Can we make investors smarter using a nudge? Maybe, but we can't prove it using the most common experimental disposition effect environment.

Nathan Rogut ([REDACTION])

Supervised by Dr. Stephen Cheung

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School of Economics

University of Sydney

Australia

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Abstract

Investors have been shown to behave in a way that reduces their earnings by being over hesitant to sell stocks that have decreased in price and over eager to sell stocks that have increased in price, exhibiting what is known as a disposition effect. This persists even in environments that make exhibiting a disposition effect always reduce expected returns. Our study uses the most common experimental disposition effect environment to test the use of a novel nudge to reduce participants disposition effects and finds that the nudge does reduce participants' disposition effects. However, several of our findings challenge the external and internal validity of the environment, and it is possible that the nudge only works for a subset of the population that understands the environment better. Despite the environment making diversification suboptimal, those who understand diversification (and therefore might perform better in real-world markets) perform worse in this environment due to diversifying more, indicating that participants bring their external beliefs about real world markets into the environment. We show that the optimal disposition effect in the environment is substantially negative, which critiques past studies that have used a rational benchmark of zero. We also find significantly negative disposition effects across the board for our sample, which is unique, potentially due to the inclusion of comprehension questions before trading that assisted participants to understand the environment better.

Contents

1. Introduction and Literature Review

The disposition effect was first documented by Shefrin and Statman (1985). Under the disposition effect, investors are overeager to sell 'winners', but over-hesitant to sell 'losers' where an asset is deemed a 'winner' when its current price exceeds a reference point, generally assumed to be the purchase price, and a 'loser' when its current price falls below it. Odean (1998), using an observational study, found that investors were, on average, 50% more likely to sell their winners compared to their losers. This is despite winners, on average, continuing to beat the market (by 2.35%), while losers, on average, continued to underperform (by 1.06%). Hence, exhibiting a disposition effect was not an optimal strategy and reduced investors' returns. Therefore, investors exhibiting a disposition effect is problematic and should be ultimately avoided.

1.1 Observational Studies

Observational studies on the disposition effect commonly use largescale data to assess for the impact of investors' characteristics on disposition effects. Beyond the findings of Odean (1998) that investors exhibit disposition effects, Feng and Seasholes (2008) illustrated, using a Chinese sample, that more sophisticated and/or experienced investors exhibit a lower disposition effect, primarily through having a reduced hesitancy to sell losers.

Additional observational findings include: Quispe-Torreblanca (2021) demonstrating that investors become more risk averse following worse portfolio performance, Kumar and Lim (2008) finding that investors who cluster their trades, on average, exhibit lower disposition effects, Dhar and Zhu (2006) illustrating that wealthier and professionally employed investors exhibit lower disposition effects, Chen and colleagues (2007) highlighting that Chinese investors exhibit higher disposition effects than US investors and individual investors exhibit higher disposition effects than institutional investors, and Lehenkari (2012) finding that investors who are personally responsible for their choices have higher disposition effects.

1.2 Experimental Literature

Observational studies find it hard to analyse the effect of specific interventions on investors' disposition effects, because it is difficult to control for or observe various relevant information. These include the information investors are using to make decisions, their beliefs, and the optimal strategy they should be following. Through using a laboratory experimental framework, these problems can be largely solved, despite laboratory experiments potentially suffering from lower external validity. Hence, laboratory experiments can allow for a greater understanding of the mechanisms behind the disposition effect and tools to reduce it. For these reasons, this study uses a laboratory experiment.

Weber and Camerer (1998) created an environment which simulates the stock market, to test for the prevalence of the disposition effect, and it has become widely used. They found that participants exhibited a disposition effect in the environment despite it being suboptimal. Additionally, enforcing the automatic selling of all assets at the end of each trading period reduced the size of disposition effects. This is the first example of an institutional factor

influencing the level of the disposition effect, but there have numerous others since. Rau (2015) demonstrated that investors in teams of two have higher disposition effects than those operating individually. Goulart and colleagues (2015) found that investors whose performance is made public exhibit a higher disposition effect through having a higher over-eagerness to sell winners. Additionally, Hermann and colleagues (2019) found that only for inexperienced investors does investing on behalf of others lead to a higher disposition effect.

Investor inexperience is an individual characteristic, not an institutional factor, and these have also been found to impact disposition effects. Jiao (2017) showed that stronger mean reversion beliefs was associated with higher disposition effects, through both a higher proportion of winners sold, and a lower proportion of losers sold. Chui (2001) found that those with a higher locus of control exhibited a lower disposition effect on average. Additionally, Rau (2014) demonstrated that on average, women exhibit higher disposition effects than men. Finally, Da Costa Jr. and colleagues (2013) found that professional investors exhibit lower disposition effects compared to university students.

Nudges have also been shown to be effective at reducing disposition effects. Fischbacher and colleagues (2017) examined the impact of price limits on investors' disposition effects and found that giving participants the opportunity to set binding limits resulted in decreased disposition effects, but that this effect vanished when participants instead had the opportunity to set non-binding limits. Whilst giving participants the technology to set limits is an institutional factor, participants not being forced to set limits makes this also an example of a nudge. Other nudges include by Frydman and Rangel (2014), who with the hypothesis that higher saliency of purchase price information causes a higher disposition effect, found that participants placed in a condition where purchase price was less salient exhibited significantly lower disposition effects. Additionally, Wierzbitzki and Seidens (2018) found that participants given specific investment goals and those given a graph of their portfolio performance did not exhibit a disposition effect, whilst those without either, exhibited a positive disposition effect. Hence, nudges have been shown to successfully reduce disposition effects in a laboratory experiment setting.

1.3 Explanations for the Disposition Effect

Why investors exhibit disposition effects is explained through several competing theories. They are relevant to understand, because to develop an intervention to reduce disposition effects, the mechanisms behind at least one of the theories explaining disposition effects needs to be targeted.

The first theory is that if investors believe that the price of their winners is likely to decrease, and the price of their losers is likely to increase, then, given their beliefs, it would be optimal for them to exhibit a disposition effect. This belief is known as mean reversion, where individuals believe that their prices will eventually return to their mean. For investors holding winners, they would want to sell them before that happens, and investors holding losers would want to hold them until the prices rise again. This fails to be optimal if mean reversion is not a factual belief, as was shown by Odean (1998), however investors could still hold a belief in mean reversion, and hence exhibit a disposition effect, despite the belief not being rational.

An alternative explanation is the prospect theory account. This refers to investors framing their investments relative to the purchase price and being risk-averse for those framed as a gain, and risk-seeking for investments framed as a loss (Shefrin & Statman, 1985). Hence, while understanding that mean reversion is unlikely, investors sell winners early to avoid any risk of the assets decreasing in price, and take a risk in holding losers, despite potentially knowing that it is unlikely for the price to recover.

The prospect theory account is related to another explanation which states that investors gain pride through making a profit and regret from making a loss. This is because making a profit indicates their initial decision was correct, whilst making a loss indicates that it was incorrect (Shefrin & Statman, 1985). Hence, to maximise their utility, investors must consider their pride and regret, meaning that they are not solely concerned about their returns, which drives a wedge between what is return-optimising and utility-optimising. To maximise utility, investors sell their winners to gain pride, and avoid selling losers to avoid regret, exhibiting a disposition effect, despite it resulting in less returns to their investments. A difficulty with this explanation is that investors may also regret selling a winner if it continues to increase in price following the sale. According to prospect theory (Kahneman & Traversky, 1982), individuals are more prone to avoiding regret over seeking pride. So, investors may be hesitant to sell either winners or losers.

The realisation utility approach takes this approach and modifies it to account for this issue. It states that investors only gain pride and regret when selling an investment (in the form of positive and negative utility bursts respectively) (Frydman & Rangel, 2014). This differs from the pride and regret approach, as the existence of winners and losers in one's portfolio has no effect on investors' utility unless they are sold. For investors exhibiting a disposition effect, they are simply maximising their utility, even if it leads to suboptimal returns.

Escalation of commitment, also referred to as the sunk cost fallacy (Arkes & Blumer, 1985), predicts that individuals who have invested a certain amount of money or time in a losing course of action tend to persist with the action and invest further time and/or money into it (Staw, 1976). This is done to nullify the regret associated with making a mistake (Arkes & Blumer). For investors, they should therefore tend to hold losers longer than winners and hence exhibit a disposition effect. Empirically, Lehenkari (2012) found this to be the most valid explanation for investor behaviour (in a Finnish sample).

An implicit assumption within most of these explanations is that investors narrowly bracket their investments using mental accounting. This means that investors view their assets as singular, rather than as part of a broader portfolio (Thaler, 1999). Kumar and Lim (2008) demonstrated that when this assumption is not held, disposition effect is reduced. They showed that investors who cluster their trades, and hence likely bracket their investments more broadly, exhibit a lower disposition effect than those who make singular trades.

1.4 Experimental Paradigm

The primary experimental environment used for understanding the disposition effect that Weber and Camerer (1998) created (W&C), was designed to make a belief in mean reversion irrational. Hence, this would rule out the possibility that an investor exhibiting a disposition effect is behaving in line with a rational belief (in mean reversion). In this environment,

exhibiting a disposition effect consistently will lead to lower returns, making it suboptimal. However, in making mean reversion an irrational belief, Weber and Camerer also destroyed any motivation for diversification.

Figure 1: W&C asset types

Asset type	Assets of this type	Probability of price increase	Probability of price decrease
++	1	65%	35%
+	1	55%	45%
0	2	50%	50%
−	1	45%	55%
−−	1	35%	65%

In their environment, they assign 6 types to assets, such that assets that have previously increased in price are likely to continue to increase in price, and vice versa (see Figure 1). Each type fluctuates in value in each period with a prespecified probability of increasing in value: one with a 65% probability (labelled ++), one with 55% (labelled +), two with 50% (labelled 0), one with 45% (labelled -) and one with 35% (labelled --), meaning that prices are unaffected by participants actions. Subjects are informed of all the asset types and their increase probabilities but not the matching of assets, labelled A-F, to the asset types. Prices never stay constant across periods and the magnitude of each price change was randomly determined being either 1, 3 or 5 points, which are all equally likely, such that the expected value of any price change for a randomly chosen stock is 0. Participants are shown asset prices up to and including for the current period in period 1 and all the subsequent periods. They are shown the price movements over the four periods before period 1 (-3 to 0), to help them better understand the assets' likely types before making any decisions.

