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Monty Hall's Three Doors for Dummies

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Abstract

Monty Hall's three doors problem is a well-known "anomaly" in economics. It appears to be an example of a systematic violation of the assumption of subjects' rationality. Many papers have studied the Monty Hall anomaly under different perspectives (i.e. computerizing, learning, grouping, talking, and even teaching how to play it), but the anomaly still survives. The most common explanation for this is that subjects are unable to carry out correctly the Bayesian updating necessary. Our approach is different from all previous attempts to explain and correct the Monty Hall anomaly, inasmuch we developed a more radical "debiasing test". Even if the game remains identical in terms of probabilities and subjects task, we eliminate the necessity for any Bayesian updating, as our new framework does not require subjects to make any probability calculations. Consequently, having eliminated the cause, also the effect should have disappeared. In order to make our results robust, we also run an intermediate treatment. Even though we observe an evident monotonic increase in the switching percentage across the three treatments, as we expected (from 41.5% in the treatment that replicates the standard design, to 45.5% for the intermediate treatment, up to 58% in the new framework), this percentage remains still too low, even though no Bayesian updating is involved. These results drive us to conclude that this anomaly, even if attenuated by design conditions, is not a weak effect, but rather a systematic behavioural regularity. It could be attributed to some psychological underpinnings, such as the *status quo bias*. We comment on these, and alternative explanations, in our conclusions.

JEL classification: C72; C91

Keywords: Learning; Anomaly; Individual decision making

1. Introduction

Since its appearance in the literature, Monty Hall’s three doors “anomaly” has attracted the attention of scientists from different fields: economists (Friedman, 1998; Page, 1998; Palacios-Huerta, 2003; Slembeck and Tyran, 2004), statisticians (Morgan et al., 1991; Puza et al., 2005), psychologists (Granberg and Brown, 1995; Krauss and Wang, 2003) and others. The reason for such attention may be explained by the fact that this “anomaly” relies on a simple, even if counterintuitive, problem. There are three doors, and only behind one of them there is a big prize. At the beginning of the game, the player is asked to choose just one door. After that, an empty door among the not chosen doors is opened and the player is asked to make a new decision: either to stick with the first chosen door or to change and choose the remaining not-opened door. If people performed the Bayes’ updating correctly, they should realise that switching is the best strategy because it doubles the percentages of winning (as we show in the next section). Nevertheless, the stylised fact from the American TV programme in which this game was firstly performed, and from the controlled experiments that replicated its basic structure (Friedman, 1998; Page, 1998; Palacios-Huerta, 2003; Slembeck and Tyran, 2004) is that only a low percentage of people choose to switch.

The aim of this paper is to contribute to understanding the possible reasons for which the people fail to adopt the best strategy, even in an environment in which they perform the task repeatedly. Our experimental results drive us to conclude that the most common reason for this anomaly, that is, the misapplication of Bayes’ rule, even if it contributes undoubtedly in reducing the anomaly, is not the only nor the most important reason for it.

The paper is structured as follows. In sections 2 and 3, we will introduce the problem and we will present the new experimental design, respectively. In section 4 our results will be presented. In section 5 some possible explanations will be proposed. Finally, in section 6, we will draw some conclusions.

2. The problem

Monty Hall’s three doors is an extremely simple game. First, subjects are asked to choose one of three doors, that are equally likely to hide a big prize. Consequently, the first chosen door has a probability of one third, whereas the two left doors taken together have a probability of two thirds hiding the prize. Moreover, if we consider the remaining two doors, we know that with probability 1, one of them is surely empty. Then, when one of the two left doors is opened, knowing precisely which one is empty does not add any relevant information, and does not affect the probability that the first chosen door hides the prize or the probability that the prize is behind the not chosen pair.

