Exposure-enhanced goods and technology disadoption[*]

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Abstract

Policymakers subsidize goods that generate positive externalities, only to see these goods disadopted. We illustrate theoretically how disadoption can be mitigated through longer exposure to the goods, which reduces disadoption via three mechanisms. We provide evidence for the effect of exposure on disadoption using data from a field experiment in which some households' period of exposure to water-efficient technologies was exogenously manipulated via a financial incentive. Complier households who persisted in using the technologies for four months only when receiving an incentive to do so were more likely to keep them installed at least a year after receiving the exposure incentive. Using the theoretical model, we then develop intuition about the optimal time distribution of subsidies. When subsidies are costly to administer and any of the three exposure-enhancing mechanisms are active, limited duration exposure subsidies can outperform subsidies offered at the point of purchase or in perpetuity conditional on use.

Keywords: Disadoption, Randomized Controlled Trial, Habit Formation, Learning by Doing, Experience Goods, Subsidies
JEL Codes: D12, D91, H23, O23

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1 Introduction

Many public policy problems have technical solutions. Widespread use of insecticide-treated bednets can reduce the transmission of malaria (Lengeler 1998). Switching from incandescent to compact fluorescent lightbulbs can reduce greenhouse gas emissions (Allcott and Taubinsky 2015). Adopting conservation agriculture practices can reduce environmental damage from industrial agriculture (Kassam et al. 2014). Switching from traditional biomass cookstoves to improved cookstoves can improve public health and reduce deforestation (Ruiz-Mercado et al. 2011).

Although governmental and nongovernmental organizations expend substantial resources to encourage people to adopt ("take up") such technologies, people often disadopt them. One year after a pair of anti-malarial insecticide-treated bed nets were distributed for free to households in Uganda, approximately 55 percent of recipient households did not own one anymore (Clark et al. 2016). Among households that received free electricity-conserving compact fluorescent lamps (CFL) in Kenya, 63 percent were no longer using a CFL approximately four years later (Figueroa 2016). After farmers in Ghana, South Africa, and Zambia were induced to take up Conservation Agriculture practices, most farmers "quickly" reverted to former crop management practices (Giller et al. 2009). In Ghana, about half of the recipients of improved cookstoves were no longer using them one year later (Burwen and Levine 2012), and in India, 32 percent of recipient households *destroyed* their improved stove within four years (Hanna, Duflo, and Greenstone 2016). None of these technologies was displaced by a superior technology—people simply reverted to a prior technology or practice.

Although the adoption of these solutions has received a lot of attention from scholars, disadoption has received far less attention (exceptions include Barrett et al. (2022), Oliva et al. (2020), Nourani (2017), Carter, Laajaj, and Yang (2021), Giller et al. (2009), Hanna, Duflo, and Greenstone (2016), Figueroa (2016), Clark et al. (2016), and Dupas (2014)). In other words, scholars have extensively studied the take-up of technologies but have allocated comparatively little attention to the post-adoption persistence of technology use.

Here, we contribute in three ways to the literature on disadoption with a focus on the disadoption of pro-social goods (i.e., goods whose use generates positive externalities), which are important components of policies and programs in environmental, health and development contexts: (1) we clarify the connections between concepts and terminologies from the disparate literatures on habit formation, learning-by-doing and experience goods, and highlight how the insights from these literatures imply that the incentive to disadopt a pro-social good can decrease with an increase in the duration of the good's use; (2) we present results from a randomized controlled trial in which an exogenously manipulated duration of use decreased subsequent disadoption; and (3) under the assumption that the duration of use affects subsequent disadoption, we develop a theoretical model that identifies the conditions under which limited-time duration subsidies for use of a pro-social good can be superior to Pigouvian subsidies offered at the point of purchase or offered in perpetuity conditional on use (Pigouvian subsidies have the same magnitude as the positive externality; Baumol (1972)).

Although prior studies have demonstrated that short-term subsidies for the take-up and use of pro-social goods can lead to longer-term behavior change (Carter, Laajaj, and Yang 2021; Dupas 2014; Oliva et al. 2020), we know of no empirical studies that show that using a subsidy to extend the duration of use of a technology generates greater behavioral persistence after the cessation of the subsidy. Moreover, we know of no theoretical studies that describe the conditions under which limited-time duration subsidies are superior to alternative subsidy durations, a topic that is important to policymakers and practitioners seeking to design effective social programs that rely on the use of pro-social goods.

We define a good as "exposure-enhanced" when past use of the good raises the expected net benefit of using the good through three mechanisms. First, using a good can provide *information* about the match quality between the good and the person using it (experience goods; Nelson (1970)). Second, using a good can strengthen the person's *taste* for using the good (habit formation; Becker and Murphy (1988)). Third, using a good can improve the person's *ability* to use the good (learning-by-doing; Foster and Rosenzweig (1995)). Information, taste, and ability are *exposure-enhancing mechanisms.*

After defining exposure-enhanced goods, we experimentally confirm whether exogenous variation in prior use of a pro-social good can affect future use. Estimating the effect of the duration of prior use on future use in non-experimental designs is challenging because the effect of prior use on future use is confounded with the agent's unobserved utility from the good. In a field experiment, plumbers installed low-flow water fixtures in randomly selected households to conserve water in an arid region of Costa Rica (Alpizar, Bernedo Del Carpio, and Ferraro 2023). The field team anticipated potential disadoption of the technologies and conjectured that households that "stuck with" the technologies for several months would be more likely to perceive the purported positive net benefits from continued use. To test this conjecture, the team randomly offered some households a cash bonus conditional on the water-conserving technologies remaining in place four months after installation. This bonus created an exogenous source of variation in the duration of exposure to the technology, which can be used to estimate the effect of exposure duration on disadoption 16 months after installation among compliers (i.e., households that would have disadopted the technology before the four-month mark in the absence of a subsidy but persist in using it to the four-month mark in the presence of a subsidy). Although we cannot disentangle the three exposure enhancing mechanisms in our experimental design, we can confirm that an exogenous increase in the duration of short-term use decreased longer-term disadoption among the complier population: 87 percent of the difference in technology use observed after four months among the cash-bonus and no-bonus groups persisted for at least a year after subsidies were no longer offered.

After presenting the experimental results, we use a theoretical model to explore the implications of exposure-enhancing mechanisms for the design of the optimal subsidy that encourages long-run use of a pro-social good. In policy discussions of such goods, attention tends to gravitate towards Pigouvian subsidies offered at the point of purchase or offered in perpetuity conditional on use. However, exposure-enhancing mechanisms disrupt the optimality of simple Pigouvian subsidies. Our model shows that in the case of exposure-enhanced goods, exposure subsidies—subsidies that extend beyond the point of take up but do not last forever—are better than point-of-sale or perpetual use subsidies when policymakers also incur administrative costs to allocate the subsidies (or if there are other frictions, such as credit constraints or present bias among households).

Our study contributes to the large literature on technology adoption (Foster and Rosenzweig 2010) and the relatively small literature on disadoption. Much of the literature on technology adoption imagines technology as an unambiguous advance from what came before it and an inevitable link to what will come after it. In that framework, people cease using a technology because it is replaced by a superior technology (e.g. Dinar and Yaron (1992) and Abera (2008)). That perspective contrasts with our theoretical framework, in which "disadoption" occurs when a firm or household reverts to a previous technology or to the absence of technology. In the diffusion of innovations literature, this form of disadoption is called "disenchantment discontinuance" (Rogers 2002).

This paper also contributes in two ways to the broader economic literatures on habit formation, learning-by-doing and experience goods (see Section 2). First, in the process of building our model, we clarify and show the connections between the concepts and terminologies from these disparate branches of the economics literature. At their core, these literatures explore goods for which exposure can increase the perceived net benefit of use. Second, we demonstrate how these literatures connect to the broader public policy question of optimal subsidy design for behaviors that generate positive externalities. Our paper highlights conditions under which policymakers can optimally use short-term incentives to induce long-term behavioral change.

Section 2 introduces a theoretical model defining exposure-enhanced goods. Section 3 describes the context in which the experiment was run. Section 4 describes the design of the experiment. Section 5 presents the results of the experiment. Section 6 builds on the model to develop policy intuition about the optimal time distribution of subsidies. Section 7 concludes.

2 Theory of exposure-enhanced goods

To be precise about the meaning of exposure-enhanced goods and the information, ability, and taste mechanisms, this section introduces definitions and a theoretical model.

We define a good as *exposure-enhanced* if past use of the good raises the expected net benefit of using the good. This new term, "exposure-enhanced," is useful because it highlights that several mechanisms might be at play when prolonged or persistent use increases the perceived net benefit of using the good, thereby increasing the chances of continued use. Furthermore, although there are some situations where a social planner would want to know the operative mechanism, there are also situations where knowing the mechanism is not necessary.

The term *good* is also intended to be broadly inclusive. An exposure-enhanced good could be a durable good like a tractor, a non-durable good that is used repeatedly like fertilizer, or a procedure or technique like planting cover crops to reduce soil erosion. Consumption goods, investment goods, intermediate goods, and technologies can all be exposure-enhanced goods.

Our model combines three mechanisms of exposure-enhancement: information, ability, and taste. First, using a good can provide information, which reveals the quality of the good, the agent's type, or the match quality between the good and the agent. Second, using a good can make the agent better at using the good—e.g. more output is produced with a fixed input of effort. Third, using a good can give the agent a stronger taste for using the good.

In the model, an agent chooses in each period whether or not to use a good to maximize the discounted stream of expected utility (or profit). Using the good contributes to a stock of exposure. Ability and taste are both increasing functions of the exposure stock. Marginal utility is increasing in both ability and taste. Using the good also reveals a signal to the agent about match quality between the good and the agent. The impact of the signal on belief about match quality expresses the information mechanism. The discounted stream of expected utility in period t is:

$$\sum_{j=0}^{\infty} \delta^j \int_{-\infty}^{\infty} u(r_{t+j}, A(S_{t+j}), T(S_{t+j}), \theta) dF_t(\theta) \tag{1}$$

where $r \in \{0,1\}$ is a discrete choice to either use the good or not, $S \geq 0$ is an exposure stock, A is ability, T is taste, F is a cumulative distribution function expressing the agent's probabilistic belief about match quality θ, and $\delta \in (0,1)$ is the agent's time discount factor. We assume that the marginal utility of using the good is weakly increasing in ability, $\frac{\partial^2 u}{\partial r \partial A} \geq 0$, in taste, $\frac{\partial^2 u}{\partial r \partial T} \geq 0$, and in match quality, $\frac{\partial^2 u}{\partial r \partial \theta} \geq 0$.

The exposure stock evolves according to the following law of motion:

$$S_{t+1} = (1-d)(S_t + r_t) \tag{2}$$

where $d \in (0, 1]$ is a depreciation parameter.

The agent can observe a signal about match quality but cannot observe past utility.[1] The population distribution of match quality is $\theta \sim F(\theta)$. If the agent has not used the good prior to period t, then the agent's belief about match quality is the same as the population distribution, $F_t = F$. If the agent uses the good in period t, then it observes a signal ω_t that depends on its own match quality θ_i, $\omega_t \sim G(\omega_t|\theta_i)$, and it updates its belief using Bayes's rule, forming posterior belief F_{t+1}. If the agent does not use the good, then it does not observe a signal, and its belief is the same in the next period, $F_{t+1} = F_t$.

Relation to terms in prior literature. The exposure-enhancing mechanisms we identify as being potentially useful for mitigating disadoption correspond to three branches of economics literature. The information mechanism is associated with the literature on experience goods (Liebeskind and Rumelt 1989; Villas-Boas 2004; Ching, Erdem, and Keane 2013; Ching, Erdem, and Keane 2017), the taste mechanism is associated with the literature on habit formation (Carroll, Overland, and Weil 2000; Hussam et al. 2022), and the ability mechanism is associated with the literature on learning by doing (Foster and Rosenzweig 1995; Van Benthem, Gillingham, and Sweeney 2008; Kverndokk and Rosendahl 2007). The mapping between terms in prior literature and exposure-enhancing mechanisms is summarized in Table 1.

However, a simple mapping can obscure as much as it clarifies. The ability mechanism is usually associated with production by firms, but consumers are certainly capable of learning how to use a good or technology to raise marginal utility. Learning about match quality is usually associated with experience goods consumed by consumers, but firms certainly encounter goods that they must use in order to discern match quality. Formal models with habit formation or learning-by-doing are often isomorphic in the sense that both use

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[1] If the agent could observe past utility, then the agent would be able to infer match quality. In our model, the signal is the only source of information about match quality.

Table 1: Exposure-enhancing mechanisms

Mechanism	Branches of literature	Description
Information	Experience goods, Consumer learning	Using the good reveals match quality between the user and the good.
Taste	Habit formation	Using the good makes subsequent use more enjoyable (or less unenjoyable).
Ability	Learning by doing	Using the good makes the user better at using the good.

Note: This table describes three mechanisms by which goods can be enhanced by exposure and relates the mechanisms to terminology in prior publications.

exposure stocks to raise marginal profit or utility. Because the labels do not map cleanly to the mechanisms, scholars have appropriated the labels to apply to multiple mechanisms. For example, although most of the literature about learning by doing corresponds to what we would call the ability mechanism, some of it also covers what we would call the information mechanism, as in the discussion of match quality in Thompson (2010).

The conceptual distinction between the taste mechanism and the ability mechanism is important even though their formal expression is similar. Following prior literature on habit formation and learning by doing, our formal model expresses the two mechanisms isomorphically; both are represented by the influence of a stock of exposure on period utility. It would be easy to separate these two mechanisms into a utility component for the taste mechanism and a productivity component for the ability mechanism. We express these components jointly for simplicity and note that the model can be applied to situations with one or both mechanisms.

We do not claim that all technologies are enhanced by exposure. Each of the three mechanisms may or may not be present for any particular good. For example, Orgill-Meyer et al. (2019) report that, as part of a sanitation campaign, a randomly assigned intervention temporarily boosted ownership of household latrines but had no long-run impact after 10 years. If any of the mechanisms were present for household latrines, they were not strong enough to impact behavior over that time horizon.

Note that our definition of "disadoption" differs from some prior studies. In order to "disadopt" a good, a person must have previously "adopted" it. In our terminology, using a good once counts as "adopting" it, but in some studies using a good only once, or for only for a trial period, does not count as adopting it (e.g., Lehmann and Parker (2017)).

Relation to models in prior literature. Because our model implies that exposure-enhancing mechanisms can be leveraged to reduce disadoption, our model also connects to the broader literature on the use of subsidies for pro-social goods. The idea that short-term subsidies might induce long-term changes in behavior is not new. Yet, most studies examining the impact of short-term subsidies on long-term behavior change present theory tailored closely to the particular policy context, e.g. Carter, Laajaj, and Yang (2014) and Kverndokk and Rosendahl (2007). These models typically incorporate intertemporal complementarities (i.e. exposure-enhancing mechanisms) without articulating the sources of the complementarities.

Among general models that are not tailored closely to a particular context, ours is unique in examining dynamic extensive margin decisions with all three exposure-enhancing mechanisms. Our model bears some resemblance to the model of addiction in Gruber and Köszegi (2001) through dynamic extensive margin decisions and the presence of an exposure stock, but they are unconcerned with match quality and impose an additional “tolerance” property of addictive goods. Ghadim and Pannell (1999) motivate a model of crop adoption with both the information and the ability mechanisms with a focus on either static extensive margin decisions or dynamic intensive margin decisions, not dynamic extensive margin decisions. Halac, Kartik, and Liu (2016) propose an adverse selection and moral hazard model with the information mechanism where an agent adopts a technology and is incentivized to keep using it with short-term transfers that are a function of observable outcomes. Oliva et al. (2020) examine takeup and disadoption in the presence of uncertainty, and their model is a special case of ours with only two periods and only the information mechanism. Although we focus discussion of our model on a binary choice where using the good generates a positive externality, our argument about the timing of subsidies also applies when failing to use the good generates a negative externality (López 2016).

A common concern when policymakers contemplate subsidies for health and development goods is that subsidy recipients will anchor on the subsidized price (Cohen and Dupas 2010). Dupas (2014) models anchoring alongside the information mechanism, but without the taste or ability mechanisms. Both (Cohen and Dupas 2010) and Dupas (2014) present empirical evidence that anchoring does not reduce future willingness to pay in the context of anti-malarial bednets. We do not model anchoring.

In the next three sections, we describe the context, design, and results of a controlled field experiment that demonstrates that incentivized exposure to a good can have a persistent causal impact on subsequent use.

3 Background

Development and environmental projects frequently include the promotion of goods, behaviors, and practices that would be socially beneficial if adopted widely but may also suffer from widespread disadoption.

The AC3 Project. As a consequence of climate change, local temperatures in Central America are predicted to increase and precipitation is predicted to decrease, exacerbating what is already an acute crisis in groundwater management (Famiglietti 2014; Imbach et al. 2015). To improve the capabilities of water management organizations in Central America to adapt to climate change, the Tropical Agricultural Research and Higher Education Center (CATIE) created, in 2013, the AC3 project (abbreviation of the Spanish for "Water Communities and Climate Change").

One component of the AC3 project was a randomized controlled trial that was implemented in a dry region of Costa Rica subject to seasonal droughts [2]. The trial aimed to test the effects of water-efficient technologies on household water use (Alpizar, Bernedo Del Carpio, and Ferraro 2023). We use a feature of the trial to empirically estimate the effect of exposure on technology disadoption.

Water prices. Water systems in rural communities of low- and middle-income nations are often managed by volunteer councils called community-based water management organizations (CBWMOs). In Costa Rica and elsewhere, CBWMOs cannot easily change the quantity of water available for the local water supply, and thus mitigating water system stress typically requires managing demand. A prominent tool for managing demand is variable pricing for water consumption. The national public utility regulator in Costa Rica sets a national price schedule, including a fixed price per month and a marginal price per cubic meter, that CBWMOs are encouraged to implement. The national price schedule is set below marginal cost because of concerns about access by low-income households. More than half of the CBWMOs in the study region charged prices lower than the national price schedule.

In this regime where water prices are below marginal costs, water consumption generates a negative externality. When concerns about equity restrict the extent to which price is used as a tool for managing this externality, policymakers seek technological solutions, such as water-conserving technologies (Renwick and Archibald 1998). The use of water-conserving technologies generates a positive externality by reducing demand on regional water systems.

Low-flow water technologies. Households in the study communities were offered low-flow water fixtures with free installation. Flow restriction limits the throughput of a pipe,

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[2] Registered through the American Economic Association registry with RCT ID AEARCTR-0007158.

reducing the maximum flow rate of water. Aeration adds air to water coming through a pipe, which has the same consequence of reducing the maximum flow rate of water and also affects the composition of water and air below the maximum. The AC3 team distributed faucet aerators, which use aeration only, as well as low-flow showerheads, which use both flow restriction and aeration. We use the term low-flow fixtures to include both faucet aerators and low-flow showerheads. Low-flow fixtures were not available commercially in the communities in the AC3 trial, so households did not have prior exposure to the fixtures. There was also no evidence of a secondary market for the low-flow fixtures during the trial.

Below, we explain below how the exposure-enhancing mechanisms modeled in section 2 may have manifested in the context of low-flow fixtures. The information mechanism could have been active if the households learned about their idiosyncratic costs or benefits by using the fixtures. By comparing water use in the treated and control households, Alpizar, Bernedo Del Carpio, and Ferraro (2023) estimate that the low-flow fixtures used in the AC3 trial reduced water use by an average household by more than two cubic meters per month. Households had access to information about their cost savings by observing their water bills with the technology installed.

The taste mechanism could have been active if households habituate to low-flow fixtures over time. Low-flow fixtures change the pressure and tactile feeling of using water, which can be unpleasant for new users. However, after using the fixtures for several months, households may grow accustomed to the new feel and feel less displeasure or even start enjoying the new sensation.