The optimal strategy for participants is therefore to identify the asset most likely to be the "++" type, which has the highest probability of increasing in any given period, by identifying the asset that has increased in price the highest number of times up until that point. Any investments other than in the asset/s that have a higher number of past price increases than all the other assets only reduce investors' expected returns, as it means holding assets that are less likely to increase in price. However, when investing in risky assets in real world markets, diversification is optimal, as it helps to mitigate risk (Magnus & Zhang, 1998). Hence, if investors are bringing in their understanding of how real-world markets operate into W&C, they may perform more poorly by excessively diversifying (holding more than just the likely "++" asset/s). This raises a potential concern for external validity with this environment.

The current literature on the disposition effect, including the experimental literature using W&C, mostly use a disposition effect of zero as their rational benchmark. This is because a disposition effect of zero implies equal selling of winners and losers, so no bias towards selling either (Odean, 1998; Weber & Camerer, 1998). However, in W&C, a disposition effect of zero is suboptimal in terms of maximising investment returns and so a different benchmark of optimal behaviour should be used. Rather than a rational disposition effect benchmark of zero, a significantly negative rational disposition effect benchmark should be used for W&C. As in W&C, a belief in mean reversion is irrational, an asset decreasing in price makes it less likely to be the "++" type, and vice versa for an asset increasing in price.

Hence, following the optimal strategy of investing only in the asset/s that are most likely to be the "++" type in any period, consistently would result in a significantly negative disposition effect, as participants would be selling substantially more losers than winners. This realisation is not unique to our study, as Fischbacher and colleagues (2017) state this to be the case in a similar but simplified environment, essentially using W&C, but with assets all starting from the same price.

The optimal disposition effect being significantly negative has a significant impact on interpretations of past studies. Research reporting that a treatment eliminates the disposition effect in W&C by it reducing the disposition effect to zero, still indicates participants behaving sub-optimally. For example, Corneille and colleagues (2018) reported that for participants who were told the matching of asset types to assets in W&C, their disposition effects went away, due to becoming zero. However, as participants being exposed to that treatment did not have a significantly negative disposition effect, this indicates that even when participants are given supposedly full information, they still behave largely sub-optimally in this environment.

A potential reason for this is participants lacking an understanding of the environment itself. Fischbacher and colleagues (2017), who used a similar environment to W&C, included comprehension questions for participants to complete, and most participants in their control condition still exhibited positive disposition effects, indicating potentially that positive disposition effects in W&C aren't a function of lacking understanding. However, participants were not informed of the correct answers to the questions before starting trading, so those who responded to any of the questions incorrectly might trade with the belief that those incorrect responses were correct, and Fischbacher and colleagues do not appear to report the relationship between comprehension and any aspect of participants' decisions, including disposition effects. No studies using W&C have used comprehension questions to ensure participants' understanding of the environment before trading, and whilst Rau (2015) did include comprehension questions, they were not related to the W&C environment, but rather to the trading interface. Therefore, this is a further concern for the external validity of past experimental findings.

2. Our experiment

2.1 Experimental Design

2.1.1 Primary Research Question

This study aims to contribute to the current disposition effect literature by creating a novel nudge which reduces investors' disposition effects specifically by encouraging investors to sell losers. This builds on past research showing that nudges can be effective at reducing disposition effects. If the nudge does so, it can be used to assist investors to make smarter decisions and minimise portfolio losses.

2.1.2 Experimental Environment

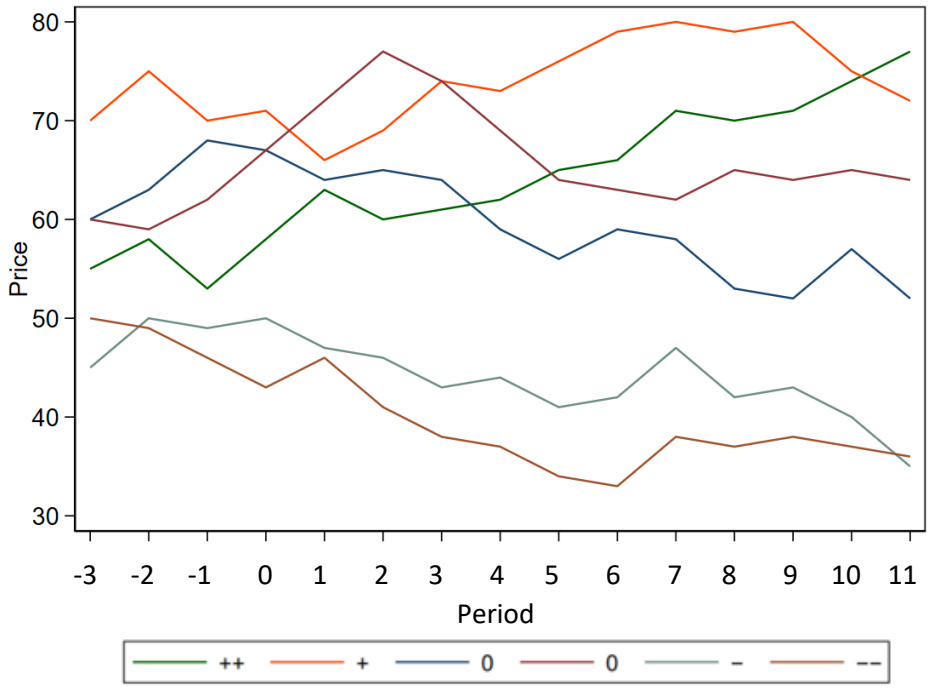
Aligning with the majority of experimental disposition research, our study also uses W&C. This is due to the environment making exhibiting a disposition effect consistently lead to

lower returns, and having an optimal strategy that participants should always follow to maximise their returns. In our experiment, participants can trade in 10 periods.

Initial stock prices were set in period -3, as between 45 and 70 points. Participants do not have to invest and can hold their endowment in cash for the entire experiment if they choose to. The price series given to participants (see Figure 3) was pre-calculated prior to the start of the experiment based on the underlying asset types and was identical for all participants to ensure comparability between subjects. However, the assignment of asset types to the assets was randomised, such that for one participant asset A might have the '++' type, but for another, asset A might have the '–' type. This was to ensure that if participants were affected by order of presentation, this wouldn't affect our results in finding disposition effects. For example, if participants were more likely to buy the A asset, this would not affect the results for whether participants were more likely to buy the asset of a specific type. Additionally, before every trading period, subjects were shown a price changes page, highlighting the recent developments in price of all assets for the following trading period to ensure that they considered the price changes before making their decisions.

We initially aimed to use the same price series as Corneille and colleagues (2018) to allow for greater comparability between our studies, however we noticed that in their price series, the asset with the most price increases was the "+" type, not the "++" type. This issue is not unique to Corneille and colleagues. For example, Wierzbitzki and Seidens (2018) noticed that investing in their "--" asset gave participants a positive average return. Hence, we created a new price series to avoid these potential issues, which is shown in Figure 3.

Figure 3: Price Series



Prior to commencing any decisions, subjects were endowed with 5000 points to buy stocks with. To our knowledge, almost all experimental disposition effect research uses fictitious currency, and we replicate this practice, using points[1], but these points were converted into

[1] For example, Hermann and colleagues (2019) use the fictional currency of Talers.

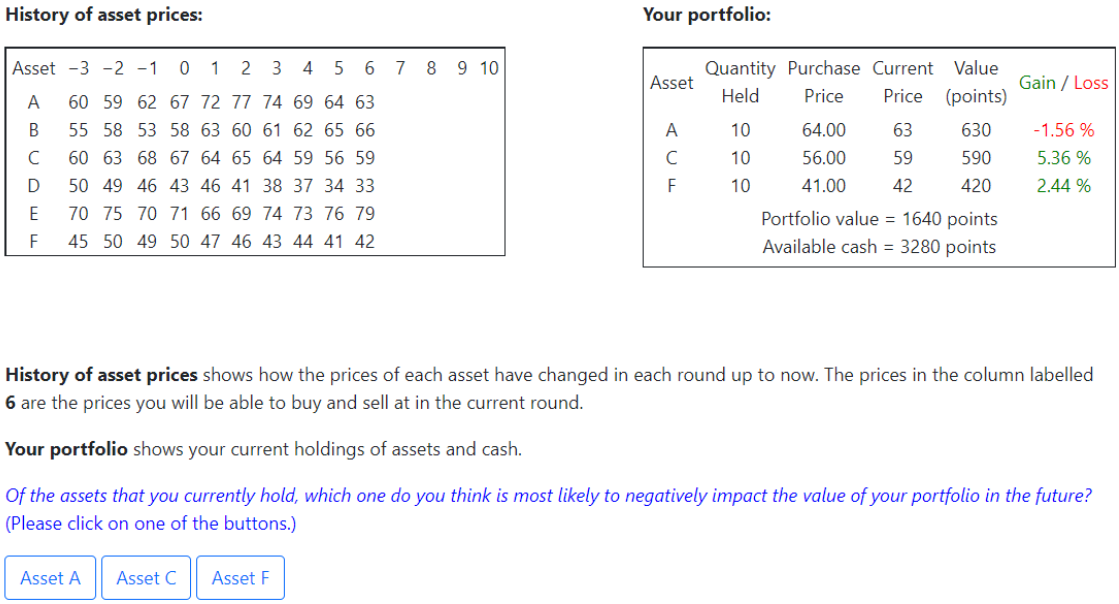
GBP at a rate of 1/2500[2], and participants were paid this amount in GBP following completion of the experiment. This was to ensure that participants are sufficiently motivated to maximise their investment earnings. The conversion of points into GBP was informed to participants before starting trading, and "Will your earnings from this study depend on the choices you make in the game?" was included as a comprehension question, to ensure that participants understood this. Participants were also paid a 2.5 GBP participation fee which was unrelated to performance.[3]

The experiment was programmed and conducted using oTree (Chen et al., 2016). The oTree code used for the trading portion of the experiment was adapted from the code of Corneille and colleagues (2018).

2.1.3 Treatments

As escalation of commitment was shown to be the most empirically valid explanation of disposition effects (Lehenkari, 2012), we devised a nudge that specifically aimed to help participants to make decisions using forward-thinking optimising, and tested if this can reduce the disposition effect. We therefore employ a between-subjects design, where one group of randomly assigned participants are shown a nudge before making decisions, whilst the control group is not.

Figure 4: Nudge Interface



In the *Nudge* treatment, participants were given the nudge on their price changes page in blue text, which stated: "Of the assets that you currently hold, which one do you think is the most likely to negatively impact the value of your portfolio in the future?" and were instructed to click the button of the asset they chose, as shown in Figure 4, which shows the nudge being applied to a participant in period 6.