Nevertheless, it seems that the players are generally unable to recognize this. This is one of the most crucial points in the Monty Hall anomaly, since it is directly related to the issue in decision-making concerning the manner in which people process new information and update beliefs. It is well-known that in the Monty Hall game the optimal strategy is to switch. This follows from a direct application of Bayes' rule: let us label the three doors A, B and C and assume a subject chooses door A. Additionally, Monty opens door B (that is an empty door, and the subject knows the door will be opened is empty). Now we can calculate the probability of winning by switching to C given that Monty opened B and the probability of winning by not switching to C given that Monty opened B:

$$\Pr\left(prize\, in\ C \mid Monty\ opened\ B\right) = \frac{\Pr\left(Monty\ opened\ B \mid prize\, in\ C\right)\Pr\left(prize\, in\ C\right)}{\Pr\left(Monty\ opened\ B\right)} =$$

$$= \frac{(1)(1/3)}{(1)(1/3) + (1/2)(1/3)} = \frac{2}{3}$$

$$\Pr\left(prize\, in\ A \mid Monty\ opened\ B\right) = \frac{\Pr\left(Monty\ opened\ B \mid prize\, in\ A\right)\Pr\left(prize\, in\ A\right)}{\Pr\left(Monty\ opened\ B\right)} =$$

$$= \frac{(1/2)(1/3)}{(1)(1/3) + (1/2)(1/3)} = \frac{1}{3}$$

A rational subject should be able to perform this calculation and therefore he/she should choose always to switch. Unfortunately, this is not the case, since many subjects decide to stay with their first choice.

Several possible reasons have been suggested to explain this *anomaly*, for example: (1) subjects could make mistakes in updating the relevant probabilities, i.e., they do not perform the Bayes'rule correctly; (2) they could suffer of the *endowment effect* (Kahneman et al., 1991) which captures the overvaluation of the winning probability of the owned door and/or the *status quo bias* (Samuelson and Zeckhauser, 1988) which is the preference to remain at the current door; (3) subjects could believe erroneously that the task, in addition to chance, entails some kinds of skill (in the psycological literature, this belief is called *illusion of control*) and, therefore, they could try to "guess" somehow the winning door using some skill as insight, and seeing one of the two remaining doors empty is nothing but a reinforcement of their prior belief; (4) subjects could act following as a strategy the *probability matching behaviour*, i.e., they could decide to choose not the optimal startegy (always switching), but they could choose each strategy according to their relative likelihood of success. In our case, this means that they should choose the two strategies, switching and not switching, in proportion of one third and two thirds, respectively.

Our experimental design enables us to discriminate better among these different explanations. In this perspective, our approach is different, inasmuch we developed a more radical “debiasing test” compared to all previous experimental attempts, whose focus has been almost exclusively on some particular aspects that could be able to mitigate the anomaly and help people to behave rationally. These treatments were designed to endorse learning and to test other institutions recognized sensitive to anomalous choice behaviour**.**

3. The new experimental design

When we first approached this problem, we were puzzled, and we were moved by a simple idea: “if something is true there should be an easy way to explain it.” Obviously, if it is true that “switching the door” is better than “keeping the door”, 2/3 chance of winning is better than 1/3, then there should be an easy, understandable, and convincing way to demonstrate it. In order to determine this easy way, we modified the *Monty Hall’s three doors* into the *Monty Hall’s three doors for dummies*. As in the basic structure, there are three doors, and only behind one of them there is a big prize. Subjects are asked to choose one of the three doors, but then they are asked if they would like to change the door they firstly chose with both the other two doors. In this way, they should readily realize that we were trading off 2/3 change of winning for 1/3, and they should take advantage of such opportunity promptly.

The experiment is composed by three treatments: CONTROL, INTERMEDIATE, and FOR DUMMIES. In the CONTROL treatment, identical to first treatment in Friedman (1998), the subject was firstly asked to choose a door among three. Then, an empty unchosen door was opened. Finally, the subject was asked to stick with to the first chosen door or to switch to the remaining unchosen door. In the FOR DUMMIES, subjects chose a door, and then they were asked if they wanted to change the chosen door with both the remaining doors. In this case, no empty door was revealed. In order to make our results robust for monotonicity, we also ran the INTERMEDIATE treatment, in which the only difference was that, after an empty door one was opened, they were asked if they wanted to keep the chosen door or if they wanted both the other two doors (one closed and one open). Summarizing:

