Technology Adoption Subsidies:
An Experiment with Managers

Rob Aalbers[1]

Eline van der Heijden[2]

Jan Potters[2]

Daan van Soest[2]

Herman Vollebergh[3]

[1] SEO Economic Research, Amsterdam;
[2] Tilburg University;
[3] Erasmus Universiteit Rotterdam, and Tinbergen Institute.

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Rob Aalbers[†], Eline van der Heijden[‡], Jan Potters[§],
Daan van Soest[¶], and Herman Vollebergh[‖]

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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 the 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.

Keywords: framed field experiment, search model, technology subsidies; JEL classification: C9, D8, H2.

[†]SEO Economic Research, Roetersstraat 29, 1018 WB Amsterdam, the Netherlands (r.aalbers@seo.nl)

[‡]Department of Economics, Tilburg University, P.O. Box 90153, 5000 LE Tilburg, the Netherlands (eline.vanderheijden@uvt.nl)

[§]Department of Economics, Tilburg University, P.O. Box 90153, 5000 LE Tilburg, the Netherlands (j.j.m.potters@uvt.nl)

[¶]Department of Economics, Tilburg University, P.O. Box 90153, 5000 LE Tilburg, the Netherlands (d.p.vansoest@uvt.nl)

[‖]corresponding author: Department of Economics, Erasmus University Rotterdam, P.O. Box 1738, 3000 DR Rotterdam, the Netherlands (vollebergh@few.eur.nl; phone: +31-10-408.1498; fax: +31-10-488.9161)

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. To stimulate adoption of such socially desirable technologies governments may decide to offer subsidies. 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.[1] 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 ineffective in stimulating adoption of energy–saving appliances since a large fraction of the households that did install an energy–efficient appliance would have done so anyway, but this conclusion was challenged by other studies (e.g., Hassett and Metcalf, 1995, and 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 ben-

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[1]See International Energy Agency (2005) for an overview of the various arguments in this discussion.

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efits 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 both 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. Subsidies are either available to all firms in a specific industry, or to none. 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 diferent 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 a so–called framed field experiment (Harrison and List, 2004). We construct an individual choice experiment in which subjects can search for and possibly adopt technologies that yield flows of benefits in each period that the experiment lasts, where there is fundamental 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 –at least to some extent– the circumstances under which decision makers within firms tend to make the investment choices. Another important special feature of our experiment is that we employ managers of small– and medium–sized firms who are experienced in making investment decisions (subsidized or otherwise), either as employees or as self–employed entrepreneurs, rather than a standard student subject pool.[2] Because of the tight control about the circumstances provided by the lab, we can create a proper counterfactual by randomly assigning firm 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

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[2]We were in the lucky position to be able to recruit such managers from small– and medium–sized firms using a data set maintained by the Dutch Ministry of Economic Affairs.

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 our study addresses 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 input 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. Although the subsidy improves the attractiveness of only the most expensive technologies, we have chosen the parameters in our experiment such that on average the subsidized technologies still have a lower expected NPV than the non–subsidized ones. That is, the subsidy narrows the profitability gap but does not close it. 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. If NPV is the decision criterion, we can expect that the introduction of the subsidy scheme leads to an increase in the search for the cheaper (non–subsidized) technologies with lower expected savings but higher expected NPV. Clearly this setup provides a very stringent test of the effectiveness of a subsidy.

In essence our framed 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, 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 section 5 we provide an explanation for the observed behavior. Section 6 concludes.

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. 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:

$$I(e) = \begin{cases} \left(\frac{1}{1-\alpha} - v\right) e & \forall e \in \left[0, \frac{1}{2}E\right] \\ \left(\frac{1}{1-\alpha} + v\right) e - vE & \forall e \in \left\langle \frac{1}{2}E, E\right] \end{cases} \tag{1}$$

where v is an (arbitrary) constant between 0 and $1/(1-\alpha)$ such that $\partial I/\partial e > 0$ in the two subdomains. 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

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is forced to exit the market with a constant probability. The probability of surviving another period is denoted by α ($0 < \alpha < 1$).[3] Using (1), the Net Present Value of a technology (π) with savings equal to e is:

$$\pi^{NS}(e) = \sum_{t=0}^{\infty} \alpha^t e - I(e) = \begin{cases} ve & \forall e \in \left[0, \frac{1}{2}E\right] \\ v(E-e) & \forall e \in \left\langle \frac{1}{2}E, E\right] \end{cases} \tag{2}$$

where superscript NS refers to the case of no subsidization.

Figure 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 expected NPV) 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.

[Insert Figure 1 about here]

The decision maker in our experiment cannot simply go and purchase the technology with the highest expected NPV. 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

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[3]Theoretically, this is equivalent to imposing a time discount factor α.

shown (see Appendix A) that under risk neutrality the optimal strategy is to search until one finds a technology with a NPV above some critical value ($\pi(e) \geqslant \pi_o$). As illustrated in Figure 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 expected NPV, $e = \frac{1}{2}E$. This distance depends on the various parameters of our model (i.e., α, E, v, and, Z). 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 NPV 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 $E_S >> \frac{1}{2}E$), the firm receives a subsidy of size $sI(e)$. That means that the subsidy function is specified as follows:

$$
s(e) = \left\{ \begin{array}{ll} 0 & \forall e \in [0, E_S\rangle \\ s > 0 & \forall e \in [E_S, E] \end{array} \right. \tag{3}
$$

Adding subsidies $s(e)I(e)$ to the NPV defined in equation (2), the expected NPV now becomes:

$$
\pi^S(e) = \left\{ \begin{array}{ll} ve & \forall e \in \left[0, \frac{1}{2}E\right] \\ v(E - e) & \forall e \in \left\langle \frac{1}{2}E, E_S \right\rangle \\ v(1 - s)(E - e) + se/(1 - \alpha) & \forall e \in [E_S, E] \end{array} \right. \tag{4}
$$

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

[Insert Figure 2 about here]

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 $[0, E_S\rangle$. Indeed, several programs offer a list of technologies that are subsi-

dized, and hence agents have the choice to look for a technology themselves, or scrutinize the list of subsidized technologies.[4] 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 expected NPV 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 expected NPV 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 π_0' of the expected NPV 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 expected NPV of technologies in the range $[0, E_S]$ is larger than the expected NPV of technologies in the range $[0, E]$. This critical NPV can again be indicated by means of a horizontal line. As indicated in Figure 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 expected NPV. 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; $\mathcal{E}\{e|e \in [\frac{1}{2}E - d'; \frac{1}{2}E + d']\}$ $= \mathcal{E}\{e|e \in [\frac{1}{2}E - d; \frac{1}{2}E + d]\} = \frac{1}{2}E$.[5] So, the main predicted effect of the subsidy is that search will be directed 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.