[2] Such that, if participants made no additional points during the experiment and still had 5000 points at the end, their portfolio would be valued at 2 GBP.
[3] This ensured that the absolute minimum participants would earn is about 4 GBP (if they made the worst possible decisions) – i.e., fulling investing in the "- -" asset.

Participants who held only one asset were excluded from being shown the nudge, and buttons were programmed to only show assets that the participant currently held any amount of. The nudge was included on the page showing the price changes before the subsequent trading period, so participants who didn't receive the nudge simply received text stating: "When you have finished studying this information, please click Next to continue to the trading screen" where the nudge would have been, and the asset buttons were replaced with a Next button. This was to ensure that the only effect of the nudge was the nudge itself, and participants not exposed to the *Nudge* treatment were not impacted beyond simply not being shown the nudge.

If the nudge succeeds in reducing the disposition effect, a potential explanation for this however, could just be a demand effect. Participants could be responding to the nudge and selling the asset chosen simply because they believe it is what we wish them to do in the experiment without believing it is the optimal strategy to follow (for example due to an irrational belief in mean reversion). Hence, the nudge succeeding may not be because of it shifting participants into a forward-thinking optimising mindset. To test for this being the case, we initially proposed to add a separate condition replicating W&C, but with mean reversion being a rational belief. This would mean that if participants responded similarly to the nudge in both the standard conditions and rational mean reversion, then their response to the nudge would be caused by a demand effect. Participants should be holding losers to increase their returns in such an environment, to sell them when they become winners, rather than selling them as losers. Hence, responding to the nudge by also selling losers in this environment would indicate that the nudge is failing to help participants make better decisions, despite seeming to succeed without this robustness check.

Unfortunately, this proved too complicated. So instead, to isolate the effect of the nudge from potential demand effects, we included an additional treatment we named *Instruction*, in which participants were explicitly told the optimal strategy to follow in W&C of investing fully in the identified "++" asset, to eliminate any potential confusion from participants. Participants in this treatment had a line included in their instructions stating: "On average, you can expect to earn the most money in this game by identifying the asset that you think is the most likely to be of Type "++" and investing fully in that asset". This was highlighted to participants through the text being in blue (compared to the rest of the text being black) and remained in the instructions that were accessible to them in every trading period.

Telling participants the optimal strategy, could also have a demand effect, as participants might behave in line with the strategy due to believing that we wish them to do so, despite not believing that it is actually the best strategy to follow. However, if the *Nudge* treatment truly succeeds in reducing disposition effects, outside of being simply the product of demand effects, those also exposed to the *Instruction* treatment should respond equally to it as those not additionally exposed. If this is the case, it would indicate that participants are responding to the *Nudge* treatment by selling losers, not because they are being told it is optimal to do so, but rather because they believe losers are the most likely to harm their portfolio performance. Therefore, the *Nudge* treatment succeeding in reducing disposition effects would give evidence for the nudge potentially succeeding in a real-world market if there is no beneficial complementarity between the treatments.

2.1.4 Behavioural Variables and Comprehension

Because of the concerns that we had with W&C, we built in two additional features to the experiment, to allow for examination of the external and internal validity of our findings. The first is the inclusion of comprehension questions to ensure that participants understood the environment prior to starting the experiment. Six comprehension questions, relating to the experimental environment, were given to all participants after they were shown the instructions. Those who answered a question incorrectly were informed of the correct answer and the reason why it was correct, and were not allowed to move on until they selected it. The instructions were also accessible to participants in all trading periods to assist participants if they were confused at any point during trading, replicating Corneille and colleagues (2018). Comprehension was measured by a dummy indicating whether they got all comprehension questions correct at the first try.

The second feature added was to measure for the influence of participants' external beliefs or behavioural characteristics. We refer to these as behavioural variables. After completing trading in the final period, participants complete 3 questionnaires, one testing for risk tolerance (including a measure specifically for tolerance in a financial domain), one testing for financial literacy and the final testing for belief in mean reversion. General and financial risk tolerance were measured through 10 item Likert scales, and financial literacy was measured by accuracy in answering 10 questions. Half of these were sourced from the Big-5 financial literacy questionnaire (Lusardi & Mitchell, 2011), and the remaining 5 were extracted from van Rooij and colleagues (2011). Due to financial and general risk tolerance being highly correlated, in our analyses only financial risk tolerance will be focussed on, as it was deemed to be the more relevant of the two. The financial literacy questionnaire includes two items specifically focussed on diversification literacy. Participants' answers to these will allow us to construct the measure of understanding of diversification as a dummy indicating whether they got both diversification literacy questions correct. To avoid any strong covariance, the measure for financial literacy excluded the responses to the two diversification literacy questions. Participants' belief in mean reversion was assessed through testing for proneness to gambler's fallacy using a roulette task, and the belief in mean reversion variable was constructed as a dummy indicating whether participants indicated any proneness to gambler's fallacy. The measures for risk tolerance and financial literacy were created as z-scores such that a one unit increase in them would indicate participants having a score for risk tolerance or financial literacy one standard deviation above the mean.

2.2 Participants

Participants were recruited through Prolific Academic. Prolific was chosen as its participants have been shown to produce data of an equivalent or higher quality than competitors (Peer et al., 2017). We decided to complete the experiment online, as was done by the likes of Corneille and colleagues (2018) and Wierzbitzki and Seidens (2018). However, unlike these previous studies, our study fully utilised the benefits of conducting the experiment online by having a substantially large participant base to allow for strong power, (which was enabled

by the low cost of compensating participants) and having compensation strongly linked to performance to ensure proper motivation[4].

Participants were required to be fluent in English and older than 18 years of age and all participants were current UK residents due to the nature of the Prolific userbase. A total of 400 participants undertook the experiment during September and October of 2022. 101 participants were assigned to the "Control" condition, with no exposure to the *Nudge* or *Instruction* treatments, 103 participants were assigned to the "Nudge" condition, with exposure only to the *Nudge* treatment, 102 participants were assigned to the "Instruction" condition, with exposure only the *Instruction* treatment, and 94 participants were assigned to the "Nudge & Instruction" condition, with exposure to both the *Nudge* and *Instruction* treatments. Hence, out of the 400 participants, 197 were exposed to the *Nudge* treatment and 196 were exposed to the *Instruction* treatment. Participants took, on average, 21 minutes and 49 seconds to complete the experiment (rounding to the nearest second) and the average earnings from the experiment was around 4.40 GBP. Table 1 and Table 2 show the descriptive statistics for participants in our sample.

Table 1: Descriptive Statistics A

Variables	Count	Proportion (%)	SD
Male	400	50	0.50
Any Investment Experience	400	37	0.48
Full time employed	400	48	0.50
Current student	400	17	0.38
University degree held	400	57	0.50
Married	400	36	0.48

Table 2: Descriptive Statistics B

Variables	Count	Mean	SD	Min	Max
Socioeconomic status (answered on a 1-10 scale)	400	5.32	1.55	2	10
Reported personal income[5]	351	2.50	1.38	1	8
Reported household income[6]	351	4.36	2.43	0	11
Age	400	37.8	13.7	19	82

Table 3 shows the balance checks for demographic variables across conditions. Chi[2] tests were conducted to identify any significant relationships between condition placement and demographic variables. By random chance, those in the Nudge & Instruction condition were significantly less likely to be fulltime employed, those in the Control condition were significantly less likely to be married and those in the Instruction condition were significantly more likely to have a higher reported household income. To ensure that this does not impact

[4] Wierzbitzki and Seidens (2018) only included 160 participants in their sample, and Corneille and colleagues (2018) only rewarded participants based on performance if their portfolios were in the top 10% of their experimental condition, meaning that for 90% of participants, their compensation was unaffected by performance.

[5] Reported personal income was answered on a 11-item scale: 1 = "Less than £10,000", 2 = "£10,000 - £19,999", 3 = "£20,000 - £29,999" … 10 = "£90,000 - £99,999", 11 = "£100,000 - £149,999". Participants could also choose to not respond.

[6] Reported household income was answered on a 12-item scale: 0 = "Less than £10,000", 1 = "£10,000 - £15,999", 2 = "£16,000 - £19,999", 3 = "£20,000 - £29,999" …, 10 = "£90,000 - £99,999", 11 = "£100,000 - £149,999". Participants could also choose to not respond.

our findings, those three demographic variables will be controlled for in all regressions that are conducted.

Table 3: Balance Sheet

	Proportion of participants in the condition with the variable = 1				
Variables	**Control**	**Nudge**	**Instruction**	**Nudge & Instruction**	**p value for significant relationship between conditions and the variable**
Any Investment Experience (1 = true)	40.59	34.95	34.31	37.23	0.788
Fulltime employment (1 = true)	53.47	54.37	50.98	34.04	0.015**
Current student (1 = true)	13.86	20.39	18.63	14.89	0.566
University degree (1 = true)	58.42	54.37	64.71	50	0.193
Gender (1 = male)	50.5	52.43	47.06	50	0.895
Married (1 = true)	24.75	33.98	47.06	38.3	0.010**
Reported socioeconomic status (1 = above median)	44.55	41.75	51.96	39.36	0.306
Reported personal income (1 = above median)	38.89	49.43	50.53	43.04	0.350
Reported household income (1 = above median)	41.11	48.28	57.89	36.71	0.078*
Age (1 = above median)	46.53	44.66	49.02	57.45	0.296

* = p < 0.1; ** = p < 0.05; *** = p < 0.01; **** = p < 0.001

2.3 Measurement of the Disposition Effect

We use two measures for the disposition effect. This is to allow for comparability with previous literature as the vast majority use one of, or both of, these measures. The first is Odean's (1998) measure (DE) as the difference in the proportion of gains (winners) realised (PGR) and the proportion of losses (losers) realised (PLR), which are defined as:

$$PGR = \frac{stocks\ sold\ at\ a\ gain}{possible\ number\ of\ stocks\ to\ sell\ at\ a\ gain}$$

$$PLR = \frac{stocks\ sold\ at\ a\ loss}{possible\ number\ of\ stocks\ to\ sell\ at\ a\ loss}$$

And,

$$DE = PGR - PLR$$

Because the same stock can be bought at different times, and therefore have different purchase prices, the purchase prices used for an investor's reference point are unknown. Odean devises four possible reference points: the investor's average, first, most recent, or highest purchase price of that stock. However, Odean solely uses the average purchase price, and claims that any of the four reference points result in similar outcomes. This is the consensus of the DE literature, who all use average price and has been illustrated by Rau (2015), so we will be also using average purchase price as the reference price.