- In the CONTROL treatment, once an empty door is opened, new information enters in the game and some probabilities have to be updated. All subjects should update their belief (i.e. the probability that the firstly chosen door hides the prize was 1/3 and it remains 1/3; the probability that the open door hides the prize was 1/3 and it fell to 0; the probability that the last door hides the prize was 1/3 and it rises to 2/3). In this treatment, it is easy to fail processing correctly the new information, subjects wrongly attached to the two still closed doors a 50-50 chance to hide the prize. In this sense, they fail the Bayesian updating;

- in the INTERMEDIATE treatment, once an empty door is opened, new information enters in the game once again and some probabilities have to be updated as well. In this treatment, since the two left doors are offered coupled, performing the correct Bayesian updating is easier, but it is still possible to fail it and attaching to the two closed doors a 50-50 chance to hide the prize.
- In the FOR DUMMIES treatment, no door is opened, and so there is no new information entering the game. The Bayesian updating is not needed and so it is impossible to fail it.

Otherwise, the three games were identical: all the relevant probabilities remained unchanged, but if in the CONTROL treatment subjects may fail to consider the opened and the left door as a pair, in the remaining treatments, they cannot fail to consider them a pair, because we offered them in pairs.

In this way, this simple design allowed us to establish if subjects fail the Bayesian updating, or if they may present some psychological underpinnings that drive them in keeping the first choice.

The experiment was programmed using the Z-tree software of Urs Fischbacher (1999) and was run at the laboratory of ESSE at the University of Bari.

Each treatment, lasting for about 45 minutes, was made up of 12 periods, 2 of which were trial periods. The trial periods were necessary in order to acquaint subjects with both the task and the computerized interface. Before the experiment was started they got the chance to ask questions about the experiment's instructions. We paid particular attention in writing the instructions and in avoiding any possible misunderstanding and/or deception (in Appendix we provide the instructions for the FOR DUMMIES treatment). For example, in explaining the structure of the game, we did not refer to any among the three cards as the opened one. This aspect is on trial in this statement: "Although, semantically, Door 3 […] is named merely as an example (Monty Hall opens another door, *say*, number 3), most participants take the opening of Door 3 for granted and base their reasoning on this fact" (Krauss and Wang, 2003).

In each treatment, we had N = 20 subjects, randomly assigned to the different treatments, all of them sat next to a PC terminal. The subjects could not see each other or communicate with the other subjects. Almost all of them were undergraduate students in Economics not familiar with previous similar experiments.

In the experiment the task was very simple: to pick on the screen a door among three, simply pressing a button. For each period the programme established which door hid the prize, and the subjects knew this.

This constituted the first stage of the game, the same in all the treatments. Then a new stage began. In all the treatments, information about subject's previous choice was displayed. Then, the three treatments diverged. In the CONTROL treatment, the programme chose and showed to the subject an empty door and then asked the subject if he/she wanted to keep his/her first choice or if he/she preferred to go for the remaining door. In the INTERMEDIATE treatment, the experimenter chose and showed to the subject an empty door and then asked if he/she wanted to keep his/her first choice or if he/she preferred the un-chosen doors (i.e. one door is opened and visibly empty, the other one is still closed). Finally, in the FOR DUMMIES treatment, subjects were given the opportunity to change the chosen door with the other two doors. In the final stage, subjects were informed about their chosen door(s), the right option and about their pay-off. They gained 0.5€ when they chose the lucky door, and zero otherwise.

4. The experimental results

Figure 1 summarizes the experimental results. It reports the switch rates in the three treatments over the ten periods. Comparing our CONTROL treatment with the experiments in the previous literature, we report an overall switch rate of 41.5%, higher than in Friedman (28.7%), however in line with all the other previous literature (Page, 1998; Palacios-Huerta, 2003; Slembeck and Tyran, 2004). The overall switch rate in INTERMEDIATE and FOR DUMMIES is 45.5% and 58%, respectively. Whereas there is no statistical difference between the CONTROL and the INTERMEDIATE treatment (Wilcoxon rank test, $p = 0.4203$), the FOR DUMMIES treatment is statistically different from both of them (Wilcoxon rank test CONTROL/FOR DUMMIES, $p = 0.0010$; INTERMEDIATE/FOR DUMMIES, $p = 0.0125$). Therefore, we can conjecture that the FOR DUMMIES treatment could have turned out to be effective in shaping a different kind of behaviour, whereas the other two treatments are statistically indistinct.