This prediction holds for unboundedly rational (risk neutral) decision makers. The subjects in our experiment are professionals in their field, and

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[4]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.

[5]The subsidy should induce exclusive search for non-subsidised 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, $\Pr\{e \in [\frac{1}{2}E - d'; \frac{1}{2}E + d'] \mid e \in [0, E_S]\} > \Pr\{e \in [\frac{1}{2}E - d; \frac{1}{2}E + d] \mid e \in [0, E]\}$. 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.

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. Moreover, to the extent that this is indeed the case, we postulate that managers from smaller firms (who can be expected to have less specialized experience in making investment decisions) are more likely to be affected by the subsidy than those of larger firms.

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 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. A copy of the instructions for the subsidy treatment can be found in Appendix B.

<div align="center">

Table 1. Overview of the treatments

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

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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 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. $\alpha = 0.9$). The number of periods of the games was randomly determined before the experiment by means of throws with a ten–sided die. This resulted in games with lengths of 4, 5, 9, 11, and 22 periods. The length of the practise game was fixed at 10 (the expected length of a game). The sequencing of game lengths was varied across subjects.

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 ($P(Q) = a_t - \frac{2}{375}Q$) and the cost function ($C(Q) = 1.6Q$), and hence 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 value of a 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 value of a but could not act on it; output was set equal to zero ($Q = 0$) and consequently the sales profits were also equal to zero. If they had chosen to set output, they could act on the information about a revealed 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 (Z) were equal to 10 (see Appendix A), and this constitutes the opportunity costs of searching for a new technology.[6]

Regarding technology choice, subjects were informed about the relationship between I and e (cf. (1)) by means of both a figure and a table (see Appendix B). 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 had to decide, first, whether they liked this technology better than the one they liked best until now (if any), and second, whether they wanted to purchase their preferred technology.[7]

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

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[6]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.

[7]In the first period of each game the preferred technology was a default technology with no savings, i.e. $e = I = 0$.

with benefits of $e = 22$ 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 $[0, 22\rangle$, 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 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 the 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.[8] The subjects were professional managers recruited by means of letters. We invited managers of whom we knew that they had recent experience with making (subsidized) investment decisions in new technologies (e.g. energy saving, noise reduction, air filtering, waste reduction) and whose companies were located within one hour's car drive from Tilburg. Addressees were informed that depending on their decisions and chance, they could expect to earn somewhere between 50 and 300 Euros. If they were interested they could react by phone or e–mail. Because of work obligations all sessions were scheduled in the evening (as of 7 p.m.). The managers had very heterogeneous backgrounds. If we define small, medium-sized and large firms as those with a turnover of less than 0.5 mln Euro, between 0.5 and 5 mln Euro, more than 5 mln Euro, respectively, then 16 managers were from small firms, 22 from medium-sized firms, and 10 from large firms.

The experimental procedure was the same in all sessions. Subjects were randomly assigned to computers, which were separated by partitions. They received a copy of the instructions (see Appendix B), 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

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[8]The experiment discussed in this paper is part of a bigger research project, which was financed by the Ministry of Economic Affairs (EZ) and the Ministry of Housing, Spatial Planning and the Environment (VROM), where the former can be regarded a sceptic 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. Treatment factors include the level of the subsidy, the set of subsidized technologies, presence of technological change, search costs, and the level of uncertainty. Because of budget limitations and because of the large numbers of subjects required, all but the treatments reported in this paper were run only with students as subjects. For a brief overview of the results see Aalbers et al. 2005 (in Dutch).

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.[9] Finally, subjects were privately paid their total earnings and left the room. The duration of the experiment varied between one and two hours.

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 and then discuss each of the two underlying decision variables.

Table 2. Mean realized savings

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)

Table 2 displays the mean realized per–period savings for each game and for both treatments (standard deviations are in parentheses). The table

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[9]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.

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 ($p = 0.013$).[10] The difference decreases somewhat over the games, but even in the last game the treatment effect is still substantial.[11] It can be concluded that the managers are affected by the introduction of a subsidy scheme. Overall, their search and adoption behavior leads to significantly higher per–period savings in the Subsidy treatment.

We now turn to the factors that determine total per–periods savings in a game: the speed of adoption and the actual technology purchased. Table 3 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 (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 3. Mean period of adoption by treatment

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[10] Unless indicated otherwise all averages and statistical tests are based on strictly independent data, namely one observation per individual. For each subject we first compute the mean realised savings per game by dividing the total savings in a game by the number of periods in that game. Next we take the (unweighted) average of all five games per subject. The reported standard deviations are also calculated at the level of the individual (rather than the game). 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.

[11] 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.

No adoption period measure	Treatment		
	No–Subsidy	Subsidy	
actual game duration[a]	2.42 (1.01)	3.33 (2.56)	$p = 0.703$
expected game duration[b]	2.88 (1.35)	3.57 (2.60)	$p = 0.936$

a: if no adoption, adoption period = actual game length

b: if no adoption, adoption period = 10

Table 3 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, Figure 3 presents a histogram of the adoption periods of all games. The bars display the percentage of games in which a technology is adopted 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 did not purchase any technologies is 11% (21%) in that treatment.[12] Moreover, in the No–Subsidy treatment subjects adopt relatively often in periods 3 to 5 compared to the Subsidy treatment.

[Insert Figure 3 about here]

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 is in line, 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 2). The fact that on average managers buy later (or not at all) in the

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[12] The percentage of games without adoption varies only little across games.

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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. It turns out that subjects in the Subsidy treatment search for subsidized (non–subsidized) technologies in 47% (53%) of the periods.[13] 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 and no technology has been adopted yet.

