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## Technology adoption subsidies: An experiment with managers<sup>☆</sup>

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### ABSTRACT

We evaluate the impact of technology adoption subsidies on investment behavior in an individual choice experiment. In a laboratory setting professional managers are confronted with an intertemporal decision problem in which they have to decide whether or not to search for, and possibly adopt, a new technology. Technologies differ in the per-period benefits they yield, and their purchase price increases with the per-period benefits provided. We introduce a subsidy on the more expensive technologies (that also yield larger per-period benefits), and find that the subsidy scheme induces agents to search for and adopt these more expensive technologies even though the subsidy itself is too small to render these technologies profitable. We speculate that the result is driven by the positive connotation (affect) that the concept 'subsidy' invokes.

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### 1. Introduction

In many OECD countries, firms and households can collect government subsidies if they adopt certain technologies or appliances with socially desirable characteristics. Many technologies and appliances provide not only benefits to the owner, but also to society at large. This certainly holds for environmentally friendly technologies such as double glazing, insulation, high-efficiency diesel engines, etc. These technologies have in common that they reduce the owner's energy bill, but they also mitigate the emissions of environmentally hazardous pollutants such as greenhouse gases and sulphur dioxide. If the private investment costs associated with such technologies are larger than their private benefits but smaller than the social benefits, adoption is socially desirable but not privately optimal. If the regulator is unwilling or unable to set environmental taxes at the Pigouvian

level (because of, for example, political economy considerations or concerns regarding international competitiveness of the domestic industry), subsidies may be used to induce adoption.<sup>1</sup> Examples of environmental subsidy programs include the US Energy Policy Act of 2005 (Public Law 109-58-Aug. 8 2005) which envisages spending \$12.3 billion over the period 2005–2015 on affecting investment behavior of both households and firms, and the Netherlands' Energy Investment Credit (EIA) program that provides subsidies targeted at small- and medium-sized firms, with a budget of close to 1% of total government spending in the Netherlands.

Notwithstanding their widespread use, the effectiveness of subsidies has been subject to debate, among politicians and scientists alike.<sup>2</sup> To date, there are relatively few empirical studies that can inform this debate, and the available evidence is mixed. The most widely studied subsidy program is the Demand Side Management (DSM) program for households, implemented by electric utilities in the US in the 1990s. According to some studies (for example Walsh, 1989; Joskow and Maron, 1992; Malm, 1996) the program was

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<sup>1</sup> That is, assuming that firms only care about their own private profits, and ignore the external benefits of adopting environmentally friendly technologies. But even if firms do take these externalities into account – because of ethical considerations, or because of reasons of corporate responsibility – they may value them less than society does. Then subsidies may still be necessary to induce firms to adopt the socially optimal technologies.

<sup>2</sup> See International Energy Agency (2005) for an overview of the various arguments in this discussion.

ineffective in stimulating the adoption of energy-saving appliances because a large fraction of the households that did install an energy-efficient appliance would have done so anyway — that is, even without subsidies. This conclusion was however challenged by other studies who find that subsidies are effective in inducing adoption after all (e.g., *Hassett and Metcalf, 1995; Revelt and Train, 1998*).

The most important reason why this debate is still unsettled is because of the lack of a counterfactual. Each specific technology's net private benefits tend to differ from firm to firm and from household to household (see for example *DeCanio and Watkins, 1998*). To determine whether subsidies really affect investment behavior, the researcher would like to know what technology each individual firm would adopt if subsidies were available, and if they were absent. Such data do not exist for obvious reasons, and there are also hardly any natural experiments available that can shed light on the investment behavior of (specific types of) firms. Between-firms data are usually not available because subsidy programs either apply to all firms in a specific industry, or to none. And it is also difficult to exploit temporal variation: comparing adoption behavior before and after the introduction of a subsidy scheme does not provide a fully reliable comparative static either since economic circumstances (business cycle, interest rates, etc.) are often different in the time periods before and after the introduction. Indeed, the *ceteris paribus* condition is essential in these types of studies because of the importance of firm characteristics and economic circumstances in determining investment behavior.

In this paper we aim to shed light on the impact of subsidies on adoption behavior by means of an economic laboratory experiment in which firm managers make decisions regarding the adoption of energy-saving technologies.<sup>3</sup> We construct an individual choice experiment in which our manager subjects can search for and possibly adopt technologies that reduce the amount of energy used, where there is uncertainty about the number of periods these technologies last and where searching is costly as it diverts away the decision maker's attention from other decisions that need to be made within a firm (for example regarding output, marketing etc.). By imposing this structure on the experiment we try to mimic the circumstances under which decision makers within firms tend to make the investment choices. Another important element of our experiment is that the managers we recruited are experienced in making investment decisions (subsidized or otherwise), either as employees or as self-employed entrepreneurs. Because of the tight control about the circumstances provided by the lab, we can create a proper counterfactual by randomly assigning managers to either a treatment in which some (but not all) technologies are subsidized, or to a treatment in which there are no subsidies available. Thus, we control for differences in economic circumstances as well as in firm characteristics, and we also prevent managers to self-select into those who are more or less prone to soliciting subsidies for (unobservable) reasons that may be present in real world situations. By using managers rather than students as subjects, we prevent our results from being biased because the lack of experience students have with investing in energy-saving technologies or appliances could affect the way in which they cope with uncertainty and complexity (*Ball and Cech, 1996, p. 266*).

The main question we address in this study is whether and how the decisions in this investment problem are affected by the

introduction of a technology adoption subsidy. We compare a control treatment without a subsidy to a treatment in which a subset of the most expensive technologies (i.e., those with the highest expected per-period savings) is subsidized. In line with subsidy programs such as the Energy Investment Credit (EIA) in the Netherlands, the presence of a subsidy scheme has a dual impact in our experimental setup. The first effect is that it increases the Net Present Value (NPV) of the technologies within the subsidized set, which are typically also the most expensive technologies. The second effect of the subsidy scheme is that it allows for directed search. If search can be directed toward the subsidized technologies, search can also be directed away from them.

Our experimental setup is characterized by two important features. First, the technology choices of the participants do not impose an externality in the experiment. There are no social consequences of the technologies adopted, only private ones. While pro-social motivations (including corporate responsibility) undoubtedly play a role in many instances of real world investment behavior, we decided to suppress such considerations in our experiment in order to prevent our results from being confounded by the possible presence of such motivations.<sup>4</sup> A second important feature of our experiment is that the subsidized technologies have a lower expected Net Present Value than the non-subsidized ones. The subsidy narrows the gap between the 'cheap' and the 'expensive' technologies, but it does not close it. Clearly this setup provides a very stringent test of the effectiveness of a subsidy — do subsidies induce adoption of the most expensive technologies even if they remain financially unattractive?

Even in such a 'hostile' environment subsidies may still be effective. In the real world as well as in our experiment, decisions about investments are complex. In view of the fact that people (even managers) have limited cognitive abilities, it is not at all obvious to see whether or not a subsidized technology is in fact profitable. For this reason, other motives than purely financial considerations can be important too. In particular, associative and affective processes may play a role here, and the presence of a subsidy may be a cue that triggers such processes as it can be perceived as an endorsement of the subsidized technologies, as an encouragement, or as some free money or a tax rebate. A subsidy may thus lead to more adoption of these technologies. Whether it does is of course another question; one that will be addressed by our experiment.<sup>5</sup>

In essence our framed field experiment is an optimal stopping problem not unlike job search models such as studied by, for example, *Cox and Oaxaca (1989, 1992)*, *Schotter and Braunstein (1981)*, and *Sonnemans (1998, 2000)*. In these experiments decision makers are confronted with random wage offers and need to decide whether to accept an offer or to ask for another one, where each additional offer involves a search cost. The decision problem that the managers in our experiment face is substantially more complex, though. For example, the search costs are uncertain, the offers are two-dimensional, and the number of periods each game lasts is uncertain.

The remainder of the paper is organized as follows. The next section describes the main features of the model. Section 3 describes the experimental design and procedure. In Section 4 we present the results and in Section 5 we provide an explanation for the observed behavior. Section 6 concludes.

<sup>3</sup> That is, we run a so-called framed field experiment. Such an experiment differs from conventional lab experiments in that it (i) uses a nonstandard subject pool, and (ii) provides field context in the commodity, task or information set that the subjects can use (*Harrison and List, 2004, p. 1014*). Our experiment does both. Using managers rather than student subjects implies that our subjects are the same agents as the ones targeted by government subsidy programs — thus making sure that our results are not biased because of student subjects using different decision rules than the agents in the field. And by framing the decision to be made as an investment problem our manager subjects have experience with, we avoid any confusion about the task in the experiment.