The second measure that we will be using is Weber and Camerer's (1998) α, which measures disposition effect by the difference in number of sales following a price increase compared to sales following a price decreased, averaged over the total number of sales.

$$\alpha = \frac{stocks\ sold\ after\ a\ price\ increase - stocks\ sold\ after\ a\ price\ decrease}{total\ stocks\ sold}$$

This was specifically created with W&C in mind, so it is easier to identify participants behaving sub-optimally in W&C using α rather than DE. Notably, participants behaving optimally would never sell assets after a price increase, and hence would have a value of α = -

1. This is because an asset increasing in price in this environment only increases the likelihood that the asset is of the "++" type. Therefore, any selling of an asset after a price increase in this environment is evidence for a disposition effect and increases α.

PLR, (from DE) will be additionally focused on. Feng and Seasholes (2008) demonstrated that reductions in disposition effects in real world markets primarily occurs through reduced hesitancy to sell losers, and therefore increased PLR. Hence, it should be the case that reductions in disposition effect in this environment also primarily occur through increased PLR. The *Nudge* treatment is specifically aiming to increase participants selling of losers, so PLR is particularly relevant.

2.4 Variables to Assess Mechanisms of Effects

To assess the mechanisms of effects, we also analysed participants' decisions beyond their disposition effects in terms of their total number of buy, hold and sell decisions and how they varied based on treatment exposure, and behavioural variables. Additionally, we were able to classify whether any decision was good or bad. In each trading period, participants were fully informed of the price distributions up until that period. Hence, they would be able to identify which asset is most likely to fit which type, based on the number of past price increases each asset has had. In each period, ignoring the true underlying types, we identified which assets were most likely to be the "--" and "-" type based on being in the lowest 1/3 of number of price increases up until that point and classified those as bad assets, as they would likely lose participants money. We did the same for likely "++" and "+" types based on being in the highest 1/3 and classified them as good assets, as they would likely make participants money. This strategy meant that if there were more than two assets that were likely to be the "++" and "+" types, or "--" and "-" types, we allowed for ties, so, for example, there could be more than two good assets in a period, but never less than two.

To understand how participants responded to the *Nudge* treatment, we also created a variable for the accuracy of the nudge choice. As the nudge is asking participants to identify the stock most likely to negatively impact their portfolio, the correct nudge choice would be to select the asset with the lowest number of price increases up until that point, as it is the most likely to be a worse asset type than the other assets held. Hence, if participants selected this asset, it would be a correct nudge choice. The response to the *Nudge* treatment was also measured by the proportion of periods participants sold the asset selected as their worst (in the nudge directly prior).

2.5 Disposition Effect Benchmarks

Figure 5: Optimal Behaviour

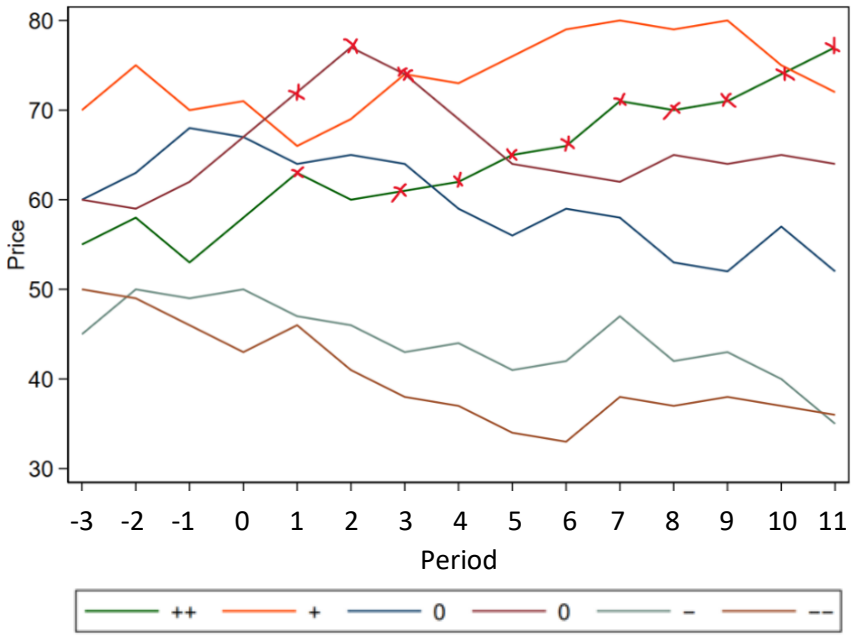


Figure 5 shows the optimal behaviour for our price series. The red crosses indicate which assets the optimal participant would be holding in each period, based on the number of price increases up until that point. Whilst participants behaving optimally would always have an α of -1 in W&C, the optimal value of DE varies based on price series[7], with its optimal value for our price series being -0.831 (as only 83.1% of losers in the optimal portfolio are sold). To identify the effects of the *Nudge* and *Instruction* treatments, we will be comparing them to the disposition effects of those exposed to neither treatment (the "Control" condition). However, as the optimal values for α and DE are significantly negative, the treatments or any other variable having a good effect will be represented by them resulting in a disposition effect closer to the optimal (i.e., more negative), rather than a movement closer to 0.

2.6 Hypotheses

Through inducing participants to be more forward-thinking and hence less focused on past actions or mistakes, the *Nudge* treatment should drag investors out of the sunk cost thinking framework which leads to escalation of commitment and therefore a disposition effect (Lehenkari, 2012) and should nudge them towards optimising their returns. We hence predict that:

1) Exposure to the *Nudge* treatment should lead to participants reducing their disposition effect.

Participants in W&C have consistently been shown to exhibit positive disposition effects despite doing so being suboptimal (e.g., Weber & Camerer, 1998; Cueva et al., 2019;

[7] For example, using the price series from Corneille and colleagues (2018), the optimal DE is -.508.

Wierzbitzki & Seidens, 2018; Corneille et al., 2018). However, when participants have been given full information (i.e., explicitly told the matching of asset types), Corneille and colleagues state that their disposition effect reduces. This indicates that the reason for the positive disposition effects in W&C is partly a lack of understanding of the environment. Therefore, as the *Instruction* treatment helps participants to better understand the optimal strategy, they should be following to maximise earnings, we predict that:

2) Exposure to the *Instruction* treatment should reduce participants' disposition effects

Conditional on finding an effect of the *Nudge* treatment that is robust to *Instruction* treatment exposure, there would be no interaction effect between the treatments. This is because the *Instruction* treatment being complementary with the *Nudge* would indicate that the *Nudge* succeeds, at least in part, due to demand effects. Even when participants are given full information about stock types, their disposition effects remain significantly more positive than the optimal (Corneille et al., 2018). If demand effects were likely to show up in W&C interventions, they should have done so there, as participants should have understood that the researchers would want them to hold the "++" stock (and potentially also the "+" stock) but no others. However, there doesn't appear to be a demand effect in Corneille and colleagues' results. Hence, we predict that the treatments will be supplementary as they should both reduce participants' disposition effects, but:

3) *Instruction* treatment exposure should not reduce disposition effects for those already exposed to the *Nudge.*

In addition to our main hypotheses, we also test the following based on participant characteristics to better understand the W&C environment:

A belief in mean reversion has been shown to lead to higher disposition effects (Jiao, 2017) and despite being made to be irrational by the environment, individuals who hold a belief in mean reversion might be influenced by it somewhat when making decisions in W&C. Therefore, we predict that:

4) Participants with a belief in mean reversion will have a higher disposition effect than those with no such belief.

More experienced investors on average have lower disposition effects (Feng & Seasholes, 2005). Additionally, those with more experience with financial products have higher financial literacy (Hogarth and Hilgert, 2002). Hence a potential mechanism behind experienced investors having lower disposition effects is their greater financial literacy. Cueva and colleagues (2019), using an environment very similar to W&C but changing the magnitudes of price increases and slightly changing the probabilities of price increases associated with each underlying asset type, found that financial literacy didn't significantly impact disposition effects. However, they don't separate out understanding of diversification from the rest of financial literacy, which could impact their findings as we predict that understanding of diversification increases disposition effects in W&C. Therefore, finding that financial literacy has no significant effect could be because understanding of diversification and the other elements of financial literacy impact disposition effects in opposite directions. Hence, we predict that:

5) Higher financial literacy decreases participants' disposition effects.

In W&C, diversification is largely suboptimal as to maximise returns, participants should be only investing in the stock/s that are the most likely to be the "++" type in any given period. Hence, any diversification taking place should only be because multiple assets are equally likely to be the "++" type (due to having the same number of past price increases). This is not the case in real world markets, as diversification helps to mitigate risk (Magnus & Zhang, 1998). So, if participants bring in their externally held knowledge about the benefits of diversification into W&C, they will exhibit higher disposition effects. Additionally, Corneille and colleagues (2018) found that even participants who are told each assets' underlying type, still diversify beyond only holding the "++" asset. An explanation for this it that it occurred due to participants bringing in their external beliefs in W&C. Therefore, we predict that:

6) Participants who understand the positive impact of diversification, should exhibit higher disposition effects in W&C compared to those who do not understand.

Risk tolerance or tendency for risk aversion have been shown to not impact disposition effects in W&C or environments very similar to it (Cueva and colleagues, 2019; Liêu & Pelster, 2020). However, no study to our knowledge has specifically looked at the impact of participants risk tolerance specifically in the financial domain, which is more likely to affect behaviour in W&C, due to it being a financial setting. Those more tolerant to financial risk might be more likely to act with risk seeking behaviour towards losses, in line with prospect theory (Kahneman & Traversky, 1982) and this would lead to them avoiding selling losers, increasing their disposition effects. We therefore predict:

7) Higher financial risk tolerance should lead to participants exhibiting higher disposition effects in W&C.

2.7 Critiques of Disposition Effect Measures

Unfortunately, both disposition effect measures are imperfect, and so investors with the same tendency to sell winners more than losers, may have different measured disposition effects due to the issues with the measures. Odean's (1998) measure is sensitive to the size of an investors' portfolio. Two investors making the exact same trades can have significantly different DEs if they have different sized portfolios (Odean). Those with larger portfolios will have DEs that are closer to 0, as it would require more trades to sell the same proportion of their winners or losers, and hence the magnitude of difference between PGR and PLR will be smaller. Participants having larger portfolios in W&C is primarily a result of investing a higher proportion of their endowment. This should be unrelated to any bias in selling decisions. If anything, a larger portfolio size might lead to disposition effects further away from zero (in a negative direction), as those behaving in line with the optimal strategy to maximise their returns would invest almost the entirety of their endowment in the likely "++" asset/s. This is improbable, as the share of participants investing the entirety of their endowment is not isolated to only those following a more optimal strategy. However, it is problematic that DE is sensitive to portfolio size.