[Insert Figure 4 about here]

The natural next question then is which technologies subjects actually buy. Figure 4 shows a histogram of the adopted technologies per game for both treatments. What stands out immediately is the spike in the interval [22, 25] in the Subsidy treatment. In this treatment, 54% of the adopted technologies is in the range [22, 25], whereas this is only 5% in the No–Subsidy treatment. 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 this range are adopted (29%), the corresponding numbers in the Subsidy treatment are 50 and 56 (89%). This is also reflected in Table 4, 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 large as that in the No–Subsidy treatment (10.90), and the difference is highly significant ($p < 0.001$). Table 4 illustrates, moreover, that this pattern is similar in all games.[14] This clearly shows that the presence of the subsidy

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[13] Here we focus on the periods in which an actual search takes place and no technology has been adopted yet. Although the fraction of searches among subsidized technolgies decreases somewhat across games (56% in game 2, 59% in game 3, 46% in game 4, 39% in game 5, and 33% in game 6) the percentage is still considerable in the last game, especially given the fact that according to the theoretical prediction no search at all should be conducted in that subset.

[14] Although the difference between the two treatments is smaller in the last game than in game 5, it is still statistically significant at the 5% level, as it is in all games. In addition, none of the mean adopted technologies within a treatment (across games) are significantly different according to a Wilcoxon matched-pairs signed-ranks test.

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induces subjects to adopt more expensive technologies.

Table 4. mean adopted technology

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

Finally, it is interesting to analyze whether the introduction of the subsidy is actually beneficial for the subjects. The fact that mean 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 $(p = 0.252)$.[15]

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.

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[15] 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 non-subsidized technology offers. The reason is that treatment S allows for directed search in the region $e \in [0, E_S\rangle$, 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 $[0, E_S\rangle$ is larger than that of a draw from $[0, E]$.

5   Discussion

How should 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. There are strong indications though that behavior is in fact not random. One indication for this can be obtained from Figure 4. This figure suggests that the adopted technologies in the No–Subsidy treatment do not follow a uniform distribution, but they depend on the level of savings; the share of technologies adopted in the higher savings range ($e > 16$) is clearly lower than for the other technologies. This idea is confirmed by the results of a logit regression (not shown here but available upon request) in which the adoption decisions in the No–Subsidy treatment are related to the level of per–period savings. The regression results indicate that the estimated probability of adopting a technology is a pyramid–shaped function of the amount of per–period savings, with a maximum at 10.0 (which is clearly below 12.5, which may be due to risk aversion). Moreover, as can be inferred from Figure 5, technologies in the range [22,25] are quite unpopular in the No–Subsidy treatment. So, we would regard it quite 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–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 do. 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.[16]

Modern theories in cognitive psychology emphasize that decision making

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[16] 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.

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. 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 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 judgement 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 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 inex-

perienced.

To explore this issue we use the classification of small, medium-sized, and large firms as defined above and calculate the averaged per–period realized savings by treatment for managers of each of these subgroups. Figure 5 presents the results of this exercise. The figure 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 $p < 0.01$).

[Insert Figure 5 about here]

Interestingly, in line with the hypothesis that investment managers from bigger 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 an 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 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 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

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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.[17]

6 Conclusions

In this paper we experimentally evaluate the behavioral impact of a technology adoption subsidy on adoption behavior. We use the experimental method to control for confounding factors that affect investment decisions. Moreover, we try to further external validity by (i) providing context to the experiment, and incorporating several features which are also relevant for actual decision making in the field (e.g., 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 (ii) using 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 disproportionally 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%

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[17]An interesting hypothesis is that it is not so much the actual level of the subsidy that matters, but more the fact that certain options are subsidized. We did not have access to enough managers to investigate this hypothesis, but we did examine this hypothesis with student subjects. The students were subjected to the same experimental design as the one described above (only with lower payoff levels). We ran one treatment with no subsidy, one with a subsidy of 6% and one with a subsidy of 13%. The results for the first two treatments are very much in line with those of the manager subjects. The presence of a subsidy significantly increased the average level of realized savings, from 11.2 to 14.3. However, increasing the level of the subsidy to 13% did not have an effect. Average realized savings (13.3) were actually (insignificantly) lower than with a subsidy of 6%.

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 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). Our results suggests 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.

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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 his output market and faces the following downward–sloping demand function:

$$P(Q_t) = a_t - bQ_t,$$

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 profits equal $(a_t - c)^2 / 4b$.

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

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

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 a Net Present Value $\pi_0 = \pi(e_0)$. If e_0 is smaller than $\frac{1}{2}E$, the range of technologies he 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 NPV of that offer is equal to $\frac{1}{e_{H0}-e_{L0}} \int\limits_{e_{L0}}^{e_{H0}} \pi(e) de$. All technology offers with $\pi \leq \pi_0$ have zero value (as the decision maker can always decide to adopt e_0 as this offer remains valid throughout the game). Therefore, using (2), the expected benefits of asking for a new technology offer (given e_0) are equal to

$$EB(\pi_0) = EB(\pi(e_{L0})) = \frac{1}{E} \int\limits_{e_{L0}}^{e_{H0}} \pi(e) de = (v/E) \left[\frac{1}{4} E^2 - e_{L0}^2 \right]. \quad (5)$$

Now we can define the critical technology offer as that technology with a specific NPV 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 NPV). When deciding to continue the search upon having received offer e_0, the decision maker forgoes the profits he could obtain in the output market, the expected value of which is equal to Z. In addition, he 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, he can continue requesting new offers as long as the game does not end (which is the case with probability α). The expected benefits of continuing searching for a more profitable technology equal $\alpha \left[EB(\pi_0) - Z \right] + \alpha^2(1 - p_0) \left[EB(\pi_0) - Z \right] + \alpha^3(1-p_0)^2 \left[EB(\pi_0) - Z \right] ...$, which converges to $\alpha \left[EB(\pi_0) - Z \right] / (1 - \alpha(1 - p_0))$. The benefits of actually adopting the current technology offer e_0 equal π_0. The critical technology offer is thus implicitly determined by

$$\alpha \left[EB(\pi_0) - Z \right] / (1 - \alpha(1 - p_0)) = \pi_0. \quad (6)$$

Given that initially the firm has a default technology (i.e., $e = 0$), the optimal strategy is to request a new technology offer. 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: Experimental Instructions

This appendix contains the instructions used in the Subsidy treatment. The instructions for the no subsidy treatment were adapted accordingly and are available from the authors upon request.