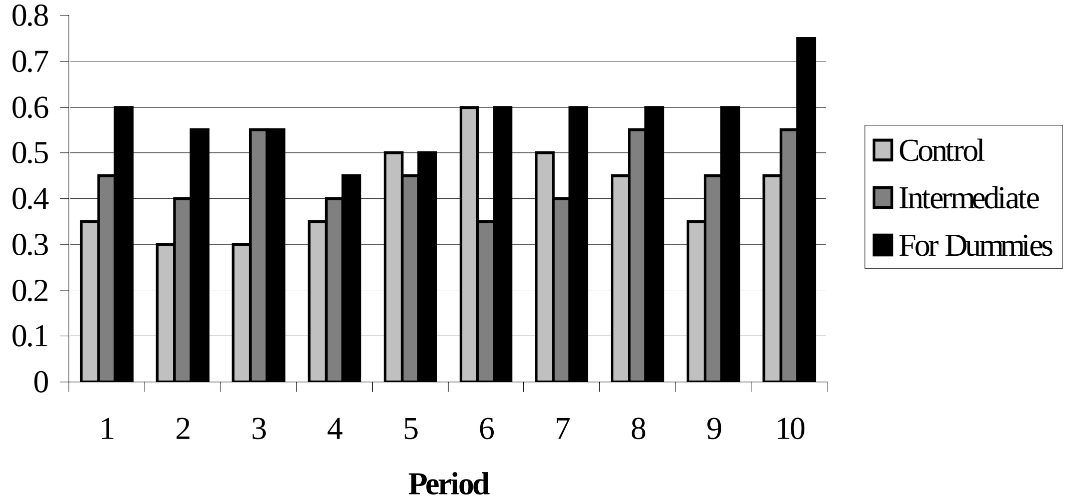

Figure 1: Switch Rate

Even though we observe a higher (or, at least, not smaller) switch rate in any single period under the FOR DUMMIES treatment, and a monotonic increasing pattern across the three treatments as expected, nevertheless the switch rate in the new framework is still too low, even in the last period (when it reaches its maximum at 75 percent). Indeed, if the real reason for this anomaly were the misapplication of the Bayes'law, since the new framework did not require subjects to make any calculations, we should have observed a switch rate that is not different from 100 percent. At this point, we cannot consider the Bayesian updating failure as the leading explanation any more. We should look for other plausible explanations.

Before going in to details, we show in figure 2 the categorization of our experimental subjects according to their different switch rate during the experiment:

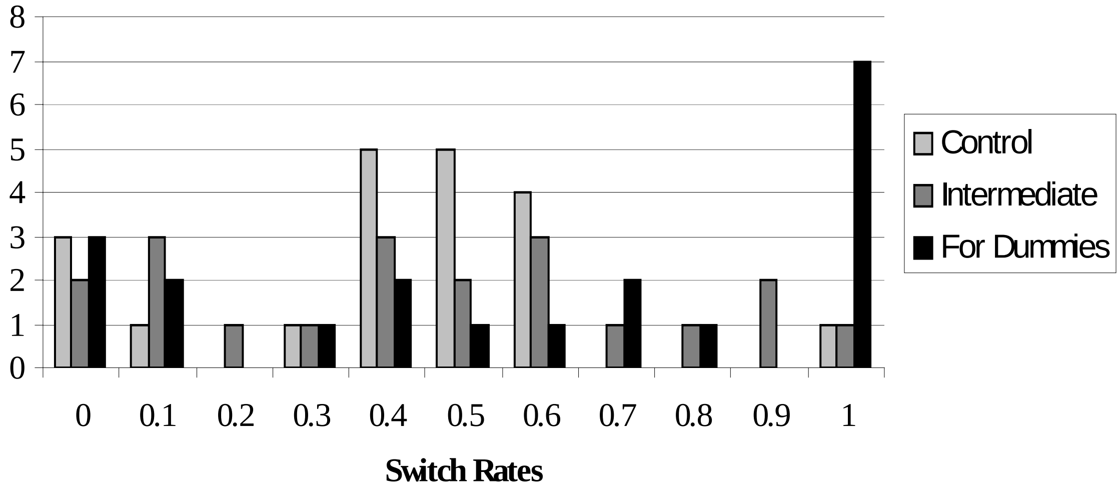

Figure 2: Categorization of subjects according to their switch rates. N = 20 in each treatment

As can be seen, even though the percentage of completely rational subjects is undoubtedly higher under the FOR DUMMIES treatment, i.e., 35% of subjects always switched, compared to the 5% in both other two treatments, nevertheless even in this case a non negligible percentage of subjects never switched (3 out of 20). We now try to list some of the possible explanations of this behavioural pattern.

As a first step, we test if the subjects behave randomly. In order to test this hypothesis, we run a one-sided binomial test in which we test as null hypothesis if the switch rate is equal to 50%, against the alternative hypothesis whereby the switch rate is greater than 50%. Very interestingly, we can reject the null hypothesis only for the FOR DUMMIES treatment (p-value = .01406), whereas we cannot reject the hypothesis of completely random behaviour in the CONTROL and INTERMEDIATE treatments (p-value = .99344 and p-value = .91052, respectively).

Given that probability matching behaviour has been invoked as a possible explanation for this anomaly, as a second step, we investigate if the switch rate is significantly different from 2/3. We have already underlined that, according to this hypothesis, subjects would play strategies in relation to their likelihood of success (and switching has 2/3 chance of winning) and not the optimal strategy (in this case, they should always decide to switch), as the axiom of rationality would require. We can reject the hypothesis that subjects behaved according to the probability matching behaviour in all three treatments.

Finally, we will follow Friedman (1998) and Slembeck and Tyran (2004) to estimate a simple learning model. We ran a probit model with the maximum likelihood estimation procedure. Specifically, we constructed a model that links the decision of switching or not with a set of determinants, as follows. The presence of learning is investigated by the use of the variable *Time* (the period number) and the variable $Time^2$, to test for concavity of learning. In order to study reinforcement learning (or fictitious play; Erev and Roth, 1998), we use the *Switchbonus* variable (the cumulated earnings from always switching minus the earnings from always not switching); directional learning (or Cournot behaviour; Selten and Buchta, 1998) is studied by using the *Switchwon* variable (a dummy variable equal to 1 if in the most recent period the subject switched and won) and *Switchlost*, (a dummy variable equal to 1 if in the most recent period the subject switched and lost).

(Note that the reported significance levels assume independent observations, though this is unlikely to be the case.)

Table1: Maximum Likelihood probit estimation[1]

Dep. Variable Switch	Friedman Run1	Friedman Run2	Slembeck-Tyran	Morone-Fiore
Constant	-1.090	-0.814	-	-
	(0.000)	(0.000)		
Time	0.055	0.032	0.0135	-0.0539
	(0.001)	(0.000)	(0.013)	(0.109)
Time^2	-	-	-0.003	0.0044
			(0.008)	(0.141)
Switchbonus	0.325	0.082	0.0017	0.0632
	(0.000)	(0.000)	(0.003)	(0.004)
Switchwon	0.106	0.293	0.3323	0.3467
	(0.344)	(0.000)	(0.000)	(0.000)
Switchlost	-	-	-0.2149	0.2735
			(0.000)	(0.000)
Fiedman's treatments				
Intense	-	-0.243	-	-
		(0.002)		
Track	-	0.276	-	-
		(0.009)		
Advice	-	0.337	-	-
		(0.012)		
Compare	-	0.208	-	-
		(0.069)		
Slembeck-Tyran's treatments				
Competition	-	-	0.1435	-
			(0.035)	
Communication	-	-	0.1549	-
			(0.022)	
*Comp*Comm*	-	-	0.0468	-
			(0.375)	
Morone-Fiore's treatments				
Intermediate	-	-	-	0.0229
				(0.661)
ForDummies	-	-	-	0.1211
				(0.022)
Log likelihood	-589.9	-927.8	-956.88	-370.95
Pseudo R^2	-	-	0.2571	0.1073
NOBs	1,040	1,407	1,880	600

