The Dependency Dilemma: How Machine Learning Decision Aids can Undermine Skill Growth

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Appendix (available online via http://link.springer.com)

Additional material

Category	Item	Overall	Treatment	Baseline	p-value
Socio-demographic information	How old are you?	26.2	25.6	26.8	p=0.23 (Wilcoxon ranksum test)
	Please indicate your gender.	Female: 0.64 Male: 0.36	Female: 0.67 Male: 0.33	Female: 0.6 Male: 0.4	p=0.24 (Chi^2-test)
	How many years of working experience do you have?	4.8	4.33	5.28	p=0.395 (Wilcoxon ranksum test)
	Please indicate your highest degree.	No degree: 0.01 Secondary school: 0.06 High school: 0.37 Bachelor: 0.39 Master: 0.15 Ph.D.: 0.02	Secondary school: 0.06 High school: 0.38 Bachelor: 0.39 Master: 0.16 Ph.D.: 0.01	No degree: 0.02 Secondary school: 0.06 High school: 0.37 Bachelor: 0.39 Master: 0.15 Ph.D.: 0.01	p=0.94 (Kolmogorov-Smirnov test)
Risk aversion	I enjoy being daring.	4.6	4.7	4.54	p=0.417 (Wilcoxon ranksum test)
	I take risks.	4.78	4.9	4.62	p=0.03 (Wilcoxon ranksum test)
	I am looking for danger.	2.32	2.2	2.42	p=0.31 (Wilcoxon ranksum test)
Technology anxiety	I feel apprehensive about using technology.	3.08	3.04	3.11	p=0.71 (Wilcoxon ranksum test)
	Technical terms sound like confusing jargon to me.	3.06	3.12	2.99	p=0.48 (Wilcoxon ranksum test)
	I have avoided technology because it is unfamiliar to me.	1.69	1.63	1.75	p=0.34 (Wilcoxon ranksum test)
	I hesitate to use most forms of technology for fear of making mistakes I cannot correct.	1.95	1.85	2..05	p=0.38 (Wilcoxon ranksum test)
Other	Do you have a background in computer science?	0.3	0.31	0.3	p=0.81 (Chi^2-test)
	Please tell us, in general, about your programming skills, using a scale from 0 to 10, where 1 means no skills at all and 10 means expert.	2.9	3.07	2.75	p=0.29 (Wilcoxon ranksum test)
	Please tell us, in general, about your machine learning expertise, using a scale from 0 to 10, where 1 means no expertise at all and 10 means expert.	3.18	3.46	2.89	p=0.04 (Wilcoxon ranksum test)
	Human trust	4.73	4.62	4.85	p=0.2 (Wilcoxon ranksum test)

Machine trust	4.58	4.49	4.68	p=0.36 (Wilcoxon ranksum test)
Experience with investing	2.77	2.93	2.61	p=0.01 (Wilcoxon ranksum test)

Table 1: *Overview of survey items. We report overall measures, and measures separately for treatment and baseline participants. We provide test statistics on treatment differences as randomization checks..*

Dep. variable:	(1) Overrule prediction	(2) Overrule incorrect prediction
No. simulation	-0.016***	-0.02*
	(p<0.001)	(p=0.052)
Prediction	0.013	-0.023
	(p=0.541)	(p=0.663)
Market state: High	-0.009	0.119***
	(p=0.524)	(p=0.010)
Expert 1: High	0.008	0.086**
	(p=0.557)	(p=0.047)
Expert 2: High	-0.065***	-0.075*
	(p<0.001)	(p=0.091)
Expert 3: High	-0.008	0.062
	(p=0.535)	(p=0.206)
Expert 4: High	0.007	0.061
	(p=0.590)	(p=0.182)
Expert and state controls	YES	YES
Observations	4470	678
p	0.000	0.000
R-squared	0.194	0.345
Adj. R-squared	0.164	0.145

Table 2: *OLS regression with individual and round fixed effects. Both regression models are estimated on the subsample of treatment participants in stage 1. The dependent variable in column (1) is a dummy indicating whether a participant overruled the observed prediction in a given round. In column (2) the dependent variable is a dummy indicating whether a participant correctly overruled the observed prediction in a given round. The independent variables indicate the simulation round and the observed prediction. We denote significance levels as *p<0.1, **p<0.05, ***p<0.01.*