<sup>4</sup> Indeed, it is not our purpose to come up with a point estimate of the subsidy elasticity of adoption; the lab is not the appropriate test environment for such an endeavor because of the many other considerations that may affect adoption behavior in the real world (including ethics and corporate responsibility considerations but also technical characteristics such as the age of firms' machines and technologies). Instead, we use the lab to have as much control as possible over the factors that may affect behavior other than the ones we intend to study.

<sup>5</sup> Note that if we had chosen parameters such that the subsidized technologies had a higher NPV than the non-subsidized ones, we would have a perfect confound if we observed managers searching for subsidized technologies — do they do so because of financial reasons, or for other reasons too?

## 2. The model

In this section we present a formal version of the decision problem that motivated our experimental design. We also outline the solution to this problem under the assumption that the decision maker is an unboundedly rational and risk neutral profit maximizer. Although we obviously cannot expect our subjects to behave in line with this solution, it still serves as a useful benchmark. First we consider the case in which no subsidies are available, and then the case in which a subset of technologies is subsidized.

The decision maker in our model faces the option to invest in a new technology. New technologies are of the efficiency-improving kind: compared to the existing technology, they yield savings on the use of a specific input, “energy”. There is a range of technologies ‘on the market’ that differ in the per-period savings they provide as well as with respect to the investment costs associated with their adoption. We use  $e \geq 0$  to denote the monetary savings per period, with  $e$  uniformly distributed on support  $[0, E]$ . Any new technology purchased is assumed to replace the one currently in use; when purchasing multiple new technologies, only the benefits of the technology most recently adopted count. The investment costs of new technologies are a positive function of the per-period savings they yield as captured by the following specification:

$$I(e) = \begin{cases} (v_0 - v)e & \forall e \in [0, \frac{1}{2}E] \\ (v_0 + v)e - vE & \forall e \in (\frac{1}{2}E, E] \end{cases} \quad (1)$$

with  $v_0$  and  $v$  being (arbitrary) constants and where  $0 < v < v_0$  such that  $\partial I / \partial e > 0$  in the two subdomains  $[0, \frac{1}{2}E]$  and  $(\frac{1}{2}E, E]$ . Note, however, that whereas  $I(e)$  is continuous on  $[0, E]$ , it is not differentiable at  $\frac{1}{2}E$ . The investment function is flatter (steeper) to the left (right) of  $\frac{1}{2}E$ .

In principle, technologies are infinitely lived, but we assume that the firm is forced to exit the market with a constant probability. The probability of surviving another period is denoted by  $\alpha$  ( $0 < \alpha < 1$ ), and hence  $1 - \alpha$  is the probability that the game ends after the current round. Using a constant probability that the game ends has two advantages. First, it is mathematically identical to time discounting but much easier for subjects to understand in the experiment. Second, using a constant continuation probability gives a natural way to end the game while it ensures that decisions are time-independent. Note that this would not be the case with a fixed terminal period.

Given our assumption of a constant probability of being forced to exit the market, the expected Net Present Value (ENPV) of a technology ( $\pi$ ) with savings equal to  $e$  is:

$$\pi^{NS}(e) = \sum_{t=0}^{\infty} \alpha^t e - I(e), \quad (2)$$

where superscript NS refers to the case of no subsidization. As stated above,  $v_0$  and  $v$  are essentially arbitrary constants of the investment

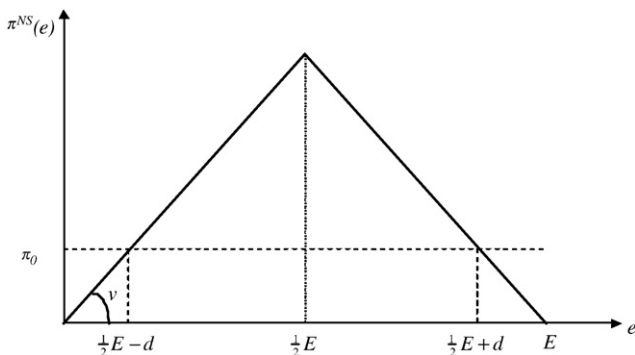


Fig. 1. Expected net present values and critical values in the absence of a subsidy.

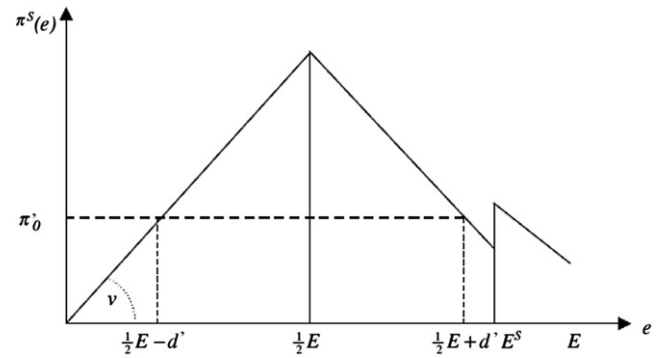


Fig. 2. Expected net present values and critical values in the presence of a subsidy.

cost function. For mathematical (and experimental) simplicity, let us set  $v_0$  equal to  $1 / (1 - \alpha)$  in Eq. (1) – and choose  $v$  such that  $v < v_0$ . Substituting  $v_0 = 1 / (1 - \alpha)$  into Eq. (1), inserting  $I(e)$  into Eq. (2) and noting that  $\sum_{t=0}^{\infty} \alpha^t e = e / (1 - \alpha) = v_0 e$ , we have

$$\pi^{NS}(e) = \begin{cases} ve & \forall e \in [0, \frac{1}{2}E] \\ v(E - e) & \forall e \in (\frac{1}{2}E, E]. \end{cases} \quad (3)$$

Fig. 1 illustrates this function. It is pyramid shaped with its top at  $e = \frac{1}{2}E$ , and symmetric to the left and right of this level of savings. Accordingly, private benefits of adopting a new technology are largest for technologies in the middle range (with technology  $e = \frac{1}{2}E$  providing the highest ENPV) and smaller the further they are away from the middle range. This specification captures the idea that the most innovative technologies are usually ‘too expensive’ even if they provide a lot of per-period benefits.<sup>6</sup>

The decision maker in our experiment cannot simply go and purchase the technology with the highest ENPV. She has to search for these technologies, and this search is costly. We assume that in each period the decision maker can search for at most one new technology. A search generates a technology offer by means of a random draw (with replacement) from the range  $[0, E]$ .

When searching for a new technology, however, the decision maker does not have time to also make optimal decisions with respect to the amount of output she wishes to produce in the same period. Demand for her output fluctuates, and hence the decision maker needs to readjust her production decisions in every period in order to maximize profits from sales. We set the expected value of the opportunity costs of searching (in terms of not being able to optimally adjust output) equal to  $Z$ ; see also the next section as well as Appendix A.

Confronted with the choice to either search for a new technology or optimally adjust her output, the decision maker has to trade off the opportunity cost of search against the possibility to find a better technology. It can be shown (see Appendix A) that under risk neutrality the optimal strategy is to search until one finds a technology with an ENPV above some critical value ( $\pi^{NS}(e) \geq \pi_0$ ). As illustrated in Fig. 1, this implies that the decision maker should search until she finds a technology within a certain maximum distance  $d$  from the technology with the highest ENPV,  $e = \frac{1}{2}E$ . This distance depends on the various parameters of our model (i.e.,  $\alpha$ ,  $E$ ,  $v$ , and  $Z$ ).

<sup>6</sup> Note that the piecewise-linear profit function, which is the result of specifying a piecewise-linear investment function (1), ensures that making incorrect choices regarding technology adoption is more costly than if we had used a function that is differentiable at its peak, such as an inverted  $U$ -shaped function. Evaluated at  $e = 0.5E$ ,  $\partial \pi / \partial e = 0$  for the latter function whereas  $|\partial \pi / \partial e| = v \gg 0$  with the piece-wise linear specification. Hence, the incentives to find the best available technology are stronger if the profit function is piece-wise linear than if it is an inverted  $U$ -shaped function.

For example, the more expensive it is to search, i.e. the higher search cost  $Z$ , the less picky one should be with respect to accepting technology offers, and hence the larger  $d$  will be. This completes the description of the decision making problem in case of no subsidies.