[1] The dependent variable is 1 in periods in which the subjects chose to switch, and 0 otherwise. Friedman reports the coefficient estimates, considering a panel structure, whereas Slembeck and Tyran, and Morone and Fiore report the marginal effects after the probit estimation and they do not consider a panel structure. *Switchbonus*: earnings from always switching minus earnings from always remaining. *Switchwon*: dummy variable equal to 1 if the decision maker switched and won the prize in the most recent period. *Switchlost*: is equal to 1 if and only if the decision maker switched in the preceding period but did not win the prize.

In table 1, we report marginal effects, since coefficients derived from models of this sort do not have the usual meaning and interpretation as in linear models, whereas marginal effects do have. The package we used in analysing our data reports the marginal effects at the sample means of the data for continuous variables, and for a discrete change from 0 to 1 for dummy variables.

We observe that among the significant variables, *Switchwon* behaves as in the previous analysis, whereas *Switchlost* has the same magnitude, but it goes in the opposite direction. That means that we cannot confirm precisely directional learning theory, because our results are not unambiguous: the variable *Switchwon* indicates that the probability of switching is 34.67% higher if the subject chose to switch and won in the most recent period, as we expected, whereas *Switchlost* suggests that even if the subject chose to switch and lost in the preceding period, this fact increases the probability of switching by 27.35%. As regards the test for the other learning theory, reinforcement learning, the variable *Switchbonus* shows the expected direction and is more effective than in the previous analysis.

The negative effect for *Time* would suggest a downward trend to switch, on the contrary, the positive effect for $Time^2$ would show that we have a non linear and convex trend over time, but neither of them are significant.

Finally, as can be observed from the table, our last treatment, *ForDummies*, is significantly effective in increasing the probability of switching (by 12.11%).

In conclusion, our results are quite in line with previous ones, except for the fact that learning is not explained by the variable *Time* nor by directional learning (however, also in Friedman *Switchwon* is never significant).

5. Discussion

In this section, we summarize our main results and present some possible explanations for the behaviour observed in our experiment.

Considering the common explanations usually supported as likely candidates, already presented in section 2, we can point out that:

(1) The *misapplication of Bayes'rule* is an important ingredient for this "anomaly", but we showed that it is not the driving explanation for this. Indeed, if it were the real motivation for this anomaly, since in our FOR DUMMIES treatment no application of this rule was required, we should have observed no irrational behaviour under this treatment. Clearly, the sharp decline in the number of subjects that made an irrational choice across the three treatments may be attributed to the fact that in the last experimental set up the game was simpler. Therefore, for a certain percentage of population, the problem lies in an incorrect probability updating. However, even in the last period,

still 25% of people did not make the rational choice. This fact drives us to look for further explanations.

(2) Oppositely, the *status quo bias* seems to have a non negligible role in understanding such a behaviour, at least for that fraction of people that never chose to switch. People seem to attach a higher value to their previous chosen door and, consequently, they seem to consider their already chosen door as their endowment. Indeed, very interestingly, even in the FOR DUMMIES treatment, at least 15% of subjects never decided to switch.

(3) The *illusion of control*, if on the one hand it could represent an explanation for the case in which subjects first face the game or when they undergo the game without repetition, it seems implausible in repeated experiments in which people have to opportunity to realize that actually the strategy of switching has a greater chance of winning with respect to the strategy of remaining (over all our treatments, only 38.71 percent of the choices of remaining were winners, whereas 65 percent of the choices of switching won);

(4) Finally, as regards the probability matching behaviour, we have already tested for this hypothesis, but our data reject it.