The ability mechanism could have been active if households learned how to use the fixtures more effectively. Two opportunities for learning are in cleaning the fixtures and in knowing when to use alternative spouts. Water supplied by water systems in this region of Costa Rica often has particulates that accumulate in low-flow fixtures. Muck needs to be cleaned out occasionally, so it is possible that households that were incentivized to keep the technology installed learned how to clean the muck rather than disadopting at the first sign of seriously impeded flow. Removing the low-flow fixtures does not require specialized tools or expertise—households that wanted to remove a fixture would have been capable of doing so without hiring a plumber. The other opportunity for enhancing ability is learning when not to use the low-flow fixtures. For example, if a pot of water with a fixed quantity is needed then households may have learned to detach the aerator occasionally or to use an alternative spout without a low-flow fixture in order to save time.

4 Experimental design

We use the AC3 randomized controlled trial to test whether longer exposure to a good can have a persistent causal effect on subsequent use. Among the households that were were randomized to receive installation of the water-efficient technologies, a randomly selected subset was offered a cash bonus if the technology was still in use during an audit four months after installation. The idea for the bonus came during the project design phase, when the AC3 team consulted with engineers about the possibility that households would disadopt the low-flow technologies. Engineers claimed that if households disadopted the technologies, it would be because the households had not "spent enough time" using them. This claim was an inspiration for the bonus treatment arm and for the theoretical model that formalizes how exposure can affect subsequent use. One year after the initial audit (16 months after treatment assignment), the field team conducted a second, unincentivized and unannounced audit.

We use random assignment of the cash bonus as an instrument to estimate the causal effect of four months of exposure on subsequent use after the bonus was no longer offered.[3]

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[3] Although the RCT is registered at the AEA registry, it was not pre-registered with a pre-analysis plan prior to treatment assignment. The RCT was designed in 2014 and implemented 2015, prior to the authors

This randomized encouragement design allows us to test the hypothesis that if a household spends more time with a technology, it will be less likely to subsequently disadopt the technology. The design does not, however, allow us to distinguish among the three exposure-enhancing mechanisms.

4.1 Sample

The sample consists of households from nine small, rural, low-income communities in the dry corridor of Costa Rica. The nine communities, mapped in Figure 1, met the following selection criteria: (1) The community's water was managed by a community-based water management organization. (2) The CBWMO charged households volume-based marginal prices for water use. (3) The CBWMO was willing and able to provide the research team with monthly household-level water use records back to 2013. (4) The CBWMO agreed that random assignment could be used to determine whether households would receive water-efficient technology. Appendix Table F.1 reports water prices and the number of households in the sample for each of the nine communities.

In May and June 2015, four installation teams knocked on doors in the nine communities to recruit households for the experiment, conduct a pre-treatment survey, and install the technology. Each installation team consisted of one interviewer and one plumber. Visits were conducted using a tablet that allowed the interviewer to show participants a video of low-flow water fixtures and explain the individual benefits of lower water bills and environmental benefits of conserving water.

Of 1898 households in the communities, installation teams made contact with an adult decision-maker in 1346 households, and 1310 households agreed to participate in the experiment and allow installation of the water-efficient technology if they were selected for installation. Sample households had low education levels and low incomes. Among the heads

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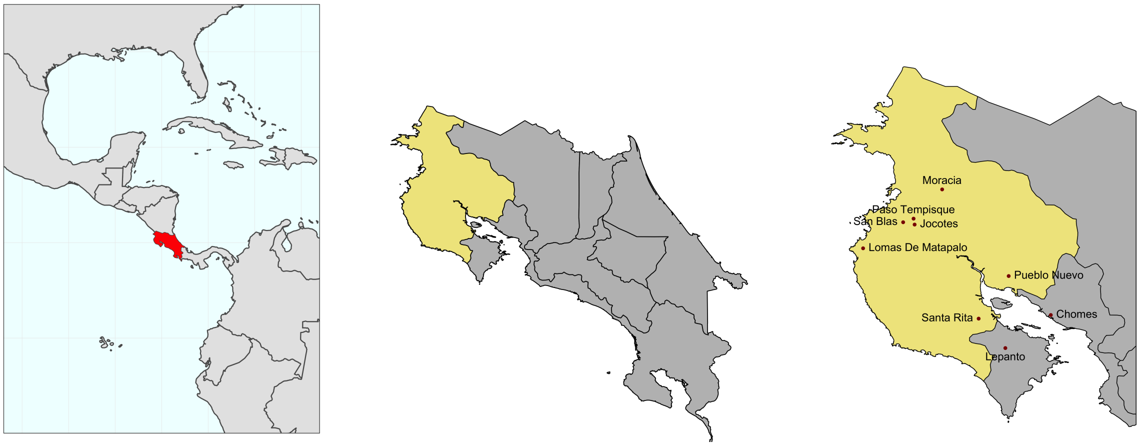
becoming aware of the importance of pre-analysis plans.

Figure 1: Map of communities in experiment



(a) (b) (c)

Note: Households were located in nine communities in the dry corridor of Costa Rica. Panel (a) depicts Costa Rica shaded red with marked borders of surrounding countries. Panel (b) depicts the Guanacaste Province shaded yellow with marked borders of other provinces in Costa Rica. Panel (c) depicts the nine communities in the experiment, all of which are in or near Guanacaste.

of household in the sample, 81% completed primary school and 27% completed secondary school. Average household monthly income in the sample was around 234,000 CRC ($440 per month). The average monthly water bill was 7,400 CRC ($13.93), so household water expenses were on average approximately 3% of household income. Awareness of the impacts of climate change in this population is low, but the environmental benefits of conserving water were explained by the installation teams.

4.2 Random assignment, intervention, and data gathering

Interviewers explained and conducted the random assignment procedure among the households that were willing to install the technologies. A member of the household drew one of three colored chips from an opaque bag. Red chips corresponded to receiving the technology and the bonus, blue chips corresponded only to receiving the technology, and white chips meant no technology. If the resident drew either a red chip or a blue chip, then the interviewer explained that the household was selected to receive the technology and that the field team would return to ask about the household's exposure to the technology. If the chip was red, then the interviewer also informed the household that it would be paid a bonus of 20,000 colones (approximately $38) if the technologies were still installed on the next visit from the field team, which would take place in the next six months. At the time of the experiment, 20,000 colones was around 9% of monthly household income, or three times as large as a monthly water bill. After the random assignment, the plumber immediately attempted to install the technology in as many fixture locations as possible. Prior to installation, some showerhead locations were open pipes, but if there was previously a showerhead present then the plumber removed the old showerhead from the household. Households in both the bonus group and the no-bonus group were told that the field team would return to ask about the household's experience with the technology within six months, but they were not given an exact date.

After randomization, 438 households received the technology and were offered a bonus, 432 households received the technology without being offered a bonus, and 440 households did not receive the technology. To examine estimate the relationship between exposure and technology disadoption, we focuses on a comparison between the bonus (treatment) group and the no-bonus (control) group, both of which received the technology.[4] Note that households in both the bonus group and the no-bonus group were told that the field team would return within six months, so both groups' disadoption decisions could have been influenced by pro-social preferences to avoid disappointing CATIE staff. But only the bonus group's decisions could have been influenced by a desire to receive the subsidy payment.

The field team conducted two subsequent audits of households in both groups, the bonus group and the no-bonus group. The first audit was approximately four months after instal-

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[4] To estimate the effect of the technology on water use, Alpizar, Bernedo Del Carpio, and Ferraro (2023) use the comparison between the two treatment arms that received the technology and the one treatment arm that did not to examine the effect of low-flow fixtures on water use. We do not use the "no-technology" group in our analysis.

lation, still in calendar year 2015, and the bonus was paid during that visit. The second audit was in 2016, approximately one year after the first audit. Both audits recorded which fixtures still had the water-efficient technology installed.

4.3 Baseline characteristics and balance

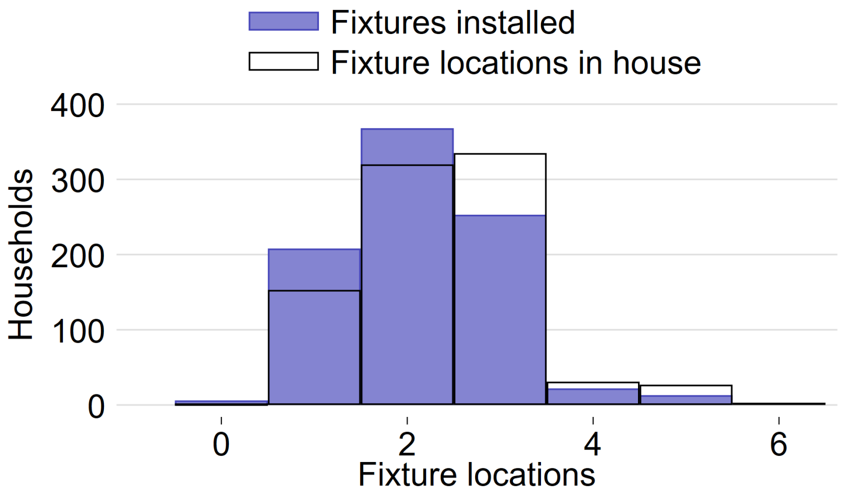
A pre-treatment survey was administered immediately prior to random assignment and installation of the water-conserving technology. Appendix Table F.2 presents summary statistics on household characteristics by treatment assignment. The differences in means between the treatment and control groups are small and, for most characteristics, not statistically different from zero.

4.4 Estimation strategy

The analysis is conducted at the fixture-location level. Each household was offered low-flow fixtures—kitchen faucets, bathroom faucets, and showerheads. As long as the household had a fixture location available, an attempt was made to install the low-flow fixtures. Figure 2 shows that most households had two or three fixture locations available.

We estimate the treatment effect using a two stage least squares regression that uses the randomly assigned bonus offer as an instrument for exposure. Figure 3 illustrates the estimation strategy with a causal graph. Exposure (the treatment) is defined here as *using the technology through the first audit*. Disadoption (the outcome) is defined as *uninstalling the technology by the second audit*. The first stage regression is $d_{ij} = \alpha_0 + \alpha_1 z_j + \alpha_2 c_k + u_{ij}$, and the second stage regression is $y_{ij} = \beta_0 + \beta_1 \hat{d}_{ij} + \beta_2 c_k + \epsilon_{ij}$, where z_j is an instrument equal to one if household j was offered a cash bonus and zero otherwise, c_k is a dummy variable for the k^{th} community (randomization was done within communities and thus community dummy variables are required for estimating standard errors appropriately, Bruhn and McKenzie

Figure 2: Success of initial installation

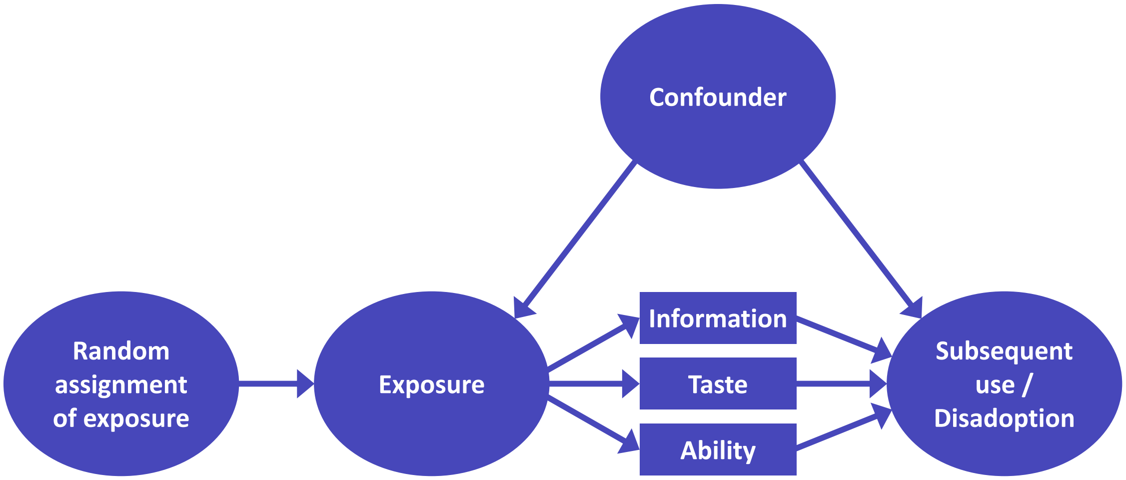


Note: Fixtures were installed in up to six locations: two kitchen faucets, two bathroom faucets, and two showerheads. Most households had between 1 and 3 fixture locations available and between 1 and 3 low-flow fixtures installed. Low-flow fixtures were installed in 89% of fixture locations available and in at least one fixture location in 99% of households.

(2009)), d_{ij} is a treatment indicator equal to one if the household had the technology in place at fixture location i during the 2015 audit and zero otherwise, $\hat{d}_{ij}$ is the predicted value of d_{ij} from the first stage, and y_{ij} is an outcome indicator equal to one if the household had the technology installed at the fixture location during the 2016 audit and zero otherwise.

The coefficient of interest is β_1, which is a complier average causal effect. This effect can be defined using the potential outcomes framework. A complier is a household's fixture location that is in use at the first (2015) audit (treated; $d_{ij} = 1$) if and only if the household was offered a bonus (assigned to the treatment group; $z_j = 1$). The complier average causal effect is the difference between the outcome if the complier fixture location were treated $(y_{ij}|d_{ij} = 1)$ and the outcome if the complier fixture location were untreated $(y_{ij}|d_{ij} = 0)$, where the outcome is subsequent use during the second (2016) audit. This interpretation requires a monotonicity assumption with regard to the randomized bonus, which we believe is a plausible assumption in this context (i.e., no defiers in the population).

Figure 3: Causal graph



Note: We estimate the causal effect of exposure on retention, using random assignment as an instrument for exposure. We posit that information, taste, and ability are the channels by which exposure affects retention.

5 Experimental results

In this section, we estimate the complier average causal effect of exposure to a resource-conserving technology on subsequent use of the technology.

Among households that were present in both audits, the cash bonus induced greater exposure in the treatment group than in the control group. Table 2 shows that, during the 2015 audit, the fraction of low-flow fixtures in use in bonus treatment households was 6.2 percentage points higher than in no-bonus control households—84.1% of low-flow fixtures were in use in the treatment group and 77.9% in the control group. The gap in use during the 2015 audit indicates correlation between the instrument (cash bonus) and the treatment (exposure).

A year after the cash bonus was no longer being offered, the treatment group was still using low-flow fixtures at a higher rate than the control group. Table 2 shows that during the 2016 audit the fraction of low-flow fixtures in use in bonus treatment households was 4.5 percentage points higher than in no-bonus control households—64.0% of low-flow fixtures

Table 2: Summary of results

	Low-flow fixtures in use					
	No-bonus control		Bonus treatment		Full sample	
	Count	%	Count	%	Count	%
Treatment assignment	829	100.0	937	100.0	1766	100.0
Installation	720	86.9	826	88.2	1546	87.5
2015 audit	646	77.9	788	84.1	1434	81.2
2016 audit	493	59.5	600	64.0	1093	61.9

Note: This table summarizes results for all fixture locations that remained in the sample for both audits.

were in use in the treatment group and 59.5% in the control group. The gap in use between the treatment and control groups during the 2016 audit is a measure of the intention-to-treat effect of the cash bonus.

Most of the gap during the first audit between the treatment and control groups persisted to the second audit. The gap during the 2016 audit (4.6 percentage points) was 74% as large as the gap during the 2015 audit (6.2 percentage points). If households that were successfully audited were representative of households that were assigned to treatment, then the fraction of the gap during the 2015 audit that persisted to the 2016 audit is an unbiased estimator of the treatment effect of exposure on subsequent use.

Column 2 of Table 3 reports the estimated complier average causal effect from the two-stage least squares regression estimator: 82%. If we were to use a simple OLS model instead to estimate the effect of exposure on disadoption (Col 1), we obtain a smaller estimated effect: 69%. We report the robust test for weak instruments proposed by Olea and Pflueger (2013) and implemented by Pflueger and Wang (2015). Because the randomized bonus could be viewed as a weak instrument, we also report Anderson-Rubin confidence sets that are robust to weak instruments (Anderson and Rubin 1949; Finlay, Magnusson, and Schaffer 2014).[5] The confidence set rules out a zero effect.

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[5] Our approach to instrument strength follows Andrews, Stock, and Sun (2019).

Table 3: Effect of exposure on subsequent use of low-flow fixtures, 2SLS estimates

	(1)	(2)	(3)	(4)	(5)
Exposure	0.680	0.816	0.257	2.623	0.868
	(0.019)	(0.320)	(0.115)	(0.959)	(0.327)
Observations	1,766	1,766	2,076	2,076	1,766
R-squared	0.340	0.328	0.190	-1.892	0.318
Mean of dep var	0.619	0.618	0.634	0.603	0.619
Imputation/weight			LB	UB	PW
MP F-stat		10.025	69.991	5.781	10.865
MP tau=20% CV		15.062	15.062	15.062	15.062
AR chi-squared		4.463	4.274	20.429	4.780
AR p-value		0.035	0.039	0.000	0.029
AR confidence set		[0.094,1.689]	[0.016,0.471]	[1.445,.]	[0.155,1.814]

Standard errors in parentheses

Note: This table presents estimates of the effect of exposure to low-flow fixtures in 2015 on continued use in 2016. Column 1 is a simple OLS estimation. Columns 2 to 5 present estimates of the complier average causal effect. Column 2 is the two-stage least squares estimator described in the text. Accounting for missing data, column 3 replicates column 2 using imputed values in order to calculate a lower bound estimate. For the 2015 audit, households with missing values assigned to the treatment group are assumed to be treated and households assigned to the control group are assumed to be untreated (widening the exposure gap). For the 2016 audit, households with missing values are assumed to be using the low-flow fixtures (narrowing the subsequent use gap). Column 4 replicates column 2 with imputed values to calculate an upper bound estimate: For the 2015 audit, households with missing values are assumed to be treated (narrowing the exposure gap). For the 2016 audit, households with missing values assigned to the treatment group are assumed to be using the low-flow fixtures, and households assigned to the control group are assumed not to be using the low-flow fixtures (widening the use gap). Column 5 weights observations according to the inverse probability of remaining in the sample, as estimated in Table 4 Column 4. Standard errors are clustered at the household level. The table reports Montiel-Pflueger effective F-statistics and critical values. An effective F-statistic below the critical value indicates a weak instrument. The table also reports Anderson-Rubin test statistics and confidence sets. The AR test is a joint test of the estimate (the effect of exposure) and the exogeneity of the instrument (treatment assignment) (Finlay, Magnusson, and Schaffer 2014). The AR confidence set is constructed by inverting the AR test such that values in the confidence set are values for which the null of the AR test would not be rejected.

Attrition from the sample was nontrivial and correlated with treatment assignment. Treatment and outcome data are present for 83.2% of households (see Appendix Table F.3). The remaining 16.8% of households were missing from one or both audits. Households that were offered a bonus were 8.5 percentage points more likely to be present for both audits than households not offered a bonus. Differential attrition by treatment assignment is a sign that attrition was nonrandom, and estimators that rely only on households that remain in the sample are potentially biased.

In the presence of attrition, estimating the treatment effect requires making untestable assumptions about unobserved households. If treatment and outcome data are missing at random, then estimators based on the subset of households that are fully observed are unbiased. However, if there is selective attrition—i.e. households with certain characteristics or behavior were more likely to be observed in audits—then estimators based on fully observed households are potentially biased.

We address attrition using two approaches: (1) bounding the treatment effect with conservative assumptions about selective attrition, and (2) applying regression weights based on the estimated probability that a household was present in both audits.