Instructions

You are about to participate in an experiment on individual decisionmaking, which means that there is no interaction with other participants. You will be asked to take a number of decisions. The decisions that you take will affect your earnings. If you take your decisions carefully, you can earn a considerable amount of money. You can collect your earnings in cash as of next week in B303. During the experiment your earnings will be denoted in points. After the experiment your earnings will be converted into Euros at a rate of 1 point is 2 Eurocents, and hence 100 points = 2 Euros. During the experiment, you are not allowed to talk to other participants.

In the experiment, you will play the role of a manager of a firm operating in a market. The experiment will consist of 5 independent games and each game will consist of several periods. In each period, you can either decide on the quantity of units of output you wish to produce, or you can decide to be informed about the possibility to buy a new technology that yields a fixed amount of benefits in each period. We will now describe these two decisions in more detail.

Setting the quantity of output you produce

Q denotes the quantity of output you decide to produce. This output will be sold at a market. P denotes the price per unit and this price decreases if you produce more units. To be precise, the price is determined by the following relationship:

Due to fluctuations in demand, which are outside of your control, A is a variable that varies from period to period. It can take any value between 1.60 and 2.40, where each value is equally likely. A is determined separately and independently for each period. The production costs are 1.60 points per unit. So if you produce Q units in a period, your production costs are 1.60Q. Your profits are equal to revenues minus production costs: PQ – 1.60Q

For your quantity you may choose any integer value between 0 and 100, that is 0, 1, 2, . . . , 99, 100.

However, rather than using the above formula, you can also use the profit table (Table 1) which is attached at the end of the instructions. This table gives your profits for different combinations of Q and A, which can help you to find the best Q

for different realizations of A. In the first column (in grey print), you find a series of possible quantities of output that you can decide to produce, ranging from 0 to 100. In the first row (in grey print), you find a series of possible values of A, ranging from 1.60 to 2.40. To determine your profits, find the intersection of the relevant column (the value of A), and row (the quantity Q). The cell in the table thus identified gives you the resulting amount of profits for this combination of Q and A.

Example. Suppose you are informed that the relevant value of A in a period equals 2.20. And suppose you decide to produce 20 units of output. Find the intersection of column A=2.20 and row Q=20. You see that your profits are 9.87 points.

If you do not enter a quantity yourself then the computer will enter a default value of Q = 0. This value gives you zero profits, independent of the value of A (see also Table 1). If you set your quantity yourself you may do better because you can adjust your quantity depending on the value of A.

Buying a new technology

You also have the possibility to buy a new technology. From the moment of purchase onwards, a new technology gives you a certain amount of benefits in every period. The per–period benefits are denoted by E. If you invest in a technology with benefits E, this means that in the present and all future periods of the present game your earnings will increase by E points. This increase in your earnings does not depend on your quantity Q or on A.

Buying a new technology also involves an investment cost which we denote by I. This cost of investment will be subtracted from your earnings if you buy the technology. Note that you incur the cost I only in the period in which you buy the technology, while you receive the benefits from the technology in the present and all future periods of the present game.

There are different technologies that vary with respect to the per–period benefits (E). The benefits range from E = 0 to E = 25. Generally, a technology with higher benefits (E) is also more expensive (higher I). In fact, there is a precise relationship between the benefits (E) and the investment cost (I) of a technology. The following figure gives this relationship.

**Relation between Benefits (E)
and Investment cost (I)**
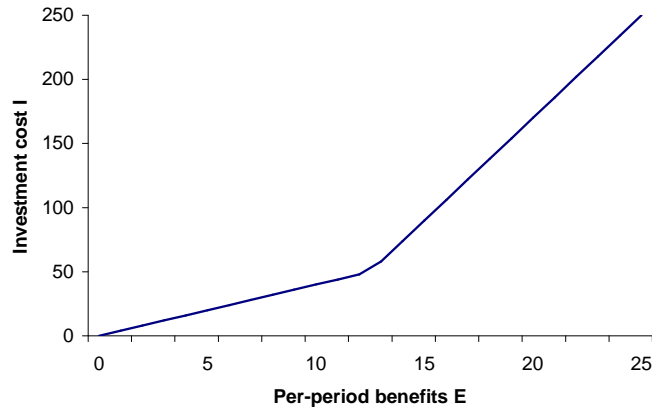
The figure shows that investment costs range from $I = 0$ points for a technology with $E = 0$ to $I = 250$ points for the technology with $E = 25$. Furthermore, the figure is relatively flat until $E = 12.5$ and becomes steeper after $E = 12.5$. To be precise, for lower levels of benefits (below $E = 12.5$), a technology that yields one additional unit of benefits in every period as compared to another, is 4 points more expensive, while for higher levels of benefits (above $E = 12.5$) each additional unit of benefits implies an additional investment cost of 16 points. Table 2, which is attached at the end of the instructions, summarizes the information about the relation between E and I.

Those technologies that yield the largest amount of per–period benefits, are subsidized. The subsidy, denoted with S, is applicable to all technologies that provide benefits of E=22, and higher (up to E=25). The subsidy is 13In principle, you can now decide which technology you like best. However, you cannot simply go and purchase a specific technology. If you want to buy a technology you will first have to search for one. This works as follows. In each period you can request to see an offer for a technology. This technology will be characterized by a certain level of per–period benefits E. To be precise, the computer will draw a number which determines the technology that is offered to you. The corresponding purchase price of this technology (investment cost I) is calculated as described above (see Figure 1 and/or the second column of Table 2). You are also informed whether the technology offered is subsidized, as well as the amount of subsidy associated with the technology (see the third column of Table 2).

After having indicated that you wish to search for a new technology, you are confronted with two buttons. If you press the button labeled 'WITH SUBSIDY', the computer randomly draws a technology with per–period benefits between E=22 and E=25, where each value of E between 22 and 25 is equally likely. You will be informed about the associated investment costs (I) as well as about the size of the subsidy (S). If you press the button labeled 'WITHOUT SUBSIDY', the computer randomly draws a technology with per–period benefits between E=0 and E=22, where each value of E between 0 and 22 is equally likely. You will be informed about the associated investment costs; as these technologies are not subsidized, the size of the subsidy is zero.