Both measures might also be affected by portfolio composition. For Odean's (1998) measure, those with portfolios containing a higher number of possible number of stocks to sell at a gain than possible number of stocks to sell at a loss would have DEs that are more negative than indicated purely by their selling decisions, as it would require more sales of winners to sell

the same proportion of their winners or losers. With the same number of sales of winners and losers, PGR would therefore be smaller than PLR. Similarly, participants' DEs would be more positive than indicated purely by their selling decisions if they have more losers in their portfolio than winners.

On the other hand, α has been criticised by Corneille and colleagues (2018) for being influenced by market trend. If the market is trending upwards and so participants have a higher number of stocks to sell at a gain in their portfolio, then they would be likely to sell relatively more winners than losers, making α more positive (Corneille et al.). Corneille and colleagues argue that in W&C, participants are incentivised to invest in assets that are the most likely to rise in price, and hence their held assets would have more gains than losses leading to a "positive but biased" α.

The critique on DE of it being affected by portfolio composition might not be valid, as it could be the case that portfolio composition is a consequence of a past selling behaviour that would therefore have influenced participants' disposition effect. For example, having a higher number of winners in a portfolio might be caused by a selling less winners in past periods, hence it should result in a more negative DE. This same logic can be applied to challenge Corneille and colleagues' (2018) critique on α. However, if it is true that α is "positive but biased" in W&C, due to the nature of the environment, this is quite problematic.

3. Results[8]

3.1 Identifying whether DE and α critiques hold for our sample

Taking a Spearman rank correlation test, the absolute value of DE is in fact significantly negatively correlated with the size of participants' portfolios ($p<0.05$). Therefore, those with larger portfolios have DE measures closer to 0. This indicates that the first critique on DE holds, which is problematic. Additionally, participants in our sample have both a significantly negative α, and hold significantly more losers than winners in their portfolios (paired t-test for significant difference in means, $p<0.001$). Therefore, participants are not investing more in assets that are most likely to rise in price, despite Corneille and colleagues (2018) claiming participants would. Hence, their critique on α does not hold empirically.

Due to these findings, α appears to be the better measure for disposition effect, at least for our sample. As previously stated, both measures will still be used to allow for comparability with previous studies, however more attention should be paid to the results for α rather than DE.

[8] All values are reported to three decimal places. The impact of demographic variables is not reported, but the unbalanced demographic variables are controlled for in all regressions. When reporting the impact of variables other than treatment exposure (i.e., behavioural variables) on disposition effects, treatment exposure will also be controlled for. Other than in section 3.4.4, PGR regressions are not reported, because as predicted, all mechanisms for changes in DE occurred through PLR (with the exception of nudge choice accuracy).

3.2 Treatment Effects

The mean α for all participants is -0.144 and the mean DE is -0.075. Taking t-tests for each being significantly less than 0 shows that this is true for both measures ($p<0.001$), and the same is true when testing for them being equal to their optimal values of -1 and -0.831. Figures 4 and 5 shows how α and DE differ across the different experimental conditions.

Figure 4: α across conditions

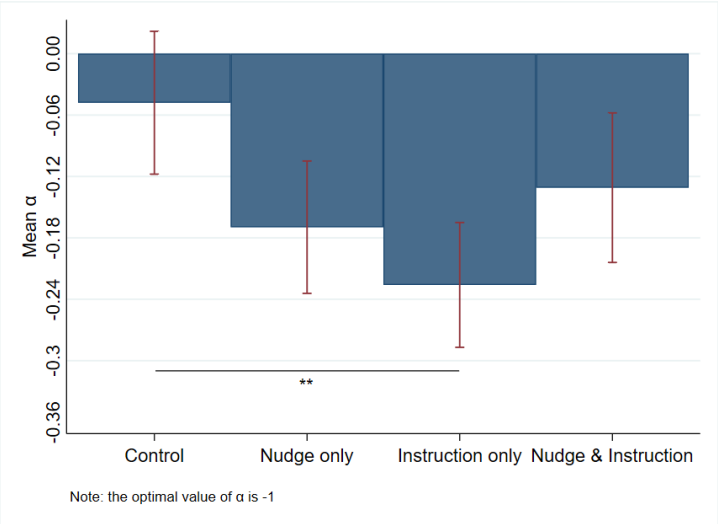
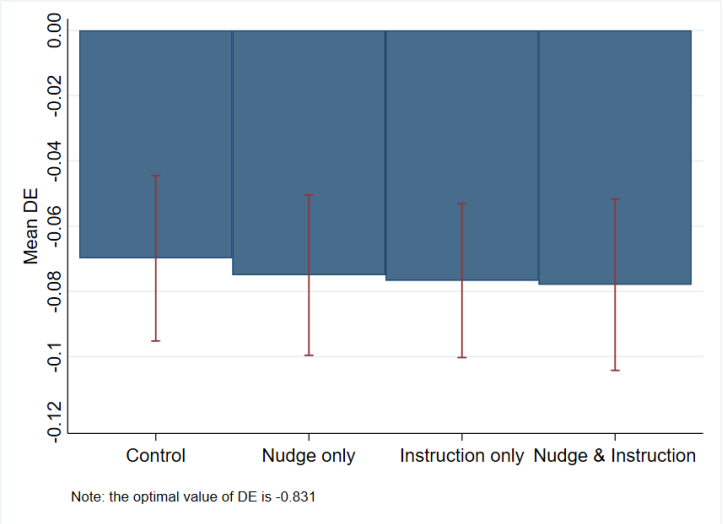


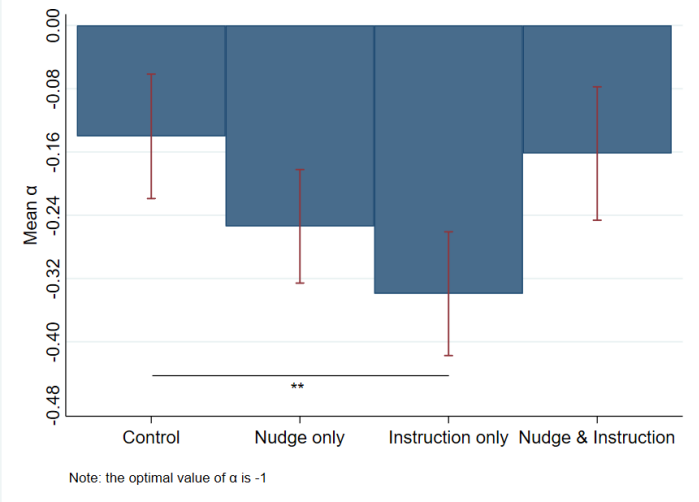
Figure 5: DE across conditions



* = p < 0.1; ** = p < 0.05; *** = p < 0.01; **** = p < 0.001

Interestingly, taking t-tests, the mean value of α for participants in the Control condition was not significantly different from 0 ($p>0.1$), whilst the mean values of α were significantly less than 0 in all the other conditions ($p<0.01$ for Nudge, $p<0.001$ for Instruction and $p<0.05$ for Nudge & Instruction). Despite, this it doesn't appear that the *Nudge* treatment has a strong impact on overall disposition effects. Whilst participants in all 3 non-control conditions appear to have lower disposition effects than those in the Control condition, the effect is only significant for participants in the Instruction condition, whose α coefficients on average are significantly closer to the optimal value of -1 ($p<0.1$). These results persisted when taking regressions of DE and α against treatment exposure, as indicated by Table 4.

Figure 6 - α across conditions when excluding decisions made before period 4



* = p < 0.1; ** = p < 0.05; *** = p < 0.01; **** = p < 0.001

Participants exposed to the *Nudge* treatment were only shown a nudge from period 4 onwards. And notably, by period 4, a single best asset has emerged, with one's confidence in it being the best asset only increasing each subsequent period. Therefore, if any treatment effects do exist, they should be shown when looking specifically at disposition effects from decisions made period 4 and onwards. So, we also looked at the impacts of treatment exposure on these disposition effects, the results of which are shown in Table 5. Figure 6 shows how α now differs across conditions.

When regressing these disposition effects on treatment exposure, exposure to the *Nudge* treatment did significantly reduce α, as shown in Table 5. Hence, the nudge did succeed in assisting participants to reduce their disposition effects, just not to a strong enough extent that their overall disposition effect is significantly reduced. Therefore, both treatments do reduce disposition effects, and Hypothesis 1 and Hypothesis 2 are supported. Additionally, the mean α for participants in the Control condition was significantly less than 0 ($p<0.05$) when excluding decisions made before period 4. Therefore, the most probable reason for the Control participants having α not significantly different from 0 is due to initial confusion that reduced as the likely "++" asset became clearer. Comparing the α from decisions in all periods to the α when excluding decisions before period 4, with a t-test, shows that the period 4 and beyond α is significantly more negative ($p<0.01$), and hence more optimal. This is also suggested by comparing Figure 6 to Figure 4, as all the treatments have nominally lower mean α when excluding pre-period 4 decisions.

Table 4: Disposition Effect Regressions across Treatment Exposure

	DE regression		**α regression**		**PLR regression**	
Variables	**t statistic**	**p value**	**t statistic**	**p value**	**t statistic**	**p value**
Nudge exposure	-0.38	0.703	-1.29	0.196	-0.21	0.830
Instruction exposure	-0.11	0.911	-1.89	0.059*	-0.65	0.515
Nudge and *Instruction* exposure	0.15	0.881	1.61	0.107	0.45	0.651

* = p < 0.1; ** = p < 0.05; *** = p < 0.01; **** = p < 0.001

Table 5: Disposition Effect Regressions across Treatment Exposure when excluding decisions made before period 4

	DE regression		**α regression**		**PLR regression**	
Variables	**t statistic**	**p value**	**t statistic**	**p value**	**t statistic**	**p value**
Nudge exposure	-0.85	0.396	-1.74	0.084*	-0.06	0.955
Instruction exposure	-0.20	0.843	-1.98	0.048**	-0.70	0.483
Nudge and *Instruction* exposure	0.36	0.717	1.93	0.055*	0.55	0.580

* = p < 0.1; ** = p < 0.05; *** = p < 0.01; **** = p < 0.001

There doesn't appear to be any beneficial complementarity between the treatments. Figures 4, 5 and 6 demonstrate this and taking a regression of treatment exposure including exposure to both treatments on disposition effects, also shows this to be true, as there is no significant interaction effect of the treatments, which is shown in Table 4. Table 5 does show a positive interaction effect ($p<0.1$), meaning that being exposed to both treatments results in less optimal α (when only considering decisions made during and following period 4) than being exposed to either treatment individually. We were mostly concerned with the interaction leading to more optimal disposition effects which would indicate demand effects in participants responding to the nudge. As this wasn't the case, we can largely conclude that

demand effects didn't impact how participants responded to the nudge. However, Hypothesis 3 does appear to be incorrect.