Bounding. To obtain a lower bound on the estimated treatment effect, we make the following imputation assumptions: (LB1) for fixture locations that were not observed in the 2015 audit, treatment status is equal to treatment assignment, i.e. a fixture location was in use if and only if the household was offered a cash bonus, and (LB2) all fixture locations that were not observed in the 2016 audit were in use. To obtain an upper bound on the estimated treatment effect, we make the following imputation assumptions: (UB1) all fixture locations that were not observed in the 2015 audit were in use, and (UB2) for fixture locations that were not observed in the 2016 audit, a fixture location was in use if and only if the household was assigned to the treatment group.

Column 3 of Table 3 shows that, under the lower bound assumptions, we can rule out a null effect of exposure on subsequent use. The effective F statistic exceeds the critical value by a wide margin, rejecting the null of weak instruments. Column 4 of Table 3 shows that, under the upper bound assumptions, the effective F statistic is below the critical value, indicating a weak instrument. In this context, a weak instrument is a consequence of the gap in exposure between the treatment group and the control group being relatively small.

Under the upper bound assumptions, the lower bound of the AR confidence set exceeds one, which we take as a signal that the upper bound assumptions are too weak.

One reason assumptions LB1 and UB1 are conservative is that households in the cash-bonus group were being paid if the technology was installed, so we would expect that there was positive selection into remaining in the sample in the cash-bonus group. In other words, we suspect that audit success was negatively correlated with disadoption in the cash-bonus group, but LB1 and UB1 imply that audit success was positively correlated with disadoption in the cash-bonus group.

Weighting. We apply inverse probability weights to the subset of fixture locations for which we observe both treatment and outcome data. This weighting approach to attrition requires stronger assumptions than were required in the bounding approach; namely, that missingness is random conditional on observable characteristics. The validity of this assumption is supported by the breadth of characteristics we observe and the fact that they have substantial explanatory power for predicting missingness.

Table 4 shows that households with more individuals, households occupied by their owners, and households with long tenure were more likely to remain in the sample. These three predictors are consistent with a story about who was likely to be physically present for an audit—households with more members, and households with longer and stronger connections in the community. Overall, households in the cash bonus treatment were less likely to attrite, which makes sense because they had a financial incentive to remain in the sample during the 2015 audit. Among households assigned to the cash bonus treatment, households in the top income quintile were more likely to attrite, which would be the case if higher income households are less responsive to the cash bonus or less likely to be at home because they have a job.

Under the assumption that missingness is random conditional on observable characteris-

Table 4: Regression estimates predicting fixture location attrition

	(1) Full sample	(2) No-bonus control	(3) Bonus treatment	(4) Full sample
Offered bonus	-0.068			-0.102
	(0.016)			(0.017)
# of individuals in household		-0.040	-0.040	-0.039
		(0.007)	(0.007)	(0.005)
Owns home		-0.070	-0.070	-0.070
		(0.033)	(0.028)	(0.022)
Years in home		-0.004	-0.004	-0.004
		(0.001)	(0.001)	(0.001)
Missing income range		-0.023	0.029	0.006
		(0.047)	(0.038)	(0.030)
Top income quintile		0.016	0.135	0.020
		(0.033)	(0.022)	(0.028)
Bonus X Top income quintile				0.142
				(0.038)
Observations	2,076	1,016	1,060	2,076
Pseudo R-squared	0.011	0.074	0.169	0.122
Mean of dep var	0.149	0.149	0.149	0.149

Standard errors in parentheses

Note: This table reports probit regressions that use treatment assignment and household characteristics to predict attrition. A household attrited if it was missing from the 2015 audit or the 2016 audit. Of 870 households in the sample, 152 attrited. Column 1 shows that treatment assignment predicts attrition. Columns 2 and 3 show that household characteristics predict attrition in the no-bonus control group and the bonus treatment group, respectively. Column 4 shows that treatment assignment retains predictive power after adjusting for household characteristics.

tics, we estimate a causal effect of exposure on subsequent use of 87%, reported in Column 5 of Table 3. The regression uses inverse probability weights based on predicted values from the regression in Column 4 of Table 4. The effective F statistic indicates a weak instrument, but the Anderson-Rubin confidence set nevertheless rules out a treatment effect of zero.

5.1 Rival Explanations

The experimental results are consistent with the claim that longer exposure to a technology can reduce the likelihood of disdoption. Yet, this conclusion relies on several auxiliary assumptions.

First, if bonus households had expected the AC3 team to offer a second bonus for continued use after the first audit, the excludability assumption (i.e., the exclusion restriction) could be violated and thus our two-stage estimator could be biased. At the first audit, however, the AC3 field team told each household (truthfully) that the project was over and the team would not be returning because the AC3 project was ending (the audit was conducted during the fourth month rather than a later month because of the imminent end of the project). We, the authors, self-financed the second audit twelve months later using a different field team because we saw the opportunity to use a second audit to test the exposure-disadoption hypothesis.

Second, in estimating the complier average causal effect, we assumed a household's potential disadoption by the second audit was independent of the treatment status of other households (i.e., no interference among units; stable unit treatment values). One potential violation of this assumption would be a type of peer effect that could arise if the no bonus households, having observed that some bonus households persisted in using the technologies, subsequently also persisted in using the technologies, which would reduce the estimated complier average causal effect (or some bonus households interfered with each other, which would increase the estimated complier causal effect). We have no way of determining if such peer effects existed, but Alpizar, Bernedo Del Carpio, and Ferraro (2023) reported that they found no spillovers from the technology group to the no-technology group in the form of households in the no-technology group adopting the technologies during the trial. Alpizar, Bernedo Del Carpio, and Ferraro (2023) also provide a engineering and hydrological explanation for why another source of interference is not plausible in this context: a form of interference that is mediated by the technology's effect on water availability in gravity-fed water systems.

Third, we assume that disadoption is driven by a change in perceived utility, as in the model in section 2, rather than through a mechanical, fixed depreciation process (e.g., 2% of fixtures are disadopted per month). If that assumption were incorrect, one could interpret our experimental results as implying not foregone disadoption (i.e., a persistent delay in disadoption) but rather a temporary delay in disadoption, after which the bonus and no-bonus groups use rates would converge sometime after our second audit. In our model, if a complier's perceived utility of using the technologies had not been affected by the longer exposure, the complier would immediately disadopt the technologies after receiving the bonus. The rival explanation that the bonus only yields a delay in disadoption requires a mechanical (non-utility-based) rate of disadoption, a process for which the behavioral underpinnings are hard to fathom.

Thus, in sum, the experiment provides evidence that exposure can mitigate disadoption, as predicted by the model in Section 2. The experiment, however, was not designed to decompose the complier average causal effect into its constituent mechanism effects and thus we cannot say whether one, two or three of the exposure-enhancing mechanisms are operative in our study context. In Appendix Section A, we use survey questions from household surveys to provide indirect, suggestive evidence that the information and taste mechanisms may have been operative.

6 Analytical results

Having demonstrated that increased exposure can reduce disadoption of a pro-social good, we next develop intuition about the conditions under which a policymaker would find it optimal to offer a limited duration subsidy aimed at enhancing exposure to the pro-social good. To develop the intuition, we build on the model introduced in Section 2.

Using the model, we contrast a limited duration subsidy with two more widely discussed subsidy options: a use subsidy offered in perpetuity conditional on use, and a purchase subsidy offered only at the time a good is initially acquired. We show that, when a social planner incurs administrative costs to operate the subsidy program and the pro-social good is subject to one or more exposure-enhancing mechanisms, a limited duration subsidy can be optimal. The administrative costs favor time-concentrated (front-loaded) subsidies to reduce the aggregate administrative costs, while the exposure-enhancing mechanisms favor time-dispersed subsidies to (a) give agents more opportunity to learn their match quality (information) and (b) give agents more opportunity to build up their stock of exposure (taste/ability). Under some conditions, these countervailing pressures will be best satisfied by a limited duration subsidy.

To show the conditions under which an exposure subsidy can be optimal, we focus here on a version of the model that includes administrative costs and the taste/ability mechanism but omits the information mechanism. Appendix D shows that similar results hold when the information mechanism is active rather than the taste/ability mechanism, as well as when there are no administrative costs of operating the subsidy program but other conditions that also favor time-concentrated subsidies exist, such as present bias or liquidity constraints.

In formal models, the ability and taste mechanisms are typically expressed the same way: using a good contributes to a stock of exposure, which subsequently raises marginal utility, raises marginal productivity, or reduces marginal cost. We mention them separately because they are conceptually distinct—ability to use a good can change without taste for the good changing, and vice versa— but the two mechanisms will be expressed isomorphically in the derivation of analytical results below.

Agents. There is a population of homogeneous agents of measure one that make decisions in discrete time. In each period t, an agent chooses whether to use a good to maximize its discounted stream of expected utility:

$$U_t = \max_{r_t \in \{0,1\}} \sum_{j=0}^{\infty} \delta^j u_{t+j} \tag{3}$$

where $r \in \{0,1\}$ is a discrete choice variable to either use the good or not, and $\delta \in (0,1)$ is the agent's time discount factor.[6]

For simplicity, we assume that the agent has a linear utility function in period t of the form:

$$u_t = u(r_t, S_t) = r_t\alpha_r + r_t S_t \alpha_{rS} + r_t\sigma_t - r_t p \mathbb{I}\Big[\forall j < 0 : r_{t+j} = 0\Big] \tag{4}$$

The term $S \geq 0$ is an exposure stock indicating taste or ability, and $\mathbb{I}$ is an indicator function equal to one if the bracketed argument is true and zero if it is false. The term $\alpha_r < 0$ is the utility from immediate use of the good. The assumption of negative utility is needed to focus the model on encouraging exposure as a means to reduce disadoption. If $\alpha_r > 0$, then a purchase subsidy is always sufficient to encourage permanent use irrespective of exposure. The term α_{rS} is the utility derived from the gradual accumulation of exposure, and $\sigma_t \in 0, \sigma$ is the subsidy set offered by the policymaker. The exposure stock evolves according to the law of motion in Equation 2, which we reproduce here:

$$S_{t+1} = (1-d)(S_t + r_t)$$

where $d \in (0,1)$ is a depreciation parameter.

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[6] The analytical results derived here are in the presence of administrative costs, which are formalized below when the social planner is introduced. Equation 3 can easily be adjusted to include present bias, as in Appendix Equation 19, or to include liquidity constraints, as in Appendix Equation 30.

If the agent does not use the good, then utility is zero. If the agent uses the good, then the agent derives utility from the net benefit of using the good (which could be negative) and from the subsidy. If the agent is using the good for the first time, then the agent also pays a price p.

Social planner. A social planner chooses a sequence of subsidies to maximize social welfare, which consists of the sum of the agent's utility and externalities net of subsidies and administrative costs. Each period the good is used, it generates a positive externality e. We assume that the sequence of subsidies is constrained to be some positive value σ for some number of periods k and, if k is finite, zero thereafter. In other words, the social planner can choose the subsidy level σ and duration k but cannot tailor the subsidy to be a different magnitude in each individual period. In each period that the subsidy is nonzero, the social planner incurs an administrative cost a. We note that $k = 1$ corresponds to a purchase subsidy, $k = \infty$ corresponds to a perpetual use subsidy, and $1 < k < \infty$ corresponds to an exposure subsidy.[7]

The social planner chooses the subsidy level and duration to maximize welfare:

$$\max_{\sigma,k} \quad \sum_{j=0}^{\infty} \delta^j (u_{t+j} + r_{t+j} e) - \sum_{j=0}^{k-1} \delta^j r_{t+j} (\sigma + a) \tag{5}$$

We assume that the social planner follows through on all promises made at the time the agent first uses the good, i.e. there are no obstacles to credibly committing to a subsidy level and duration.

Solution for the social planner. The social planner might choose to pay a subsidy σ to encourage the use of a good that generates a positive externality only if the price of the good is such that $p > p^*$, where p^* is defined as the highest price at which the agent would

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[7] In our model we define the purchase subsidy as having a duration of k=1 periods. We can reasonably argue that this is a purchase subsidy given that time is discrete in our model, and using the good for one period is akin to bringing the good to the place where it will be used after being acquired.

choose to use the good with zero subsidy:

$$p^* \equiv \Big(\frac{1}{1-\delta}\Big)\Big(\alpha_r + \alpha_{rS}\frac{1-d}{d}\Big) - \Big(\frac{1}{1-\delta(1-d)}\Big)\alpha_{rS}\Big(\frac{1-d}{d}\Big) \tag{6}$$

We now focus on the exposure stock S. S^* is the smallest exposure stock at which the agent would choose to continue using the good in perpetuity without a subsidy, after the price has been paid. In other words, once exposure has reached S^* the agent will choose not to disadopt the good, and the subsidy is not necessary. In the social planner's optimization, S^* is defined as:

$$S^* \equiv -\left(\frac{1-\delta(1-d)}{1-\delta}\right)\frac{\alpha_r}{\alpha_{rS}} - \left(\frac{\delta(1-d)}{1-\delta}\right) \tag{7}$$

The value of S^* and the speed at which exposure S accumulates will determine the duration of the subsidy. The threshold level of exposure (S^*) is decreasing in the return to exposure ($\frac{\partial S^*}{\partial \alpha_{rS}} < 0$), decreasing in the direct utility of the good ($\frac{\partial S^*}{\partial \alpha_r} < 0$), and increasing in the depreciation rate of exposure ($\frac{\partial S^*}{\partial d} > 0$). The sign of $\frac{\partial S^*}{\partial \delta}$ is ambiguous and depends on the relationship among the depreciation rate of exposure, the direct disutility, and the return to exposure. The sign of $\frac{\partial S^*}{\partial \delta}$ has the same sign as $d(1-\frac{\alpha_r}{\alpha_{rS}})-1$. Appendix Section B gives more details on comparative statics around the threshold level of exposure.

Next we present three propositions that describe sufficient conditions under which a purchase subsidy, a perpetual use subsidy, or an exposure subsidy are optimal.

Proposition 1. ***Conditions for the optimality of a purchase subsidy.*** *Given* $p > p^*$*, a purchase subsidy (*$k=1$*) with magnitude* $\sigma = \sum_{j=0}^{\infty}\delta^j e - a$ *is optimal if: (1)* $\sum_{j=0}^{\infty}\delta^j e > a$ *and (2)* $0 \geq S^*$*, where* p^* *and* S^* *are as defined above. Proof in appendix.*

In other words, a positive purchase subsidy is optimal if the present value of the positive externality exceeds the cost of administering the purchase subsidy (Condition (1)) and if either the accumulation of exposure reaches S^* instantaneously or exposure is not relevant to the decision (Condition (2), which, given that we defined $S \geq 0$ in equation (4), implies $S \geq 0 \geq S^*$).

Proposition 2. ***Conditions for the optimality of a perpetual use subsidy.*** *Given $p > p^*$, a perpetual use subsidy ($k = \infty$) of magnitude $\sigma = e - a$ is optimal if: (1) $e > a$ and (2) $\frac{1-d}{d} < S^*$, where p^* and S^* are as defined above. Proof in appendix.*

Condition (1) simply states that a perpetual use subsidy only makes sense if the value of the externality is above the administrative costs of paying the subsidy in every period. Condition (2) implies that the threshold of exposure S^* is not reachable because it is above the maximum possible stock of exposure. Therefore, in the absence of the subsidy, the agent will never choose to use the good.

Proposition 3. ***Conditions for the optimality of an exposure subsidy.*** *Given $p > p^*$, an exposure subsidy of magnitude σ^* and duration k^* is optimal if: (1) $\sum_{j=0}^{\infty} \delta^j e > \sum_{j=0}^{k^*-1} \delta^j(\sigma^* + a)$ and (2) $0 < S^* < \frac{1-d}{d}$, where p^* and S^* are as defined above and k^* and σ^* are defined as follows:*

$$k^* \equiv \mathit{ceiling}\bigg(\frac{\log(\frac{1-d}{d} - S^*) - \log(\frac{1-d}{d} - S_t)}{\log(1-d)}\bigg)$$

$$\sigma^* \equiv \Big(\frac{1-\delta}{1-\delta^{k^*}}\Big)p - \Big(\frac{1}{1-\delta^{k^*}}\Big)\alpha_r - \Big(\frac{1-d}{1-\delta^{k^*}}\Big)\Big(\frac{\delta}{1-\delta(1-d)}\Big)\alpha_{rS}$$

Proof in appendix.

The first condition states that the present value of the externality exceeds the cost of administering the subsidy for k^* periods. The second condition guarantees that the stock of exposure S^* is attainable.

The subsidy stops at k^*, after which the social planner no longer incurs the administrative cost. The value of k^* is determined by the exposure threshold S^* and the parameter that determines the speed at which the stock of exposure increases (d). The intuition underlying the expression for σ^* is the following:

- The first term is positive and reflects a share of the price of the good to be paid in each period. Focusing on this term only, we can say that the shorter duration of subsidized exposure (i.e. the shorter k^*), the larger the share of the price that needs to be paid each period. The larger the price, the larger the needed subsidy.
- The second term is positive (because direct utility α_r is negative). The larger the utility (i.e. smaller the disutility) from using the good directly the smaller the subsidy. Moreover, the shorter k^* the smaller the optimal subsidy.
- Finally, the third term is negative and depends on the share of utility that comes from exposure. The higher α_{rS}, the smaller the needed subsidy. Once again, the shorter k^*, the smaller the optimal subsidy.

All else equal, if exposure plays a negligible role in the utility derived from the good, then a purchase subsidy will be optimal. On the other hand, if exposure accumulates slowly, then a perpetual use subsidy will be optimal as the utility from increased exposure will not be sufficient to ensure perpetual use. Importantly, if exposure accumulates in a middle range, then an exposure subsidy will be optimal. Those implications are reflected in the second condition of each proposition, which describes the range of values of S^* for which the exposure subsidy is optimal. Similarly, each proposition states the need to ensure that the present value of the externality is larger than the present value of the administrative costs, as otherwise society will be incurring a loss by paying the subsidy. Finally, the actual size of the exposure subsidy will depend on the duration of the subsidy, the disutility from using the good ($\frac{\partial u}{\partial \alpha_r} < 0$), and the indirect utility that comes from exposure ($\frac{\partial u}{\partial \alpha_{rS}} > 0$).

Appendix D presents versions of the model with different combinations of one exposure-enhancing mechanism and any of the conditions that favor time-concentrated subsidies—administrative costs, present bias, and liquidity constraints. These derivations show that exposure subsidies can be optimal in these conditions. As in the model above, when only the taste/ability mechanism is operative, intermediate values of key parameters yield opportunities for an exposure subsidy to be optimal. In contrast, when the information mechanism is present, exposure subsidies are almost always optimal —in that case the social planner should subsidize the good as long as the marginal social gain from doing so (i.e. helping incremental agents with high match quality learn that they have high match quality) exceeds the marginal social cost from doing so (i.e. "wasting" administrative resources on agents who already know their match quality).

Note that the cash bonus in the experiment of Section 4 was designed to generate exogenous variation in exposure, not to be an optimal exposure subsidy or even welfare-enhancing. Appendix Section E conducts a retrospective policy analysis and concludes that recruiting additional households (by offering a "purchase subsidy" in the form of free low-flow fixtures and free installation) would have been a better strategy in this context than subsidizing exposure at the specific level of the cash bonus offered in the experiment. Future experiments could vary the bonus to ascertain what bonus level would be optimal.

7 Conclusion

Through a model that unifies concepts from several branches of the economics literature and a field experiment that exogenously manipulates the duration of technology use, we show that longer exposure to a technology can raise the perceived net benefits from continued use of the technology, thereby reducing disadoption. Building on those results, we show the conditions under which exposure subsidies, which are offered over a finite period, can be preferred to more popular one-time purchase (adoption) subsidies or perpetual use subsidies.

