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Common Expectations in Experimental Asset Markets**

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## ABSTRACT

### **To See Is To Believe: Common Expectations in Experimental Asset Markets<sup>\*</sup>**

We challenge the recent claim that mispricing in the experimental asset markets introduced by Smith, Suchanek, and Williams (1988) is merely an artefact of confusion over declining fundamental value, and can be eliminated through appropriate training. We instead propose that when training is public knowledge, it reduces uncertainty over the behavior of others and facilitates the formation of common expectations. We disentangle the effect of training from the effect of its public knowledge, and find that when all subjects are trained to understand fundamental value, but this is not public knowledge, mispricing is as great as when training is absent.

JEL Classification: C92, D84, G12

Keywords: asset market experiment, price bubbles, common knowledge of rationality

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In a wide range of decision problems, the optimal course of action for an agent depends critically on their expectations regarding the behavior – and therefore implicitly the rationality – of others. This is the case not only in many important applied problems of business strategy, but also in the corpus of theory that economists have developed to model such interactions. As is well known, standard solution concepts such as rationalizability and backward induction demand high levels of mutual knowledge of rationality, resulting in stark equilibrium predictions that frequently fail in the experimental laboratory (Nagel, 1995; McKelvey and Palfrey, 1992). Yet, what is less commonly acknowledged is that these settings arguably also stretch the limits of the experimental method itself. For while an experimenter can control such features as the set of players, the strategies at their disposal and resultant material payoffs, it is far more difficult for the experimenter to credibly control the *epistemic* conditions that are also required for equilibrium predictions to obtain – in particular the beliefs that players hold regarding the rationality of their counterparts. Nonetheless, when experimental findings fail to confirm equilibrium predictions, it is tempting to conclude that this must reflect some failure of rationality itself rather than the common knowledge thereof.

In this paper, we reconsider these issues in the context of the mispricing commonly observed in the asset market experiments introduced by Smith, Suchanek, and Williams (1988, hereinafter SSW). In particular, we reexamine the recent claim that this mispricing is due to confusion, and can be ameliorated by training subjects to understand fundamental value (FV). We instead reassert the centrality of subjects' expectations, by proposing that the coordination of expectations may be facilitated when it is public knowledge that such training has taken place. To test this conjecture, we manipulate whether or not it is public knowledge that all traders in a market have undergone training. We show that training to reduce confusion is alone not sufficient to diminish mispricing, and that it is also necessary to make known to the market that confusion has been rectified.

The phenomenon of price “bubbles and crashes” in SSW-style asset market experiments was for many years considered a paradox or anomaly. Over the two decades that followed publication of SSW, a large body of research sought to identify and eliminate the sources of this mispricing, with only limited success.<sup>1</sup> SSW's original interpretation of their discovery was that differences between

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<sup>1</sup>King, Smith, Williams, and van Boening (1993), van Boening, Williams, and LaMaster (1993), Porter and Smith (1995), and Haruvy and Noussair (2006) manipulate aspects of the rules of the institutions that govern exchange. Porter and Smith (1995), Smith, van Boening, and Wellford (2000), Noussair, Robin, and Ruffieux (2001), and

price and FV “may be due to a lack of common, not irrational, expectations” (p. 1120), and that “it is the failure of the assumption of common expectations, *not backward induction incompetence by subject agents* that explains bubbles” (p. 1148, emphasis added). That is, although the dividend structure of the asset was made public knowledge by the experimenter, each subject might still have been uncertain as to how others would use that information. However it was neither necessary, nor did it seem likely to SSW, that subjects actually failed to comprehend the information itself.

More recently, however, a new conventional wisdom has taken hold. According to this view, mispricing in SSW markets is simply a product of subject confusion over the FV process, which declines over time due to the finite life of the dividend-paying experimental asset (and may thus be inconsistent with subjects’ homegrown expectations derived from real-world assets). Consistent with this view, several recent studies find that when care is taken to train subjects to correctly understand the declining FV, mispricing in SSW markets is substantially diminished.<sup>2,3</sup> Huber and Kirchler (2012, p. 89) summarize the new view by asserting that “all bubble reducing factors have one common feature: they allow subjects to understand the non-intuitive declining FV-process of the SSW-model better and thus reduce subjects’ confusion”.<sup>4</sup> Of course, if this view is correct the entire twenty-five year trajectory of the SSW literature would have largely been an enormous intellectual *cul de sac*.

The first conclusive evidence of confusion was provided by Lei, Noussair, and Plott (2001, hereinafter LNP). They made explicit the implication of SSW’s conjecture that mispricing arises from

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Hussam, Porter, and Smith (2008) manipulate aspects of the dividend process of the experimental asset. James and Isaac (2000) study the effect of incentives; Dufwenberg, Lindqvist, and Moore (2005) study the effect of experience; Haruvy, Lahav, and Noussair (2007) elicit subjects’ price predictions; and Cheung and Palan (2012) study the effect of group decision-making. Recent surveys of this literature include Porter and Smith (2008), and Palan (2012).