Dep. Variable: Payoff maximizing decision	(1) Baseline	(2) Treatment
No. simulation	0.083***	0.035*
	(p<0.001)	(p=0.078)
Stage 2	0.530***	-0.338***
	(p<0.001)	(p=0.004)
No. simulation*Stage 2	-0.091***	-0.028
	(p=0.001)	(p=0.305)
Market state: High	-0.036	0.086
	(p=0.529)	(p=0.146)
Expert 1: High	0.044	0.015
	(p=0.396)	(p=0.792)
Expert 2: High	0.145***	0.231***
	(p=0.006)	(p<0.001)
Expert 3: High	-0.033	-0.066
	(p=0.514)	(p=0.210)
Expert 4: High	-0.087*	0.098*
	(p=0.091)	(p=0.057)
Constant	0.099	1.419***
	(p=0.725)	(p<0.001)
p-value of F-test: No. simulation + No. simulation *Stage 2	0.69	0.71
Round and individual fixed effects	YES	YES
Observations	8520	8940
p	0.000	0.000

Table 7: *Logit regression with individual and round fixed effects. Column (1) shows estimates for the subsample of baseline participants, whereas column (2) shows results for treatment participants. We report p-values in parentheses. The dependent variable is a dummy indicating whether a participant chose the payoff maximizing option in a given investment scenario. We denote significance levels as *p<0.1, **p<0.05, ***p<0.01.*

Dep. Variable: Payoff maximizing decision	(1) Baseline	(2) Treatment
No. simulation	0.019***	0.007*
	(p<0.001)	(p=0.076)
Stage 2	0.120***	-0.080***
	(p<0.001)	(p<0.001)
No. simulation*Stage 2	-0.021***	-0.005
	(p=0.001)	(p=0.352)
Market state: High	-0.008	0.012
	(p=0.554)	(p=0.322)
Expert 1: High	0.010	-0.004
	(p=0.389)	(p=0.738)
Expert 2: High	0.033***	0.042***
	(p=0.005)	(p<0.001)
Expert 3: High	-0.007	-0.018*
	(p=0.543)	(p=0.087)
Expert 4: High	-0.019*	0.021*
	(p=0.092)	(p=0.058)
p-value of F-test: No. simulation + No. simulation *Stage 2	0.69	0.36
Round and individual fixed effects	YES	YES
Observations	8520	8940
p	0.000	0.000

Table 8: *OLS regression with individual and round fixed effects. Column (1) shows estimates for the subsample of baseline participants, whereas column (2) shows results for treatment participants. We report p-values in parentheses. The dependent variable is a dummy indicating whether a participant chose the payoff maximizing option in a given investment scenario. We denote significance levels as *p<0.1, **p<0.05, ***p<0.01.*

Dep. Variable: Investing in stock	(1)	(2)
ML prediction: High	2.184***	2.359***
	(p<0.001)	(p<0.001)
Expert 1: High	0.625***	0.671***
	(p<0.001)	(p<0.001)
Expert 2: High	0.756***	0.815***
	(p<0.001)	(p<0.001)
Expert 3: High	0.417***	0.493***
	(p<0.001)	(p<0.001)
Expert 4: High	0.510***	0.559***
	(p<0.001)	(p<0.001)
No. simulation		-0.006
		(p=0.793)
Market state: High		0.061
Round and individual fixed effects	No	YES
Observations	8520	8940
p	0.000	0.000

Table 9: *Logit regressions for treatment participants in stage 1 (with individual and round fixed effects in column 2). Column (1) shows estimates for the subsample of baseline participants, whereas column (2) shows results for treatment participants. We report p-values in parentheses. The dependent variable is a dummy indicating whether a participant chose to invest in the stock in a given investment scenario. We denote significance levels as *p<0.1, **p<0.05, ***p<0.01.*