Our results suggest that incentivizing exposure is a promising avenue for mitigating the disadoption of pro-social goods. Nevertheless, our experiment only provides a proof of principle and our theoretical model only builds intuition about the optimal duration of subsidies. For field applications, more research in disparate contexts will be needed to characterize the prevalence and strength of exposure-enhancing mechanisms and the optimal subsidy magnitudes and durations. To help contribute to that goal, policymakers in the health, development, and environment fields can experiment with different subsidy strategies that incentivize exposure rather than initial adoption or perpetual use.

Although disadoption of pro-social goods occurs in diverse contexts, overcoming disadoption seems to be especially relevant for technologies promoted in developing economies. In addition to the administrative costs and liquidity constraints that we model, state capacity constraints and political constraints frequently make perpetual use subsidies impossible to implement, and as a result technologies are not utilized optimally. Low-capacity states and NGOs may have an easier time implementing exposure subsidies precisely because they are short lived. Our analytical and theoretical results show that exposure subsidies may be able to achieve the same behavior change as perpetual use subsidies.

Data availability statement

The data and code underlying this research is available at `https://osf.io/faw8d/`.

Declaration of competing interest

The authors do not have competing interests to declare.

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Appendix A Evidence of the exposure-enhancing mechanisms in the experiment (for online publication)

This section explores which of the three mechanisms in the model were active in the field experiment. The water billing data and the survey data support the activation of an information mechanism and a taste mechanism, but we find no evidence to support the activation of an ability mechanism.

Information. On average, the low-flow fixtures saved households money. Making use of the bonus group, the no-bonus group, and also the no-technology group, Appendix Figure G.1 shows that households with the technology had monthly bills on average around 6% lower than households without the technology (around 450 CRC off of 7400 CRC).

Households that used the technology for longer had more of an opportunity to learn about match quality—how much money the technology was saving them specifically in practice. All else equal, we would expect households with the highest match quality—saving the most money—to be the most likely to continue using the technology. Table A.1 shows two survey responses that indicate that households in the bonus group with high match quality were more aware of saving money than households in the no-bonus group with high match quality. First, during the 2015 audit, households in the bonus group were 10 percentage points more likely than households in the no-bonus group to mention saving money as a motive for continuing to use the technology. Second, during the 2016 audit, households in both groups guessed how much they had saved, and guesses in the bonus group were around 300 CRC per month more on average than guesses in the no-bonus group. Both of these differences between the bonus group and the no-bonus group would be expected if more of the households with high match quality in the bonus group realized they were saving money because they had kept the technology in use for longer in order to obtain the bonus.

Taste. After 16 months, households in the bonus group had developed a stronger pref-

Table A.1: Survey evidence of exposure-enhancing mechanisms by treatment assignment

Variable	(1) No-bonus control	(2) Bonus treatment	(3) Difference
Information			
Plan to keep because saving money, 2015 audit	0.31	0.42	0.10
	(0.46)	(0.49)	(0.04)
Estimated savings, CRC per month, 2016 audit	1427.08	1714.83	287.75
	(1324.15)	(1372.49)	(109.10)
Taste			
Prefer bathroom faucet jet with less water	0.92	0.94	0.02
	(0.28)	(0.24)	(0.03)
Prefer kitchen faucet jet with less water	0.81	0.90	0.09
	(0.39)	(0.31)	(0.04)
Prefer showerhead jet with less water	0.68	0.83	0.15
	(0.47)	(0.38)	(0.04)
Ability			
Removed bathroom aerator because low flow requires more time	0.02	0.00	-0.01
	(0.14)	(0.07)	(0.01)
Removed kitchen aerator because low flow requires more time	0.05	0.03	-0.03
	(0.22)	(0.16)	(0.02)
Removed showerhead because low flow requires more time	0.06	0.03	-0.03
	(0.23)	(0.17)	(0.01)
Removed bathroom aerator because broken or clogged	0.09	0.08	-0.01
	(0.29)	(0.27)	(0.03)
Removed kitchen aerator because broken or clogged	0.21	0.24	0.03
	(0.40)	(0.44)	(0.03)
Removed showerhead because broken or clogged	0.18	0.16	-0.02
	(0.39)	(0.38)	(0.03)
Observations	432	438	870

Standard errors in parentheses

Note: The statistics for "Prefer bathroom faucet/kitchen faucet/showerhead jet with less water" are calculated as a fraction of households that expressed a positive or negative preference. The questions that we interpret as being about taste were specifically about the feeling of the water, not a general preference for the presence or absence of the fixture—the survey question used the Spanish word "chorro," meaning jet or stream. The reasons for removal statistics are calculated as a fraction of households that ever had the technology installed.

erence for low-flow fixtures than households in the no-bonus group. Households were asked during the 2016 audit whether they preferred the jet of the water with or without the new technology. Among households that expressed a preference either for or against the low-flow showerhead, households in the bonus group were 15 percentage points more likely than households in the no-bonus group to prefer the lower flow. Among households that expressed a preference either for or against the low-flow kitchen faucet, households in the bonus group were 9 percentage points more likely than households in the no-bonus group to prefer the lower flow. Preferences for the low-flow bathroom faucet were similar across treatments.

Ability. We investigate two possible ways in which households may have become better at using the technologies, and we do not find evidence for either one. First, water fixtures accumulate muck over time, especially in this region of Costa Rica, and households may have been motivated by the cash bonus to learn how to clean out the muck more efficiently. If it were the case that households got better at cleaning out muck, then we would expect to see fewer fixture removals in the bonus group for the stated reason that the fixture was "broken" or "clogged". Table A.1 shows that those reasons were given a bit less frequently in the bonus group, but not enough to rule out sampling variability as the source of the difference.

Second, some tasks require a fixed volume of water, like filling a one-gallon jug. Households may have been motivated by the cash bonus to find ways around the low-flow fixtures for those tasks, such as using an alternative spigot. If it were the case that households found ways around the low-flow fixtures for fixed-volume tasks, then we would expect to see fewer fixture removals in the bonus group for the stated reason that "low flow requires more time". Table A.1 shows that the frequency of that reason was similar in the bonus group and the no-bonus group.

Appendix B Comparative statics with exposure threshold (for online publication)

This section elaborates on comparative statics around the threshold level of exposure S^* introduced in Section 6. Recall that:

$$S^* \equiv -\Big(\frac{1-\delta(1-d)}{1-\delta}\Big)\frac{\alpha_r}{\alpha_{rS}} - \Big(\frac{\delta(1-d)}{1-\delta}\Big)$$

A larger return to exposure α_{rS} reduces the exposure threshold S^*:

$$\frac{\partial S^*}{\partial \alpha_{rS}} = \underbrace{\Big(\frac{1-\delta(1-d)}{1-\delta}\Big)}_{(+)} \underbrace{\alpha_r}_{(-)} \underbrace{\alpha_{rS}^{-2}}_{(+)} < 0 \tag{8}$$

The smaller in magnitude the direct disutility α_r (i.e. as this negative parameter increases), the lower the exposure threshold S^*:

$$\frac{\partial S^*}{\partial \alpha_r} = -\Big(\frac{1-\delta(1-d)}{1-\delta}\Big)\frac{1}{\alpha_{rS}} < 0 \tag{9}$$

The higher the depreciation of exposure stock d, the higher the exposure threshold:

$$\frac{\partial S^*}{\partial d} = \Big(\frac{\delta}{1-\delta}\Big)\Big(1-\frac{\alpha_r}{\alpha_{rS}}\Big) > 0 \tag{10}$$

The sign of $\frac{\partial S^*}{\partial \delta}$ depends on the relationship among the depreciation rate of exposure, the direct disutility, and the return to exposure. If $d(1-\frac{\alpha_r}{\alpha_{rS}}) > 1$, then the derivative is positive:

$$\frac{\partial S^*}{\partial \delta} = \Big(\frac{d(1-\frac{\alpha_r}{\alpha_{rS}})-1}{(1-\delta)^2}\Big) \tag{11}$$

In other words, if direct disutility is large relative to the return to exposure, then the amount of required exposure is higher when the future is valued more highly. If direct disutility is low relative to the return to exposure, then the amount of required exposure is lower when the future is valued more highly.

Appendix C Proofs of propositions in the main text (for online publication)

We start with a lemma for a convenient expression of the exposure stock (through which the taste and ability mechanisms operate):

Lemma 1. Exposure stock. If the agent uses the good between period t and period $t+j$, then the exposure stock at time $t+j$ can be expressed as:

$$S_{t+j} = (1-d)^j\Big(S_t - \frac{1-d}{d}\Big) + \frac{1-d}{d}$$

Proof.

$$\begin{aligned}
S_{t+1} = &\quad (1-d)(S_t+1) \\
S_{t+2} = &\quad (1-d)^2 S_t + (1-d)^2 + (1-d) \\
S_{t+j} = &\quad (1-d)^j S_t + \sum_{m=1}^{j}(1-d)^m \\
S_{t+j} = &\quad (1-d)^j S_t + \frac{1-(1-d)^j}{1-(1-d)}(1-d) \\
S_{t+j} = &\quad (1-d)^j\Big(S_t - \frac{1-d}{d}\Big) + \frac{1-d}{d} \quad \square
\end{aligned}$$

Next, we derive the minimum number of periods of use required to attain a particular target exposure stock.

Lemma 2. Duration. If the exposure stock is S_t in period t, the agent is using the good in each period, and $\frac{1-d}{d} \geq \hat{S} \geq S_t$, then the minimum number of periods required to attain an exposure stock at least as large as $\hat{S}$ is $\hat{k}$, where:

$$\hat{k} = \quad \text{ceiling}\bigg(\frac{\log(\frac{1-d}{d} - \hat{S}) - \log(\frac{1-d}{d} - S_t)}{\log(1-d)}\bigg)$$

Proof.

$$\begin{aligned}
S_{t+j} &= (1-d)^j \left(S_t - \frac{1-d}{d}\right) + \frac{1-d}{d} \\
\hat{S} &= (1-d)^{\tilde{k}} (S_t - \frac{1-d}{d}) + \frac{1-d}{d} \\
(1-d)^{\tilde{k}} (\frac{1-d}{d} - S_t) &= \frac{1-d}{d} - \hat{S} \\
\tilde{k} \log(1-d) + \log(\frac{1-d}{d} - S_t) &= \log(\frac{1-d}{d} - \hat{S}) \\
\tilde{k} &= \frac{\log(\frac{1-d}{d} - \hat{S}) - \log(\frac{1-d}{d} - S_t)}{\log(1-d)} \\
\hat{k} &= \text{ceiling}\left(\frac{\log(\frac{1-d}{d} - \hat{S}) - \log(\frac{1-d}{d} - S_t)}{\log(1-d)}\right)
\end{aligned}$$

The first line is from Lemma 1. The last step occurs because we must round up in discrete time. □

Next, we show that, in the model presented in Section 6, subsidy policies that result in disadoption are not optimal.

Lemma 3. Disadoption. Policies that result in disadoption are not optimal.

Proof. Proof is by contradiction. Assume that (σ, k) is optimal and that it results in disadoption (so k is finite). If the policy is optimal, then $e > \sigma + a$. (If that were not true then a policy with subsidy equal to zero would be better.) Furthermore, extending the subsidy by one day would result in use for one more day with positive net welfare because period utility is increasing in the exposure stock and $e > \sigma + a$. So a policy of $(\sigma, k+1)$ is strictly better than (σ, k). That contradicts the assumption that (σ, k) is optimal. □

Lemma 4. Experience threshold. If the purchase price has already been paid and there is no subsidy, then the agent chooses to use the good in all subsequent periods if and only if $S_t \geq S^*$, where:

$$S^* = -\Big(\frac{1-\delta(1-d)}{1-\delta}\Big)\frac{\alpha_r}{\alpha_{rS}} - \Big(\frac{\delta(1-d)}{1-\delta}\Big)$$

Proof. Following equations 3 and 4:

$$\begin{aligned}
U\Big(S_t\Big) &= \max_{r_t} \sum_{j=0}^{\infty} \delta^j \Big(\alpha_r r_{t+j} + \alpha_{rS} r_{t+j} S_{t+j} + \sigma_{t+j} r_{t+j}\Big) \\
&= \max_{r_t} \sum_{j=0}^{\infty} \delta^j \Big(\alpha_r r_{t+j} + \alpha_{rS} r_{t+j} \Big((1-d)^j \Big(S_t - \frac{1-d}{d}\Big) + \frac{1-d}{d}\Big)\Big) \\
&= \max_{r_t} \sum_{j=0}^{\infty} \delta^j r_{t+j} (\alpha_r + \alpha_{rS} \Big((1-d)^j \Big(S_t - \frac{1-d}{d}\Big) + \frac{1-d}{d}\Big)) \\
&= \max \Big\{ \Big(\frac{1}{1-\delta}\Big)\Big(\alpha_r + \alpha_{rS}\frac{1-d}{d}\Big) + \Big(\frac{1}{1-\delta(1-d)}\Big)\alpha_{rS}\Big(S_t - \frac{1-d}{d}\Big), 0 \Big\}
\end{aligned}$$

The substitution for S_{t+j} follows from lemma 1. The subsidy substitution follows from the assumption that there is no subsidy. Using the good in one period implies the exposure stock will be larger in the next period, $r_t = 1 \implies S_{t+1} \geq S_t$. The period utility function is increasing in the exposure stock, so if the good is used in one period then it will also be used in the next period. To find the exposure threshold, we set the utility of using the good equal to the utility of not using the good.

$$\begin{aligned}
0 = &\quad \Big(\frac{1}{1-\delta}\Big)\Big(\alpha_r + \alpha_{rS}\frac{1-d}{d}\Big) + \Big(\frac{1}{1-\delta(1-d)}\Big)\alpha_{rS}\Big(S^* - \frac{1-d}{d}\Big) \\
S^* - \frac{1-d}{d} = &\quad -\Big(\frac{1-\delta(1-d)}{1-\delta}\Big)\Big(\frac{\alpha_r}{\alpha_{rS}} + \frac{1-d}{d}\Big) \\
S^* = &\quad -\Big(\frac{1-\delta(1-d)}{1-\delta}\Big)\frac{\alpha_r}{\alpha_{rS}} - \frac{1-d}{d}\Big(\frac{1-\delta+\delta d}{1-\delta} - \frac{1-\delta}{1-\delta}\Big) \\
S^* = &\quad -\Big(\frac{1-\delta(1-d)}{1-\delta}\Big)\frac{\alpha_r}{\alpha_{rS}} - \Big(\frac{\delta(1-d)}{1-\delta}\Big) \quad \square
\end{aligned}$$

Building on these lemmas, we prove Proposition 1:

Proposition 1. Purchase subsidy. A purchase subsidy with $\sigma = \sum_{j=0}^{\infty} \delta^j e - a$ and $k = 1$ is optimal if: (1) $p > p^*$, (2) $0 \geq S^*$, and (3) $\sum_{j=0}^{\infty} \delta^j e > a$, where p^* and S^* are defined as follows:

$$p^* \equiv \Big(\frac{1}{1-\delta}\Big)\Big(\alpha_r + \alpha_{rS}\frac{1-d}{d}\Big) - \Big(\frac{1}{1-\delta(1-d)}\Big)\alpha_{rS}\Big(\frac{1-d}{d}\Big)$$

$$S^* \equiv -\Big(\frac{1-\delta(1-d)}{1-\delta}\Big)\frac{\alpha_r}{\alpha_{rS}} - \Big(\frac{\delta(1-d)}{1-\delta}\Big)$$

Proof. Using the good in one period implies the exposure stock will be larger in the next period, $r_t = 1 \implies S_{t+1} \geq S_t$. The period utility function is increasing in the exposure stock, so if the good is used in one period then an agent would only choose to disadopt (use the good in period t but not in period $t+1$) if the subsidy is removed. Following equations 3 and 4:

$$\begin{aligned} U_t(\sigma, k) &= \max_{r_t \in \{0,1\}} \quad -r_t p + \sum_{j=0}^{\infty} \delta^j (r_{t+j}\alpha_r + r_{t+j}S_{t+j}\alpha_{rS}) + \sum_{j=0}^{k-1} \delta^j r_{t+j}\sigma \\ &= \max \Bigg\{ \underbrace{-p + \Big(\frac{1-\delta^k}{1-\delta}\Big)\Big(\alpha_r + \alpha_{rS}\frac{1-d}{d} + \sigma\Big) - \Big(\frac{1-\delta^k(1-d)^k}{1-\delta(1-d)}\Big)\alpha_{rS}\Big(\frac{1-d}{d}\Big)}_{r_{t+j}=1 \text{ for } j<k \text{ and } r_{t+j}=0 \text{ for } j\geq k}, \\ &\qquad \underbrace{-p + \Big(\frac{1}{1-\delta}\Big)\Big(\alpha_r + \alpha_{rS}\frac{1-d}{d}\Big) - \Big(\frac{1}{1-\delta(1-d)}\Big)\alpha_{rS}\Big(\frac{1-d}{d}\Big) + \Big(\frac{1-\delta^k}{1-\delta}\Big)\sigma}_{r_{t+j}=1 \text{ for } j\geq 0}, \\ &\qquad \underbrace{0}_{r_{t+j}=0 \text{ for } j\geq 0} \Bigg\} \end{aligned}$$

There are three possibilities: (1) the agent may use the good forever (perpetual use), (2) the agent may use the good until the subsidy is removed (disadoption), or (3) the agent may decline to use the good (non-adoption). By Lemma 3, the optimal policy will result in either perpetual use or non-adoption. In order to prove that $\sigma = \sum_{j=0}^{\infty} \delta^j e - a$ and $k = 1$ is optimal, we will show that (a) the subsidy achieves perpetual use if and only if perpetual use is socially optimal, and (b) perpetual use cannot be achieved at lower cost.

First, we show that if the subsidy achieves perpetual use, then it is socially optimal. Then from the agent's problem we know that:

$$0 < -p + \left(\frac{1}{1-\delta}\right)\left(\alpha_r + \alpha_{rS}\frac{1-d}{d}\right) - \left(\frac{1}{1-\delta(1-d)}\right)\alpha_{rS}\left(\frac{1-d}{d}\right) + \sum_{j=0}^{\infty}\delta^j e - a$$

This is exactly the condition that implies that perpetual use is socially optimal.

Next, we show that if perpetual use is socially optimal, then the subsidy achieves perpetual use. By assumption, $0 \geq S^*$. That means that if the purchase price were paid (i.e. the agent used the good for at least one period), then the choice problem would be equivalent to the conditions in Lemma 4, and the subsidy achieves perpetual use. Furthermore, the condition from the agent's problem above, which is an implication of perpetual use being socially optimal, shows that the agent would also use the good in the first period. So we have shown that the subsidy achieves perpetual use if and only if perpetual use is socially optimal.

To show perpetual use cannot be achieved at lower cost, we note that, by assumption, $p > p^*$. Applying that condition to the agent's problem, we see that the agent is not willing to purchase the good without a subsidy, so perpetual use cannot be achieved in fewer periods than $k = 1$. From the perspective of a social planner, one period of subsidy minimizes administrative costs. To the extent that the subsidy magnitude $\sigma = \sum_{j=0}^{\infty}\delta^j e - a$ exceeds the minimum required for perpetual use, it is a transfer to the agent, not a social loss. So we have shown (b). □

Next we prove Proposition 2:

Proposition 2. **Use subsidy.** A use subsidy with $\sigma = e - a$ and $k = \infty$ is optimal if: (1) $p > p^*$, (2) $\frac{1-d}{d} < S^*$, and (3) $e > a$, where p^* and S^* are as defined in Proposition 1.