<sup>2</sup>Noussair and Tucker (2006) sequentially open a complete set of futures markets, in reverse order of maturity, prior to opening the spot market; they state explicitly that this is intended to facilitate backward-induction reasoning over the FV. Lei and Vesely (2009) introduce a pre-market phase in which subjects passively experience a flow of dividends. After this they ask subjects to state, for each period, the value of an asset that pays dividends in every remaining period of its life. Kirchler, Huber, and Stöckl (2012) introduce a new framing (“stocks of a depletable gold mine”) intended to call to mind a declining FV. Huber and Kirchler (2012) present FV information in a graph instead of a table, and ask subjects to state their estimate of the FV before the start of each period. Huber, Kirchler, and Stöckl (2012) display the current FV on the trading screen throughout the experiment. Each of these protocols is found to produce patterns of mispricing that are less pronounced than is typical in SSW-style markets.

<sup>3</sup>In our interpretation, if subjects were to trade appropriately conditional upon an incorrect understanding of FV (as the confusion view suggests might be the case), it is debatable whether the resulting price trajectory should be characterized as a “bubble”. It is for this reason that we adopt the language of “mispricing” throughout our paper.

<sup>4</sup>Thus, for example, the well-known result that mispricing in SSW markets is diminished with repetition – which SSW interpreted to show that subjects came to form common expectations by learning the behavior of others through experience – is reinterpreted to indicate that subjects were instead learning to understand FV. It follows that an appropriate training protocol could serve as a substitute for such experience (Lei and Vesely, 2009).

uncertainty over the behavior of others – namely that some subjects must doubt the rationality of others, and thus perceive an opportunity for speculation. To test this, LNP designed treatments in which speculation was not possible (by prohibiting subjects in the role of buyers from reselling, and subjects in the role of sellers from repurchasing), and nonetheless observed many transactions at prices that were as a consequence certain to be unprofitable. From this, LNP were careful to conclude that “the lack of common knowledge of the rationality of market participants . . . can be ruled out as being the *only* cause of the bubble phenomenon” (p. 834, emphasis in original).<sup>5</sup>

In this paper, we reassert the centrality of common expectations, as first emphasized by SSW, in the wake of the finding of confusion and the new conventional wisdom that confusion “is the main driver for mispricing” (Kirchler, Huber, and Stöckl 2012, p. 865) in SSW markets. Since LNP establish that doubts over the behavior of others are well-founded, it follows that protocols that facilitate common expectations cannot wholly substitute for ones that address the underlying confusion. However, it does not follow that the two may not be complements. Nonetheless, we submit that all recent bubble-reducing protocols in fact share a second common feature – namely *the fact that it is public knowledge that all subjects in the market have been jointly exposed to the protocol*.

We assert that in making the training of declining FV public knowledge, these recent studies may have inadvertently had the effect of reducing uncertainty over the behavior of others and resolving the problem of coordinating subjects’ price expectations – and that this may in itself have contributed to the finding of diminished mispricing.<sup>6</sup> To evaluate this conjecture, we report new experiments in which we manipulate both whether or not subjects are trained to understand FV, and whether or not it is public knowledge that all subjects in the market have undergone this training.<sup>7</sup>

Through this design, we are able to disentangle the direct effect of training in reducing confusion

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<sup>5</sup>Smith (2010, p. 6) acknowledges that SSW’s original interpretation of their bubble finding was falsified by the LNP result; however he does not wholeheartedly endorse the notion that the subjects were “confused”.

<sup>6</sup>Noussair and Tucker (2006, p. 169) acknowledge that their futures market protocol cannot discriminate between the effects of coordinating expectations and reducing confusion. Lei and Vesely (2009, p. 256) are less circumspect, asserting that “individual rationality induced in the pre-market phase was so profound that uncertainty about the behaviour of others . . . never became strong enough to divert market prices away from the fundamental values”. This overlooks the possibility that behavioral uncertainty might itself have been diminished as a byproduct of the protocol.

<sup>7</sup>We speak of *public knowledge of training* to make clear that we do not claim that this suffices to establish *common knowledge of rationality*. This is because the formal concept of common knowledge involves higher-order beliefs, about which we have no direct evidence. Nonetheless, since LNP establish the presence of *actual irrationality in the absence of training*, we assert that common knowledge of rationality is impossible when i) confusion has been reduced through training, however ii) this is not public knowledge.

from the effect of its public knowledge in facilitating common expectations.

We find that when all subjects in a market are trained to understand diminishing FV, but this is not public knowledge, mispricing is as great as when training is absent. However, mispricing is substantially diminished when it is public knowledge that all subjects have been trained. Thus while redressing confusion is necessary to diminish mispricing in SSW markets, it is not sufficient without also making it known to the market that confusion has been corrected. We conclude that just as SSW were mistaken to disregard the possibility of confusion, the recent literature has itself been remiss in neglecting the importance of common expectations as first emphasized by SSW.<sup>8</sup>

Our paper is organized as follows. Section 1 outlines our design, including details of our training and public knowledge manipulations. Section 2 presents our results, and Section 3 concludes.