3.3 Effects of Behavioural Variables

Table 6: Disposition Effect Regressions across Behavioural variables

	DE regression		**α regression**		**PLR regression**	
Variables	**t statistic**	**p value**	**t statistic**	**p value**	**t statistic**	**p value**
Nudge exposure	-0.4	0.692	-1.52	0.130	-0.23	0.816
Instruction exposure	-0.24	0.813	-1.63	0.102	-0.57	0.572
Nudge and *Instruction* exposure	0.24	0.814	1.38	0.170	0.39	0.695
Understanding of diversification	1.81	0.071*	2.12	0.034**	-2.26	0.025**
Financial literacy	-0.94	0.349	-0.40	0.686	1.32	0.187
Belief in mean reversion	0.02	0.983	1.07	0.283	-0.64	0.521
Financial risk tolerance	2.28	0.023**	0.63	0.536	-2.53	0.012**
Comprehension	1.58	0.114	0.54	0.588	-2.25	0.025**

* = p < 0.1; ** = p < 0.05; *** = p < 0.01; **** = p < 0.001

The results from taking a regression of all the behavioural variables[9] on disposition effects are displayed in Table 6. In summary, our findings indicate that those with an understanding of diversification have higher disposition effects, supporting Hypothesis 6, but financial literacy and belief in mean reversion do not appear to have strong impacts, despite Hypothesis 4 and 5 predicting otherwise. Financial literacy does appear to somewhat increase disposition effects, but not with α, meaning that Hypothesis 7 is not fully supported, and comprehension has no strong impact on disposition effects (even though those with comprehension had significantly lower PLR). This indicates that the comprehension questions likely succeeded in ensuring that participants who didn't initially understand the environment understood it to a better extent before starting trading.

3.3.1 Understanding of Diversification, Belief in Mean Reversion and Financial Risk Tolerance

The first result that stands out is that participants who understand diversification have higher disposition effects. Understanding of diversification was quite balanced across our sample, with 49% of participants understanding diversification[10], but it appears to harm participants in W&C, as those who did understand it, had disposition effects significantly further away from the optimal than those who didn't which is shown in Figure 7 and 8, and this was robust to controlling for all other behavioural variables, treatment exposure and unbalanced demographics (Table 6). Hence, Hypothesis 6 is supported.

[9] Comprehension was also included for the purpose of an exploratory analysis, which will be discussed further in section 3.3.2.

[10] Taking a chi^2 test also showed that it was balanced across conditions (p>0.1).

Figure 7 - α on understanding of diversification

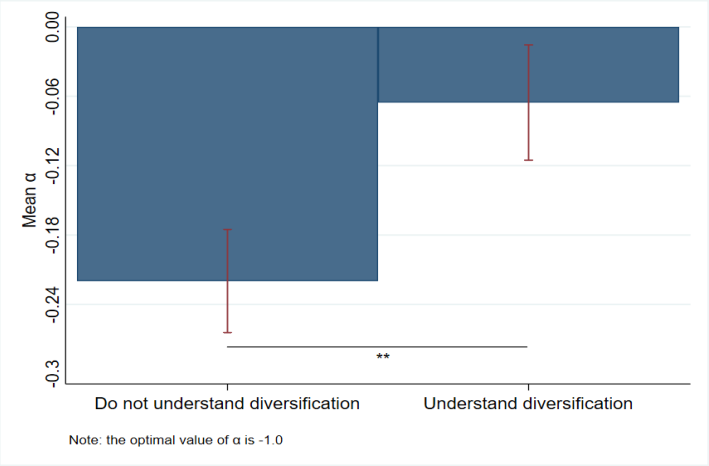
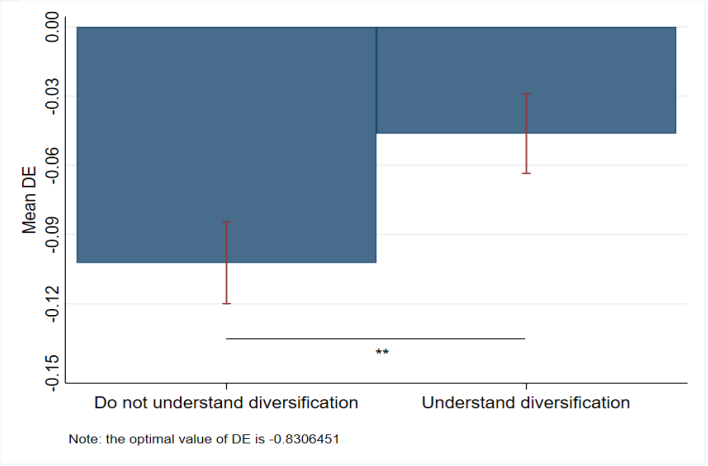


Figure 8 - DE on understanding of diversification



* = p < 0.1; ** = p < 0.05; *** = p < 0.01; **** = p < 0.001

Participants' belief in mean reversion appeared to have no strong impact on disposition effects, contradicting Hypothesis 4. This is indicated by our finding of significantly negative mean disposition effects for our sample, despite a majority (56.75%) of participants exhibiting a belief in mean reversion[11]. Table 6 also shows that when controlling for additional variables, belief in mean reversion doesn't have any significant impact on disposition effects. T-tests of belief in mean reversion on disposition effect, do show that those with a belief in mean reversion have significantly higher α ($p<0.05$), but our findings indicate that even if belief in mean reversion does impact disposition effects, it is not the sole cause of them in W&C. If participants with the belief were acting fully in line with it, they would have had significantly positive disposition effects, but the mean α for those with a belief in mean reversion was still negative at -0.093.

Participants with higher financial risk tolerance exhibited higher DE ($p<0.05$), as indicated by Table 6, specifically through a lower proportion of losses sold ($p<0.05$), as predicted in Hypothesis 7. However, this is not the case with α, as financial risk tolerance does not significantly impact it. So, while higher financial risk tolerance does appear to increase disposition effects, this is questionable, particularly as α has been established to be the more valid measure of disposition effect for our sample. Hence, Hypothesis 7 is not fully supported. Additionally, although not included in the table, when replacing financial risk tolerance with general risk tolerance, risk tolerance was found to have no impact on any of the disposition effect measures[12]. This explains why both Cueva and colleagues (2019) and Liêu and Pelster (2020) found risk tolerance to not impact disposition effects.

3.3.2 Financial Literacy and Comprehension

Surprisingly, looking at Table 6, participants' financial literacy when excluding their understanding of diversification appears to also have no significant impact on disposition effects. This contradicts Hypothesis 5. Hence, it is not the case that understanding of diversification and the remaining elements of financial literacy operated in opposite

[11] Belief in mean reversion was balanced across conditions (chi^2 test, $p>0.1$).
[12] This is despite financial and general risk tolerance being highly correlated (Spearman rank correlation test $p<0.001$)

directions, as was previously believed would happen. Rather, the remaining elements of financial literacy don't impact disposition effects and the impact of participants' understanding of diversification isn't strong enough to make the entirety of financial literacy have an impact[13].

It could be the case that financial literacy didn't impact disposition effects as participants understood the environment well due to the comprehension questions. Financial literacy measures understanding of how real-world financial markets work and the ability to use that understanding to effectively manage financial resources (Hung et al., 2009. Hence, if participants already understand the environment, then they may not benefit as much from financial literacy. Regressing behavioural variables on comprehension, only financial literacy had a significant impact, with participants who had greater financial literacy being significantly more likely to have comprehension ($p<0.01$). Therefore, with the absence of comprehension questions, financial literacy may have had an impact on disposition effects due to helping participants understand the environment better. However, interpreting the regression shows that those with financial literacy of one standard deviation above the mean were only 7.59% more likely to have comprehension, which serves as evidence for W&C being distinct from real-world markets.

For an exploratory analysis, we also included comprehension in our regression of disposition effects on behavioural variables, and our findings support the notion that the comprehension questions helped all participants understand the environment to a good extent. Table 6 shows that participants' comprehension didn't significantly impact their disposition effect. Those with comprehension even had significantly lower PLR ($p<0.05$), meaning that in this domain, they performed worse. However, because this wasn't a strong enough effect to impact DE, or α, it can largely be ignored.

3.4 Understanding Differences in Behaviour

3.4.1 Aggregate Decision variables

Table 7: Regressions for decision variables

Variables	Active trades (t stat)	Sell decisions (t stat)	Buy decisions (t stat)	Hold decisions (t stat)
Nudge exposure	0.15	0.33	0.51	-0.61
Instruction exposure	-0.50	-0.14	0.60	-2.07**
Nudge and *Instruction* exposure	0.68	-0.37	-1.00	0.82
Understanding of diversification	-0.99	-0.67	0.71	1.45
Financial literacy	-1.89*	-3.40***	-1.87*	0.43
Belief in mean reversion	0.54	-0.18	0.43	0.10
Financial risk tolerance	-1.89*	-0.43	-1.72*	0.14
Comprehension	-2.77***	-1.21	-1.79*	1.23

* = p < 0.1; ** = p < 0.05; *** = p < 0.01; **** = p < 0.001

[13] despite understanding of diversification constituting 1/3 of the financial literacy score used by Cueva and colleagues (2019)

As seen in Table 7, regressing aggregate buy, hold and sell decisions on treatment exposure and behavioural variables, shows that neither treatment impacts the aggregate number of buy or sell decisions, but those exposed to the *Instruction* treatment make significantly less hold decisions ($p<0.05$). Those with higher financial literacy make both less sell decisions ($p<0.01$) and less buy decisions ($p<0.1$) on average, leading to less active trades ($p<0.1$). Both those who initially comprehended the environment and those with higher financial risk tolerance make fewer active trades ($p<0.01$ and $p<0.1$ respectively) due to making less buy decisions on average ($p<0.1$ for both).