Proof. By assumption, $p > p^*$. Applying that condition to the agent's problem, we see that the agent is not willing to purchase the good without a subsidy. By assumption, $\frac{1-d}{d} < S^*$. The largest possible value for the exposure stock is $\frac{1-d}{d}$, so this assumption implies that perpetual use cannot be achieved with a subsidy of finite duration. By assumption, $e > a$. A subsidy of $\sigma = e - a$ is a Pigouvian perpetual use subsidy adjusted for administrative costs. If it induces use initially, then it will induce perpetual use. If it induces perpetual use then the net private cost is at least zero, and the externalities net of administrative costs have been internalized by the agent by setting the subsidy to exactly $\sigma = e - a$. This subsidy is no worse than a zero subsidy (if it results in non-adoption), better than any subsidy of finite duration (by Lemma 3), and possibly better than a zero subsidy (if it results in perpetual use). It is in the set of best possible policies, but possibly not unique (if it results in non-adoption). $\square$

Next we prove Proposition 3:

Proposition 3. Exposure subsidy. An exposure subsidy with $\sigma = \sigma^*$ and $k = k^*$ is optimal if: (1) $p > p^*$, (2) $0 < S^* < \frac{1-d}{d}$, and (3) $\sum_{j=0}^{\infty} \delta^j e > \sum_{j=0}^{k^*-1} \delta^j (\sigma^* + a)$, where p^* and S^* are as defined in Proposition 1 and k^* and σ^* are defined as follows:

$$k^* \equiv \text{ceiling}\left(\frac{\log(\frac{1-d}{d} - S^*) - \log(\frac{1-d}{d} - S_t)}{\log(1-d)} \right)$$

$$\sigma^* \equiv \left(\frac{1-\delta}{1-\delta^{k^*}} \right) p - \left(\frac{1}{1-\delta^{k^*}} \right) \alpha_r - \left(\frac{1-d}{1-\delta^{k^*}} \right) \left(\frac{\delta}{1-\delta(1-d)} \right) \alpha_{rS}$$

Proof. In order to prove that $\sigma = \sigma^*$ and $k = k^*$ is optimal, we will show that (a) it achieves perpetual use, (b) perpetual use cannot be achieved at lower cost, and (c) perpetual use is better than non-adoption.

By assumption, $0 < S^* < \frac{1-d}{d}$. That means there is some exposure stock greater than zero that is attainable in a finite number of periods at which the agent would choose to continue using the good without a subsidy.

By assumption, $p > p^*$. Applying that condition to the agent's problem, we see that the agent is not willing to purchase the good without a subsidy. By Lemma 2, k^* is the minimum number of periods required to attain an exposure stock of at least S^*. So among all possible nonzero subsidy policies, perpetual use cannot be achieved at lower administrative cost.

We consider whether an exposure subsidy with $\sigma = \sigma^*$ and $k = k^*$ achieves perpetual use. Using the agent's indifference condition between perpetual use and nonadoption (written out in the proof for Proposition 1), we see that σ^* is the minimum subsidy required to achieve perpetual use when $k = k^*$. Thus, this policy achieves perpetual use.

Because σ^* is chosen such that the discounted stream of utility is exactly zero, the externality generated by perpetual use must exceed both the administrative cost of the subsidy (a) and the direct cost of the subsidy (σ^*), which is true by assumption: $\sum_{j=0}^{\infty} \delta^j e > \sum_{j=0}^{k^*-1} \delta^j (\sigma^* + a)$. $\square$

Appendix D Additional analytical results (for online publication)

We consider versions of the model with each possible combination of time-concentrating feature (administrative costs, present bias, or liquidity constraints) and an exposure-enhancing mechanism (information or taste/ability). The main text presents analytical results for the model with administrative costs and the taste/ability mechanism. The other five combinations are presented in this appendix.

We present the models with one time-concentrating feature and one exposure-enhancing mechanism at a time for simplicity. There is no reason to think there would be a negative interaction among the time-concentrating features or exposure-enhancing mechanisms if they were present simultaneously. In other words, if an exposure subsidy can be optimal in these simple versions of the model, then an exposure subsidy can also be optimal with multiple time-concentrating features or exposure-enhancing mechanisms.

D.1 Model with administrative costs and information mechanism

Intuition. With administrative costs and the information mechanism, the social planner chooses the subsidy duration k such that the net marginal welfare impact of subsidizing the good for one additional period would be approximately zero. The positive component of the welfare impact of subsidizing the good for one additional period is that more agents with high match quality learn that they have high match quality, and therefore they continue using the good and continue generating the positive externality after the subsidy is no longer offered. The negative component of the welfare impact includes both (i) the administrative cost and (ii) the social cost of subsidizing agents with low match quality. The social planner chooses the subsidy level σ that minimally induces an agent with unknown match quality to try the good.

One additional period of subsidy has a diminishing benefit (because there are fewer uninformed agents with high match quality remaining) and a constant or diminishing cost (depending on whether agents with low match quality continue using the subsidized good after they learn that they have low match quality). A perpetual use subsidy with the same present value as an exposure subsidy chosen this way would incur larger administrative costs and subsidize more agents with low match quality. A purchase subsidy with the same present value would induce fewer agents with high match quality to learn their types and would miss out on the positive externality that those agents would have generated.

Agents. There is a population of agents of measure one. Each agent chooses in each period whether or not to use a good to maximize the discounted stream of expected utility. If the agent does not use the good, then utility is zero. If the agent uses the good, then the agent derives utility from the direct net benefit of using the good (which could be negative) and from a subsidy σ set by a policymaker. If the agent is using the good for the first time, then the agent also pays a price p. The discounted stream of expected utility in period t is:

$$U_t = \max_{r_t \in \{0,1\}} \sum_{j=0}^{\infty} \delta^j \int_{-\infty}^{\infty} u_{t+j} \;\, dF_t(\theta) \tag{12}$$

where $r \in \{0, 1\}$ is a discrete choice to either use the good or not and $\delta \in (0, 1)$ is the agent's time discount factor.

Utility in period t takes the form:

$$u_t = u(r_t, \theta_i) = r_t\alpha_r + r_t\theta_i\alpha_{r\theta} + r_t\sigma_t - r_t p \;\, \mathbb{I}\Big[\forall j < 0 : r_{t+j} = 0\Big] \tag{13}$$

where θ is match quality and $\mathbb{I}$ is an indicator function equal to one if the argument is true and zero if it is false. The population comprises agents with low and high match quality between the agent and the good. We assume that a fraction q of agents have low match quality, and $1 - q$ have high match quality, such that the population distribution of match quality can be expressed with the following probability mass function f with $q \in (0, 1)$:

$$f(\theta) = \begin{cases} q & \text{if } \theta = 0 \\ 1 - q & \text{if } \theta = 1 \end{cases} \tag{14}$$

We assume the signal is either fully informative or totally uninformative, such that the distribution of signals can be expressed with the following probability mass function g with $\gamma \in (0, 1)$:

$$g(\omega_t|\theta_i) = \begin{cases} \gamma & \text{if } \omega_t = -1 \\ 1 - \gamma & \text{if } \omega_t = \theta_i \end{cases} \tag{15}$$

Social planner. A social planner chooses a sequence of subsidies to maximize social welfare, which consists of the sum of all agents' utility and externalities net of subsidies and administrative costs. Each period the good is used, it generates a positive externality e. We assume the sequence of subsidies is constrained to be some positive value σ for some number of periods k and, if k is finite, zero thereafter. In other words, the social planner can choose the subsidy level σ and duration k but cannot tailor the subsidy to be a different magnitude in each individual period. In each period that the subsidy is nonzero, the social planner incurs an administrative cost a. The social planner thus chooses the subsidy level and duration to maximize welfare:

$$\max_{\sigma,k} \quad \sum_{j=0}^{\infty} \delta^j \int_{-\infty}^{\infty} (u_{t+j} + r_{t+j}e) dF_t(\theta) - \sum_{j=0}^{k-1} \delta^j r_{t+j}(\sigma + a) \tag{16}$$

where F is the cumulative distribution function corresponding to f.

We assume that the social planner follows through on all promises made at the time the agent first uses the good, i.e. there are no obstacles to credibly committing to a subsidy level and duration.

We assume:

- The net private benefit to an agent who knows she has high match quality is positive: $\alpha_r + \alpha_{r\theta} > 0$
- The net social benefit for an agent with low match quality is negative: $\alpha_r + e < 0$
- The net private benefit to an agent who does not know her match quality is negative:[8] $\alpha_r + \alpha_{r\theta}(1-q) + (1-q)(1-\gamma)\frac{\delta}{1-\delta}(\alpha_r + \alpha_{r\theta}) < 0$
- The net social benefit for an agent who does not know her match quality is positive: $\alpha_r + \alpha_{r\theta}(1-q) + e + (1-q)(1-\gamma)\frac{\delta}{1-\delta}(\alpha_r + \alpha_{r\theta} + e) > 0$

Solution for the agents. If $k = 1$ and $p = 0$, then expected utility at time t is:

$$\begin{aligned} U_t(\sigma, k) &= \max_{r_t \in \{0,1\}} \; r_t\sigma + \sum_{j=0}^{\infty} \delta^j \int_{-\infty}^{\infty} (r_{t+j}\alpha_r + r_{t+j}\theta_i\alpha_{r\theta}) dF_t(\theta) \\ &= \max \left\{ \alpha_r + \alpha_{r\theta}(1-q) + \sigma + (1-q)(1-\gamma)\frac{\delta}{1-\delta}(\alpha_r + \alpha_{r\theta}), 0 \right\} \end{aligned}$$

Pooling equilibrium. Define $\hat{\sigma}$ as the minimum subsidy such that an agent who knows she has low match quality chooses to use the good when $k = 1$ and $p = 0$: $\hat{\sigma} = -\alpha_r$. If the agent has not previously used the good (i.e. the price p must be paid) and $\sigma \geq \hat{\sigma}$ (i.e. an agent who knows she has low match quality behaves the same way as an agent with unknown

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[8] If this assumption does not hold, then the agent would try the good on her own, and a subsidy would not be necessary.

match quality), then expected utility at time t is:

$$
\begin{aligned}
U_t(\sigma,k) &= \max_{r_t\in\{0,1\}} \quad -r_t p + \sum_{j=0}^{\infty}\delta^j \int_{-\infty}^{\infty}(r_{t+j}\alpha_r + r_{t+j}\theta_i\alpha_{r\theta})dF_t(\theta) + \sum_{j=0}^{k-1}\delta^j r_{t+j}\sigma \\
&= \max\Bigg\{0, \quad -p + \frac{1-\delta^k}{1-\delta}\Big(\alpha_r + (1-q)\alpha_{r\theta} + \sigma\Big) \\
&\qquad + (1-q)(1-\gamma^k)\frac{\delta^k}{1-\delta}\Big(\alpha_r + \alpha_{r\theta}\Big)\Bigg\}
\end{aligned}
$$

Separating equilibrium. Define $\tilde{\sigma}$ as the minimum subsidy such that an uninformed agent chooses to use the good when $k = 1$ and $p = 0$:

$$
\tilde{\sigma} = -\alpha_r - \alpha_{r\theta}(1-q) - (1-q)(1-\gamma)\frac{\delta}{1-\delta}(\alpha_r + \alpha_{r\theta})
$$

If the agent has not previously used the good (i.e. the price p must be paid) and $\tilde{\sigma} < \sigma < \hat{\sigma}$ (i.e. an agent who knows she has low match quality behaves differently from an agent with unknown match quality), then expected utility at time t is:

$$
\begin{aligned}
U_t(\sigma,k) &= \max_{r_t\in\{0,1\}} \quad -r_t p + \sum_{j=0}^{\infty}\delta^j \int_{-\infty}^{\infty}(r_{t+j}\alpha_r + r_{t+j}\theta_i\alpha_{r\theta})dF_t(\theta) + \sum_{j=0}^{k-1}\delta^j r_{t+j}\sigma \\
&= \max\Bigg\{0, \quad -p + \underbrace{(1-q)\frac{1-\delta^k}{1-\delta}\Big(\alpha_r + \alpha_{r\theta} + \sigma\Big)}_{\text{utility of high match quality during first } k \text{ periods}} \\
&\qquad + \underbrace{(q)\frac{1-\delta^k\gamma^k}{1-\delta\gamma}\Big(\alpha_r + \sigma\Big)}_{\text{utility of low match quality during first } k \text{ periods}} \\
&\qquad + \underbrace{(1-q)(1-\gamma^k)\frac{\delta^k}{1-\delta}\Big(\alpha_r + \alpha_{r\theta}\Big)}_{\text{utility of known high match quality from period } k \text{ onward}} \Bigg\}
\end{aligned}
$$

There are three possibilities: (1) the agent learns she has high match quality, (2) the agent learns she has low match quality, (3) the agent does not learn her match quality. If she learns she has low match quality, then she immediately disadopts the good. If she does not learn her match quality, then she disadopts when the subsidy ends after k periods. If she learns she has high match quality, then she continues using the good in perpetuity even after the subsidy ends.

Solution for the social planner. There are two policy regimes in which a subsidy induces use by some agents:

- Pooling equilibrium. All agents use the good as long as the subsidy is offered. After the subsidy ends, only agents who have discovered that they have high match quality use the good.

- Separating equilibrium. Agents with unknown match quality and agents who know they have high match quality use the good as long as the subsidy is offered. After the subsidy ends, only agents who have discovered that they have high match quality use the good.

We derive the optimal subsidy size and duration in each equilibrium, then we derive a condition that describes whether the separating equilibrium is supportable. If the separating equilibrium is supportable, then the social planner chooses the optimal subsidy size and duration from the separating equilibrium. If the separating equilibrium is not supportable, then the social planner chooses the optimal subsidy size and duration from the pooling equilibrium.

Pooling equilibrium. When the social planner subsidizes the good, the goal is to induce agents who do not know their match quality to use the good and possibly learn their match quality. The marginal social net benefit of one period of subsidy is (1) the net social benefit of unknown match quality agents using the good, plus (2) the net social benefit of low match quality agents using the good, plus (3) the fraction of agents who learn that they have high match quality times the social benefit of their future choices to use the good, minus (4) the administrative cost of the subsidy. We find the number of periods k that the subsidy is offered by setting the marginal social net benefit equal to zero.

$$\begin{aligned}0 = {} & \gamma^{\tilde{k}}\Big[\alpha_r + \alpha_{r\theta}(1-q) + e\Big] \\ & + (1-\gamma^{\tilde{k}})(q)\Big[\alpha_r + e\Big] \\ & + \gamma^{\tilde{k}}(1-\gamma)(1-q)\Big[\frac{\delta}{1-\delta}(\alpha_r + \alpha_{r\theta} + e)\Big] \\ & - \Big[a\Big]\end{aligned}$$

We solve for $\tilde{k}$ and round up to find the optimal subsidy duration k^*:

$$k^*_{\text{pool}} = \text{ceiling}\left(\frac{\log\Big(a - q(\alpha_r + e)\Big) - \log\Big(\frac{1-\delta\gamma}{1-\delta}(1-q)(\alpha_r + \alpha_{r\theta} + e)\Big)}{\log(\gamma)}\right)$$

Next, using the indifference condition from the pooling equilibrium solution for the agents, we find the subsidy level σ^* that makes an agent with unknown match quality indifferent between using the good and not using the good for the first time:

$$\sigma^*_{\text{pool}} = \left(\frac{1-\delta}{1-\delta^{k^*}}\right)p - \alpha_r - (1-q)\alpha_{r\theta} - (1-q)(1-\gamma^{k^*})\left(\frac{\delta^{k^*}}{1-\delta^{k^*}}\right)(\alpha_r + \alpha_{r\theta})$$

Separating equilibrium. When the social planner subsidizes the good, the goal is to induce agents who do not know their match quality to use the good and possibly learn their match quality. The marginal social net benefit of one period of subsidy is (1) the net social benefit of unknown match quality agents using the good, plus (2) the fraction of agents who learn that they are high match quality times the social benefit of their future choices to use the good, minus (3) the fraction of agents who already knew they were high match quality times the administrative cost of the subsidy. We find the number of periods k that the subsidy is offered by setting the marginal benefit equal to zero.

$$
\begin{aligned}
0 = {} & \gamma^{\tilde{k}}\Big[\alpha_r + \alpha_{r\theta}(1-q) + e - a\Big] \\
& + \gamma^{\tilde{k}}(1-\gamma)(1-q)\Big[\frac{\delta}{1-\delta}(\alpha_r + \alpha_{r\theta} + e)\Big] \\
& - (1-\gamma^{\tilde{k}})(1-q)\Big[a\Big]
\end{aligned}
$$

We solve for $\tilde{k}$ and round up to find the optimal subsidy duration k^*:

$$
k^*_{\text{sep}} = \text{ceiling}\left(\frac{\log(a-qa) - \log\Big(\alpha_r + \alpha_{r\theta}(1-q) + e + \frac{\delta(1-\gamma)(1-q)}{1-\delta}(\alpha_r + \alpha_{r\theta} + e) - qa\Big)}{\log(\gamma)}\right)
$$

Next, using the indifference condition from the separating equilibrium solution for the agents, we find the subsidy level that makes an agent with unknown match quality indifferent between using the good and not using the good for the first time:

$$
\begin{aligned}
\sigma^*_{\text{sep}} = -\alpha_r + \Bigg[(1-q)\frac{1-\delta^{k^*}}{1-\delta} + (q)\frac{1-\delta^{k^*}\gamma^{k^*}}{1-\delta\gamma}\Bigg]^{-1}\Bigg[& p - \Big((1-q)\frac{1-\delta^{k^*}}{1-\delta}\Big)\Big(\alpha_{r\theta}\Big) \\
& - \Big((1-q)(1-\gamma^{k^*})\frac{\delta^{k^*}}{1-\delta}\Big)\Big(\alpha_r + \alpha_{r\theta}\Big)\Bigg]
\end{aligned}
$$

Recall that, for $k = 1$ and $p = 0$, the minimum subsidy to induce a known low match quality to use the good is $\hat{\sigma} = -\alpha_r$ and the minimum subsidy to induce an uninformed agent to use the good:

$$
\tilde{\sigma} = -\alpha_r - \alpha_{r\theta}(1-q) - (1-q)(1-\gamma)\frac{\delta}{1-\delta}(\alpha_r + \alpha_{r\theta})
$$

If $k^* = 1$ and $p = 0$, then $\sigma^* = \tilde{\sigma}$ and a separating equilibrium is supportable. The optimal subsidy in the separating equilibrium σ^* is increasing in k^* and p. The separating equilibrium is supportable for $\tilde{\sigma} < \sigma^* < \hat{\sigma}$. If $\sigma^* \geq \hat{\sigma}$ then the optimal subsidy size and duration is set according to the pooling equilibrium.

The optimal subsidy duration k^* is a decreasing function of administrative cost a. Using the formula from the pooled equilibrium:

$$\frac{\partial k^*}{\partial a} = \underbrace{\frac{1}{a - q(\alpha_r + e)}}_{(+)} \underbrace{\frac{1}{\log(\gamma)}}_{(-)} < 0 \tag{17}$$

The first expression is positive because $\alpha_r + e < 0$, and the second expression is negative because $\gamma < 1$.

The optimal subsidy duration k^* is an increasing function of the magnitude of match quality difference $\alpha_{r\theta}$. Using the formula from the pooled equilibrium:

$$\frac{\partial k^*}{\partial \alpha_{r\theta}} = \underbrace{\frac{1}{\alpha_r + \alpha_{r\theta} + e}}_{(+)} \underbrace{\frac{1}{\log(\gamma)}}_{(-)} \underbrace{(-1)}_{(-)} > 0 \tag{18}$$

The first expression is positive because $\alpha_r + \alpha_{r\theta} > 0$, and the second expression is negative because $\gamma < 1$.