## 1 Design

### 1.1 Market environment

In each market, ten subjects trade shares of a dividend-paying asset in exchange for experimental currency units (ECU) in a computerized double auction over fifteen four-minute trading periods. The distribution of initial endowments is summarized in Appendix A; valued at FV, each subject has the same initial wealth. After each period, each share pays a common dividend which, following SSW’s classic “Design 4” parameters, takes values of 0, 8, 28, or 60 ECU, each with equal probability. After the fifteenth period, shares expire without any terminal value. The FV of a share is thus given by the product of its expected dividend per period (24 ECU) and the number of dividends remaining. In particular, the FV is 360 in period one, and declines by 24 in each subsequent period. We follow standard practice in the SSW literature by making FV information public knowledge in the form of an “average holding value table” which is contained within the instructions.<sup>9</sup>

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<sup>8</sup>We do not contest the view, also advanced in the recent literature, that the SSW design has some unusual features that may lack external validity (Oechssler 2010, Kirchler, Huber, and Stöckl 2012). In addition to declining FV, these include a finite horizon, increasing cash-to-asset ratio, and high dividend yields.

<sup>9</sup>See the Online Appendix for the full instructions, which also include a screen shot of the double auction interface.

## 1.2 Training protocol

Our protocol to train subjects in the FV process consists of two sets of control questions – one framed from the perspective of buying a share, and the other framed from the perspective of selling. We include fifteen questions in each frame, ordered from period fifteen to period one.

In the buyer frame subjects were asked, for  $t = \{15, 14, \dots, 1\}$ :

Suppose that you buy one share in period  $t$  and that you keep it until the end of the market (i.e. until period 15). What is the average total dividend that you will receive from this share?

Similarly, in the seller frame subjects were asked, for  $t = \{15, 14, \dots, 1\}$ :

Suppose that you sell one share in period  $t$  and that you do not buy it back. What is the average total dividend that you give up on this share?

We require subjects to answer both sets of questions, thereby effectively requiring them to enter the FV values from the average holding value table twice, from the bottom up.<sup>10</sup> In each of the sessions in which subjects were required to answer these questions, the experiment did not commence until all of the subjects who were required to do so had answered all of the questions correctly.

## 1.3 Treatments

We operated two markets in each session, for a total of twenty subjects. Our design consists of four treatments, which differ in whether or not subjects were required to complete the training task before the experiment could begin, and whether or not this was public knowledge. In the two treatments in which subjects answered control questions, it was always the case that all ten subjects

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<sup>10</sup>By presenting the questions in reverse order, our protocol was intended to highlight the backward induction of FV, as opposed to its declining value *per se*. In this respect, it was modeled upon the futures market protocol of Noussair and Tucker (2006). At the time that we developed it, we were unaware of several of the more recent protocols described in footnote 2. Nonetheless, we consider the various procedures to be comparable, in that they all seek to reinforce subjects' understanding of the FV information contained in the instructions.

in the market were required to do so; these treatments therefore differ only in whether or not this fact was public knowledge. We collected a total of six observations (markets) in each treatment.<sup>11</sup>

In the Public Knowledge (PK) treatment, all subjects were required to successfully complete the training task, and this was public knowledge. Subjects were informed that the experiment would not begin until all twenty subjects in the session had correctly answered all of the questions.

To obtain the treatments we refer to as NPK and WAIT, we informed all twenty subjects in a session that some of them would be asked to answer some control questions, and that those subjects would have to answer all of the questions correctly before the experiment could begin. The remaining subjects would not be asked any questions, and would simply wait for the experiment to begin.

Of the twenty subjects in these sessions, we required ten to answer the full set of questions. Through a message on their computer screens, we informed these subjects that exactly ten of the subjects in the session would be required to answer the questions. What they were not told is that all ten would be grouped together to trade in the same market. This market thus consisted of ten subjects who had all completed the training task successfully but who did not know that all others in the market had also done so. We refer to this treatment as Not Public Knowledge (NPK).

As a byproduct of NPK we also had ten subjects in these sessions who did not complete the training task and were simply required to wait for the others to finish. These ten subjects were grouped together to make up the second market in the session. Through a message on their computer screens, we informed these subjects that when the experiment began, none of the subjects in their market would have answered any questions.<sup>12</sup> We refer to this treatment as WAIT.

Finally, in our BASE treatment none of the subjects in the session were required to complete the training task, and they did not have to wait for others to do so before the experiment could begin.

Thus, to reiterate the key feature of our design: In both treatments PK and NPK, all subjects in the market were trained to understand the declining FV process by requiring them to correctly answer the control questions; however only in treatment PK was this made public knowledge.