Additional information on the experiment

To generate combinations of the economic situation, market states, and signals we used the python library *random*. The procedure for both training data generation and the data generation in the study worked as depicted in the following code example:

```python
import random

data = []
data_large = []
for i in range(1000000):
    # ECONOMIC STATE
    rs = (0 if int(random.uniform(0, 1) // 0.5)==0 else 1)
    if rs == 1:
        # MARKET STATE
        outcome = (int(0) if int(random.uniform(0, 1) // 0.3) == 0 else 1)
        # EXPERTS
        if outcome == 0:
            exp1 = (int(0) if int(random.uniform(0, 1) // 0.8) == 0 else 1)
        elif outcome == 1:
            exp1 = (int(0) if int(random.uniform(0, 1) // 0.2) == 0 else 1)
        exp2 = (int(0) if int(random.uniform(0, 1) // 0.5) == 0 else 1)
        exp3 = (_int(0) if int(random.uniform(0, 1) // 0.8) == 0 else 1)
        if outcome == 0:
            exp4 = 0
        if outcome == 1:
            exp4 = (int(0) if int(random.uniform(0, 1) // 0.5) == 0 else 1)

        l_= [exp1, exp2, exp3, exp4, outcome]
        l_large = [rs, exp1, exp2, exp3, exp4, outcome]

    elif rs == 0:
        # MARKET STATE
        outcome = (int(0) if int(random.uniform(0, 1) // 0.7) == 0 else 1)
        # EXPERTS
        exp1 = (int(0) if int(random.uniform(0, 1) // 0.5) == 0 else 1)
        if outcome == 0:
            exp2 = (int(0) if int(random.uniform(0, 1) // 0.8) == 0 else 1)
        if outcome == 1:
            exp2 = (int(0) if int(random.uniform(0, 1) // 0.2) == 0 else 1)
        if outcome == 0:
            exp3 = (int(0) if int(random.uniform(0, 1) // 0.5) == 0 else 1)
        if outcome == 1:
            exp3 = 1
        exp4 = (int(0) if int(random.uniform(0, 1) // 0.2) == 0 else 1)

        l_= [exp1, exp2, exp3, exp4, outcome]
        l_large = [rs, exp1, exp2, exp3, exp4, outcome]

    data.append(l_)
    data_large.append(l_large)
```

Figure 7: Python code for market state and expert signal generation.

Experimental Instructions

General instruction:

This experiment comprises two subsequent stages. In both parts, you will have to make a series of choices between investing into either a stock or bond. Contingent on your choice, you earn monetary units. The number of units you earn in every decision is summed up at the end of the experiment. For every monetary unit you have earned, you are paid 2 Eurocents. In addition, you will receive a fixed income of 2 Euros for your participation.

Example 1: Assume you earn 280 monetary units in the experiment. Your ultimate income in the experiment, which you are paid out, equals: 280*0.02 + 2 = 7.60 Euros.

Example 2: Assume you earn 220 monetary units in the experiment. Your ultimate income in the experiment, which you are paid out, equals: 220*0.02 + 2 = 6.40 Euros.

Please make your decisions carefully as they determine your ultimate income that you receive at the end of the experiment. The use of any decision support which is not provided on screen is strictly forbidden.

Instruction part 1:

Your task:

You participate in 6 asset market games. Each game consists of 5 consecutive rounds. In every round, you can invest in one of two assets:

- A risk-free bond that is always paying 2 monetary units for certain. A bond is a fixed income instrument that represents a loan made by an investor to a borrower (typically corporate or governmental) that traditionally pays a fixed interest rate (coupon) to investors.
- A risky stock which is either paying 0 (Low Payoff) or 4 (High Payoff) monetary units.

The probability that an investment into the stock yields the high payoff (4 units), depends on the stock's fundamental state, which you only observe at the end of the five rounds. With an equal probability (50% / 50%), the fundamental state can either be good, or bad. Depending on the market fundamental state, the probability of high and low payoffs looks as follows:

- Good state: If the stock is in a good state, the probability for the high payoff equals 70%. This is, with a chance of 70% you receive the payoff of 4, and with 30% you receive the payoff of 0.
- Bad state: If the stock is in a bad state, the probability for the high payoff equals 30%. This is, with a chance of 30% you receive the payoff of 4, and with 70% you receive the payoff of 0.

The fundamental state is the same across the 5 consecutive rounds and may only vary across the seven asset market games.

Available information

In every round, before you make your decision, you observe expectations about the stock's payoff in the given round from 4 independent experts.

Each expectation can either say High Payoff, or Low Payoff, indicating the expert's expectation about the stock's payoff in this round, which can be correct or incorrect.