3.4.2 Good and Bad Decisions

Table 8: Regressions for decision variables when classified as good or bad

Variables	Bad decisions (t stat)	Good decisions (t stat)	Bad sell decisions (t stat)	Good sell decisions (t stat)	Bad buy decisions (t stat)	Good buy decisions (t stat)	Bad hold decisions (t stat)	Good hold decisions (t stat)
Nudge exposure	-0.36	0.49	-0.57	0.95	0.37	0.65	-0.5	-0.28
Instruction exposure	-1.16	-0.78	0.21	-0.33	0.18	0.41	-1.79*	-1.45
Nudge and *Instruction* exposure	0.23	-0.19	0.32	-0.54	-0.69	-0.81	0.60	0.67
Understanding of diversification	1.32	0.18	0.55	-1.24	1.57	-0.47	0.67	1.37
Financial literacy	-1.47	-0.81	-3.30***	-2.03**	-1.65	-1.09	0.25	0.71
Belief in mean reversion	1.67*	-1.42	0.63	-0.85	0.94	-0.26	1.49	-1.63
Financial risk tolerance	0.44	-1.53	-0.34	-0.08	0.67	-2.75***	0.34	-0.09
Comprehension	-0.77	0.21	-1.50	-0.94	-1.20	-1.14	0.23	1.83*

* = p < 0.1; ** = p < 0.05; *** = p < 0.01; **** = p < 0.001

When repeating the same regressions but coding decisions as good or bad, the *Nudge* treatment still didn't have any significant impacts, but those exposed to the *Instruction* treatment did make less decisions to hold bad stocks ($p<0.1$) as shown in Table 8. Participants with higher financial literacy made less decisions to sell bad and good stocks on average ($p<0.05$ and $p<0.01$ respectively), but this is just indicative of them selling less stocks on aggregate. Notably, belief in mean reversion did cause participants to make significantly more bad decisions ($p<0.1$), despite the belief not appearing to strongly impact disposition effects. Those with higher financial risk tolerance made significantly less decisions to buy good stocks ($p<0.01$) and participants who initially comprehended the environment made more decisions to hold good stocks ($p<0.1$).

Notably, these results indicate that the *Nudge* treatment on average didn't affect participants decisions, which explains why treatment exposure didn't impact overall disposition effects. However, the *Instruction* treatment did have some positive impact on participants' choices, by reducing their number of bad hold decisions, which presumably explains why the treatment significantly reduced α.

3.4.3 Diversification and External Beliefs

Regressing for diversification (in terms of number of assets held) also on treatment exposure and behavioural variables, shows that only understanding of diversification significantly impacted the number of assets held. Those with an understanding of diversification diversified more than those without the understanding ($p<0.1$). Through taking a t-test, those exposed to the *Instruction* treatment, also, on average, diversified less ($p<0.05$), although this was not robust to controlling for the additional variables. As the average amount of assets

held by all participants was over 3, whilst the amount of average assets held when following the optimal strategy of only holding asset/s that would be the most likely to be the "++" type, is 1.3, those exposed to the *Instruction* treatment did respond as intended to it, but not to the full extent. Only 11.25% of participants only held good stocks, but no participants, exposed to the *Instruction* treatment or not, only held assets that were the most likely to be the "++" type. So, all participants either diversified more than was optimal, or did not hold the likely "++" asset/s. This replicates Corneille and colleagues' (2018) finding of participants diversifying more than they optimally should in W&C. Our finding demonstrates that this still occurs even when participants are told to not excessively diversify if they wish to maximise their returns.

Notably, the only significant difference in behaviour between those with an understanding of diversification and those without is that participants with the understanding of diversification, like those exposed to the *Instruction* treatment, diversified more on average bringing them further away from the optimal level of diversification. However, this finding was robust to the additional controls, making a stronger result. As belief in mean reversion did impact participants' decisions in a negative way, this indicates that participants do appear to bring their external beliefs in W&C, just more so for understanding of diversification.

3.4.4 Looking Further at Those Exposed to the *Nudge* Treatment

The *Nudge* treatment completely failing to influence participants' decisions on aggregate, was surprising, as despite having no impact on overall disposition effects, treatment exposure was shown to help participants reduce their disposition effect, just only after the nudge started to be shown. Participants exposed to the treatment, on average, only sold stocks of the asset they identified as their worst type in 36.33% of periods[14]. This suggests that participants largely ignored the nudge. However, the average participant only identified their worst asset correctly in 63.65%[15] of periods. Therefore, a substantial proportion of participants were unable to identify their worst asset in any given period.

The results of taking a regression of disposition effects on nudge choice accuracy (only for participants exposed to the *Nudge* treatment) is seen in Table 9. It shows that those who identified their worst asset correctly in a higher proportion of periods had lower α ($p<0.0001$), lower DE ($p<0.0001$), higher PLR ($p<0.05$) and lower PGR ($p<0.01$). This indicates significant heterogeneity in how effective the treatment is in reducing disposition effects based on participants' accuracy in identifying underlying asset types. Additionally, those who answered the nudge more accurately also responded stronger to it. Regressing whether participants decided to sell holdings of their chosen worst asset on nudge choice accuracy, controlling for the same variables as before, shows that those who answered the nudge more accurately were more likely to sell holdings of their chosen worst asset in the subsequent trading period ($p<0.1$). And, when regressing participants nudge choice accuracy on *Instruction* treatment exposure and comprehension, comprehension significantly increased accuracy ($p<0.1$)[16]. This potentially suggests that the *Nudge* treatment only was able to

[14] Taking a t-test, this proportion was significantly less than 100% ($p<0.001$).
[15] Taking a t-test, this proportion was significantly less than 100% ($p<0.001$).
[16] *Instruction* treatment exposure had no significant effect ($p>0.1$).

succeed in reducing disposition effects for participants with a better understanding of the environment.

Table 9: Regressions for disposition effects on nudge choice accuracy

	DE regression		α regression		PLR regression		PGR regression	
Variables	**t statistic**	**p value**	**t statistic**	**p value**	**t statistic**	**p value**	**t statistic**	**p value**
Nudge choice accuracy	-3.67	0.000****	-4.33	0.000****	1.98	0.049**	-3.14	0.002***
Instruction exposure	-0.44	0.663	-0.24	0.814	0.37	0.710	-0.24	0.813
Understanding of diversification	1.22	0.223	1.27	0.206	-1.35	0.179	0.35	0.727
Financial literacy	0.30	0.764	0.12	0.902	0.93	0.354	1.36	0.518
Belief in mean reversion	0.21	0.836	-0.40	0.688	-0.93	0.355	-0.65	0.733
Financial risk tolerance	0.66	0.511	-0.51	0.611	-1.25	0.213	-0.34	0.234
Comprehension	-0.30	0.766	-1.52	0.132	-0.77	0.444	-1.20	0.460

* = p < 0.1; ** = p < 0.05; *** = p < 0.01; **** = p < 0.001

4. Discussion

Participants were shown to bring in both their beliefs about diversification and mean reversion into W&C, but our finding that understanding of diversification leads to participants making worse decisions is particularly problematic. This is for two reasons: the first is that understanding of diversification affects participants' decisions to the point where it significantly impacts their disposition effect whilst belief in mean reversion does not, and the second is that diversification is optimal in real world markets as it helps to minimise risk (Magnus & Zhang, 1998), whereas a belief in mean reversion is not usually a rational belief, even in real markets (Odean, 1998). Therefore, this finding suggests that the W&C environment may not have strong external validity. Participants who likely would perform better in a real-world market, due to behaving more optimally, and who bring in their understanding of how real-world markets work into W&C, perform worse in W&C. This indicates that most experimental studies on the disposition effect likely suffer from poor external validity, as a large proportion, to our knowledge, either use this environment, or one very similar to it[17], (which have not addressed this issue).

While the *Instruction* treatment didn't appear to assist participants to identify which asset matched with each type, (which is evidenced through participants exposed to it not having higher nudge choice accuracy), it did succeed in helping participants to better understand the optimal strategy. This is because, those exposed to the treatment behave more in line with it. However, it also could be the case that participants are responding to the treatment in this way simply due to demand effects, and our results cannot rule this out. Demand effects would have led participants to likely behave more in line with the optimal strategy than they ordinarily would, but even out of the participants exposed to the *Instruction* treatment, all of them excessively diversified. So, the finding that even when exposed to the *Instruction* treatment, all participants still behaved sub-optimally, indicates that in W&C, participants do not, at least fully, understand the optimal strategy, even with the comprehension questions to help them understand the environment better and being told what the optimal strategy is.

[17] E.g., the environment used by Fischbacher and colleagues (2017)

Demand effects potentially occurring only leaves open the possibility that it is even harder to get participants to understand the optimal strategy than our results would indicate.

It is possible that participants excessively diversify, even when exposed to the *Instruction* treatment, due to having a diversification heuristic, where they have an inherent preference for diversification. However, De Giorgi and Mahmoud (2017) describe a diversification heuristic as occurring, at least partly due to perceiving diversification as reducing risk, which is not the case with W&C, as excess diversification increases the chance of having lower returns, rather than decreasing it. Participants using a diversification heuristic to make decisions in W&C, would therefore indicate a lack of understanding of the environment, and provides additional evidence for participants bringing in their external beliefs about how real-world markets work into W&C. The results of Corneille and colleagues (2018) show that this excessive diversification is likely not a result of participants being unsure of assets' typing, as participants who are explicitly told each assets' underlying type still excessively diversify. Hence, if participants are assuming that W&C has similar properties to real-world markets in terms of high diversification being optimal, then they might not believe that exhibiting a disposition effect higher than the optimal disposition effect would lead to lower expected returns. Therefore, participants with suboptimal disposition effects might be exhibiting a level of disposition effect that is optimal subject to their beliefs, which challenges the internal validity of W&C.

Only about ¼ (96/400) of participants initially fully comprehended the environment. Hence, it is possible that without our comprehension questions, ¾ of participants would have continued onto trading with an incorrect belief of how the trading environment worked. Comprehension not significantly impacting disposition effects (either α or DE) suggests that the comprehension questions were largely successful in aiding participants who did not initially understand the environment to understand the environment better. To our knowledge, all previous studies using W&C have reported a mean α which is substantially greater than zero[18] and none have reported a mean DE which is significantly less than zero. Hence even the mean α of those in the Control condition being not significantly different from zero (although it becomes significantly less than zero when removing decisions made before period 4) combined with the mean DE for those participants being significantly less than zero, still differentiates our findings. As the optimal value of α is always -1, regardless of the price series used, the mean α found in this study is likely closer to the optimal value than all other studies have found, which is potentially due to participants having a better understanding of the environment because of the comprehension questions. However, to confirm this, future research should replicate our experiment but remove the comprehension questions or not inform participants of their incorrect answers[19]. If disposition effects increase when comprehension questions are removed or participants aren't informed of incorrect answers, then this would prove that our comprehension questions did lead to participants exhibiting more optimal disposition effects.

This being proven would be evidence for a lack of external validity with W&C, as the environment is significantly different from real markets. Having a greater understanding of

[18] To our knowledge, the lowest value of α for a control group found in any study using W&C is 0.084 by Liêu and Pelster (2020).