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<sup>11</sup>We thus have the same number of markets in each of our treatments as in the recent papers by Kirchler, Huber and Stöckl (2012) and Huber and Kirchler (2012), and a larger number than in the seminal paper by LNP.

<sup>12</sup>We did this to control these subjects' expectations with respect to the training history of their counterparts, and thereby enable us to test for the pure effect of waiting time in WAIT compared to BASE.

## 1.4 Procedures

We conducted our experiments at the University of Copenhagen between October 2009 and June 2010. No subject had taken part in any previous asset market experiment. We recruited subjects using ORSEE (Greiner 2004), and the experiment was programmed in z-Tree (Fischbacher 2007).

At the start of each session, we distributed and read aloud the first part of the instructions dealing with the mechanics of using the computer interface to make price offers and to buy and sell shares. This was followed by a ten-minute practice period, which did not count toward subjects' earnings. To minimize any anchoring effect of the practice prices, subjects completed the practice task before being told the dividend structure of the asset or how their earnings would be determined.

We next circulated and read aloud the remainder of the instructions, dealing with the dividends, average holding value table and calculation of earnings. Following this, some subjects were required to complete the training task as appropriate to the treatment (as detailed above).

Upon conclusion of the experiment, subjects completed a questionnaire consisting of some basic demographic items, the three-item Cognitive Reflection Test (Frederick 2005), and a ten-item test of financial literacy derived from van Rooij, Lusardi, and Alessie (2011).<sup>13</sup> Sessions lasted up to 2.5 hours, and the average earnings were DKK 239 (approximately USD 48 as of November 2009).

## 1.5 Hypotheses

Our design allows us to tease apart the effects of requiring subjects to wait before the experiment can begin (under treatment WAIT), of requiring all subjects in the market to successfully complete the training protocol when this is not public knowledge (under treatment NPK), and of making it public knowledge that all subjects successfully completed the training (under treatment PK). The existing literature indicates that there is likely to be substantial mispricing under BASE, and considerably less under PK. By examining the decomposition of this difference, as seen through the

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<sup>13</sup>We conducted a comparison of subject characteristics across the four treatments. The only significant differences were that there were fewer females in PK compared to BASE, and that subjects in PK had lower financial literacy than those in NPK and WAIT. We do not think it plausible that these differences would account for our results.

intermediate treatments WAIT and NPK, we expect to be able to shed light upon the mechanism through which training results in diminished mispricing.

Our first testable hypothesis concerns the effect of requiring our WAIT subjects to wait for others to complete the training task before the experiment can begin. By giving these subjects more time in which to think through the information in the instructions, it is possible that this might itself result in reduced mispricing even in the absence of any training.

***Hypothesis 1: Mispricing is less severe under WAIT compared to BASE.***

Our second hypothesis states that we expect to replicate the recent finding that mispricing is reduced when all subjects have been trained to understand FV, and this is public knowledge.

***Hypothesis 2: Mispricing is less severe under PK compared to WAIT and BASE.***

Our next two hypotheses are concerned with disentangling the effect of training from that of its public knowledge. Insofar as the effect is due to training *per se*, we would expect it to also be observed when it is not public knowledge that all subjects successfully completed the training.

***Hypothesis 3: Mispricing is less severe under NPK compared to WAIT and BASE.***

On the other hand, insofar as it is the public knowledge of training that accounts for diminished mispricing, we would expect the effect to be more pronounced under PK compared to NPK.

***Hypothesis 4: Mispricing is less severe under PK compared to NPK.***

## **1.6 Measures of mispricing and overvaluation**

We follow the recent literature in reporting the measures of *Relative Absolute Deviation (RAD)* for mispricing, and *Relative Deviation (RD)* for overvaluation, as introduced by Stöckl, Huber, and Kirchler (2010). The formal definitions of these measures are stated in Table 1. *RAD* measures the average *absolute* deviation of price from FV, and may thus be interpreted as a measure of the overall severity of mispricing without regard for sign. On the other hand, *RD* measures the average *direction* of price deviations, permitting periods of over and undervaluation to cancel out.

Table 1: Measures of mispricing and overvaluation

Measure	Definition
<i>Relative Absolute Deviation</i>	$RAD = \frac{1}{T} \sum_t  \bar{P}_t - f_t  /  \bar{f} $
<i>Relative Deviation</i>	$RD = \frac{1}{T} \sum_t (\bar{P}_t - f_t) /  \bar{f} $

*Note:*  $T$  = total number of trading periods;  $\bar{P}_t$  = mean transaction price in period  $t$ ;  $f_t$  = fundamental value in period  $t$ ;  $\bar{f}$  = mean fundamental value over the life of the asset.