Now suppose the government wishes to stimulate the adoption of technologies that provide higher per-period physical (and monetary) input savings. As these technologies have a lower ENPV than those in the middle range, the government may decide to subsidize those technologies at the top end. Therefore we assume that when adopting technologies with savings  $e$  in the range  $[E_S, E]$  (with  $E_S \gg \frac{1}{2}E$ ), the firm receives a subsidy of size  $s(e)I(e)$ . That means that the subsidy function is specified as follows:

$$s(e) = \begin{cases} 0 & \forall e \in [0, E_S) \\ s > 0 & \forall e \in [E_S, E] \end{cases} \quad (4)$$

Adding subsidies  $s(e)I(e)$  to the ENPV defined in Eq. (3), the ENPV now becomes:

$$\pi^S(e) = \begin{cases} ve & \forall e \in [0, \frac{1}{2}E] \\ v(E - e) & \forall e \in (\frac{1}{2}E, E_S) \\ v(1 - s)(E - e) + se / (1 - \alpha) & \forall e \in [E_S, E] \end{cases} \quad (5)$$

where superscript S refers to the case of subsidization. Fig. 2 illustrates this function. Its top is still at  $e = \frac{1}{2}E$ , but now there is a discontinuous upward jump at  $e = E_S$ .

As is the case in many (environmental) subsidy programs, decision makers in the Subsidy treatment can indicate whether they wish to receive a technology offer from the range of subsidized technologies  $[E_S, E]$ , or not  $[0, E_S)$ . Indeed, several programs offer a list of technologies that are subsidized, and hence agents have the choice to look for a technology themselves, or scrutinize the list of subsidized technologies.<sup>7</sup> Hence, we allow for directed search.

Subsidies have a dual impact on decision making in this setup, compared to the no-subsidies case. They affect the technologies' relative profitability, and they allow decision makers to deliberately search for subsidized or non-subsidized technologies. For the parameters  $E_S$  and  $s$  we chose in our experiment, the ENPV of a technology offer drawn from the set of subsidized technologies is smaller than that of an offer drawn from the set of non-subsidized technologies. Therefore, it is never optimal to search for a subsidized technology because the ENPV on domain  $[0, E_S]$  is strictly higher. As a result, the optimal search rule is analogous to the case without subsidies: a critical value  $\pi'_0$  of the ENPV can be calculated below which search should continue, and above which adoption is optimal. This critical value is larger than in the case without the subsidy ( $\pi'_0 > \pi_0$ ) because the ENPV of technologies in the range  $[0, E_S]$  is larger than the ENPV of technologies in the range  $[0, E]$ . This critical ENPV can again be indicated by means of a horizontal line. As indicated in Fig. 2, this implies that the decision maker should search until she finds a technology within a certain maximum distance  $d'$  from the technology with the highest ENPV. Because  $\pi'_0 > \pi_0$ , we have  $d' < d$ . Since the critical range is symmetric, the technology that will ultimately be adopted has in expectation the same value of savings  $e$ ;  $\varepsilon\{e | e \in [\frac{1}{2}E - d'; \frac{1}{2}E + d']\} = \varepsilon\{e | e \in [\frac{1}{2}E - d; \frac{1}{2}E + d]\} = \frac{1}{2}E$ .<sup>8</sup> So, the main predicted effect of the subsidy is that search will be directed

<sup>7</sup> An example of such a program is the Energy Investment Credit (EIA) program in the Netherlands, which only subsidizes energy-saving technologies that appear on the so-called Energy List. See Aalbers et al. (2007) for details.

<sup>8</sup> The subsidy should induce exclusive search for non-subsidized technologies. This increases the probability that a technology offer will be within the acceptable range even though the acceptable range is somewhat smaller in this case ( $d' < d$ ). Formally,  $Pr\{e \in [\frac{1}{2}E - d'; \frac{1}{2}E + d'] | e \in [0, E_S]\} > Pr\{e \in [\frac{1}{2}E - d; \frac{1}{2}E + d] | e \in [0, E]\}$ . As a result the subsidy scheme will increase the adoption speed compared to the no-subsidies case. For the parameters in our experiment, however, this effect is rather small.

**Table 1**  
Overview of the treatments.

Treatment	Subsidy	# subjects	# games
NS	No	25	125
S	6%	23	115

away from the subsidized technologies. The technologies actually adopted, though, will be characterized by the same level of average savings, irrespective of the presence of the subsidy.

As stated in the first paragraph of this section, this prediction is based on the assumption that managers are risk neutral. However, allowing for risk aversion only reinforces the fact that searching for a non-subsidized technology is the optimal strategy. Consider two technologies that have the same expected net present value,  $e_L = \bar{e} - \frac{1}{2}E$  and  $e_H = E - \bar{e} > \frac{1}{2}E$ . Absent risk aversion, these two technologies are equally preferred as they yield the same level of expected profits, and all technologies in between (i.e.,  $\bar{e} < e < E - \bar{e}$ ) are even more attractive. With risk aversion, this is no longer true. Investment costs are incurred in the early periods of the game, whereas the benefits (in terms of per-period savings) materialize as the game continues. If the game ends after the first round, the subject makes a negative profit equal to  $e - I(e) < 0$ , and this loss is clearly larger for technology  $e_H$  than for technology  $e_L$ . If subjects are sufficiently risk averse, they will try to reduce their expected losses by choosing less expensive technologies. Hence, for the same expected net present value, risk averse subjects' expected utility is largest for the one with the lower up-front investment costs. Given that the (technologically superior but very expensive) subsidized technologies have lower expected net present values than the technology the subject expects to draw in the non-subsidized region, risk aversion reinforces the agent's preference for non-subsidized technologies.<sup>9</sup>

Thus, our main prediction is that search will be directed away from the subsidized technologies. The subjects in our experiment are professionals in their field, and experienced in making investment decisions in complex environments. So the natural null hypothesis is that they will make decisions much in line with these predictions, rendering the subsidy ineffective. The alternative hypothesis is that the subsidy adds something distinctly positive to the top-end technologies, making them more attractive and leading to more investments in these expensive technologies than absent any subsidies.

### 3. The experiment

#### 3.1. Experimental design

The experiment was run as a between-subjects design with the level of the subsidy (no subsidy or 6% subsidy) as treatment factor. Subjects are randomly assigned to one of the treatments and in total 48 managers participated in the experiment, distributed about equally between the two treatments (see Table 1). The experiment is an individual decision making experiment, i.e. with no interaction between subjects, and this was also stressed to the subjects. The instructions for the subsidy treatment are posted as Appendix B on the journal's web site.

Each subject played 6 games; the first was an unpaid practise trial, the last five were paid out. All games were identical, apart from the realization of random variables (see below). Each game consisted of a

<sup>9</sup> One may argue that requesting a technology offer from the subsidized region may still be attractive because conditional on searching in that area the probability of getting a successful offer is larger than when searching in the non-subsidized region. For our parameters and for reasonable levels of risk aversion, however, the expected utility of drawing a technology from the subsidized region is smaller than the expected utility of not adopting at all (that is, focusing on the output market).

sequence of periods. After each period there was a 90% chance that the game would go to the next period and a 10% chance that the game would end (i.e.  $\alpha = 0.9$ ).

At the beginning of each period subjects had to choose between (i) setting output, and (ii) searching for a new technology. If they chose to set output they could not search for (or adopt) a new technology, and vice versa. When subjects decided to set output, they had to choose the number of units of output they wanted to produce. They knew the demand function ( $P(Q) = a_t - 2 / 375Q$ ) and the cost function ( $C(Q) = 1.6Q$ ), and hence sales profits were equal to  $PQ - 1.6Q$ . The variable  $a_t$  was a random variable (fluctuations in demand) drawn independently in each period from a uniform distribution on [1.6, 2.4]. The realization of  $a_t$  was revealed to the subjects only after they had made their choice whether to set output or to search for a new technology. If they had chosen to search, they were informed about the realization of  $a_t$  but could not act on it; output was set equal to zero ( $Q = 0$ ) and consequently the sales profits were also equal to zero.<sup>10</sup> If they had chosen to set output, they could act on the revealed information about  $a$  by optimally adjusting output  $Q$ . To facilitate finding the optimal amount, subjects were also provided with a profit table which gave the value of profits as a function of  $Q$  for different realizations of  $a$ . With the help of this table it was easy to determine the optimal level of  $Q$  given  $a$  (and subjects made few mistakes here). It can be derived that with this setup expected sales profits per period ( $Z$ ) were equal to 10 (see Appendix A), and this constitutes the opportunity costs of searching for a new technology.<sup>11</sup>

Regarding technology choice, subjects were informed about the relationship between  $I$  and  $e$  (cf. Eq. (1)) by means of both a figure and a table. At the beginning of each game, subjects were endowed with a default technology that did not yield any savings ( $e = I = 0$ ). When searching for a new technology in the No-Subsidy treatment, subjects knew they would receive a technology offer randomly drawn from the uniform distribution on [0,25] (i.e.  $E = 25$ ), and they were informed about both the per-period savings  $e$  and the associated investment costs  $I(e)$ . Then they first had to decide whether they liked this technology better than the one they were currently using, and also whether they liked it better than the technologies they were offered in earlier rounds of the game (if any). And finally they needed to decide whether they wanted to purchase their preferred technology.