As the technology offered is random, an offer may be made which is or is not to your liking. If you do not like the technology offered, you can decide to continue your search in the next period. Alternatively, you may like the technology offered, but may be uncertain as to whether you want to purchase it now, or in a later period. That means that in each period in which you are searching for a new technology, you have to answer two questions. First, whether you prefer the technology to the technology offers you (may) have received in earlier periods. Second, whether you wish to purchase the technology you liked best so far, or whether you want to postpone this decision.

If you decide to buy the technology the amount I will be subtracted from your earnings in that period, and an amount E will be added to your earnings in that period and all future periods. If you decide not to buy the technology (yet), then there is no effect on your earnings in that period.

If you decide not to buy the offered technology, you can request a new offer in the next period or in any later period. If you do so, you will get a new offer. The benefits E of the new offer will again be between E = 0 and E = 25 and again you can request to have an offer for a technology without a subsidy (E randomly drawn between 0 and 22) or with a subsidy (E randomly drawn between 22 and 25).

You can purchase as many new technologies as you like. However, if you buy a new technology while you already bought one in an earlier period, then the benefits E of this new technology will replace the benefits E of the old technology. In other words, the benefits E do NOT ADD UP if you purchase more than one technology.

A period

As was indicated above in each period you can decide to either set the quantity you wish to produce or to be informed about a new technology.

If you decide to be informed about a new technology, you will not be able to set your quantity and the computer will automatically set your quantity at Q = 0. That means that you will make zero profits, independent of the realized value of A (see also Table 1). On the other hand, if you decide to set your quantity yourself, you will not get information about a new technology and you will also not be able to buy a new technology.

Games

As was indicated above, the experiment consists of 5 games. The decision task in each of these games is exactly the same. Furthermore, the games are completely independent. This means that the decisions that you take in the present game do not affect your profits in a later game. Your total earnings in a game are:

The profits you make with your quantity Q in each period

+ the sum of all per–period benefits (E) on the technology used in each period

– the investment costs (I) for each technology that you buy

+ the subsidy (S) you receive on each technology that you buy.

Each game consists of several periods. You do not know how many periods a game will have. The number of periods for each game is determined as follows. After each period the computer will determine whether there will be another period. There is a probability of 90This completes the instructions. However, we will now also briefly describe the computer screens.

Computer screens

The first screen of a game is the following.
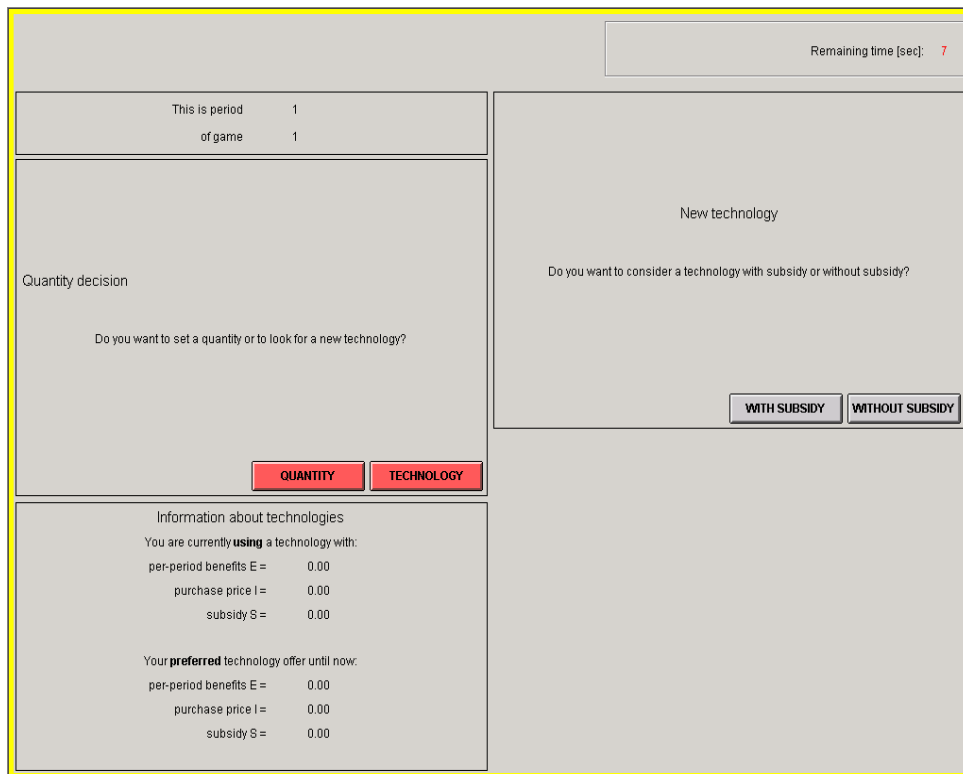
In the top–left box you can see the game you are in as well as in which period of that game.

In the middle–left box of this screen, you can indicate whether you want to set the quantity (Q) in this period (by pressing the red button 'QUANTITY'), or to look for a new technology (by pressing the red button 'TECHNOLOGY'). If you press 'QUANTITY', you will be informed about the realized value of A in this period, and you can enter the quantity of output (Q) you wish to produce.

The top–right box of the screen becomes active if you choose 'TECHNOLOGY'. When pressing 'TECHNOLOGY', you will not have the opportunity to set the quantity of output Q in this period. After having pressed 'TECHNOLOGY', the buttons 'WITH SUBSIDY' and 'WITHOUT SUBSIDY' show up in red. By pressing 'WITH SUBSIDY', you will get an offer for technologies that yield per–period benefits of at least 22 points, and a subsidy with a value of 13After pressing either of the two red buttons, the following screen will appear.

In the top–right box of the screen, you see the characteristics of the technology that is being offered in this period. In the bottom–right part of the screen, you see the characteristics of the technology that you preferred until now. Obviously, this part of the screen only contains zeros if you are searching for the first time in this game.

You can now compare the new offer of this period (top right; NEW) to the offer you liked best until now (bottom right; OLD). Please indicate which of the two technologies you prefer by clicking the button in front of either the label 'NEW' or 'OLD'. Next, indicate whether you wish to buy this technology or not (by clicking on the button YES or NO).

If you click YES, you buy the technology. Its per–period benefits (E) are added to your earnings in this period and in all future periods, the investment costs (I) are subtracted from your earnings, and the associated subsidy (S, if any) is added to your earnings. In the next period, this information will be shown in the first three lines of the bottom–left box of the screen called 'Information about technology'.