Since we express our hypotheses in terms of mispricing, our preferred measure is *RAD*: if the effect of our treatments were to reduce the incidence of both over and undervaluation, this would be clearly evident in the form of a lower *RAD*, but the same would not necessarily be true of *RD*.<sup>14</sup>

## 2 Results

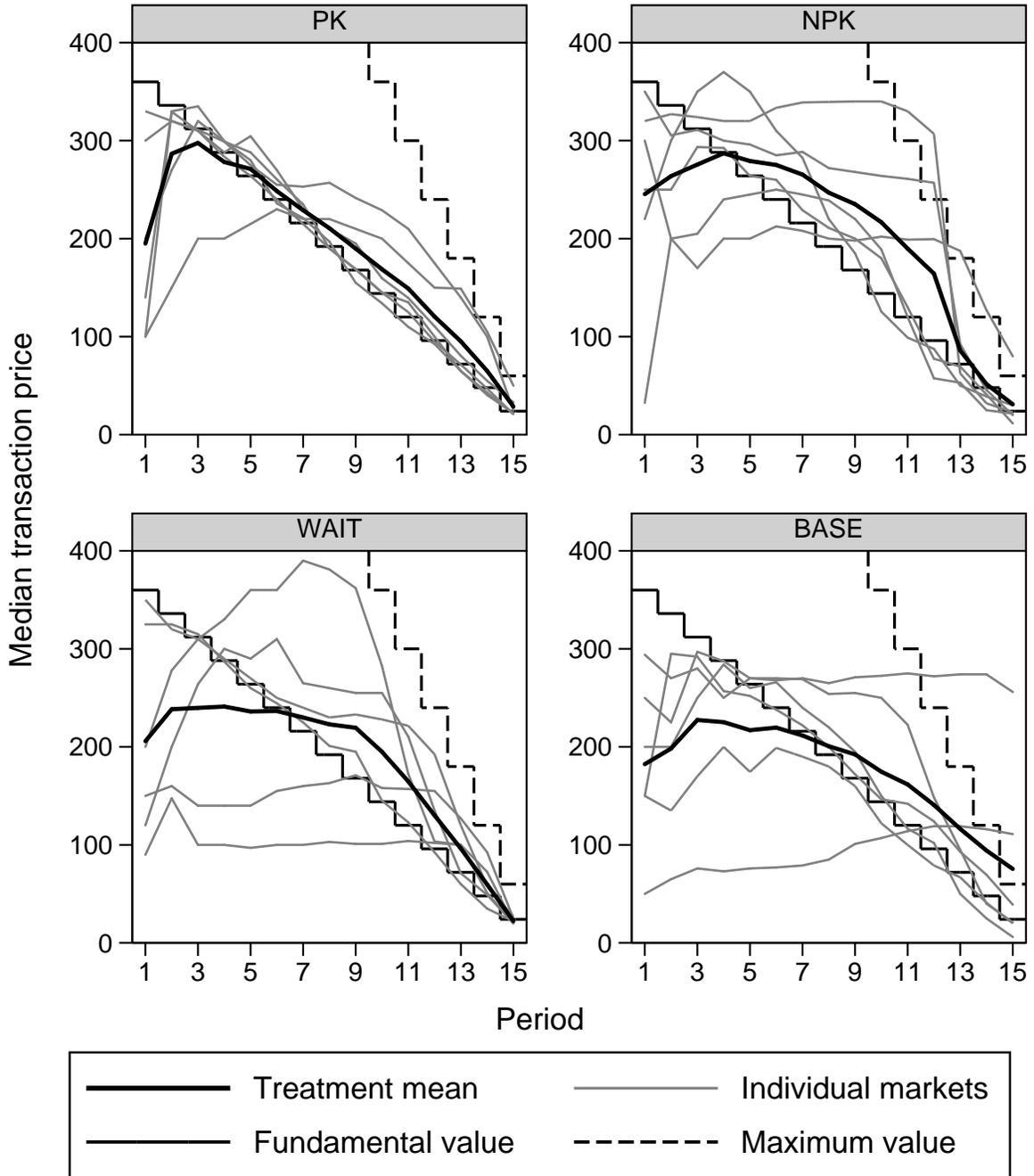
Figure 1 provides an overview of the period-wise median price trajectories in each of the individual markets (gray lines) together with the corresponding treatment means (thick black lines), with each treatment depicted in a separate panel. For comparison, the lower stepped line depicts the time path of FV, while the upper stepped line represents the maximum dividend value of a share (in the event that the maximum dividend of 60 is realized in every remaining period).

Looking firstly at the thick black line that represents the treatment mean, while it is evident that this tracks most closely to FV under treatment PK, it is also clear that it does not differ all that greatly across the four treatments. *On average*, it is the case in each treatment that prices tend to be moderately undervalued in the early periods and somewhat overvalued in the middle to later periods. This provides a first indication that there do not appear to be strong differences between the treatments in terms of *average overvaluation*.

However, turning to the gray lines that depict the price paths in individual markets, it is equally evident that there are clear differences between treatments in the degree of dispersion of the individual market trajectories around the treatment means. In particular, in some of the treatments

<sup>14</sup>In addition, we follow Kirchler, Huber, and Stöckl (2012) in also reporting a variety of other “bubble measures” from the earlier SSW literature. These additional measures are defined and reported in Appendix Tables B1 and B2.