In the Subsidy treatment, subjects were informed that there was a subsidy of 6% off the investment cost  $I(e)$  if they decided to buy a technology with per-period benefits 22 or higher (i.e.  $E_S = 22$ ). Here subjects had to decide whether they wanted to search for a technology without subsidy, in which case  $e$  would be randomly drawn from the uniform distribution on [0,22], or to search for a subsidized technology, in which case  $e$  would be randomly drawn from the uniform distribution on [22,25]. After this choice subjects were informed about the benefits  $e$ , the corresponding investment costs  $I(e)$ , and the size of the subsidy  $S$  of the current technology offer. Then, as in the No-Subsidy treatment, they had to decide whether they liked this offer better than the one they liked best so far, and whether they wanted to purchase their preferred technology.

At the end of the period, subjects were informed about their earnings for the period. If the game continued, the procedure in the new period was identical to the previous one. If the game ended, the

<sup>10</sup> The main advantage of using a zero default value for  $Q$  is that this implies that the opportunity costs of search are constant (and non-negative) across periods, which also means that the optimal search pattern is constant across periods. If, for example, the default quantity were set equal to last period's value the critical ENPV would be dependent on the level of  $Q$  chosen in the previous period, making theoretical predictions and statistical analyses unnecessarily cumbersome.

<sup>11</sup> Note that the fact that we embed the investment choice in a richer decision environment implies search costs that are not exogenous as in most search experiments. This special feature of our framed field experiment is included to better mimic reality.

**Table 2**

The distribution of the firm sizes in the Ministry Agency's database, in the Netherlands, and in our experiment.

Firm size (# employees)	Database Senter	Netherlands <sup>a</sup>	Our experiment
0–10	43%	81.5%	56% (27)
11–50	34%	14%	25% (12)
51–100	7%	2%	8% (4)
101–250	4%	1.5%	0% (0)
>250	10%	1%	10% (5)

<sup>a</sup> All industries except agriculture and fisheries, utilities, government and education (source: CBS Statline).

experiment would proceed to period 1 of the next game, or, if there had been six games already, the experiment would end. A subject's earnings in the experiment were equal to the accumulated earnings in games 2–6. Note that in each game, the total earnings are equal to the sum of the profits from setting quantity  $Q$  plus the sum of all per-period benefits ( $e$ ) from the technology used minus the investment cost ( $I$ ) for each technology purchased plus any subsidies ( $S$ ) on technologies purchased.

By inserting the parameter values used in the experiment in the model, and assuming risk neutral payoff maximizing agents we can derive the optimal search strategy. We only mention the most important properties of that strategy here. First of all, parameters are chosen such that the expected net benefits of searching for a new technology are positive. Next, it is always best to start searching in the first period of a game. A new technology that is adopted becomes productive in the same period in which the adoption takes place, and neither new information arrives over time nor do available technologies become more efficient over time. By postponing searching, one foregoes the profit flow associated with the use of the technology earlier in the game. Third, in the No-Subsidy treatment it is optimal to purchase any technology offer with savings ( $e$ ) between 3.93 and 21.07 (i.e.,  $d = 8.57$ ). The probability of receiving such an offer in every period equals  $(21.07 - 3.93) / 25 = 0.69$ , and hence the expected number of periods before adoption takes place (the optimal expected adoption speed) equals  $1 / 0.69 = 1.46$ . In the Subsidy treatment, we chose the parameter values such that it is optimal to direct search toward the non-subsidized technologies. When doing so it is optimal to purchase any technology with savings ( $e$ ) between 4.39 and 20.61 (i.e.,  $d' = 8.11$ ), which implies an optimal expected adoption speed of 1.36 periods.

3.2. Experimental procedure

All sessions of the computerized experiment were run at CentERLab, Tilburg University, between May and October 2004, using the software z-Tree (Fischbacher, 2007). A total of 48 subjects participated in the treatments reported in this paper. We recruited our participants as follows. Senter, an agency of the Netherlands' Ministry of Economic Affairs maintains a database of all firms that have requested information on (but did not necessarily subsequently apply for) the government's subsidy programs to stimulate investments in new technologies that save energy, reduce noise, filter air, or reduce waste. On our behalf Senter sent an invitation letter to 900 randomly selected firms in their database that were located within a 1 h car drive from Tilburg. The letter was addressed to the person in charge of investment decisions. Addressees were informed that by participating in an economic experiment they could expect to earn somewhere between 50 and 300 Euros, depending on their decisions and chance. If they were interested they could send in an answering sheet or react by e-mail. We then contacted them by phone or e-mail and assigned them to a session. Because of work obligations all sessions were scheduled in the evening (as of 7 p.m.). Participants were randomly assigned to either the Subsidy treatment or the No-Subsidy treatment. Hence, there was no self-selection in this respect.

**Table 3**  
Additional characteristics of our manager subject pool.

	Yes	No
Turnover < 500,000	16 (33%)	32 (66%)
Turnover > 5000,000	12 (25%)	36 (75%)
Purchased technology over past 5 years?	38 (79%)	10 (21%)
If so, did you apply for a subsidy?	28 (74%)	10 (26%)

A relevant question is whether the participants in our experiments are representative for the firms in the Senter database and how this relates to the overall population of firms in the Netherlands. Table 2 presents the frequency distributions of firm sizes for the three samples. The demand for environmentally friendly technologies tends to be higher in larger firms, and hence larger firms are relatively overrepresented in Senter's database as compared to the Netherlands in general. In our experiment this effect is to some extent mitigated by the fact that in our subject pool the smaller firms are overrepresented as compared to the Senter database. Overall, the distribution of firm sizes which our manager subjects represent seems to be a decent representation of the distribution of firm sizes in the Netherlands.

As shown in Table 3, other characteristics of our participants also suggest that our subject pool is reasonably balanced (although representativeness is hard to assess). One third of the managers represent companies with an annual turnover of less than 500,000 Euros, a quarter of firms have a turnover of more than 5000,000 Euros, and slightly less than half of the managers represent companies with a turnover between 500,000 and 5 mln. Additional information about our firms' background was obtained via a post-experimental questionnaire. Of our subjects, 79% report that they were involved in the adoption of a technology to reduce water pollution, air pollution or energy use over the past five years, and 74% state that they also subsequently applied for a subsidy. However, a reasonable share of the managers who participated in our experiment either did not purchase a new energy-friendly technology at all (10 out of 48, 21%) or did not apply for a subsidy when adopting (10 out of the 38 that did adopt; that is 26%).

The same experimental procedure was followed in all sessions. Subjects were randomly assigned to computers, which were separated by partitions. They received a copy of the instructions and the experimenter read the instructions aloud. Subjects were told that they would play the role of a manager in a firm operating in a market and that the experiment would consist of 5 independent games and one practise game, each lasting several periods. After that the subjects could privately ask questions. Then the experiment started with the practise game, which had a fixed and known length of 10 periods. When subjects finished the practise game they could continue with the rest of the experiment and complete it at their own pace. After finishing game 6, subjects were asked to fill in a questionnaire about some background information of their firm, for which they received 50 euros extra.<sup>12</sup> Finally, subjects were privately paid their total earnings and left the room.

The duration of the experiment varied between one and 2 h. We ensured this by not letting the computer draw a number between 1 and 10 ( $1 - \alpha = 0.1$ ) at the end of each period for each individual participant, but we determined the game lengths by throwing a ten-sided die before the experiment took place. This resulted in games with lengths of 4, 5, 9, 11, and 22 periods, and the order in which the games were played was randomized across subjects. The subjects, however, were informed about neither the lengths nor the order of the games. Randomly determining the game lengths before but not during the experiment has the advantage of reducing the noise arising from

<sup>12</sup> This 50 euros may be viewed as a show up fee. Managers received a much higher fee than the usual student fee to cover travel expenses and the extra time needed to complete the questionnaire.

**Table 4**  
Mean realized per-period savings (*e*) by game and by treatment.

Game	No-Subsidy	Subsidy
2	10.04 (4.64)	15.62 (8.28)
3	10.52 (6.91)	14.05 (9.77)
4	9.64 (7.89)	14.58 (8.68)
5	8.31 (5.61)	12.34 (9.63)
6	7.56 (6.17)	9.99 (9.78)
Total	9.21 (6.34)	13.31 (9.30)

subjects playing games of different lengths, which would reduce the statistical power of the experiment.

In the experiment it is possible to actually make losses, and in fact, two subjects did. Negative earnings in the experiment translated into zero earnings for the experiment, but all subjects were entitled to the 50 euros show up fee. The managers earned on average 200 euros.

#### 4. Results

From a policy perspective, the main variable of interest is the average realized cost-savings. This variable is determined by two underlying decision variables: the period in which a technology is adopted (the adoption speed) and the savings associated with the adopted technology. We will first look at the average realized cost savings (or per-period benefits, *e*) and then discuss each of the two underlying decision variables.