D.2 Model with present bias and taste/ability mechanism

Intuition. With present bias and the taste/ability mechanism, the social planner chooses the minimal exposure subsidy duration k such that the agent, having built up a sufficient exposure stock, would continue using the good on her own after the subsidy is removed. The social planner chooses the exposure subsidy level σ such that the present value of the subsidy matches the present value of the externalities in perpetuity. An exposure subsidy chosen this way can be better than a perpetual use subsidy if the portion of the perpetual use subsidy delivered after the first period is so heavily discounted by a present-biased agent that it results in nonadoption. An exposure subsidy can be better than a purchase subsidy because under the purchase subsidy the agent would never attain sufficient exposure to continue using the good on her own, thus resulting in adoption in the first period and subsequent disadoption.

Agents. There is a population of identical agents of measure one. Each agent chooses in each period whether or not to use a good to maximize the discounted stream of expected utility. If the agent does not use the good, then utility is zero. If the agent uses the good, then the agent derives utility from the direct net benefit of using the good (which could be negative) and from a subsidy σ set by a policymaker. If the agent is using the good for the first time, then the agent also pays a price p. The agent is present-biased in the sense that the discount applied between the current period and the next period is larger than the discount applied between any other two consecutive periods (quasi-hyperbolic discounting or beta-delta discounting). The discounted stream of utility in period t is:

$$U_t = \max_{r_t \in \{0,1\}} u_t + \beta \sum_{j=1}^{\infty} \delta^j u_{t+j} \tag{19}$$

where $r \in \{0,1\}$ is a discrete choice to either use the good or not, $\delta \in (0,1)$ is the agent's time discount factor, and $\beta \in [0,1]$ expresses the extent of the agent's present bias (smaller β implies greater present bias).

Utility in period t takes the form:

$$u_t = u(r_t, S_t) = r_t \alpha_r + r_t S_t \alpha_{rS} + r_t \sigma_t - r_t p \ \mathbb{I}\Big[\forall j < 0 : r_{t+j} = 0\Big] \tag{20}$$

where $S \geq 0$ is an exposure stock indicating taste or ability and $\mathbb{I}$ is an indicator function equal to one if the argument is true and zero if it is false. The exposure stock evolves according to the following law of motion:

$$S_{t+1} = (1-d)(S_t + r_t) \tag{21}$$

where $d \in (0,1)$ is a depreciation parameter.

Social planner. A social planner chooses a sequence of subsidies to maximize social welfare, which consists of the sum of the agent's utility and externalities net of subsidies. Unlike the agent, the social planner uses a consistent discount rate of δ, i.e. even though the agent is present-biased the social planner is not. Each period the good is used, it generates a positive externality e. We assume the sequence of subsidies is constrained to be some positive value σ for some number of periods k and, if k is finite, zero thereafter. In other words, the social planner can choose the subsidy level σ and duration k but cannot tailor the subsidy to be a different magnitude in each individual period. The social planner thus chooses the subsidy level and duration to maximize welfare:

$$\max_{\sigma,k} \quad \sum_{j=0}^{\infty} \delta^j (u_{t+j} + r_{t+j}e) - \sum_{j=0}^{k-1} \delta^j r_{t+j}(\sigma) \tag{22}$$

We assume that the social planner follows through on all promises made at the time the agent first uses the good, i.e. there are no obstacles to credibly committing to a subsidy level and duration.

Solution for the agents. If the agent has not previously used the good (i.e. $S_t = 0$

and the price p must be paid), then expected utility at time t is:

$$\begin{aligned}
U_t(\sigma,k) &= \max_{r_t\in\{0,1\}} \; r_t\Big(\alpha_r + S_t\alpha_{rS} + \sigma - p\Big) + \beta\sum_{j=1}^{\infty}\delta^j(r_{t+j}\alpha_r + r_{t+j}S_{t+j}\alpha_{rS}) + \beta\sum_{j=1}^{k-1}\delta^j r_{t+j}\sigma \\
&= \max\Bigg\{\Big(\alpha_r + S_t\alpha_{rS} + \sigma - p\Big) + \beta\Big(\frac{\delta-\delta^k}{1-\delta}\Big)\Big(\alpha_r + \alpha_{rS}\frac{1-d}{d} + \sigma\Big) \\
&\qquad \underbrace{-\beta\Big(\frac{\delta(1-d)-\delta^k(1-d)^k}{1-\delta(1-d)}\Big)\alpha_{rS}\Big(\frac{1-d}{d}\Big)}_{r_{t+j}=1 \text{ for } j<k \text{ and } r_{t+j}=0 \text{ for } j\geq k}, \\
&\qquad \Big(\alpha_r + S_t\alpha_{rS} + \sigma - p\Big) + \beta\Big(\frac{\delta}{1-\delta}\Big)\Big(\alpha_r + \alpha_{rS}\frac{1-d}{d}\Big) \\
&\qquad \underbrace{-\beta\Big(\frac{\delta(1-d)}{1-\delta(1-d)}\Big)\alpha_{rS}\Big(\frac{1-d}{d}\Big) + \beta\Big(\frac{\delta-\delta^k}{1-\delta}\Big)\sigma}_{r_{t+j}=1 \text{ for } j\geq 0}, \\
&\qquad \underbrace{0}_{r_{t+j}=0 \text{ for } j\geq 0}\Bigg\}
\end{aligned}$$

There are three possibilities: (1) the agent may use the good forever (perpetual use), (2) the agent may use the good until the subsidy is removed (disadoption), or (3) the agent may decline to use the good (non-adoption).

Solution for the social planner. A policy that results in disadoption cannot be optimal. Proof is by contradiction. Suppose that (σ, k) were optimal and that it resulted in disadoption (so k is finite). If the policy is optimal, then $e > \sigma$. (If that were not true then a policy with subsidy equal to zero would be better.) Furthermore, extending the subsidy by one day would result in use for one more day with positive net welfare because period utility is increasing in the exposure stock and $e > \sigma$. So a policy of $(\sigma, k+1)$ is strictly better than (σ, k). That contradicts the assumption that (σ, k) is optimal.

So the optimal policy either results in perpetual use or non-adoption.

First, we find the exposure threshold at which an agent would continue using the good if the good had already been used in prior periods:

$$S^* = -\Big(\frac{1-\delta(1-d)}{1-\delta}\Big)\frac{\alpha_r}{\alpha_{rS}} - \Big(\frac{\delta(1-d)}{1-\delta}\Big)$$

Use subsidy. If $S^* \geq \frac{1-d}{d}$, then perpetual use can only be achieved with an ongoing use subsidy with $k = \infty$ and $\sigma = e$ is optimal.

The agent uses the good in perpetuity if:

$$\Big(\alpha_r + S_t\alpha_{rS} + e - p\Big) + \beta\Big(\frac{\delta}{1-\delta}\Big)\Big(\alpha_r + \alpha_{rS}\frac{1-d}{d}\Big) - \beta\Big(\frac{\delta(1-d)}{1-\delta(1-d)}\Big)\alpha_{rS}\Big(\frac{1-d}{d}\Big) + \beta\Big(\frac{\delta}{1-\delta}\Big)e > 0$$

Exposure subsidy. If $S^* > 0$ and $S^* < \frac{1-d}{d}$, then perpetual use can be achieved with a subsidy of finite duration. The minimum number of periods required for the agent to reach the exposure threshold (and continue using the good without a subsidy) is:

$$k^* = \text{ceiling}\Bigg(\frac{\log(\frac{1-d}{d} - S^*) - \log(\frac{1-d}{d} - S_t)}{\log(1-d)}\Bigg)$$

We consider the following exposure subsidy, which has the same discounted value as the externalities in perpetuity:

$$\sigma^* = \frac{1}{1-\delta^{k^*}}e$$

This exposure subsidy has the effect of concentrating the subsidies in a shorter time interval. Because the agent is present-biased, subsidies in the first period have a larger impact on the present value of discounted utility than subsidies in later periods with the same present value from the social planner's perspective.

The agent uses the good in perpetuity if:

$$\Big(\alpha_r + S_t\alpha_{rS} + \frac{1}{1-\delta^{k^*}}e - p\Big) + \beta\Big(\frac{\delta}{1-\delta}\Big)\Big(\alpha_r + \alpha_{rS}\frac{1-d}{d}\Big)$$
$$-\beta\Big(\frac{\delta(1-d)}{1-\delta(1-d)}\Big)\alpha_{rS}\Big(\frac{1-d}{d}\Big) + \beta\Big(\frac{\delta-\delta^{k}}{1-\delta}\Big)\frac{1}{1-\delta^{k^*}}e > 0$$

Thus, the exposure subsidy ($\sigma^* = \frac{1}{1-\delta^{k^*}}e$) is superior to a use subsidy ($\sigma = e$) if:

$$\frac{1}{1-\delta^{k^*}} + \beta\Big(\frac{\delta-\delta^{k^*}}{1-\delta}\Big)\frac{1}{1-\delta^{k^*}} > \eta > 1 + \beta\Big(\frac{\delta}{1-\delta}\Big)$$

Where:

$$\eta = \Big[p \;-\; \alpha_r - S_t\alpha_{rS} - \beta\Big(\frac{\delta}{1-\delta}\Big)\Big(\alpha_r + \alpha_{rS}\frac{1-d}{d}\Big) + \beta\Big(\frac{\delta(1-d)}{1-\delta(1-d)}\Big)\alpha_{rS}\Big(\frac{1-d}{d}\Big)\Big]\frac{1}{e}$$

For all other parameter values, the exposure subsidy is equally as good as the use subsidy (i.e. agents would make the same choices and social welfare would be the same under both regimes).

Observe that:

- If $\beta = 1$ (i.e. no present bias), then the exposure subsidy is equally good to the use subsidy for all parameter values.
- As β declines, the range of values for which an exposure subsidy is superior to a use subsidy widens.

If the optimal policy is an exposure subsidy, then the optimal subsidy duration k^* is a decreasing function of the return to exposure (expressed by the exposure parameter α_{rS}):

$$\frac{\partial k^*}{\partial \alpha_{rS}} = \underbrace{\frac{1}{log(1-d)}}_{(-)} \underbrace{\frac{1}{\frac{1-d}{d} - S^*}}_{(+)} \underbrace{\frac{1-\delta(1-d)}{1-\delta}}_{(+)} \underbrace{\frac{\alpha_r}{\alpha_{rS}^2}}_{(-)} \underbrace{(-1)}_{(-)} < 0 \tag{23}$$

The first expression is negative because $d \in (0,1)$, the second expression is positive because $\frac{1-d}{d} > S^*$ if the optimal policy is an exposure subsidy, the third expression is positive because $d \in (0,1)$ and $\delta \in (0,1)$, and the fourth expression is negative because $\alpha_r < 0$. The intuition is that a larger return to exposure α_{rS} reduces the exposure threshold S^* at which an agent would choose to use the good on her own, which reduces the number of periods needed to achieve the exposure threshold.

D.3 Model with present bias and information mechanism

Intuition. With present bias and the information mechanism, we compare an exposure subsidy to a purchase subsidy and a perpetual use subsidy with present value equal to the present value of generating the externality in every subsequent period. With magnitudes calibrated by the externality, an exposure subsidy can be better than a perpetual use subsidy when the perpetual use subsidy is insufficient to induce a present-biased agent to use the good because so much of the subsidy is heavily discounted in the distant future. If a sufficiently large portion of the exposure subsidy is delivered immediately, then it would induce an uninformed agent to use the good (by concentrating the subsidy in the first period that is not heavily discounted) even though the agent would not be induced by the perpetual use subsidy. In that case, the exposure subsidy would also be superior to a purchase subsidy, which would induce a smaller fraction of agents to learn their match quality and would miss out on the positive externality that those agents would have generated.

Agents. There is a population of agents of measure one. Each agent chooses in each period whether or not to use a good to maximize the discounted stream of expected utility. If the agent does not use the good, then utility is zero. If the agent uses the good, then the agent derives utility from the direct net benefit of using the good (which could be negative) and from a subsidy σ set by a policymaker. If the agent is using the good for the first time, then the agent also pays a price p. The agent is present-biased in the sense that the discount applied between the current period and the next period is larger than the discount applied between any other two consecutive periods (quasi-hyperbolic discounting or beta-delta discounting). The discounted stream of expected utility in period t is:

$$U_t = \max_{r_t \in \{0,1\}} \int_{-\infty}^{\infty} u_t \ dF_t(\theta) + \beta \sum_{j=1}^{\infty} \delta^j \int_{-\infty}^{\infty} u_{t+j} \ dF_t(\theta) \tag{24}$$

where $r \in \{0, 1\}$ is a discrete choice to either use the good or not, $\delta \in (0, 1)$ is the agent's time discount factor, and $\beta \in [0, 1]$ expresses the extent of the agent's present bias.

Utility in period t takes the form:

$$u_t = u(r_t, \theta_i) = r_t \alpha_r + r_t \theta_i \alpha_{r\theta} + r_t \sigma_t - r_t p \ \mathbb{I}\Big[\forall j < 0 : r_{t+j} = 0\Big] \tag{25}$$

where θ is match quality and $\mathbb{I}$ is an indicator function equal to one if the argument is true and zero if it is false. The population comprises agents with low and high match quality between the agent and the good. We assume that a fraction q of agents have low match quality, and $1 - q$ have high match quality, such that the population distribution of match quality can be expressed with the following probability mass function f with $q \in (0, 1)$:

$$f(\theta) = \begin{cases} q & \text{if } \theta = 0 \\ 1 - q & \text{if } \theta = 1 \end{cases} \tag{26}$$

We assume the signal is either fully informative or totally uninformative, such that the distribution of signals can be expressed with the following probability mass function g with $\gamma \in (0, 1)$:

$$g(\omega_t|\theta_i) = \begin{cases} \gamma & \text{if } \omega_t = -1 \\ 1-\gamma & \text{if } \omega_t = \theta_i \end{cases} \tag{27}$$

Social planner. A social planner chooses a sequence of subsidies to maximize social welfare, which consists of the sum of the agent's utility and externalities net of subsidies. Unlike the agent, the social planner uses a consistent discount rate of δ, i.e. even though the agent is present-biased the social planner is not. Each period the good is used, it generates a positive externality e. We assume the sequence of subsidies is constrained to be some positive value σ for some number of periods k and, if k is finite, zero thereafter. In other words, the social planner can choose the subsidy level σ and duration k but cannot tailor the subsidy to be a different magnitude in each individual period. The social planner thus chooses the subsidy level and duration to maximize welfare:

$$\max_{\sigma,k} \quad \sum_{j=0}^{\infty} \delta^j \int_{-\infty}^{\infty} (u_{t+j} + r_{t+j}e) dF_t(\theta) - \sum_{j=0}^{k-1} \delta^j r_{t+j}(\sigma) \tag{28}$$

where F is the cumulative distribution function corresponding to f.

We assume that the social planner follows through on all promises made at the time the agent first uses the good, i.e. there are no obstacles to credibly committing to a subsidy level and duration.

We assume:

- The net private benefit to an agent who knows she has high match quality is positive: $\alpha_r + \alpha_{r\theta} > 0$
- The net social benefit to a low match quality agent is negative: $\alpha_r + e < 0$

- The net private benefit to an agent who does not know her match quality is negative: $\alpha_r + \alpha_{r\theta}(1-q) + (1-q)(1-\gamma)\frac{\beta\delta}{1-\delta}(\alpha_r + \alpha_{r\theta}) < 0$
- The net social benefit for an agent with an unknown match quality is positive: $\alpha_r + \alpha_{r\theta}(1-q) + e + (1-q)(1-\gamma)\frac{\delta}{1-\delta}(\alpha_r + \alpha_{r\theta} + e) > 0$

Solution for the agents. If $k = 1$ and $p = 0$, then expected utility at time t is:

$$\begin{aligned} U_t(\sigma, k) &= \max_{r_t \in \{0,1\}} \int_{-\infty}^{\infty} r_t(\alpha_r + \theta_i\alpha_{r\theta} + \sigma)dF_t(\theta) + \beta\sum_{j=1}^{\infty}\delta^j \int_{-\infty}^{\infty}(r_{t+j}\alpha_r + r_{t+j}\theta_i\alpha_{r\theta})dF_t(\theta) \\ &= \max\left\{\alpha_r + \alpha_{r\theta}(1-q) + \sigma + (1-q)(1-\gamma)\frac{\beta\delta}{1-\delta}(\alpha_r + \alpha_{r\theta}), 0\right\} \end{aligned}$$

Pooling equilibrium. Define $\hat{\sigma}$ as the minimum subsidy such that an agent who knows she has low match quality chooses to use the good when $k = 1$ and $p = 0$: $\hat{\sigma} = -\alpha_r$. If the agent has not previously used the good (i.e. the price p must be paid) and $\sigma \geq \hat{\sigma}$ (i.e. an agent who knows she has low match quality behaves the same way as an agent with unknown match quality), then expected utility at time t is:

$$\begin{aligned} U_t(\sigma, k) &= \max_{r_t \in \{0,1\}} r_t(\alpha_r + \theta_i\alpha_{r\theta} + \sigma - p) + \beta\sum_{j=1}^{\infty}\delta^j \int_{-\infty}^{\infty}(r_{t+j}\alpha_r + r_{t+j}\theta_i\alpha_{r\theta})dF_t(\theta) + \beta\sum_{j=1}^{k-1}\delta^j r_{t+j}\sigma \\ &= \max\Bigg\{0, \quad -p + \left(1 + \beta\frac{\delta - \delta^k}{1-\delta}\right)\Big(\alpha_r + (1-q)\alpha_{r\theta} + \sigma\Big) \\ &\qquad + (1-q)(1-\gamma^k)\frac{\beta\delta^k}{1-\delta}\Big(\alpha_r + \alpha_{r\theta}\Big)\Bigg\} \end{aligned}$$

Separating equilibrium. Define $\tilde{\sigma}$ as the minimum subsidy such that an uninformed agent chooses to use the good when $k = 1$ and $p = 0$:

$$\tilde{\sigma} = -\alpha_r - \alpha_{r\theta}(1-q) - (1-q)(1-\gamma)\frac{\beta\delta}{1-\delta}(\alpha_r + \alpha_{r\theta})$$

If the agent has not previously used the good (i.e. the price p must be paid) and $\tilde{\sigma} < \sigma < \hat{\sigma}$

(i.e. an agent who knows she has low match quality behaves differently from an agent with unknown match quality), then expected utility at time t is:

$$
\begin{aligned}
U_t(\sigma,k) &= \max_{r_t\in\{0,1\}} \; r_t(\alpha_r+\theta_i\alpha_{r\theta}+\sigma-p)+\beta\sum_{j=1}^{\infty}\delta^j\int_{-\infty}^{\infty}(r_{t+j}\alpha_r+r_{t+j}\theta_i\alpha_{r\theta})dF_t(\theta)+\beta\sum_{j=1}^{k-1}\delta^j r_{t+j}\sigma \\
&= \max\Big\{0, \quad -p+\underbrace{(1-q)\Big(1+\beta\frac{\delta-\delta^k}{1-\delta}\Big)\Big(\alpha_r+\alpha_{r\theta}+\sigma\Big)}_{\text{utility of high match quality during first } k \text{ periods}} \\
&\qquad + \quad \underbrace{(q)\Big(1+\beta\frac{\delta\gamma-\delta^k\gamma^k}{1-\delta\gamma}\Big)\Big(\alpha_r+\sigma\Big)}_{\text{utility of low match quality during first } k \text{ periods}} \\
&\qquad + \quad \underbrace{(1-q)(1-\gamma^k)\frac{\beta\delta^k}{1-\delta}\Big(\alpha_r+\alpha_{r\theta}\Big)}_{\text{utility of known high match quality from period } k \text{ onward}} \qquad \Big\}
\end{aligned}
$$

There are three possibilities: (1) the agent learns she has high match quality, (2) the agent learns she has low match quality, (3) the agent does not learn her match quality. If she learns she has low match quality, then she immediately disadopts the good. If she does not learn her match quality, then she disadopts when the subsidy ends after k periods. If she learns she has high match quality, then she continues using the good in perpetuity even after the subsidy ends.