[19] as was done by Fischbacher and colleagues (2017)

W&C may not indicate a better understanding of financial markets, particularly due to W&C having a strategy that is always optimal, making a belief in mean reversion completely irrational, and making diversification largely suboptimal. Whilst those who had higher financial literacy were found to be more likely to have comprehension, this was only to a small extent so still substantially leaves open the possibility of W&C not producing externally valid results.

Another consequence of proving that the comprehension questions did help participants to understand the environment better and hence behave more optimally, would be that our findings on the impacts of belief in mean reversion and diversification understanding on disposition effects might have been more pronounced without the comprehension questions. For example, participants with a belief in mean reversion might have behaved more in line with that belief and exhibited significantly positive disposition effects, if they didn't have the greater environmental understanding that the comprehension questions provided them.

It is likely that understanding of underlying asset types does not substantially influence disposition effects in W&C, as participants told the underlying types of each asset in Corneille and colleagues (2018), on average still exhibited significantly positive α[20]. Therefore, if the comprehension questions were responsible for the more negative disposition effects in our sample, this would likely not be because it increased participants' ability to identify asset types.

This also has a significant implication on our findings for the effectiveness of the *Nudge* treatment. It indicates that it was the *Nudge* treatment that led to a reduction in disposition effects for participants who understand the environment better, rather than those who were more able to correctly identify their worst asset type having lower disposition effects regardless of being exposed to the treatment. However, this doesn't fully eliminate the possibility of the latter being true. It would therefore still be helpful to test for the impact of likely asset type identification accuracy on disposition effects, which regrettably we did not do. This is because, it could be the case that participants in Corneille and colleagues (2018) simply didn't pay attention to the underlying asset types when making decisions despite being told them. If for those with a better understanding of likely underlying asset types, being exposed to the *Nudge* treatment resulted in lower disposition effects compared to those not exposed to the treatment, then this would prove that the treatment succeeds better when participants can more easily identify their best and worst assets. If so, this would indicate that the *Nudge* treatment is likely to succeed in real world markets, where investors potentially understand the environment better, despite W&C likely not having strong external validity.

Participants not being able to identify their worst held asset a substantial proportion of times also potentially gives rise to an alternative explanation of the suboptimal disposition effects that participants exhibit in W&C. Identifying the likely asset types, notably the "++" type, is required to follow the optimal strategy. Hence, if participants are unable to do so, not exhibiting optimal disposition effects may not be a function of any bias, but rather a function of a lack of full understanding of the environment, as participants may not realise that an

[20] The mean value of α was also larger for those informed of the underlying types than those who weren't (although it is unclear if this difference is statistically significant).

asset increasing in price makes it more likely to be the "++" type. This is a further concern about the internal validity of disposition effect findings using W&C.

Despite the range of potential issues with W&C our study has found, our findings do appear to support Weber and Camerer (1998) by showing that a suboptimal disposition effect can persist without a belief in mean reversion. Therefore, this indicates that disposition effects found in W&C cannot be simply chalked up to participants believing in mean reversion despite it being irrational. This also supports Lehenkari's (2012) finding of escalation of commitment being the most empirically valid explanation of disposition effects rather than an irrational belief in mean reversion. However, as to our knowledge, there is no standard measure for belief in mean reversion, our measure relies on a simple gambler's fallacy roulette task. Therefore, it may not be internally valid.

In summary, our findings indicate that a large proportion of current experimental literature on the disposition effect fails to recognise that their experimental approach may lead to their results lacking external and internal validity. Hence, a change of approach is likely needed. Despite seeking to answer the question of "Can we make investors smarter using a nudge?", due to the nature of W&C, we unfortunately have failed to definitively answer it. However, our results do give promising findings for a nudge akin to the one we used, that helps individuals to consider the likely negative ramifications of holding losers, potentially succeeding in a real-world environment to reduce investors' disposition effects. Therefore, yes, we likely can make investors smarter using a nudge.

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Appendix

Comprehension Questions

1. *Does your trading activity influence the prices at which assets are bought or sold?*
   - Yes
   - No (Correct)

   If answer incorrectly receive text stating: *Incorrect: All price changes are determined randomly by the computer.*
2. *Are the prices of the six assets determined independently?'*
   - Yes (Correct)
   - No

   If answer incorrectly receive text stating: *Incorrect: Prices are determined independently for every asset in every round.*
3. *Does every asset have the same probability of increasing in price?'*
   - Yes
   - No (Correct)

   If answer incorrectly receive text stating: *Incorrect: There are five types of assets, with different chances to increase or decrease in price.*
4. *If the price of an asset is 60 in Round 1, is it possible that its price is also 60 in Round 2?*
   - Yes
   - No (Correct)

   If answer incorrectly receive text stating: *Incorrect: The price of every asset will either increase or decrease in every round.*
5. *When the price of an asset increases, does it have the same chance of increasing by 1, 3, or 5 points?'*
   - Yes (Correct)
   - No

   If answer incorrectly receive text stating: *Incorrect: All three sizes of price change (1, 3, or 5 points) are equally likely.*
6. *Will your earnings from this study depend on the choices you make in the game?'*
   - Yes (Correct)
   - No

   If answer incorrectly receive text stating: *Incorrect: Your earnings will depend on the final value of your portfolio.*

Instructions

In this study, you will play a simple investment game. More specifically, you will manage a portfolio of assets, starting with a budget of 5,000 "points" (units of experimental money). Don't worry if you are not familiar with trading, as the game is really quite simple.

Basically, you will have the opportunity to invest your money (or part of it) in any of six different assets (A, B, C, D, E, and F). You may choose to buy, sell, or continue to hold these assets, in each of **10 trading rounds** that make up the game. Please note that you are not allowed to borrow money, or to short sell (sell assets that you do not own). Also, no interest

is earned on the money you do not invest (cash), and there are no transaction costs for buying and selling assets.

In each round, the six assets will be quoted on the market at prices that change randomly from one round to the next. You may think of rounds as successive days on the stock market, where the share prices for the six assets change from one day to the next.

In each round, and for each asset, the computer will randomly determine whether the price will rise or fall, and by how much. These price changes are determined independently, both for every asset and in every round. Each price may change by 1, 3, or 5 points, and all three of these values (1, 3, or 5 points) are equally likely.

Importantly, the computer has pre-determined, for each asset, the likelihood that its price will increase or decrease in each round, as described in the following table:

Asset type	Assets of this type	Probability of price increase	Probability of price decrease
++	1	65%	35%
+	1	55%	45%
0	2	50%	50%
−	1	45%	55%
−−	1	35%	65%

Also important, you will not know which asset (A, B, C, D, E, and F) has which chance of increasing or decreasing in price from one round to the next. You only know that there are two assets of Type "0" (which have an equal chance to rise or fall), and one asset of each of the four other types.

It is your task to work out which asset is associated with which type, so you can increase your portfolio value and make the most money from your investment. To help you with this, you will also be shown the prices of the assets in the four rounds before the start of trading. These will be shown as rounds −3 to 0 on your screen.

ONLY FOR THOSE IN EXPOSED TO THE *INSTRUCTION* TREATMENT: *On average, you can expect to earn the most money in this game by identifying the asset that you think is most likely to be of Type "++", and investing fully in that asset.*

In each round, you will see the current state of your portfolio and be able to make trading decisions (buying and/or selling) at the **current prices** in that round. The **purchase prices** displayed in the tables will refer to the average purchase price per unit of each asset you hold (it is zero if you don't hold that asset).

After the tenth round of trading the prices of the assets will update one last time, and your **final wealth** will be computed as the sum of your final cash balance and the value of your final portfolio of assets valued at the final prices. Once the portfolio game is completed, you will be asked to fill out a questionnaire.

Provided you play the game seriously and complete the questionnaire conscientiously, you will receive a base payment of GBP 2 for completing the study. In addition, you will receive

a bonus payment (in GBP) equal to the value of your final wealth in points divided by 2,500, such that the more money you earn in the game, the higher your earnings from the study.

For your convenience, these instructions will remain visible throughout the game.

Questionnaire

Risk Tolerance

General Risk Tolerance: How willing are you to take risks, *in general?* Please select a number on the scale, where the value 0 means "not at all willing to take risks", and the value 10 means "very willing to take risks".

(Participants selected a number between 1 – 10 on a scale)

Financial Risk Tolerance: How willing are you to take risks, *in financial matters?* Please select a number on the scale, where the value 0 means "not at all willing to take risks", and the value 10 means "very willing to take risks".

(Participants selected a number between 1 – 10 on a scale)

Mean Reversion

Suppose that you are going to play the roulette. You first sit and observe, and you notice that the last five times it came up black. Would you bet on red or black?

- Definitely bet on red.
- Probably bet on red
- No preference for red or black
- Probably bet on black
- Definitely bet on black

(Participants selecting either of the first two options was coded as them having a belief in mean reversion).

Financial Literacy

Suppose that you had 100 pounds in a savings account, and the interest rate was 2% per year. If you left the money to grow, how much would you have in the account after five years?

- More than 110 pounds (Correct)
- Exactly 110 pounds
- Less than 110 pounds
- Do not know

Suppose that the interest rate on your savings account was 2% per year and inflation was 3% per year. After one year, how much would you be able to buy with the money in this account?

- More than today

- Exactly the same as today
- Less than today (Correct)
- Do not know

* Do you think the following statement is true or false? *Buying a single company stock usually provides a safer return than a stock mutual fund.*

- True
- False (Correct)
- Do not know

Do you think the following statement is true or false? *A 15-year mortgage typically requires higher monthly payments than a 30-year mortgage, but the total interest over the life of the loan will be less.*

- True (Correct)
- False
- Do not know

If interest rates rise, what will typically happen to bond prices?

- They will rise
- They will stay the same
- They will fall (Correct)
- There is no relationship

Suppose that in the year 2030 your income has doubled, and the prices of all goods and services have doubled too. In 2030, how much will you be able to buy with your income?

- More than today
- Exactly the same as today (Correct)
- Less than today
- Do not know

When someone buys the shares of a company in the stock market, which of the following statements is true?

- They own a part of the company (Correct)
- They have lent money to the company
- They are liable for the debts of the company
- None of the above
- Do not know

Considering a long time period (for example 10 or 20 years), which of the following assets usually has the greatest returns?

- Savings accounts
- Bonds
- Stocks (Correct)
- Do not know

Which of the following assets usually has the greatest fluctuations in value over time?

- Savings accounts
- Bonds
- Stocks (Correct)
- Do not know

* When an investor spreads their money among different assets, their risk of losing money:

- Increases
- Stays the same
- Decreases (Correct)
- Do not know

* = used to construct the Understanding of Diversification variable