Table 4 displays the mean realized per-period savings (*e*) for each game and for both treatments (standard deviations are in parentheses). To calculate these, we first computed, for each individual manager, the mean realized per-period savings per game by dividing the total amount of realized savings in a game by the number of periods in that game. Then the overall mean realized per-period savings for a game were computed by taking the average of these mean savings of all individuals. The table shows that in all games more savings are attained in the Subsidy treatment than in the No-Subsidy treatment. As can be seen in the bottom row, taking all games together, per-period savings in the Subsidy treatment (13.31) are about 45% higher than in the No-Subsidy treatment (9.21). This difference is highly significant according to a non-parametric Mann-Whitney *U* test ( $p = 0.013$ ).<sup>13</sup>

As subjects play the same multiperiod game six times, there may be room for them to learn, and also fatigue is potentially relevant. Somewhat surprisingly perhaps, we did not find any evidence for a temporal pattern in behavior. In Table 4, none of the within-treatment between-games differences in the mean realized per-period savings are significant at the 10% level, or better (the low mean realized savings in game 6 are mainly caused by the fact that by coincidence game 6 on average consists of fewer periods than the other games). Also the percentage of games without any adoption is rather stable across games, as is the fraction of searches directed toward subsidized technologies (not shown here, but data are available upon request). Moreover, we examined whether the time it took subjects to take decisions was getting shorter over time, but again we did not find a significant pattern. So it seems that subjects' behavior is rather stable over time. Surprising as it may seem that we fail to detect a temporal pattern, it is also fair to say that the experiment is not very conducive to learning because of the multiple sources of uncertainty (regarding the technology offers as well as the number of rounds a game lasts). Note, however, that there is not much opportunity for learning in real world investments either, as new technologies are adopted only very occasionally.

<sup>13</sup> Unless indicated otherwise all averages and statistical tests are based on strictly independent data, namely one observation per individual. As experimental data are generally highly non-normal we use non-parametric tests. More specific, statistical significance of the treatment effect is based on two-sided Mann-Whitney *U* tests.

**Table 5**  
Mean period of adoption by treatment.

No adoption period measure	Treatment		
	No-Subsidy	Subsidy	
Actual game duration <sup>a</sup>	2.42 (1.01)	3.33 (2.56)	<i>P</i> = 0.703
Expected game duration <sup>b</sup>	2.88 (1.35)	3.57 (2.60)	<i>P</i> = 0.936

<sup>a</sup>If no adoption, adoption period = actual game length.  
<sup>b</sup>If no adoption, adoption period = 10.

We can thus conclude that the managers are affected by the introduction of a subsidy scheme; their search and adoption behavior leads to significantly higher per-period savings in the Subsidy treatment. Let us now turn to the factors that determine total per-period savings in a game: the speed of adoption and the actual technology purchased. Table 5 presents the adoption speed by treatment, that is the average period in which the first technology is bought. Two different measures for the adoption speed are used in the table depending on how they account for games in which no adoption takes place (after all, what is the speed of something that did not yet happen?). When no technology is bought the adoption period is either set equal to the actual duration of that game (upper row) or to the average expected duration of a game, i.e. 10 periods (bottom row). Irrespective of the measure we see that on average managers adopt a technology somewhat later in the Subsidy treatment than in the No-Subsidy treatment. In either case, however, the hypothesis of equal adoption speeds across the two treatments cannot be rejected, as indicated by the high *p*-values in the last column.

Table 5 suggests the presence of a substantial amount of variation in adoption speed, in particular in the Subsidy treatment. To look into this in more detail, Fig. 3 presents a histogram of the adoption periods of all games. The bars display the percentage of games in which managers invest for the first time in that game (from here onwards referred to as ‘first technology adoption’) in periods 1, 2, 3, and so on, as well as the percentage of games in which no technology is bought at all (No). The figure shows that the majority of managers do in fact buy at least one technology and predominantly do so early in a game. In the No-Subsidy (Subsidy) treatment managers seem to be somewhat more (less) willing to invest as the percentage of those who do not purchase any technology is 11% (21%) in that treatment. Moreover, in the No-Subsidy treatment subjects adopt relatively often in periods 3 to 5 compared to the Subsidy treatment.

If we only consider the games in which subjects in fact adopt a technology there is little difference between the treatments. Compared to the theoretical prediction derived in Section 3.1, it turns out that the average adoption speed is too low, i.e. subjects search too much. This seems to be in contrast to much of the search literature, which suggests that people search too little compared to a risk neutral benchmark (e.g. Schotter and Braunstein, 1981; Cox and Oaxaca, 1989,

1992; Sonnemans 1998, 2000). It accords well, however, with the idea that under-searching is prevalent in simple environments, but that over-searching is more likely to occur in richer environments like ours (see Zwick and Lee, 1999; Zwick et al., 2003).

These findings on the adoption speed cannot explain the large – and significant– difference in realized savings across the two treatments (see Table 4). The fact that on average managers buy later (or not at all) in the Subsidy treatment has a negative effect on realized savings. Therefore, the treatment effect must be driven by differences in the type of technologies that are actually adopted. To this we turn now.

First recall that in the Subsidy treatment, subjects can decide to direct search to the subsidized or non-subsidized technologies. Focusing on the periods in which an actual search takes place and no technology has been adopted yet, it turns out that subjects in the Subsidy treatment search for subsidized (non-subsidized) technologies in 47% (53%) of the periods. Given their search direction, subjects in the Subsidy treatment are confronted with offers of expensive technologies more often than subjects in the No-Subsidy treatment. To be precise, in the No-Subsidy treatment managers are offered an expensive technology (with savings between 22 and 25) in only 11% of the periods in which a search takes place (when no technology has been adopted yet).

The natural next question then is which technologies subjects actually buy. Fig. 4 shows a histogram of the technologies adopted per game for both treatments (in case of multiple adoptions, we just include the one that was adopted first). What stands out immediately is the spike in the interval [22,25] in the Subsidy treatment. Of all the first-adopted technologies in this treatment, 46% are in the range [0,22) and 54% are in the range [22,25]. Conversely, in the No-Subsidy treatment, 95% are in the range [0,22) and only 5% fall in the interval [22,25]. Hence, the Subsidy treatment does not only lead to more search in the range [22,25], it also leads to much more adopted technologies in that range.

In terms of the number of offered technologies actually purchased, this difference is indeed substantial. Whereas in the No-Subsidy treatment 5 out of 17 technologies in the range [22,25] are adopted (29%), the corresponding numbers in the Subsidy treatment are 50 out of 56 (89%). This is also reflected in Table 6, which presents the mean level of per-period savings of the technologies adopted in the two treatments. The average adopted technology in the Subsidy treatment (18.29) is almost twice as efficient (in terms of savings provided) as that in the No-Subsidy treatment (10.90), and the difference is highly significant (*p* < 0.001). Table 6 illustrates, moreover, that this pattern is similar in all games. This clearly shows that the presence of the subsidy induces subjects to adopt more expensive technologies.

Finally, it is interesting to analyze whether the introduction of the subsidy is actually beneficial for the subjects. The fact that mean

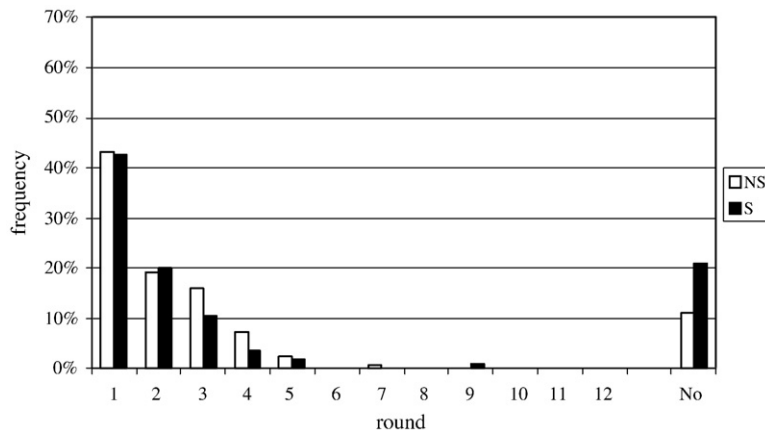


Fig. 3. Histogram of the rounds in which subjects invested in the Subsidy and No-Subsidy treatments.



