)(n-1)w. \tag{48}$$

We know from Step 4 that condition (46) holds. Using condition (46), we can easily show that (48) also holds if $\Delta \geq 0$.

Step 6: In this step, I show that the least cost unique implementation contract is the least cost DAC unique implementation contract.

A unique implementation contract is such that, for any outcome $x \neq 1^n$, at least one agent has an incentive to deviate. Consider outcome $(0,...,0)$, that is, no agent adopt the technology. In this case, at least one agent has an incentive to deviate (i.e. the DAC property holds for this agent). Let us rank this agent first. Consider outcome where only the first agent adopts the technology, $(1,0,...,0)$. In this case, at least one other agent has an incentive to deviate (i.e. the DAC property holds for this agent). Let us rank this agent second. Consider outcome $(1,1,0...,0)$, that is, only the two first agent adopt the technology. There are two possibilities here: (i) a third agent has an incentive to deviate (i.e. the DAC property holds for this agent) or the first agent has an incentive to deviate. Assume that the latter holds, that is, agent 1 prefers $(0,1,0...,0)$ over $(1,1,0,...,0)$:

$$\begin{aligned}&(1-\theta)(c+w_0)+\theta\eta min\{c+w_0,v_2\}+\theta(1-\eta)((n-1)(c+w_0)+v_2)\\ &\geq (1-\theta)(v_1+w)+\theta\eta min\{v_1+w,v_2+w,c+2w_0\}+\theta(1-\eta)\left[(n-2)(c+2w_0)+v_1+v_2+2w\right]\end{aligned} \tag{49}$$

We know that the DAC holds for agent 1 and that this is equivalent to $v_1 \geq c+w_0$. Thus, condition (49) is equivalent to

$$\begin{aligned}&(1-\theta)(c+w_0-v_1-w)+\theta\eta\left[min\{c+w_0,v_2\}-min\{v_2+w,c+2w_0\}\right]\\ &\geq \theta(1-\eta)\left[v_1+2w-c-w_0\right].\end{aligned} \tag{50}$$

The left hand side in condition (50) is strictly negative and the right hand side is positive, which is a contradiction. Hence, when agent 1 and 2 adopt the technology, at least one other agent has an incentive to deviate and to adopt the technology. Let us rank this agent in third position.

Let us show that this result holds for any outcome such that the first $j \geq 3$ agents adopt the technology and the DAC property holds for these agents. Using the same argument as in Step 1,

we can show that the subsidies of these agents are the subsidies they receive under the least cost DAC unique implementation contract. The payoff of these agents, when the j first agents adopt the technology, is denoted π_k^j with $k = 1, ..., j$ and it is thus such that $\pi_j^j \leq c + jw_0$, $\pi_j^j < \pi_k^j$ and $v_k > v_j$ for all $k < j$ (see steps 2 and 3). Consider the outcome where the first j agents exert effort and the other agents do not exert effort. Agent $i < j$ has an incentive to deviate if and only if:

$$\begin{aligned}(1-\theta)\left(c+(j-1)w_0\right)+\theta\eta min\{c,\pi_j^j-w\} \\ +\theta(1-\eta)\left[(n-j+2)(c+(j-1)w_0)+\sum_{k\leq j,k\neq i}(\pi_k^j-w)\right] \\ \geq (1-\theta)\pi_i^j+\theta\eta min\{c+jw_0,\pi_j^j\}+\theta(1-\eta)\left[(n-j+1)(c+jw_0)+\sum_{k\leq j}\pi_k^j\right],\end{aligned}$$

which is equivalent to:

$$v_i \leq \phi \equiv c-(j-1)\Delta-\frac{\theta\eta}{1-\theta\eta}w-\frac{\theta(1-\eta)}{1-\theta\eta}\left[(n+1-j)w_0+(j-1)w\right]. \tag{51}$$

After some computations, I obtain

$$\begin{aligned}v_j-\phi=\frac{\theta\eta}{1-\theta\eta}\Delta+(j-1)\frac{\theta(1-\eta)}{1-\theta\eta}\left[1+\frac{(\theta\eta)^j}{1-\theta\eta}\right]\Delta+\theta(1-\eta)\Delta\sum_{t=1,...,j-2}t(\theta\eta)^t \\ +\frac{\theta(1-\eta)+(\theta\eta)^i\left[1+\theta(1-\eta)(n-1)\right]}{1-\theta\eta}w_0\geq 0.\end{aligned}$$

Hence, using (51), we have $v_i \leq v_j$, which is a contradiction.

Step 7: It remains to show that the least cost unique implementation contract is induces full adoption as a unique equilibrium once the individual subsidies are increased by any positive amount. Let me consider agent 1. If the subsidy of each agent i is $v_i^* + \epsilon$, she strictly prefers to adopt the technology when no other agent do so if and only if:

$$\begin{aligned}(1-\theta)(\epsilon-\theta(1-\eta)(n-1)w_0)+\theta\eta min\{\epsilon-\theta(1-\eta)(n-1)w_0,c+w_0\} \\ +\theta(1-\eta)(n-1)w_0(1-\theta(1-\eta))>0,\end{aligned} \tag{52}$$

which is equivalent to

$$(1-\theta)\epsilon+\theta\eta min\{\epsilon,c+\theta(1-\eta)(n-1)w_0+w_0\}>0, \tag{53}$$

which is true.

Now consider agent $2 \leq j+1 \leq n-1$. If the subsidy of each agent i is $v_i^* + \epsilon$, she strictly

prefers to adopt the technology when no other agent do so if and only if:

$$(1-\theta\eta)(v^*_{j+1}+\epsilon+j\Delta-c)+\theta(1-\eta)\left((n-1)w_0+j\Delta\right)$$
$$>\theta\eta\left[min\{v^*_j+\epsilon+(j-1)w, c+jw_0\}-min\{v^*_{j+1}+\epsilon+jw, c+(j+1)w_0\}\right]. \quad (54)$$

If $\theta(1-\eta)=w_0=0$, we have $v^*_i=c-(i-1)w$ for all i and then condition (54) is equivalent to $(1-\theta\eta)\epsilon>0$, which is true. If $w_0>0$ or $\theta(1-\eta)>0$, one can easily check that $v^*_i+(i-1)w+\epsilon<c+iw_0$ for all i. Hence, given that v^*_{j+1} and v^*_j are such that (54) holds with equality when $\epsilon=0$, we have that condition (54) is equivalent to $\epsilon>0$, which is true. This concludes the proof.□

Proof of Corollary 4: Compared to the situation considered in Corollary 3, the difference between the subsidy levels of two subsequent agents $v^*_i-v^*_{i+1}$ is augmented by $(1+\theta(1-\eta)(n-1))(\theta\eta)^i w_0$. This additional term increases when θ increases.

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