Important: There exists a pattern behind the expert expectations, which does not change throughout the entire experiment. If you have figured out the underlying patterns, the expectations can help you identify when the stock will yield a high payoff. Understanding the pattern will be useful throughout the experiment by helping you to maximize your personal income.

[BEGIN: TREATMENT ONLY]

In addition to the expectations of the four experts, you observe the prediction of a Machine Learning System that was trained to predict the stock's payoff in a given round based on the four experts' stated

expectations. In other words: The Machine Learning System was designed to recognize the underlying pattern of expert expectations.

The Machine Learning System was trained and tested on 1.000.000 distinct observations. Each observation comprised the four expectations of the experts as independent variables and the stock's actual payoff as dependent variable. In a test, the trained Machine Learning System correctly predicts the stock's payoff in a given round in more than 85% of the cases. In several tests, the Machine Learning System systematically outperformed other researchers when it comes to correctly predicting the stock's payoff. Below you can find additional information about the structure of the system. We use a Random Forest Learning model.

Additional Information about the Machine Learning System

The Random Forest is one of the simplest, yet one of the most powerful machine learning models for classification. In the context of the experiment, classification refers to correctly predicting whether the stock will yield a high payoff or low payoff.

Random Forests are an ensemble learning method for classification, regression and other tasks that operates by constructing a multitude of decision trees at training time (Wikipedia). Each individual decision tree makes a single prediction. The majority prediction of the set of trees determines the ultimate prediction of the Random Forest. In other words: the forest uses the "wisdom of the crowd".

In this experiment, the Random Forest computes the probability that the stock will yield a high payoff. In other words, the model captures the underlying relationship between experts' expectations and the stock's actual payoff and can therefore help you make the payoff maximizing choice. You are only shown a High Payoff prediction if the probability for this event is the maximum. Otherwise, you are shown a Low Payoff prediction.

Some real-world applications:

E-Commerce

- Product Recommendation
- Price Optimization

Stock Market

- Stock Market Prediction
- Stock Market Sentiment Analysis

Healthcare and Medicine

- Cardiovascular Disease Prediction
- Diabetes Prediction

If you have further questions regarding the Machine Learning System or would like to obtain the entire code, please contact our research team on Prolific or via mail: [blinded for peer review]

[END: TREATMENT ONLY]

To ensure that you understand the task at hand, there will be two mock rounds of investment decisions, before the main part of the experiment starts. Note that the results of these mock rounds will not be paid out.

Instruction part 2:

You have finished part 1. Part 2 is about to start. Below you find instructions for the second part of the experiment.

Your task

You again participate in 6 asset market games. The games have the identical structure as before

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except for the fact that you do not observe predictions of the Machine Learning System anymore.

[END: TREATMENT ONLY]

Each game consists of 5 consecutive rounds. As before, you can always invest in one of two assets:

- A risk-free bond that is always paying 2 monetary units for certain. A bond is a fixed income instrument that represents a loan made by an investor to a borrower (typically corporate or governmental) that traditionally pays a fixed interest rate (coupon) to investors.
- A risky stock which is either paying 0 (Low Payoff) or 4 (High Payoff) monetary units.

The probability that an investment into the stock yields the high payoff (4 units), depends on the stock's fundamental state, which you only observe at the end of the five rounds. With an equal probability (50% / 50%), the fundamental state can either be good, or bad. Depending on the market fundamental state, the probability of high and low payoffs looks as follows:

- Good state: If the stock is in a good state, the probability for the high payoff equals 70%. This is, with a chance of 70% you receive the payoff of 4, and with 30% you receive the payoff of 0.
- Bad state: If the stock is in a bad state, the probability for the high payoff equals 30%. This is, with a chance of 30% you receive the payoff of 4, and with 70% you receive the payoff of 0.

The fundamental state is the same across the 5 consecutive rounds and may only vary across the seven asset market games.

Available information

As in the previous games, in every round, before you make your decision, you observe expectations about the stock's payoff in the given round from 4 independent experts.

The pattern behind the expert expectations, is exactly the same as in the previous games and does not change. If you have already figured out the underlying patterns in stage 1, you can apply your knowledge to better identify when the stock will yield a high payoff.