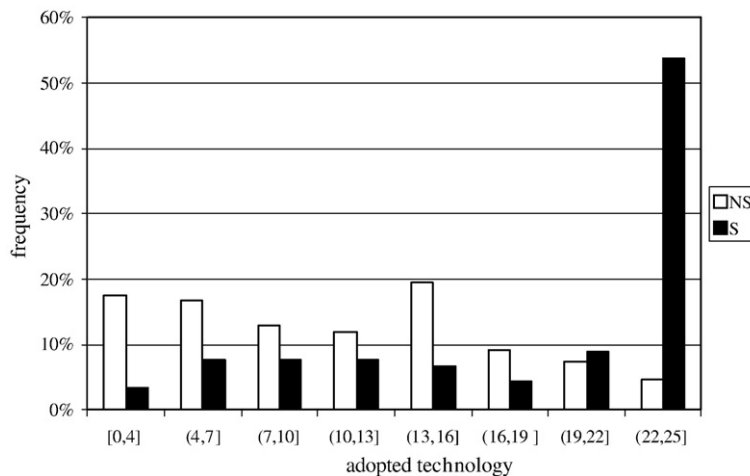


Fig. 4. Histogram of the technologies ( $e$ ) adopted (first investment) in the Subsidy and No-Subsidy treatments.

realized savings are higher need not imply that the subjects in this treatment do better in terms of final payoffs (as the technically more efficient technologies are also the more expensive ones). In fact, the average payoffs are lower in the Subsidy than in the No-Subsidy treatment: payoffs drop from 125.2 (standard deviation 29.6) to 115.6 (standard deviation 21.2) with the introduction of the subsidy. The difference is not statistically significant though ( $p = 0.252$ ).<sup>14</sup>

In sum, our results indicate that enabling directed search for subsidized technologies has two effects. The first effect is that in the Subsidy treatment many more expensive technologies are searched for and adopted. Secondly, the presence of the subsidy also seems to make subjects somewhat more reluctant to adopt a technology, as is witnessed by the increase in the percentage of games without adoptions. The significantly higher realized average per-period savings in the Subsidy treatment clearly imply that the first effect dominates the second. The presence of the subsidy leads to a significant and persistent change in behavior which, however, runs counter to the predictions of the rational choice model.

## 5. Discussion

How can the positive effect of the subsidy on the level of investments be explained? One possibility is that given the complexity of the decision problem in our experiment, we just pick up random behavior. However, there are strong indications that behavior is in fact not random. Table 7 gives the results of a logit regression in which the adoption decisions in the No-Subsidy treatment are related to the level of per-period savings. The estimation procedure was as follows. For each individual we include all periods in a game in which (i) she had not yet purchased a new technology in the previous rounds of the game, and (ii) she did request a technology to be offered (i.e., the subject searched for a new technology). From these periods we construct the dependent variable ‘adopted’, which is 1 (0) if the offered technology was (was not) adopted. We may therefore have multiple observations in a game for a specific subject – if she rejected one or more technologies offered. As independent variables we have included characteristics of the technology offered (per-period savings

<sup>14</sup> Note that for a risk-neutral rational decision maker the expected payoffs are actually a little higher in the Subsidy than in the No-Subsidy treatment. This is not because the subsidies make some technologies less expensive; after all, it is optimal to request unsubsidized technology offers. The reason is that the Subsidy treatment allows for directed search in the region  $e \in [0, E_S)$ , through which the unprofitable technologies in the region  $[E_S, E]$  are excluded from the search process, whereas they remain possible in the No-Subsidy treatment. Consequently, the expected value of a technology offer from the range  $[0, E_S)$  is somewhat larger than that of a draw from  $[0, E]$ .

and per-period savings squared), dummies for rounds 1, 2, 3 and dummies for games 3–6. Note that we only include dummies for periods 1 to 3 (so that the omitted variable is a dummy for periods 4 and higher) because the bulk of the investments take place in the first three periods (see also Fig. 3). And we only included dummies for games 3–6 because game 1 was the trial game; the omitted dummy is thus the one for game 2. In addition to the game and period fixed effects, we also account for the panel data structure of our data by clustering the (heteroscedasticity adjusted) error terms at the subject level.

This analysis suggests that indeed adoption decisions were not random in the No-Subsidy treatment. The regression results indicate that the estimated probability of adopting a technology is highest at  $e = 10.5$  (and hence below 12.5) and asymmetric in that for the same expected net present value, the technology with the lower  $e$  (and hence the lower investment costs) is more likely to be purchased than the one with the higher  $e$ . Both observations are consistent with our subjects being risk averse. And results are qualitatively similar if we only consider the outcomes of the first search, such that we have at most one observation per game per subject rather than possibly multiple observations per game per individual.

Another piece of evidence supporting the hypothesis that behavior is not random follows from Fig. 4, which shows that technologies in the range  $[22, 25]$  are quite unpopular in the No-Subsidy treatment. So, we would regard it unlikely that, when given the chance to direct search toward these technologies, subjects would do so merely out of confusion or by mistake.

In view of the fact that the adoption decisions follow quite a consistent and reasonable pattern in the No-Subsidy treatment, we conjecture that from the subjects' perspective the subsidy must add something distinctly positive. The financial aspect of the subsidy is clearly part of this, but as we have discussed above, this is not enough to make the subsidized technologies more profitable than the non-

Table 6  
Mean adopted technology by game and by treatment.

Game	Treatment	
	No-Subsidy	Subsidy
2	9.86	19.20
3	11.55	18.70
4	14.01	18.96
5	9.72	18.59
6	10.02	15.52
Total	10.90	18.29

Note: In case of subjects purchasing multiple technologies in a specific game, these averages are based on the characteristics of the technology that is adopted first.

**Table 7**  
Logit regression of technology adoption in the No-Subsidy treatment.

Variable	Coeff.	Robust st.err.	p-value
Constant	0.044	0.717	.951
Per-period savings of the technology offered	0.358	0.120	.003
Per-period savings of the technology offered squared	−0.017	0.006	.002
Dummy round 1	0.042	0.496	.932
Dummy round 2	−0.612	0.468	.191
Dummy round 3	−0.647	0.731	.376
Dummy game 3	0.083	0.493	.866
Dummy game 4	0.199	0.561	.723
Dummy game 5	−0.651	0.577	.259
Dummy game 6	0.026	0.343	.940
N	171		
Wald Chi <sup>2</sup>	28.16		.001

Notes: Dependent variable is a binary variable indicating whether the technology is adopted or not (1 = yes, 0 = no). Robust standard errors are clustered at the subject level.

subsidized ones. An additional factor may be that the presence of a subsidy invokes a positive connotation, in much the same way as a discount, a rebate or a sales price does. Such a positive connotation may carry enough weight in an agent's decision making process to tip the balance in favor of the subsidized technologies.<sup>15</sup>

Modern theories in cognitive psychology emphasize that decision making in complex situations is driven not only by conscious, cognitive, consequentialist reasoning but also by spontaneous, associative, affective processes; see for example the literature on the affect heuristic (Slovic et al., 2002), risk-as-feelings (Loewenstein et al., 2001), and dual-process models (Kahneman, 2003). We expect that the basic decision environment as presented to the subjects in our experiment is relatively neutral and generates little affective valence. In such an environment, we can expect cognitive processing to supply the main inputs for the decisions at hand. At the same time, the decision problem is also quite complex, and it is unlikely that the subjects will be fully confident that they are able to solve this problem in a purely rational and calculative manner. Environments like these are particularly prone to the influence of affective processes (Lucey and Dowling, 2005; De Vries et al., 2008). If a certain element of the decision environment evokes a positive feeling or association – even though only weak – this may exert quite a strong influence on subjects' judgments and choices. Hence, to the extent that the presence of a “subsidy” generates a positive affect, this will render the subset of options to which this subsidy is attached more attractive than in its absence.

Another factor may be that search among subsidized technologies gives more precise and less uncertain results. If subjects search among subsidized technologies any offer has savings between 22 and 25. In contrast, the range of possible savings is much larger if they search among non-subsidized technologies in the Subsidy treatment. That this reduction in variation between options may positively affect the search for subsidized technologies is in line with the so-called evaluability principle. This says that not only the valence but also the precision of an affective impression may affect judgment and decision making, and easier and more precise signals are weighted more heavily (Slovic et al., 2002).

We do not have any direct evidence that subsidies generate a positive affect nor that it is a main driver of the decision to search for subsidized technologies. There is some circumstantial evidence which

<sup>15</sup> Alternatively, the presence of a subsidy may be interpreted by the subjects as a kind of endorsement and as a signal that there is something “good” about these technologies that warrants their purchase to be stimulated. However, the converse, that the subjects see the subsidy as a signal that these technologies are not in their best self-interest cannot be excluded either. What matters is people's attitude toward and interpretation of (government) subsidies, and there is little direct evidence on this as far as we know.

**Table 8**  
Regression of mean realized savings on the availability of subsidies, firm turnover and the interaction between these two variables.