Solution for the social planner. We compare:

- A use subsidy with $\sigma = e$ and $k = \infty$
- A purchase subsidy with the same present value, with $k = 1$
- An exposure subsidy with the same present value, that minimally supports a separating equilibrium, i.e. the smallest k that achieves $\sigma < -\alpha_r$

For each subsidy, we set the present discounted value equal to $\frac{1}{1-\delta}e$. So:

$$\begin{aligned}
\sigma^*_{use} =& e \\
\sigma^*_{pur} =& \frac{1}{1-\delta}e \\
\sigma^*_{exp} =& \frac{1}{1-\delta^{k^*_{exp}}}e
\end{aligned}$$

We derive k^*_{exp} (the duration of the exposure subsidy) as follows:

$$\begin{aligned}
-\alpha_r =& \frac{1}{1-\delta^{\tilde{k}}}e \\
1-\delta^{\tilde{k}} =& \frac{e}{-\alpha_r} \\
\delta^{\tilde{k}} =& \frac{-e-\alpha_r}{-\alpha_r} \\
\tilde{k}\log(\delta) =& \log(-e-\alpha_r) - \log(-\alpha_r) \\
k^*_{exp} =& \text{ceiling}\bigg(\frac{\log(-e-\alpha_r)-\log(-\alpha_r)}{\log(\delta)}\bigg)
\end{aligned}$$

Where the last step is taken so that k^*_{exp} is the whole number that minimally achieves a separating equilibrium (where agents who know they have low match quality choose not to use the good).

Use subsidy. We know that the use subsidy supports a separating equilibrium because the utility of an agent who knows they have low match quality is negative ($\alpha_r + \sigma = \alpha_r + e < 0$). Using the indifference condition from the separating equilibrium solution for the agents, we see that an agent with unknown match quality is willing to use the good for the first time under a use subsidy if:

$$p < \underbrace{\alpha_r + (1-q)\alpha_{r\theta} + \sigma}_{\text{utility during first period}} + \underbrace{(1-q)\bigg(\frac{\beta\delta}{1-\delta}\bigg)\bigg(\alpha_r + \alpha_{r\theta} + \sigma\bigg)}_{\text{utility of high match quality}} + \underbrace{(q)\bigg(\frac{\beta\delta\gamma}{1-\delta\gamma}\bigg)\bigg(\alpha_r + \sigma\bigg)}_{\text{utility of low match quality}} = U^*_{use}$$

Purchase subsidy. Using the indifference condition from the separating equilibrium solution for the agents, we see that an agent with unknown match quality is willing to use the good for the first time under a purchase subsidy if:

$$p < \underbrace{\alpha_r + (1-q)\alpha_{r\theta} + \sigma}_{\text{utility during first period}} + \underbrace{(1-q)(1-\gamma)\frac{\beta\delta}{1-\delta}\Big(\alpha_r + \alpha_{r\theta}\Big)}_{\text{utility of high match quality after the first period}} = U^*_{pur}$$

Exposure subsidy. Using the indifference condition from the separating equilibrium solution for the agents, we see that an agent with unknown match quality is willing to use the good for the first time under an exposure subsidy if:

$$\begin{aligned} p < & \underbrace{\alpha_r + (1-q)\alpha_{r\theta} + \sigma}_{\text{utility during first period}} \\ & + \underbrace{(1-q)\Big(\beta\frac{\delta-\delta^k}{1-\delta}\Big)\Big(\alpha_r + \alpha_{r\theta} + \sigma\Big)}_{\text{high match quality during first } k \text{ periods}} \\ & + \underbrace{(q)\Big(\beta\frac{\delta\gamma-\delta^k\gamma^k}{1-\delta}\Big)\Big(\alpha_r + \sigma\Big)}_{\text{low match quality during first } k \text{ periods}} \\ & + \underbrace{(1-q)(1-\gamma)\frac{\beta\delta^k}{1-\delta}\Big(\alpha_r + \alpha_{r\theta}\Big)}_{\text{high match quality after } k \text{ periods}} = U^*_{exp} \end{aligned}$$

An exposure subsidy is superior to a use subsidy if $U^*_{exp} > p > U^*_{use}$ because in that case the exposure subsidy induces use and the use subsidy does not.

An exposure subsidy is superior to a purchase subsidy if $U^*_{exp} > p$. (This condition implies that $U^*_{pur} > p$ because the value of the subsidy is concentrated in the first period with the purchase subsidy.) In that case, a larger fraction of high match quality agents learn their match quality and continue using the good indefinitely.

D.4 Model with liquidity constraint and taste/ability mechanism

Intuition. With a liquidity constraint and the taste/ability mechanism, the social planner chooses the minimal exposure subsidy duration k such that the agent, having built up a sufficient exposure stock, would continue using the good on her own after the subsidy is removed. The social planner chooses the exposure subsidy level σ such that the present value of the subsidy matches the present value of the externalities in perpetuity. An exposure subsidy chosen this way can be better than a perpetual use subsidy if the portion of the perpetual use subsidy delivered in the first period is inadequate to overcome the liquidity constraint, thus resulting in nonadoption. An exposure subsidy can be better than a purchase subsidy because under the purchase subsidy the agent would never attain sufficient exposure to continue using the good on her own, thus resulting in adoption in the first period and subsequent disadoption.

Agents. There is a population of identical agents of measure one. Each agent chooses in each period whether or not to use a good to maximize the discounted stream of expected utility. If the agent does not use the good, then utility is zero. If the agent uses the good, then the agent derives utility from the direct net benefit of using the good (which could be negative) and from a subsidy σ set by a policymaker. If the agent is using the good for the first time, then the agent also pays a price p. The agent is liquidity-constrained in the sense that the agent cannot make decisions that would result in period utility falling below some lower bound. The discounted stream of utility in period t is:

$$U_t = \max_{r_t \in \{0,1\}} \sum_{j=0}^{\infty} \delta^j u_{t+j} \tag{29}$$

$$s.t. \quad \forall j \;\; u_{t+j} \geq \underline{\mathrm{u}} \tag{30}$$

where $r \in \{0, 1\}$ is a discrete choice to either use the good or not, $\delta \in (0, 1)$ is the agent's time discount factor, and $\underline{\mathrm{u}} < 0$ is the lower bound on period utility[9].

Utility in period t takes the form:

$$u_t = u(r_t, S_t) = r_t\alpha_r + r_t S_t \alpha_{rS} + r_t\sigma_t - r_t p \ \mathbb{I}\Big[\forall j < 0 : r_{t+j} = 0\Big] \tag{31}$$

where $S \geq 0$ is an exposure stock indicating taste or ability and $\mathbb{I}$ is an indicator function equal to one if the argument is true and zero if it is false. The exposure stock evolves according to the following law of motion:

$$S_{t+1} = (1-d)(S_t + r_t) \tag{32}$$

where $d \in (0,1)$ is a depreciation parameter.

We assume:

- With zero subsidy and zero exposure ($\sigma = 0$ and $S_t = 0$), the liquidity constraint is binding: $\alpha_r - p < \underline{\mathrm{u}}$

Social planner. A social planner chooses a sequence of subsidies to maximize social welfare, which consists of the sum of the agent's utility and externalities net of subsidies. Each period the good is used, it generates a positive externality e. We assume the sequence of subsidies is constrained to be some positive value σ for some number of periods k and, if k is finite, zero thereafter. In other words, the social planner can choose the subsidy level σ and duration k but cannot tailor the subsidy to be a different magnitude in each individual

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[9] For a similar modeling approach, see Zeldes (1989). In that model, a liquidity constraint is modeled as a lower bound on assets. We express a similar idea with a lower bount on period utility because we do not model assets explicitly.

period. The social planner thus chooses the subsidy level and duration to maximize welfare:

$$\max_{\sigma,k} \quad \sum_{j=0}^{\infty} \delta^j (u_{t+j} + r_{t+j} e) - \sum_{j=0}^{k-1} \delta^j r_{t+j}(\sigma) \tag{33}$$

We assume that the social planner follows through on all promises made at the time the agent first uses the good, i.e. there are no obstacles to credibly committing to a subsidy level and duration.

Solution for the agents. If the agent has not previously used the good (i.e. $S_t = 0$ and the price p must be paid), then expected utility at time t is:

$$\begin{aligned}
U_t(\sigma, k) = &\max_{r_t \in \{0,1\}} \; r_t\Big(\alpha_r + S_t\alpha_{rS} + \sigma - p\Big) + \sum_{j=1}^{\infty} \delta^j (r_{t+j}\alpha_r + r_{t+j}S_{t+j}\alpha_{rS}) + \sum_{j=1}^{k-1} \delta^j r_{t+j}\sigma \\
= &\max\Bigg\{ \underbrace{\Big(\alpha_r + S_t\alpha_{rS} + \sigma - p\Big) + \Big(\frac{\delta - \delta^k}{1-\delta}\Big)\Big(\alpha_r + \alpha_{rS}\frac{1-d}{d} + \sigma\Big) - \Big(\frac{\delta(1-d) - \delta^k(1-d)^k}{1-\delta(1-d)}\Big)\alpha_{rS}\Big(\frac{1-d}{d}\Big)}_{r_{t+j}=1 \text{ for } j<k \text{ and } r_{t+j}=0 \text{ for } j\geq k}, \\
&\underbrace{\Big(\alpha_r + S_t\alpha_{rS} + \sigma - p\Big) + \Big(\frac{\delta}{1-\delta}\Big)\Big(\alpha_r + \alpha_{rS}\frac{1-d}{d}\Big) - \Big(\frac{\delta(1-d)}{1-\delta(1-d)}\Big)\alpha_{rS}\Big(\frac{1-d}{d}\Big) + \Big(\frac{\delta - \delta^k}{1-\delta}\Big)\sigma}_{r_{t+j}=1 \text{ for } j\geq 0}, \\
&\underbrace{0}_{r_{t+j}=0 \text{ for } j\geq 0} \Bigg\}
\end{aligned}$$

There are three possibilities: (1) the agent may use the good forever (perpetual use), (2) the agent may use the good until the subsidy is removed (disadoption), or (3) the agent may decline to use the good (non-adoption). In order for the agent to use the good even once, utility in the first period the agent uses the good must exceed the lower bound: $\alpha_r + \sigma - p \geq \underline{u}$. If that criterion is not met, then non-adoption is the only feasible choice for the agent.

Solution for the social planner. A policy that results in disadoption cannot be optimal. Proof is by contradiction. Suppose that (σ, k) were optimal and that it resulted in disadoption (so k is finite). If the policy is optimal, then $e > \sigma$. (If that were not true then a policy with subsidy equal to zero would be better.) Furthermore, extending the subsidy by one day would result in use for one more day with positive net welfare because period utility is increasing in the exposure stock and $e > \sigma$. So a policy of $(\sigma, k+1)$ is strictly better than (σ, k). That contradicts the assumption that (σ, k) is optimal.

So the optimal policy either results in perpetual use or non-adoption.

First, we find the exposure threshold at which an agent would continue using the good if the good had already been used in prior periods:

$$S^* = -\Big(\frac{1-\delta(1-d)}{1-\delta}\Big)\frac{\alpha_r}{\alpha_{rS}} - \Big(\frac{\delta(1-d)}{1-\delta}\Big)$$

Use subsidy. If $S^* \geq \frac{1-d}{d}$, then perpetual use can only be achieved with an ongoing use subsidy with $k = \infty$ and $\sigma = e$ is optimal.

The agent uses the good in perpetuity if:

$$\Big(\alpha_r + S_t\alpha_{rS} + e - p\Big) + \Big(\frac{\delta}{1-\delta}\Big)\Big(\alpha_r + \alpha_{rS}\frac{1-d}{d}\Big) - \Big(\frac{\delta(1-d)}{1-\delta(1-d)}\Big)\alpha_{rS}\Big(\frac{1-d}{d}\Big) + \Big(\frac{\delta}{1-\delta}\Big)e > 0$$

And:

$$\alpha_r + S_t\alpha_{rS} + e - p \geq \underline{\mathrm{u}}$$

Exposure subsidy. If $S^* > 0$ and $S^* < \frac{1-d}{d}$, then perpetual use can be achieved with a subsidy of finite duration. The minimum number of periods required for the agent to reach the exposure threshold (and continue using the good without a subsidy) is:

$$k^* = \text{ceiling}\left(\frac{\log(\frac{1-d}{d} - S^*) - \log(\frac{1-d}{d} - S_t)}{\log(1-d)}\right)$$

We consider the following exposure subsidy, which has the same discounted value as the externalities in perpetuity:

$$\sigma^* = \frac{1}{1-\delta^{k^*}} e$$

This exposure subsidy has the effect of concentrating the subsidies in a shorter time interval. Because the agent is liquidity-constrained, subsidies in the first period may relax a binding constraint that would otherwise prevent the agent from adopting the good.

The agent uses the good in perpetuity if:

$$\left(\alpha_r + S_t\alpha_{rS} + \frac{1}{1-\delta^{k^*}}e - p\right) + \left(\frac{\delta}{1-\delta}\right)\left(\alpha_r + \alpha_{rS}\frac{1-d}{d}\right)$$
$$-\left(\frac{\delta(1-d)}{1-\delta(1-d)}\right)\alpha_{rS}\left(\frac{1-d}{d}\right) + \left(\frac{\delta-\delta^k}{1-\delta}\right)\frac{1}{1-\delta^{k^*}}e > 0$$

And:

$$\alpha_r + S_t\alpha_{rS} + \frac{1}{1-\delta^{k^*}}e - p \geq \underline{\mathrm{u}}$$

The first condition is that the discounted stream of utility must be positive, and it is satisfied for the exposure subsidy if and only if it is satisfied for the use subsidy (because the exposure subsidy has the same present value as the use subsidy). The second condition may be satisfied for the exposure subsidy even when it is not satisfied for the use subsidy.

Thus, the exposure subsidy ($\sigma^* = \frac{1}{1-\delta^{k^*}}e$) is superior to a use subsidy ($\sigma = e$) if:

$$\frac{1}{1-\delta^{k^*}}e > \underline{\mathrm{u}} + p - \alpha_r - S_t\alpha_{rS} > e$$

I.e., the exposure subsidy is large enough to boost period utility above the lower bound, but the use subsidy is not large enough to boost period utility above the lower bound.

If the optimal policy is an exposure subsidy, then the optimal subsidy duration k^* is a decreasing function of the return to exposure (expressed by the exposure parameter α_{rS}):

$$\frac{\partial k^*}{\partial \alpha_{rS}} = \underbrace{\frac{1}{log(1-d)}}_{(-)} \underbrace{\frac{1}{\frac{1-d}{d} - S^*}}_{(+)} \underbrace{\frac{1-\delta(1-d)}{1-\delta}}_{(+)} \underbrace{\frac{\alpha_r}{\alpha_{rS}^2}}_{(-)} \underbrace{(-1)}_{(-)} < 0 \tag{34}$$

The first expression is negative because $d \in (0,1)$, the second expression is positive because $\frac{1-d}{d} > S^*$ if the optimal policy is an exposure subsidy, the third expression is positive because $d \in (0,1)$ and $\delta \in (0,1)$, and the fourth expression is negative because $\alpha_r < 0$. The intuition is that a larger return to exposure α_{rS} reduces the exposure threshold S^* at which an agent would choose to use the good on her own, which reduces the number of periods needed to achieve the exposure threshold.

D.5 Model with liquidity constraint and information mechanism

Intuition. With a liquidity constraint and the information mechanism, we compare an exposure subsidy to a purchase subsidy and a perpetual use subsidy with present value equal to the present value of generating the externality in every subsequent period. With magnitudes calibrated by the externality, an exposure subsidy can be better than a perpetual use subsidy when the perpetual use subsidy is insufficient to induce a present-biased agent to use the good because so much of the subsidy is heavily discounted in the distant future.

If a sufficiently large portion of the exposure subsidy is delivered immediately, then it would induce an uninformed agent to use the good (by overcoming the liquidity constraint) even though the agent would not be induced by the perpetual use subsidy. In that case, the exposure subsidy would also be superior to a purchase subsidy, which would induce a smaller fraction of agents to learn their match quality and would miss out on the positive externality that those agents would have generated.

Agents. There is a population of agents of measure one. Each agent chooses in each period whether or not to use a good to maximize the discounted stream of expected utility. If the agent does not use the good, then utility is zero. If the agent uses the good, then the agent derives utility from the direct net benefit of using the good (which could be negative) and from a subsidy σ set by a policymaker. If the agent is using the good for the first time, then the agent also pays a price p. The agent is liquidity-constrained in the sense that the agent cannot make decisions that would result in period utility falling below some lower bound. The discounted stream of expected utility in period t is:

$$U_t = \max_{r_t \in \{0,1\}} \sum_{j=0}^{\infty} \delta^j \int_{-\infty}^{\infty} u_{t+j} \;\; dF_t(\theta) \tag{35}$$

$$s.t. \quad \forall j \;\; u_{t+j} \geq \underline{\mathrm{u}} \tag{36}$$

where $r \in \{0,1\}$ is a discrete choice to either use the good or not, $\delta \in (0,1)$ is the agent's time discount factor, and $\underline{\mathrm{u}} < 0$ is the lower bound on period utility.

Utility in period t takes the form:

$$u_t = u(r_t, \theta_i) = r_t \alpha_r + r_t \theta_i \alpha_{r\theta} + r_t \sigma_t - r_t p \;\; \mathbb{I}\Big[\forall j < 0 : r_{t+j} = 0\Big] \tag{37}$$

where θ is match quality and $\mathbb{I}$ is an indicator function equal to one if the argument is true and zero if it is false. The population comprises agents with low and high match quality between the agent and the good. We assume that a fraction q of agents have low match quality, and $1 - q$ have high match quality, such that the population distribution of match quality can be expressed with the following probability mass function f with $q \in (0, 1)$:

$$f(\theta) = \begin{cases} q & \text{if } \theta = 0 \\ 1 - q & \text{if } \theta = 1 \end{cases} \tag{38}$$

We assume the signal is either fully informative or totally uninformative, such that the distribution of signals can be expressed with the following probability mass function g with $\gamma \in (0, 1)$:

$$g(\omega_t|\theta_i) = \begin{cases} \gamma & \text{if } \omega_t = -1 \\ 1 - \gamma & \text{if } \omega_t = \theta_i \end{cases} \tag{39}$$

Social planner. A social planner chooses a sequence of subsidies to maximize social welfare, which consists of the sum of the agent's utility and externalities net of subsidies. Each period the good is used, it generates a positive externality e. We assume the sequence of subsidies is constrained to be some positive value σ for some number of periods k and, if k is finite, zero thereafter. In other words, the social planner can choose the subsidy level σ and duration k but cannot tailor the subsidy to be a different magnitude in each individual period. The social planner thus chooses the subsidy level and duration to maximize welfare:

$$\max_{\sigma, k} \quad \sum_{j=0}^{\infty} \delta^j \int_{-\infty}^{\infty} (u_{t+j} + r_{t+j} e) dF_t(\theta) - \sum_{j=0}^{k-1} \delta^j r_{t+j}(\sigma) \tag{40}$$

where F is the cumulative distribution function corresponding to f.

We assume that the social planner follows through on all promises made at the time the agent first uses the good, i.e. there are no obstacles to credibly committing to a subsidy level and duration.