If you click NO, you do not buy the technology, but all relevant information is retained so that the technology you liked best until now, remains available in the future in case you wish to buy it later. In the next period, this information will be

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shown in the last three lines of the bottom–left box of the screen.

When you have entered your quantity decision or your investment decision, you proceed to the final screen of the period:
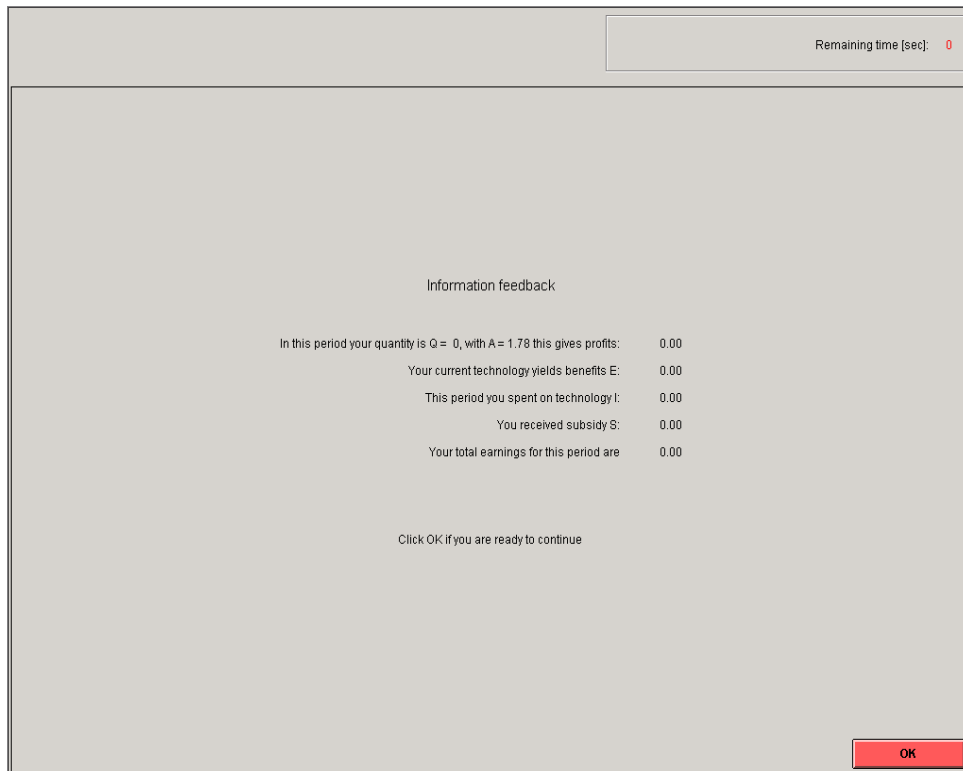
In this screen, you receive information about your earnings in this period. If you are ready to continue, please press 'OK'.

Whether the game proceeds to the next period or ends, is determined by the computer by means of a random draw. There is a probability of 90If the random draw is such that the game ends, you will be informed about that, and when pressing CONTINUE the computer starts the first period of the next game (unless you have already played all five games).

If the random draw is such that the game continues, you will be informed about that, and the first screen of the next period appears.

If there are any questions at this point, please raise your hand.

If there are no questions left, we will start the program. You will first play one practice game, called game 1, for which you are not being paid. If you have any questions after having played that practice game, please raise your hand. Otherwise,

you are free to continue with game 2, which is the first of the five games you play for real money.

The following table gives your profits for different values of Q and different values of A. The table only lists the profits for some discrete values of Q and A. If you wish to find profits for intermediate values you can use the formulas in the text.

Profits as a function of quantity produced:

Quantity produced:	Realization of A: 1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	-0.13	0.12	0.37	0.62	0.87	1.12	1.37	1.62	1.87	2.12	2.37	2.62	2.87	3.12	3.37	3.62	3.87
10	-0.53	-0.03	0.47	0.97	1.47	1.97	2.47	2.97	3.47	3.97	4.47	4.97	5.47	5.97	6.47	6.97	7.47
15	-1.20	-0.45	0.30	1.05	1.80	2.55	3.30	4.05	4.80	5.55	6.30	7.05	7.80	8.55	9.30	10.05	10.80
20	-2.13	-1.13	-0.13	0.87	1.87	2.87	3.87	4.87	5.87	6.87	7.87	8.87	9.87	10.87	11.87	12.87	13.87
25	-3.33	-2.08	-0.83	0.42	1.67	2.92	4.17	5.42	6.67	7.92	9.17	10.42	11.67	12.92	14.17	15.42	16.67
30	-4.80	-3.30	-1.80	-0.30	1.20	2.70	4.20	5.70	7.20	8.70	10.20	11.70	13.20	14.70	16.20	17.70	19.20
35	-6.53	-4.78	-3.03	-1.28	0.47	2.22	3.97	5.72	7.47	9.22	10.97	12.72	14.47	16.22	17.97	19.72	21.47
40	-8.53	-6.53	-4.53	-2.53	-0.53	1.47	3.47	5.47	7.47	9.47	11.47	13.47	15.47	17.47	19.47	21.47	23.47
45	-10.80	-8.55	-6.30	-4.05	-1.80	0.45	2.70	4.95	7.20	9.45	11.70	13.95	16.20	18.45	20.70	22.95	25.20
50	-13.33	-10.83	-8.33	-5.83	-3.33	-0.83	1.67	4.17	6.67	9.17	11.67	14.17	16.67	19.17	21.67	24.17	26.67
55	-16.13	-13.38	-10.63	-7.88	-5.13	-2.38	0.37	3.12	5.87	8.62	11.37	14.12	16.87	19.62	22.37	25.12	27.87
60	-19.20	-16.20	-13.20	-10.20	-7.20	-4.20	-1.20	1.80	4.80	7.80	10.80	13.80	16.80	19.80	22.80	25.80	28.80
65	-22.53	-19.28	-16.03	-12.78	-9.53	-6.28	-3.03	0.22	3.47	6.72	9.97	13.22	16.47	19.72	22.97	26.22	29.47
70	-26.13	-22.63	-19.13	-15.63	-12.13	-8.63	-5.13	-1.63	1.87	5.37	8.87	12.37	15.87	19.37	22.87	26.37	29.87
75	-30.00	-26.25	-22.50	-18.75	-15.00	-11.25	-7.50	-3.75	0.00	3.75	7.50	11.25	15.00	18.75	22.50	26.25	30.00
80	-34.13	-30.13	-26.13	-22.13	-18.13	-14.13	-10.13	-6.13	-2.13	1.87	5.87	9.87	13.87	17.87	21.87	25.87	29.87
85	-38.53	-34.28	-30.03	-25.78	-21.53	-17.28	-13.03	-8.78	-4.53	-0.28	3.97	8.22	12.47	16.72	20.97	25.22	29.47
90	-43.20	-38.70	-34.20	-29.70	-25.20	-20.70	-16.20	-11.70	-7.20	-2.70	1.80	6.30	10.80	15.30	19.80	24.30	28.80
95	-48.13	-43.38	-38.63	-33.88	-29.13	-24.38	-19.63	-14.88	-10.13	-5.38	-0.63	4.12	8.87	13.62	18.37	23.12	27.87
100	-53.33	-48.33	-43.33	-38.33	-33.33	-28.33	-23.33	-18.33	-13.33	-8.33	-3.33	1.67	6.67	11.67	16.67	21.67	26.67