Variable	Coeff.	Robust st. err.	p-value
Constant	9.912	2.138	.000
Subsidy treatment dummy	2.659	3.267	.420
Small firm (turnover < 500,000)	−3.852	2.730	.166
Medium-sized firm (turnover between 500,000 and 5 mln)	−0.602	2.516	.812
Small firm × subsidy treatment dummy	8.617	4.025	.038
Medium-sized firm × subsidy treatment dummy	3.865	3.822	.330
Applied for subsidies in the past	1.492	2.154	.492
Applied for subsidies in the past × subs.treatment dummy	−5.039	3.195	.123
N	48		
R <sup>2</sup>	0.214		

Note: OLS regression with stepwise deletion of explanatory variables.

is consistent with this hypothesis though. In particular, the dual-process models of behavior suggest that feelings are less likely to play a role in case a neutral, effortful, cognitive evaluation can handle a problem well and leads to an unambiguous solution (Loewenstein and Lerner, 2003). We should therefore expect subjects with more experience and more confidence in handling complicated risky investment decisions to be less influenced by a positive affect which the presence of a subsidy may engender than those who are relatively inexperienced.

To explore this issue we use the classification of small, medium-sized, and large firms as defined before and calculate the averaged per-period realized savings by treatment for managers of each of these subgroups. We also examined whether participants' behavior was systematically related to not just whether they had the option to request a subsidized technology in the experiment, but also to any of the background variables we had information on: turnover, number of employees, whether they had recently adopted a new technology for their firm and if so, whether they had applied for a subsidy, and whether they use formal decision rules in their professional lives (like net present value criteria or internal rates of return thresholds). The only variable that comes up significantly is the Subsidy treatment dummy; none of the coefficients on the background characteristics was found to be significantly different from zero (the results of this regression analysis are available upon request).

However, one can hypothesize that the presence of a subsidy may interact with managers' characteristics; conditional on firm size, the presence of a subsidy affects managers differently. We ran regressions using a full set of explanatory variables (see above) and the explanatory variables interacted with ‘participation in the subsidy treatment’, and none of the coefficients (except for the constant) showed up significantly. However, this specification is very demanding in terms of degrees of freedom, and hence we decided to remove variables one by one starting with the ones with the highest p-values. The results are presented in Table 8.<sup>16</sup>

The only effect we find is with respect to the interaction between the option of purchasing subsidized technologies with firm size. As shown in Table 8, offering a subsidy does not affect the mean realized savings by managers of medium-sized and large firms, but the mean realized savings of the managers of small firms is increased significantly ( $p = 0.038$ ). Note that by allowing asymmetric effects of subsidies for the various firm sizes, the Subsidy treatment dummy itself is no longer significantly different from zero. And this is the case even if we control for whether managers have invested in subsidized technologies in the past, or not.

Obviously, parametric tests are hazardous because of the type of data we have as well as because of the relatively small number of

<sup>16</sup> The results are qualitatively similar if the last two variables from Table 8 are not included.

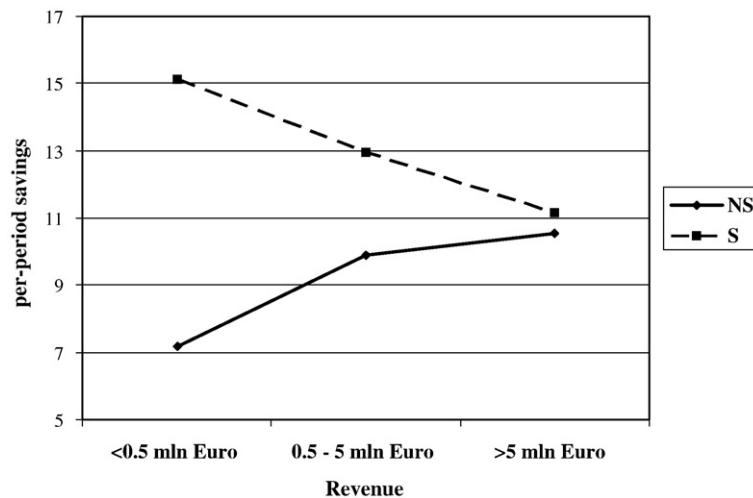


Fig. 5. Average per-period savings by revenue size of the manager's firm.

observations. However, the observed asymmetric impact of subsidies for the various firm sizes suggests that the regression results do not just reflect some sort of spurious correlation. Fig. 5 indicates that the effect of the subsidy is much smaller for managers operating in larger firms; for managers of large firms there is hardly any effect of the subsidy, while for managers of small firms its introduction results in a more than 100% increase in the per-period savings obtained (and the latter difference is significant at  $p < 0.01$ ).

Interestingly, in line with the hypothesis that investment managers from larger firms approach the problem in a more cognitive and affectively neutral way is the fact that in the post-experimental questionnaire these managers indicate more often that their decisions were based on some kind of decision rule, like the calculation of a critical payback period of a technology investment. To be precise 31% of the managers from small firms indicated that their decisions were rule-based, while as much as 75% (60%) of the managers from large (intermediately large) firms indicated so. Obviously, when decisions are rule-based, there is little room for an influence of affect.

Further support for the hypothesis that subsidies generate a positive affect is obtained from subjects' search behavior. First, it turns out that subjects conduct more searches until they buy a technology in the No-Subsidy treatment than in the Subsidy treatment. Focusing on search behavior before the first adoption, the subjects in the No-Subsidy treatment on average use 1.60 searches for every adoption (173/108), whereas in the Subsidy treatment this is only 1.32 (120/91). The difference between the two treatments is significant at the 2% level on the basis of a two-sided Fisher Exact test on game level data. This finding is consistent with the hypothesis that actors become less uncertain when they receive a clear affective signal. More evidence in favor of this hypothesis obtains if we look at continued search behavior. Continued search refers to the fact that subjects may continue their searches even after they have already adopted a technology—even though this is not consistent with rationality. In the 91 games in the Subsidy treatment in which a technology was bought a total of 30 additional searches were carried out, which gives an average 'continued search' percentage of 33%. In the No-Subsidy treatment this occurred 80 times in 108 games, so that the average 'continued search' percentage is as high as 74%. So subjects in the No-Subsidy treatment not only search more until the first adoption, they also carry on searching more often after they have purchased a technology.

Although these findings are short of being direct evidence, they are all in line with the hypothesis that introducing a subsidy generates a positive affect, which reduces ambiguity and facilitates decision making. A natural question is whether the main results will generalize

to other environments. To truly answer this question we would have to run more experiments with other environments. Because of budget constraints we could not do so with other managers, but we did examine various different environments using student subjects.<sup>17</sup> For example, we examined environments in which the technologies did in fact exert a positive externality. We also implemented environments with a larger range of subsidized technologies, or with a lower continuation probability  $\alpha$ . In all of these, the subsidy turned out to have a significantly positive effect on investment levels. Hence, our main results seem to be very robust to various changes in the environment.

A related question is whether the results will generalize to managers from other countries. This is more difficult to answer. If it is indeed true that affective processes are related to the effectiveness of subsidies, then it cannot be excluded that this is to some extent country and/or culture specific. Governments in general, and subsidies in particular, may well carry a different connotation in different countries. At the same time, an important component of a subsidy is that it gives "something for free". That this generates a positive feeling is much less likely to be country or culture specific. In this sense, there is reason to expect that our main result will apply to non-Dutch manager subject pools as well.

Although experiments with a culturally heterogeneous student subject pool can never be used as a proof that our results will also apply to managers in other countries or cultures, it is interesting to note here that the results obtained using Tilburg University's international student pool are remarkable similar to the ones reported here for the Dutch managers. For example, the mean adopted technology in the No-Subsidy treatment is 12.90 for the culturally heterogeneous student subject pool (with students from not just the Netherlands but also from Germany, Belgium, China, Vietnam, etc.) and 9.21 for the Dutch managers (see Table 4), while the associated numbers for the Subsidy treatment are 16.99 and 13.31, respectively. So, independent of whether culturally mixed student subjects are used or just Dutch managers, the presence of a 6% subsidy

<sup>17</sup> The experiment discussed in this paper is part of a bigger research project, which was financed by the Ministry of Economic Affairs and the Ministry of Housing, Spatial Planning and the Environment, where the former can be regarded a skeptic and the latter a believer of investment subsidies. In this project we ran a total of 17 different treatments to investigate the effect of the design of subsidies on technology adoption. In this paper we report the results of the treatments using manager subjects. Because of budget limitations and because of the large numbers of subjects required, managers were used as subjects in the two key treatments only, the one without and the one with an upfront investment subsidy. For a brief overview of all results see Aalbers et al. (2005).

substantially and significantly increases the per-period savings. And also the adoption speeds of the student subjects are similar to those of the Dutch managers, the adoption periods being 2.16 (2.54) for measure a (b) in the No-Subsidy treatment and 2.40 (2.45) in the Subsidy treatment; none of these differences are statistically significant.