We assume:

- The net private benefit to an agent who knows she has high match quality is positive: $\alpha_r + \alpha_{r\theta} > 0$
- The net social benefit for a low match quality agent is negative: $\alpha_r + e < 0$
- The net private benefit to an agent who does not know her match quality is negative: $\alpha_r + \alpha_{r\theta}(1-q) + (1-q)(1-\gamma)\frac{\delta}{1-\delta}(\alpha_r + \alpha_{r\theta}) < 0$
- The net social benefit for an agent who does not know her match quality is positive: $\alpha_r + \alpha_{r\theta}(1-q) + e + (1-q)(1-\gamma)\frac{\delta}{1-\delta}(\alpha_r + \alpha_{r\theta} + e) > 0$

Solution for the agents. In order for the agent to use the good even once, utility in the first period the agent uses the good must exceed the lower bound: $\alpha_r + \sigma - p \geq \underline{\mathrm{u}}$. For an agent who does not know her match quality, the liquidity constraint binds as if she were known to have low match quality. If that criterion is not met, then non-adoption is the only feasible choice for the agent.

If $k = 1$ and $p = 0$, then expected utility at time t is:

$$\begin{aligned} U_t(\sigma, k) &= \max_{r_t \in \{0,1\}} \; r_t\sigma + \sum_{j=0}^{\infty} \delta^j \int_{-\infty}^{\infty} (r_{t+j}\alpha_r + r_{t+j}\theta_i\alpha_{r\theta}) dF_t(\theta) \\ &= \max\left\{\alpha_r + \alpha_{r\theta}(1-q) + \sigma + (1-q)(1-\gamma)\frac{\delta}{1-\delta}(\alpha_r + \alpha_{r\theta}), 0\right\} \end{aligned}$$

Pooling equilibrium. Define $\hat{\sigma}$ as the minimum subsidy such that an agent who knows she has low match quality chooses to use the good when $k = 1$ and $p = 0$: $\hat{\sigma} = -\alpha_r$. If the agent has not previously used the good (i.e. the price p must be paid) and $\sigma \geq \hat{\sigma}$ (i.e. an agent who knows she has low match quality behaves the same way as an agent with unknown match quality), then expected utility at time t is:

$$\begin{aligned}
U_t(\sigma, k) = \max_{r_t \in \{0,1\}} \quad & -r_t p + \sum_{j=0}^{\infty} \delta^j \int_{-\infty}^{\infty} (r_{t+j}\alpha_r + r_{t+j}\theta_i \alpha_{r\theta}) dF_t(\theta) + \sum_{j=0}^{k-1} \delta^j r_{t+j}\sigma \\
= \max \Bigg\{ 0, \quad & -p + \frac{1-\delta^k}{1-\delta}\Big(\alpha_r + (1-q)\alpha_{r\theta} + \sigma\Big) \\
& + (1-q)(1-\gamma^k)\frac{\delta^k}{1-\delta}\Big(\alpha_r + \alpha_{r\theta}\Big)\Bigg\}
\end{aligned}$$

Separating equilibrium. Define $\tilde{\sigma}$ as the minimum subsidy such that an uninformed agent chooses to use the good when $k = 1$ and $p = 0$:

$$\tilde{\sigma} = -\alpha_r - \alpha_{r\theta}(1-q) - (1-q)(1-\gamma)\frac{\delta}{1-\delta}(\alpha_r + \alpha_{r\theta})$$

If the agent has not previously used the good (i.e. the price p must be paid) and $\tilde{\sigma} < \sigma < \hat{\sigma}$ (i.e. an agent who knows she has low match quality behaves differently from an agent with unknown match quality), then expected utility at time t is:

$$\begin{aligned}
U_t(\sigma, k) = \max_{r_t \in \{0,1\}} \quad & -r_t p + \sum_{j=0}^{\infty} \delta^j \int_{-\infty}^{\infty} (r_{t+j}\alpha_r + r_{t+j}\theta_i \alpha_{r\theta}) dF_t(\theta) + \sum_{j=0}^{k-1} \delta^j r_{t+j}\sigma \\
= \max \Bigg\{ 0, \quad & -p + \underbrace{(1-q)\frac{1-\delta^k}{1-\delta}\Big(\alpha_r + \alpha_{r\theta} + \sigma\Big)}_{\text{utility of high match quality during first } k \text{ periods}} \\
& + \underbrace{(q)\frac{1-\delta^k\gamma^k}{1-\delta\gamma}\Big(\alpha_r + \sigma\Big)}_{\text{utility of low match quality during first } k \text{ periods}} \\
& + \underbrace{(1-q)(1-\gamma^k)\frac{\delta^k}{1-\delta}\Big(\alpha_r + \alpha_{r\theta}\Big)}_{\text{utility of known high match quality from period } k \text{ onward}} \Bigg\}
\end{aligned}$$

There are three possibilities: (1) the agent learns she has high match quality, (2) the agent learns she has low match quality, (3) the agent does not learn her match quality. If she learns she has low match quality, then she immediately disadopts the good. If she does not learn her match quality, then she disadopts when the subsidy ends after k periods. If she learns she has high match quality, then she continues using the good in perpetuity even after the subsidy ends.

Solution for the social planner. Using the indifference condition from the separating equilibrium solution for the agents, we see that an agent with unknown match quality is willing to use the good for the first time under an exposure subsidy if:

$$\begin{aligned} p < \underbrace{\alpha_r + (1-q)\alpha_{r\theta} + \sigma}_{\text{utility during first period}} \\ + \underbrace{(1-q)\left(\frac{\delta - \delta^k}{1-\delta}\right)\left(\alpha_r + \alpha_{r\theta} + \sigma\right)}_{\text{high match quality during first } k \text{ periods}} \\ + \underbrace{(q)\left(\frac{\delta\gamma - \delta^k\gamma^k}{1-\delta}\right)\left(\alpha_r + \sigma\right)}_{\text{low match quality during first } k \text{ periods}} \\ + \underbrace{(1-q)(1-\gamma)\frac{\delta^k}{1-\delta}\left(\alpha_r + \alpha_{r\theta}\right)}_{\text{high match quality after } k \text{ periods}} \end{aligned}$$

And:

$$\alpha_r + \sigma - p \geq \underline{\mathrm{u}}$$

The first condition is that the discounted stream of utility must be positive, and it is satisfied for the exposure subsidy under the same conditions as for the purchase subsidy and the use subsidy. This is because the subsidies have been constructed with equal present value, and their only influence on the discounted stream of utility is through present value.

We compare:

- A use subsidy with $\sigma = e$ and $k = \infty$

- A purchase subsidy with the same present value, with $k = 1$
- An exposure subsidy with the same present value, that minimally satisfies the second criterion (liquidity constraint), i.e. the largest k that achieves $\alpha_r + \sigma - p \geq \underline{u}$

For each subsidy, we set the present discounted value equal to $\frac{1}{1-\delta}e$. So:

$$\begin{aligned}
\sigma^*_{use} &= e \\
\sigma^*_{pur} &= \frac{1}{1-\delta}e \\
\sigma^*_{exp} &= \frac{1}{1-\delta^{k^*_{exp}}}e
\end{aligned}$$

If $\alpha_r + e - p \geq \underline{u}$ then a use subsidy with $k = \infty$ and $\sigma = e$ is optimal.

Assuming $\alpha_r + e - p < \underline{u}$, we derive k^*_{exp} (the duration of the exposure subsidy) as follows:

$$\begin{aligned}
\alpha_r + \tilde{\sigma} - p &= \underline{u} \\
\alpha_r + \frac{1}{1-\delta^{\tilde{k}}}e - p &= \underline{u} \\
\frac{1}{1-\delta^{\tilde{k}}}e &= \underline{u} + p - \alpha_r \\
\frac{e}{\underline{u} + p - \alpha_r} &= 1 - \delta^{\tilde{k}} \\
\delta^{\tilde{k}} &= \frac{\underline{u} + p - \alpha_r - e}{\underline{u} + p - \alpha_r} \\
\tilde{k} &= \frac{\log(\underline{u} + p - \alpha_r - e) - \log(\underline{u} + p - \alpha_r)}{\log(\delta)} \\
k^*_{exp} &= \text{floor}\left(\frac{\log(\underline{u} + p - \alpha_r - e) - \log(\underline{u} + p - \alpha_r)}{\log(\delta)}\right)
\end{aligned}$$

Where the last step is taken so that k^*_{exp} is the whole number that minimally satisfies the liquidity constraint (where the utility in period t exceeds $\underline{u}$).

An exposure subsidy defined in this way is superior to a purchase subsidy because a larger fraction of high match quality agents learn their match quality and continue using the good indefinitely.

There exists some subsidy level σ that (a) satisfies the liquidity constraint and (b) supports a separating equilibrium if and only if $p < -\underline{\mathrm{u}}$.

Assume $p < -\underline{\mathrm{u}}$. Then:

$$\begin{aligned} p &< -\underline{\mathrm{u}} \\ p + \underline{\mathrm{u}} &< 0 \\ p + \underline{\mathrm{u}} - \alpha_r &< -\alpha_r \end{aligned}$$

By continuity, $\exists \sigma$ such that:

$$p + \underline{\mathrm{u}} - \alpha_r < \sigma < -\alpha_r$$

The first inequality ensures that the liquidity constraint is satisfied. The second inequality ensures that a separating equilibrium is supportable.

Going in the opposite direction, assume that there exists a subsidy that (a) satisfies the liquidity constraint and (b) supports a separating equilibrium. Then:

$$\begin{aligned} p + \underline{\mathrm{u}} - \alpha_r < \sigma &< -\alpha_r \\ p + \underline{\mathrm{u}} &< 0 \\ p &< -\underline{\mathrm{u}} \end{aligned}$$

If $p > -\underline{\mathrm{u}}$, then the solution is a pooling equilibrium, and the solution trades off between subsidy "wasted" on agents who know they have low match quality and subsidy "spent" on agents who learn they have high match quality, along the lines of the solution to the model with administrative costs and information.

Appendix E Retrospective policy analysis (for online publication)

This section compares the relative effectiveness of the specific subsidies offered to promote the persistent use of water-efficient technologies in the field experiment. In other words, it considers whether a program manager with a fixed budget and a goal of maximizing the number of households using the technology at endline (2016) would have been better off spending an incremental dollar on the bonus for keeping the technology in place through the first audit at four months (exposure subsidy) or on the free installation (purchase subsidy).

To be concrete, we consider how the program manager could use an additional $1000. If the program manager spent $1000 on additional no-bonus installations, then the expected number of additional low-flow fixtures in use after 16 months would be 52 fixtures:

$$\underbrace{\frac{0.595}{0.869}}_{\text{No-bonus retention rate}} \times \underbrace{\$1000}_{\text{Budget}} \;/\; \underbrace{\$13.12}_{\text{Cost of installation}} = 52.2 \tag{41}$$

The cost of installing three low-flow fixtures is the sum of three components: (1) the price in San Jose for a bundle of one low-flow showerhead and two faucet aerators ($22.49), (2) the estimated cost of additional components (fixtures and adapters) required for the low-flow fixtures to operate ($14.59), and (3) the local cost of a plumber for installing these items ($2.28).[10] The cost of installing one fixture is the total cost of installing three fixtures divided by three ($13.12 = $39.36 / 3).

In contrast, if the program manager spent $1000 on subsidies of the same size and timing as in the bonus group to households where the technology was already installed but were not yet being offered a bonus, then the expected number of additional low-flow fixtures in use after 16 months would be 3.3 fixtures.

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[10] The bundle was not sold in the communities, but it was available in the capital city of San Jose, approximately 100 kilometers from the nearest community in the study.

$$\underbrace{\frac{0.640 - 0.595}{0.841}}_{\text{New fixtures per fixture receiving bonus}} \times \underbrace{\$1000}_{\text{Budget}} \;/\; \underbrace{\$16.4}_{\text{Average bonus per fixture}} = 3.3 \qquad (42)$$

The components of the calculation for new fixtures per fixture receiving the bonus are from Table 2. Each household in the cash-bonus group was offered 20,000 colones (approximately $36) if all installed low-flow fixtures were in use during the 2015 audit. The bonus payment was equal to the fraction of low-flow fixtures in use times the maximum possible bonus. For example, if two fixtures were installed in a household, and only one fixture was in use during the 2015 audit, then that household was paid 10,000 colones (20,000 colones x 1 fixture in use during audit / 2 fixtures installed). The average bonus per fixture was $16.4, which was a result of the interaction between the distribution of low-flow fixtures (shown in Figure 2) and the pattern of retention and disadoption.

We find that, in this context, it would have been better to recruit additional households. It is possible that other patterns of exposure subsidies—e.g. a larger subsidy at a later date—would have outperformed additional recruitment. In particular, holding fixed the size of the exposure subsidy, we suspect that it would have had a greater impact on use at 16 months if it were awarded more than four months after initial installation. The four-month disadoption rate in the no-bonus control group was just 22 percent, so the subsidy only had an opportunity to change behavior among that subset of the population.

Appendix F Tables (for online publication)

Table F.1: Households in sample and water prices by community

		Price (Costa Rican Colones)		
Community	Households	Fixed price per month	First block per m^3	Last block per m^3
Chomes	150	3415	160	195
Los Jocotes	86	2745	150	150
Lepanto	106	3415	160	195
Lomas Matapalo	23	3180	185	225
Moracia	127	2695	155	200
Paso Tempisque	159	3415	160	195
Pueblo Nuevo	50	2800	190	230
San Blas	133	3415	160	195
Santa Rita-Zapal	36	3085	190	230
Total	870			

Note: Households were recruited from nine communities in Guanacaste and Puntarenas provinces in Costa Rica. Households in most communities paid a monthly water bill according to a fixed price per month and schedule of four marginal block prices. Households in Los Jocotes faced a single marginal price of 150 Costa Rican Colones per cubic meter. One Costa Rican Colón was approximately 0.0018 U.S. Dollars at the time of the experiment.

Table F.2: Summary statistics – balance by treatment assignment

Variable	(1) No-bonus control	(2) Bonus treatment	(3) Difference
# of individuals in household	3.81	3.54	-0.27
	(1.89)	(1.66)	(0.12)
Owns home	0.85	0.90	0.05
	(0.36)	(0.30)	(0.02)
Years in home	17.98	18.50	0.52
	(15.80)	(14.83)	(1.04)
Missing income range	0.08	0.07	-0.01
	(0.27)	(0.26)	(0.02)
Less than 75,000 CRC/mo	0.12	0.11	-0.02
	(0.33)	(0.31)	(0.02)
75,000 to 125,000 CRC/mo	0.20	0.21	0.00
	(0.40)	(0.40)	(0.03)
125,000 to 250,000 CRC/mo	0.28	0.30	0.02
	(0.45)	(0.46)	(0.03)
250,000 to 450,000 CRC/mo	0.20	0.20	-0.00
	(0.40)	(0.40)	(0.03)
More than 450,000 CRC/mo	0.12	0.12	0.01
	(0.32)	(0.33)	(0.02)
Imputed income, CRC/mo, thousands	232.05	235.69	3.64
	(162.76)	(162.11)	(11.46)
Missing water use	0.03	0.03	-0.00
	(0.18)	(0.18)	(0.01)
Cubic meters per month, 2014	24.72	25.44	0.71
	(14.00)	(15.62)	(1.02)
Avg monthly water bill, CRC, thousands	7.37	7.47	0.11
	(2.53)	(2.71)	(0.18)
Household head completed primary school	0.81	0.81	0.01
	(0.40)	(0.39)	(0.03)
Household head completed secondary school	0.29	0.25	-0.04
	(0.45)	(0.43)	(0.03)
Fixture locations	2.35	2.42	0.07
	(0.92)	(0.97)	(0.06)
Showerhead fixture locations	1.02	1.04	0.02
	(0.26)	(0.33)	(0.02)
Bathroom faucet fixture locations	0.76	0.79	0.03
	(0.46)	(0.46)	(0.03)
Kitchen faucet fixture locations	0.57	0.60	0.02
	(0.57)	(0.59)	(0.04)
Observations	432	438	870

Standard deviations and standard errors in parentheses

Note: This table reports the mean and standard deviation of observable characteristics for households that agreed to participate in the experiment and install water-efficient technology. The baseline survey asked households about income ranges. Imputed income is the average of the lower bound and upper bound of the income range indicated by the household. For the highest income range, imputed income is 125% of the lower bound, 450,000 Costa Rican Colones per month, which is approximately equivalent to $810 per month, or $9,720 per year. One Costa Rican Colón was approximately 0.0018 U.S. Dollars at the time of the experiment.

Table F.3: Summary of attrition

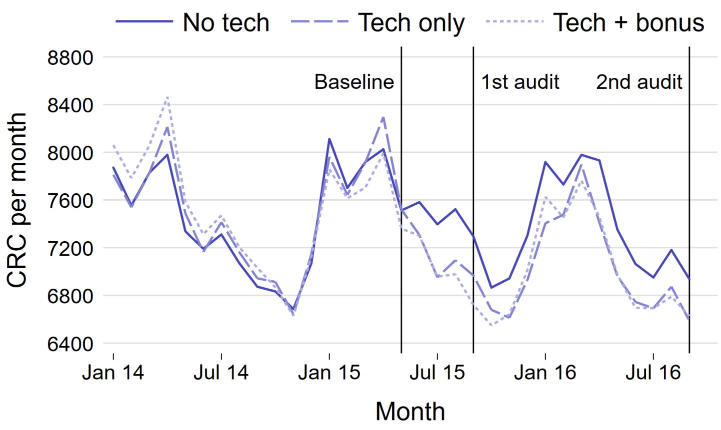
	Household presence in audits					
	No-bonus control		Bonus treatment		Full sample	
	Count	%	Count	%	Count	%
Treatment assignment	432	100.0	438	100.0	870	100.0
Treatment and outcome data present	341	78.9	383	87.4	724	83.2
Missing treatment	60	13.9	34	7.8	94	10.8
Missing outcome	19	4.4	11	2.5	30	3.4
Missing both	12	2.8	10	2.3	22	2.5

	Fixture presence in audits					
	No-bonus control		Bonus treatment		Full sample	
	Count	%	Count	%	Count	%
Treatment assignment	1016	100.0	1060	100.0	2076	100.0
Treatment and outcome data present	829	81.6	937	88.4	1766	85.1
Missing treatment	123	12.1	75	7.1	198	9.5
Missing outcome	42	4.1	26	2.5	68	3.3
Missing both	22	2.2	22	2.1	44	2.1

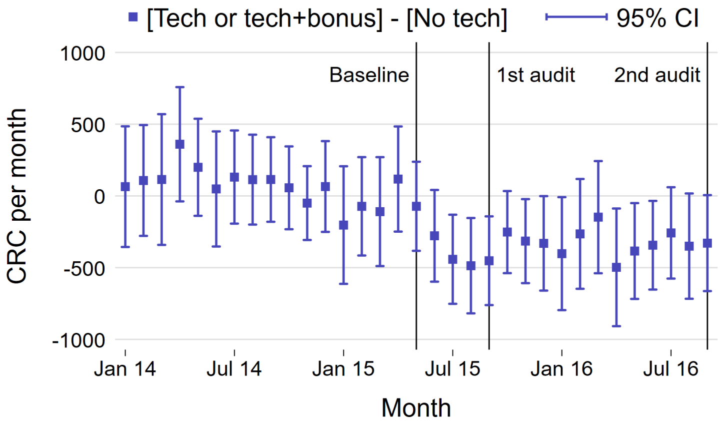
Note: Of the 870 households in the sample, installation was unsuccessful in 6 households, 122 households were missing from the 2015 audit and an additional 30 were missing from the 2016 audit. Fewer households attrited from the bonus treatment group than from the no-bonus control group.

Appendix G Figures (for online publication)

Figure G.1: Average monthly water bill by treatment assignment



(a)



(b)

Note: During a visit by the field team in May–June 2015, households were randomly assigned to one of three treatment conditions: (1) no-technology control (no tech), (2) low-flow water fixtures (tech), or (3) low-flow water fixtures plus a cash bonus if the fixtures were still in use during the first audit (tech+bonus). Households were not told to expect a second audit, and no bonus was promised or paid after the first audit.