Figure 1: Median price trajectories in individual markets



*Note:* This figure shows the period-wise median transaction price trajectories in each of the six individual markets in each of our four treatments. In each panel, the thick black line represents the treatment mean, while the lower solid stepped line represents the time path of FV and the upper dashed stepped line represents the maximum dividend value of a share.

in which average overvaluation is only mild, this only holds because we observe both some markets that exhibit pronounced overvaluation and others that are characterized by dramatic undervaluation – and these cancel out in computing the treatment means. That is to say, we do indeed observe substantial *total mispricing*, and moreover this does indeed appear to vary across the treatments.

In particular, it is clear that the price paths of the individual markets typically track FV more closely in the PK treatment than under either WAIT or BASE. Interestingly, however, this does not appear to be the case for the NPK treatment. This provides the first indication that simply training subjects to understand FV may not on its own be sufficient to reduce mispricing relative to treatments in which training is absent. On the other hand, when it is also public knowledge that all subjects have completed the training, then mispricing does indeed appear to be diminished.<sup>15</sup>

To formalize these observations, Table 2 reports an analysis of the measures *RAD* (for mispricing) and *RD* (for overvaluation). The top panel reports means of these measures for each of our four treatments.<sup>16</sup> For example, in treatment PK the mean *RAD* of 0.182 indicates that prices in these markets deviate from FV in absolute terms by an average of 18.2%, while the mean *RD* of  $-0.028$  indicates that the markets are on average undervalued by 2.8%. The treatment means of *RAD* are ranked in the expected order, with the greatest mispricing observed in BASE followed by WAIT then NPK, and the lowest value observed under PK. The mispricing under PK is roughly half of that observed in BASE and WAIT. The mean overvaluation is clearly closest to zero in the PK treatment; there is no obvious interpretation for the ranking of *RD* across the remaining treatments, which display tendencies toward both over and undervaluation.<sup>17</sup>

In the lower panel of Table 2, we report results of formal tests of our four hypotheses using the Fisher-Pitman exact permutation test for independent samples.<sup>18</sup> Since we state our hypotheses in one-sided terms, we report corresponding one-sided *p*-values. Our preferred measure is the *RAD*, because we state our hypotheses in terms of mispricing, and because we believe that this measure

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<sup>15</sup>We ran an additional PK market in which prices tracked FV from period two through twelve, at which time we experienced a fatal server crash. Data from this crashed PK market are not reported in the analysis in this section.

<sup>16</sup>Measures for each of the individual markets are reported in Appendix Table B2, along with values of the additional measures defined in Appendix Table B1.

<sup>17</sup>The PK treatment also exhibits the lowest mean for each of the additional measures in Appendix Table B2, with the exception of *Share Turnover*. Note that a high turnover need not imply that a market is inefficient *when it is the case that prices track closely to FV*, as is the case under PK (Smith, van Boening, and Wellford 2000, p. 577).

<sup>18</sup>This is a more powerful but computationally demanding alternative to the Wilcoxon rank-sum test (Kaiser 2007).

Table 2: Analysis of mispricing and overvaluation

	<i>RAD</i>	<i>RD</i>
Treatment means		
PK	0.182	-0.028
NPK	0.283	0.106
WAIT	0.348	-0.071
BASE	0.370	-0.101
Permutation test <i>p</i> -values (one-sided)		
H1: WAIT vs. BASE	0.420	0.570
H2: PK vs. WAIT + BASE	0.023 **	0.682
H3: NPK vs. WAIT + BASE	0.186	0.921
H4: PK vs. NPK	0.080 *	0.088 *

*Note:* The top panel of this table reports the treatment means of *RAD* (mispricing) and *RD* (overvaluation) for the six markets in each of our four treatments. The bottom panel reports exact one-sided *p*-values for Fisher-Pitman independent samples permutation tests (Kaiser 2007) comparing these measures across treatments and groups of treatments as per our four hypotheses. \*  $p < 0.10$ ; \*\*  $p < 0.05$ .

more accurately accounts for the possibility that our treatments might reduce the incidence of both over and undervaluation. Nonetheless, we report corresponding tests for *RD* in the second column.<sup>19</sup>

***Result 1: Mispricing is not significantly lower under WAIT compared to BASE. Hypothesis 1 is not supported.***

Our first hypothesis concerns the possibility that simply allowing subjects in WAIT more time to think might itself have the effect of reducing mispricing. However, we clearly cannot reject the null hypothesis that *RAD* is at least as great under WAIT as under BASE ( $p = 0.420$ ). We thus pool the data from WAIT and BASE in our tests of hypotheses 2 and 3.<sup>20</sup>

***Result 2: Mispricing is significantly lower under PK compared to WAIT and BASE. Hypothesis 2 is supported.***

Our second hypothesis states that we expect to replicate the finding of previous studies which show that when all subjects are trained to understand the FV process, and this is public knowledge,

<sup>19</sup>The *p*-values in the second column of Table 2 thus correspond to tests of hypotheses, analogous to the ones stated in Section 1.5, in which the words “Mispricing is less severe” are replaced by the words “Overvaluation is lower”.