### 6. Conclusions

Whether or not subsidies are effective in stimulating the adoption of energy-saving (or other environmentally friendly) technologies is highly debated in the literature to date. Some studies find that subsidies are highly effective, whereas others find that most of the agents adopting the subsidized technologies would have done so anyway – even with zero subsidies. The reason why this issue is so difficult to settle is because of the lack of a counterfactual. Between-firms analyses are usually not feasible because either subsidies are available to all firms in a specific industry, or to none. And over-time analyses are difficult because the ceteris paribus condition is usually not met before and after the introduction of a subsidy program (as other factors affecting adoption behavior also change over time).

Because of these reasons, we turn to addressing this issue by developing an economic experiment to experimentally evaluate the behavioral impact of a technology adoption subsidy on adoption behavior. We use the experimental method to control for the many confounding factors that affect investment decisions including firm characteristics (for example the age of the current abatement technology, issues of corporate responsibility, etc.). The experiment is set up such that it includes the main factors that may interact with the presence of a subsidy (uncertainty about whether the search for a good technology will be successful, accounting for the fact that a search comes at a cost because of scarce managerial time), and we use professional managers experienced in investment decision making as subjects (rather than students). Consistent with reality, the range of new technologies currently ‘on the market’ consists of technologies that differ in the amount of input savings they provide as well as with respect to their purchase price, with the higher savings technologies being disproportionately more expensive than the lower savings technologies.

We compare search and adoption behavior across two treatments, one in which no subsidies are available, and one in which the top 12% of the technologies (as measured in per-period savings) are subsidized. The theoretical predictions are straightforward. First, the subsidy provided is too low to render the top 12% technologies economically profitable so that search should be directed at the non-subsidized technologies. Second, and as a result, search and adoption behavior should be identical in the two treatments.

The results of our experiment do not support these predictions. We find that providing a subsidy results in increased search for and adoption of the top-end technologies, and subsequently results in a substantial and persistent increase in the amount of savings obtained over the game’s duration. Actually establishing why ‘a nominal’ subsidy is so effective in changing investment behavior is difficult, but analysis of the actual behavior of individual managers suggests that the main impact of the subsidy is via reducing complexity. The subsidy adds an element of positive affective valence to an otherwise neutral but complex decision problem. Managers’ perception of the complexity problem is likely to be a function of whether or not they use formal adoption rules, and indeed we find that our subsidy is much less effective in changing the behavior of managers of larger firms (who self-report that they use formal decision rules) than of those of smaller firms (whose decision making process seems to be less well-structured).

Because our experiments abstracts from many of the factors that affect real-world decision making regarding energy-saving investments (including equipment age, market structure, social orientation

of firms regarding corporate responsibility issues), the results of this paper should not be interpreted as providing a point estimate of the investment elasticity with respect to subsidies. However, our results do suggest that even ‘nominal’ subsidies may be highly effective – which is not to say efficient – in changing (investment) behavior, particularly so for decision environments which are perceived as complex by the decision makers and which have low affective valence to them.

### Appendix A. Optimal search strategy

The optimal search strategy depends on both the opportunity costs of searching and the benefits of finding an even better technology. We first calculate the opportunity costs of searching, and then present the optimal search strategy.

The decision maker in our experiment is assumed to be a monopolist in her output market and faces the following downward-sloping demand function:

$$P(Q_t) = a_t - bQ_t, \tag{6}$$

The consumers’ willingness to pay for the firm’s output thus depends on the quantity of output produced, but also on the state of the economy. The demand function’s vertical intercept ( $a_t$ ) is assumed to be stochastic, and is drawn in each period from a uniform distribution  $a_t \in [a - \varepsilon, a + \varepsilon]$ , with  $0 < \varepsilon < a$ . Marginal production costs equal  $c$ , so that the firm’s objective is to maximize  $P(Q_t|a_t)Q_t - cQ_t$ , and hence the best-response function of the monopolist to fluctuations in demand is  $Q_t^*(a_t) = (a_t - c) / 2b$ , and associated optimized sales profits equal  $(a_t - c)^2 / 4b$ .

Information about the state of the economy ( $a_t$ ) is disclosed only after the manager has decided whether to search for a new technology, or not. If she requested to receive a technology offer, she is unable to optimally adjust output and, for simplicity, output is set equal to zero (and hence sales profits are zero too). If she decided not to search, she is able to optimally adjust output, and the opportunity costs of searching for a new technology are:

$$Z = \frac{1}{2\varepsilon} \int_{a-\varepsilon}^{a+\varepsilon} \frac{(z-c)^2}{4b} dz = \frac{(a-c)^2}{4b} + \frac{\varepsilon^2}{12b}. \tag{7}$$

Next we determine the optimal investment strategy under risk neutrality. We focus on the case in which no technology subsidies are available; the case of subsidization is analogous and available from the authors upon request.

Suppose that the decision maker receives a technology offer  $e_0$  (from the range  $[0, E]$ ) with an expected Net Present Value  $\pi_0 = \pi(e_0)$ . If  $e_0$  is smaller than  $\frac{1}{2}E$ , the range of technologies she would prefer lies in the region  $[e_0, E - e_0]$ . If  $e_0$  is larger than  $\frac{1}{2}E$ , the range of technologies she would prefer lies in the region  $[E - e_0, e_0]$ . So, if we define  $e_{L0} \equiv \min [e_0, E - e_0]$  and  $e_{H0} \equiv \max [e_0, E - e_0]$ , we have  $\pi_0 \equiv \pi(e_0) = \pi(e_{L0}) = \pi(e_{H0})$ , and the range of technologies that are preferred to the current offer  $e_0$  is  $[e_{L0}, e_{H0}]$ . When requesting a new offer, the probability ( $p_0 \equiv p(e_0)$ ) of receiving a better offer thus equals  $p_0 = (e_{H0} - e_{L0}) / E = (E - 2e_{L0}) / E$ , and, conditional on receiving a better offer, the ENPV of that offer is equal to  $\frac{1}{e_{H0} - e_{L0}} \int_{e_{L0}}^{e_{H0}} \pi(e) de$ , where  $\pi(e)$  is given by Eq. (3). All technology offers with  $\pi\pi_0$  have zero value (as the decision maker can always decide to adopt  $e_0$  as this offer remains valid throughout the game). Therefore, multiplying  $p_0$  and the conditional ENPV, the expected benefits of asking for a new technology offer (given  $e_0$ ) are equal to

$$EB(\pi_0) = EB(\pi(e_{L0})) = \frac{1}{E} \int_{e_{L0}}^{e_{H0}} \pi(e) de = (v/E) \left[ \frac{1}{4} E^2 - e_{L0}^2 \right]. \tag{8}$$

We can now define the critical technology offer as that technology with a specific ENPV for which a risk-neutral decision maker is indifferent between adopting it and continuing the search for an even better technology (that is, a technology with a higher ENPV). When deciding to continue the search upon having received offer  $e_0$ , the decision maker forgoes the profits she could obtain in the output market, the expected value of which is equal to  $Z$  (see Eq. (7)). In addition, she needs to take into consideration (i) the probability  $(1 - \alpha)$  that the game does not continue to a next period, and (ii) the fact that if the next offer does not yield a better technology offer, she can continue requesting new offers as long as the game does not end (which is the case with probability  $\alpha$ ). The expected benefits of continuing searching for a more profitable technology equal  $\alpha[EB(\pi_0) - Z] + \alpha^2(1 - p_0)[EB(\pi_0) - Z] + \alpha^3(1 - p_0)^2[EB(\pi_0) - Z] \dots$ , which converges to  $\alpha[EB(\pi_0) - Z] / (1 - \alpha(1 - p_0))$ . The benefits of actually adopting the current technology offer  $e_0$  equal  $\pi_0$ . The critical technology offer is thus implicitly determined by

$$\alpha[EB(\pi_0) - Z] / (1 - \alpha(1 - p_0)) = \pi_0. \quad (9)$$

Given that (i) initially the firm has a default technology yielding zero savings (i.e.,  $e = 0$ ) while new technologies have a non-negative ENPV and (ii) choosing output now and searching later has a lower payoff than searching now and choosing output later, the optimal strategy is to request a new technology offer in the first period of the game. If the technology offered has  $e_L \geq e_{L0}$ , the agents should adopt it and focus on optimal output decisions for the remaining periods. If the offer has  $e_L < e_{L0}$ , the agent should continue to search in the next period.

## Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at [doi:10.1016/j.eneco.2008.12.002](https://doi.org/10.1016/j.eneco.2008.12.002).

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