Table 1. Quantities and profits

The following table gives the relationship between the per–period benefit (E) a technology yields and its investment costs (I) for the relevant range of technologies, as well as the relevant level of investment subsidies (S).

per-period benefits	cost of investment	investment subsidy
E	I	S
0	0	0
1	4	0
2	8	0
3	12	0
4	16	0
5	20	0
6	24	0
7	28	0
8	32	0
9	36	0
10	40	0
11	44	0
12	48	0
13	58	0
14	74	0
15	90	0
16	106	0
17	122	0
18	138	0
19	154	0
20	170	0
21	186	0
22	202	26.26
23	218	28.34
24	234	30.42
25	250	32.50

Table 2. Investment costs for the relevant range of technologies

1

$\pi^{NS}(e)$

π_0

v

$\frac{1}{2}E - d$ $\frac{1}{2}E$ $\frac{1}{2}E + d$ E

e
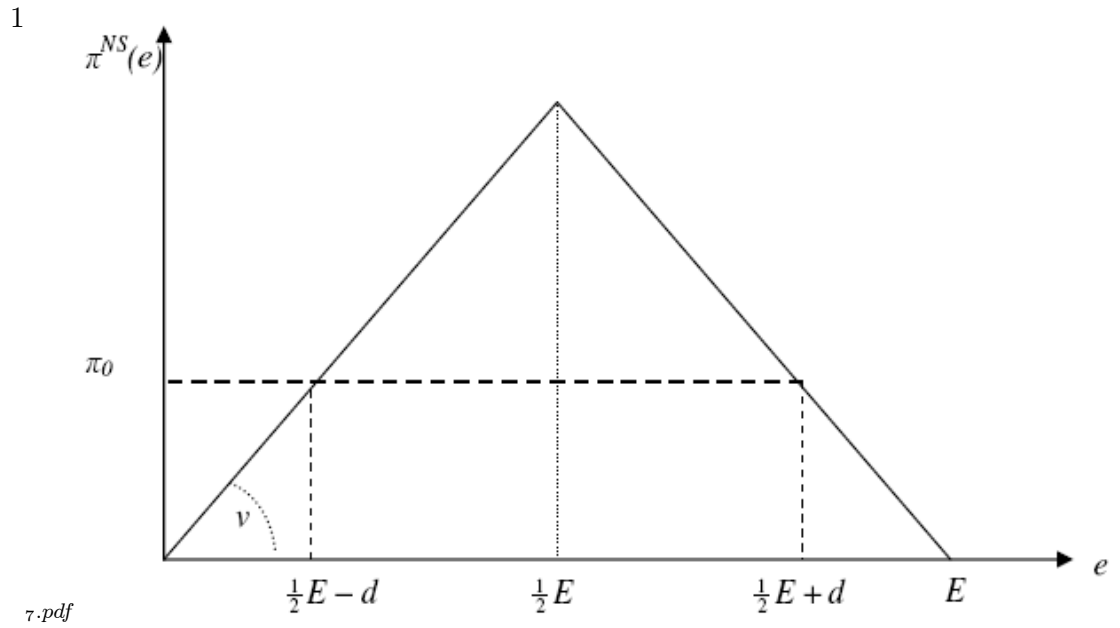
Figure 1: Expected net present values and critical values in the absence of a subsidy

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$\pi^{S}(e)$

π'_0

v

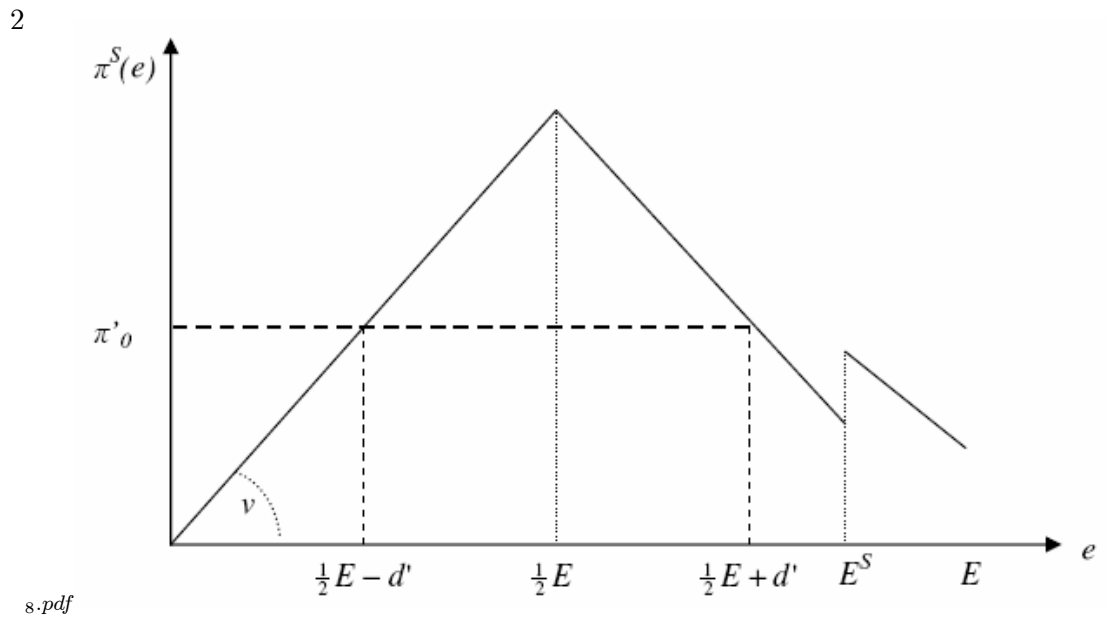$\frac{1}{2}E - d'$ $\frac{1}{2}E$ $\frac{1}{2}E + d'$ E^S E