<sup>20</sup>The two-sided *p*-values for the null hypotheses of equality of WAIT and BASE are 0.840 (*RAD*) and 0.861 (*RD*).

mispricing is less than when training is absent. We indeed find that  $RAD$  is significantly lower under PK than under WAIT and BASE pooled ( $p = 0.023$ ). This confirms that our training protocol produces results that are comparable to those of other recent studies.

***Result 3: Mispricing is not significantly lower under NPK compared to WAIT and BASE. Hypothesis 3 is not supported.***

Having established that training has a significant effect when it is public knowledge, our next hypothesis concerns whether the effect continues to be observed when all subjects in the market are trained, but this is no longer public knowledge. This is what we would expect if the effect of training operated simply through reducing subjects' confusion, and not through facilitating the coordination of expectations. We find that this is not the case, as we cannot reject the null hypothesis that  $RAD$  is at least as great under NPK as under WAIT and BASE pooled ( $p = 0.186$ ). When training is not public knowledge, mispricing is not significantly less than in markets in which training is absent, indicating that training alone is not sufficient to produce an effect in our setting.

***Result 4: Mispricing (and overvaluation) is marginally significantly lower under PK compared to NPK. There is mild support for Hypothesis 4.***

Our final hypothesis concerns the effect of making it public knowledge in treatment PK that all subjects have been trained to understand the FV process, compared to treatment NPK in which all subjects have been trained but this is not public knowledge. Note that the significance of this comparison is inhibited by the limited number of observations, and the presence of considerable within-treatment heterogeneity in NPK in particular. Nonetheless, we indeed confirm that  $RAD$  is marginally significantly lower under PK than under NPK ( $p = 0.080$ ). We also note that there is a marginally significant effect on overvaluation as measured by  $RD$  ( $p = 0.088$ ).

Thus to summarize, in both NPK and PK all subjects were trained to understand diminishing FV; all that differs is whether or not this was public knowledge. Consistent with previous studies, we find a significant reduction in mispricing *when training is combined with public knowledge*. However when training is not public knowledge it has no significant effect, and mispricing is substantial.

### 3 Conclusion

Our results are consistent with the few other experimental studies we are aware of that credibly manipulate subjects' expectations regarding the rational play of their counterparts. Thus, Fehr and Tyran (2001) find that subjects exhibit substantially more pronounced money illusion when playing a price-setting game with other humans than with computerized agents who they know to have been pre-programmed to play optimally. They interpret this to show that the greater part of money illusion operates indirectly through strategic uncertainty over the behavior of others, which is absent in the computerized condition. Likewise, Palacios-Huerta and Volij (2009) study the play of student subjects and chess players in a laboratory centipede experiment. They find that students in the role of the first mover are ten times more likely to stop the game at the first decision node (as predicted by subgame perfect equilibrium) when playing a chess player as opposed to another student. Conversely, chess players are less likely to stop the game when their opponent is a student as compared to another chess player. They interpret these results to indicate that players' assessment of the rationality of opponents is critical in determining whether subgame-perfect play emerges.

We interpret our own results to indicate that the greater part of the effect of training subjects to understand FV in SSW markets does not simply operate through reducing confusion, as recent studies have presumed, but instead relies upon making known to the market that confusion has indeed been reduced. It appears that when it is public knowledge that everyone has undergone training, subjects perceive less uncertainty over the behavior of others and – since they may be less inclined to doubt the rationality of others – less opportunity for speculation. In short, the effect of making training public knowledge may be to facilitate the coordination of subjects' common expectations on FV as the equilibrium price path. These effects cannot operate in the absence of public knowledge, even when it is in fact the case that all subjects indeed have a correct understanding of FV.

Our interpretation is consistent with SSW's original conjecture that a price "bubble" could form even when all traders were sophisticated, if that fact was not common knowledge. Indeed, we believe that our NPK treatment represents a reasonable approximation to the conditions that SSW originally postulated. These conditions did not hold in the original SSW experiments because of the very real possibility of confusion, as first demonstrated by LNP. In our NPK treatment, while training

addresses confusion at an individual level, the common knowledge of rationality is nonetheless rendered impossible. Under these conditions, we continue to observe substantial mispricing.

We also note that our interpretation aligns with the conclusion of a recent study by Xiong and Yu (2011), who examine the sources of a bubble in Chinese put warrants in the period 2005–2008. They take advantage of the finite life of these warrants to derive an upper bound on FV using a form of backward induction logic. Their preferred explanation for this bubble combines constraints on short sales (also present in standard SSW markets) with heterogeneous beliefs, and they explicitly interpret their data in terms of SSW’s hypothesis of the non-common knowledge of rationality.