Additionally to the reason cited above, as a likely explanation, we can mention a kind of intertemporal inconsistency, i.e., subjects' decisions at the different decision nodes as if related to different "selves". Anyway, it is quite unlikely that people do the same "mistake" repeatedly over the 10 periods: at the end, in our new treatment, they should realise that they are given the double chance of winning after the first stage.

6. Conclusion

The main goal of our experiment is to create a simple experimental set up that preserved all the basic features of the so called Monty Hall's problem, but such that subjects were not required to apply the Bayes' rule. This experimental design enabled us to discriminate among the most cited explanations for this kind of anomaly.

Our main results have been clear: the misapplication of Bayesian updating is important in reducing the "anomaly", as we can derive from the monotonic increase of switch rate across the three treatments (the control that replicated exactly the structure of the game as in the TV programme and in the previous experiments, the second designed to test for monotonicity, but that is resulted not statistically distinct from the control, the new treatment in which subjects were simply required to choose between one door or two doors), but still, it does not appear as the leading explanation. In this sense, Monty Hall's three doors anomaly has proved stronger than peviously thought.

Having discarded some other common suggested explanations (the illusion of control, the probability matching behaviour), now we can affirm that this anomaly, even if attenuated by design conditions, it is not a weak effect, but rather a systematic behavioural regularity. It could rely on some psychological underpinnings, such as the *status quo bias*. In this sense, a future line of research could be test for this effect. For example, a 'super for dummies' treatment could be implemented, in which subjects play only one stage in which they are required to choose among the possibility of one door or the possibility of two doors. In this case, the endowment effect would play no role. It is important to note that loss aversion, along with status quo bias, has proved to explain some other important phenomenon, such as the equity premium puzzle (see Camerer and Loewenstein, 2004 for a review). Moreover, our data suggest that also some learning models could be helpful in understanding such phenomena (indeed, our data support to the reinforcement learning, so that switching would be chosen only when sufficient favourable evidence has been accumulated).

Finally, these results could contribute to dismiss the idea that people actually use probabilities at all in making some kinds of decisions.

Appendix

Instructions. - This experiment is designed to study how people make decisions.

The experiment is very simple, and you will have the possibility of earning money, which will be paid to you in cash at the end of the experiment.

This amount will depend, on the one hand, on your decisions and, on the other hand, on luck.

The game is as simple as possible. 3 "cards" will appear on your screen: you will be asked to choose one of them simply pressing a button placed in the bottom right angle. During our experiment, each time the programme will establish in a complete random way which card is the winner one, i.e. the card behind which a prize is hidden. Whenever you choose the right card, you will win 0.5€, nothing otherwise.

Still, in each period a second chance will be given to you: after you have chosen your first card, you will have two opportunities: or sticking with your already-chosen card or choosing both two remaining cards.

At the end of each period, winning card and your correspondent earning will be shown to you with a message on your screen.

This game will be repeated for 10 times, in addition to the 2 trial periods at the beginning. At the end, you will be paid your total payoff (trial periods excepted) and free to leave the laboratory.

Rules are very simple. Communicating with other participants is forbidden (you can ask some questions to the experimenters only during trial periods), otherwise you will leave out from the laboratory and another player will be given your place in the experiment.

Good luck!

Trial Periods.-In order to test trial periods did not affect learning during subsequent periods, in the next table, we report maximum likelihood estimation in which data over these two periods in each treatment have been added.

Table A 1: Marginal Effects from probit estimation

Dep. Variable Switch	Trial and No Trial Periods
Time	-0.0088
	(0.728)
Time^2	0.0008
	(0.676)
Switchbonus	0.0562
	(0.001)
Switchwon	0.3580
	(0.000)
Switchlost	0.2715
	(0.000)
Intermediate	0.0161
	(0.734)
ForDummies	0.1396
	(0.004)
Log likelihood	-438.63
Pseudo R^2	0.1172
NOBs	720

Notes: The dependent variable is 1 in periods in which the subjects chose to switch and 0 otherwise.

If we compare these results with those in the last column of Table 2 above, we can note no notable differences, neither in the magnitude, nor in the direction, nor in the significance of the marginal effects. Consequently, we cannot make any mistakes in omitting trial periods in previous analyses.

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