e

Figure 2: Expected net present value and critical values in the presence of a subsidy
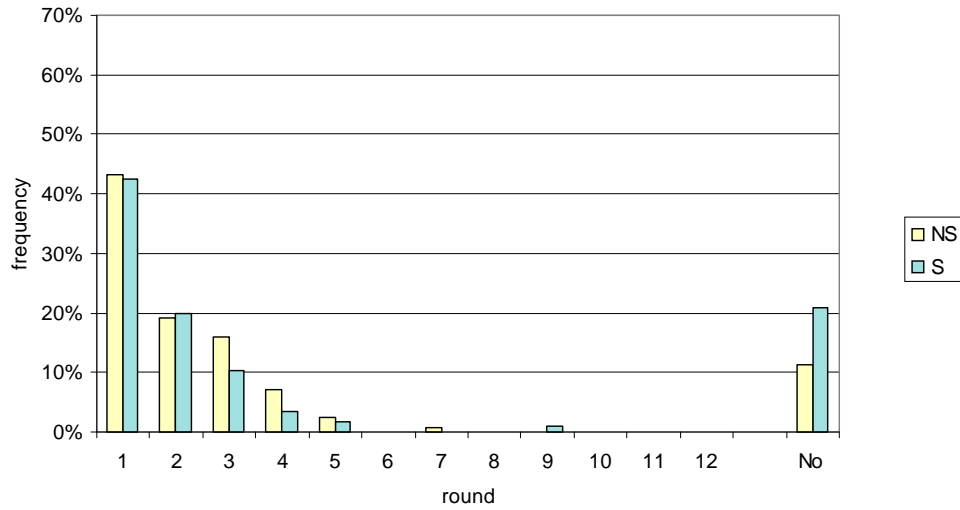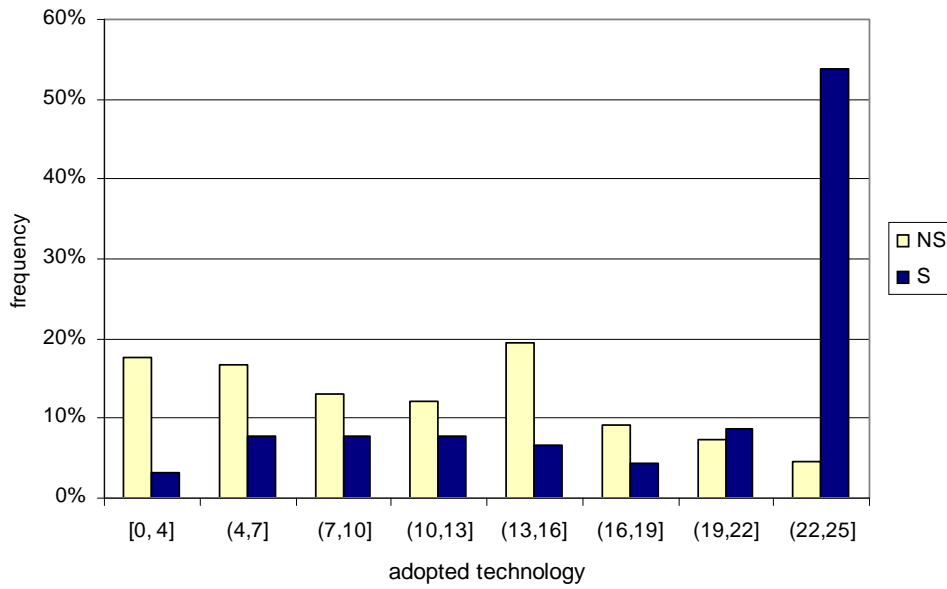
Figure 3: Period of adoption
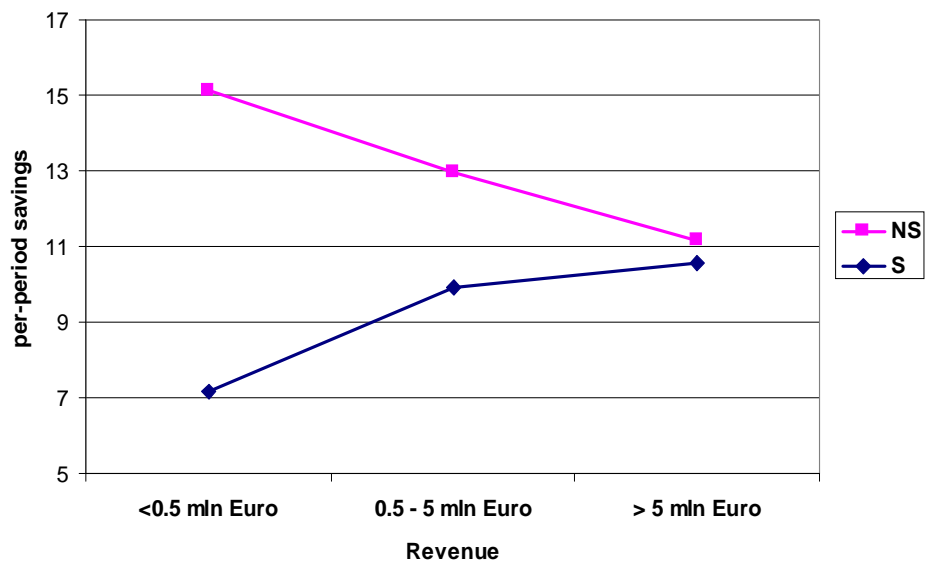

Figure 4: Adopted technologies

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Figure 5: Average per-period savings by revenue size of the manager's firm