In conclusion, we challenge the claim of recent several studies that mispricing in SSW-style markets is purely an artefact of subject confusion. Instead, we submit that by not only training subjects to understand declining FV, *but also making this public knowledge*, these studies did not only resolve the problem of confusion, they also inadvertently resolved the problem of coordination of expectations. Thus, just as SSW were mistaken to disregard the possibility of confusion, the recent literature has also been premature in reaching the conclusion that confusion is solely to blame. This is because that literature has itself neglected SSW’s original insight regarding the centrality of common expectations, which we find to be fundamentally sound.

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## Appendices

### A Experiment parameters

Table A1: Endowment and exchange rate parameters

Endowment type	I	II	III
Number of traders of this type	3	4	3
Initial stock	2	4	6
Initial cash	1,890	1,170	450
Endowment value (ECU)	2,610		
Exchange rate (DKK/ECU)	1/11		
Endowment value (DKK)	237.27		
Total Stock of Units (TSU)	40		

*Note:* One DKK is approximately equal to 0.20 USD (as of November 2009).

### B Additional bubble measures

Table B1: Additional bubble measure definitions

Measure	Definition
<i>Relative Absolute Deviation</i> <sup>a</sup>	$RAD = \frac{1}{T} \sum_t  \bar{P}_t - f_t  /  \bar{f} $
<i>Relative Deviation</i> <sup>a</sup>	$RD = \frac{1}{T} \sum_t (\bar{P}_t - f_t) /  \bar{f} $
<i>Share Turnover</i> <sup>b</sup>	$ST = (\sum_t q_t) / q$
<i>Price Amplitude</i> <sup>b</sup>	$PA = \max [(\bar{P}_t - f_t) / f_1] - \min [(\bar{P}_t - f_t) / f_1]$
<i>Total Dispersion</i> <sup>c</sup>	$TD = \sum_t  \tilde{P}_t - f_t $
<i>Average Bias</i> <sup>c</sup>	$AB = \sum_t (\tilde{P}_t - f_t) / T$

*Note:*  $T$  = total number of trading periods;  $\bar{P}_t$  = mean transaction price in period  $t$ ;  $\tilde{P}_t$  = median transaction price in period  $t$ ;  $f_t$  = fundamental value in period  $t$ ;  $\bar{f}$  = mean fundamental value over the life of the asset;  $q_t$  = number of transactions in period  $t$ ;  $q$  = total number of shares outstanding. <sup>a</sup> Introduced by Stöckl, Huber, and Kirchler (2010); <sup>b</sup> Introduced by King (1991); <sup>c</sup> Introduced by Haruvy and Noussair (2006).

Table B2: Additional bubble measure results

Treatment	Market	<i>RAD</i>	<i>RD</i>	<i>ST</i>	<i>PA</i>	<i>TD</i>	<i>AB</i>
PK	1	0.056	-0.048	11.45	0.265	68.0	-3.60
	2	0.125	-0.060	8.63	0.578	347.5	-9.43
	3	0.192	-0.049	5.40	0.731	472.0	-4.33
	4	0.386	-0.119	9.83	0.837	1,104.0	-20.40
	5	0.101	-0.065	4.78	0.555	342.0	-14.73
	6	0.230	0.175	8.33	0.408	664.5	34.03
Mean		0.182	-0.028	8.06	0.562	499.7	-3.08
NPK	1	0.467	0.405	4.20	0.749	1,328.5	78.50
	2	0.225	0.043	3.25	0.634	648.5	9.23
	3	0.303	0.266	5.25	0.534	832.0	49.07
	4	0.149	-0.053	4.13	0.445	389.5	-8.03
	5	0.331	0.063	7.18	1.124	1,322.0	-17.60
	6	0.223	-0.086	5.30	0.499	636.0	-18.00
Mean		0.283	0.106	4.88	0.664	859.4	15.53
WAIT	1	0.198	0.128	6.00	0.466	516.0	30.67
	2	0.531	-0.484	10.73	0.731	1,559.0	-96.13
	3	0.417	-0.270	9.23	0.728	1,213.5	-52.43
	4	0.057	-0.013	3.05	0.245	138.0	-1.67
	5	0.436	-0.097	5.98	0.887	982.5	8.30
	6	0.450	0.310	4.25	0.907	1,268.5	54.70
Mean		0.348	-0.071	6.54	0.661	946.3	-9.43
BASE	1	0.320	-0.320	5.50	0.569	892.5	-59.50
	2	0.572	0.382	8.58	0.957	1,585.5	78.77
	3	0.167	-0.081	3.80	0.630	444.0	-12.53
	4	0.266	0.097	9.18	0.627	769.5	18.30
	5	0.680	-0.525	14.78	1.082	1,962.0	-100.80
	6	0.217	-0.159	8.13	0.530	549.0	-21.03
Mean		0.370	-0.101	8.33	0.733	1,033.8	-16.13

# Online Appendix (not for publication): Experiment Instructions

## General Instructions

This is an experiment on decision making in a market. The instructions are simple and if you follow them carefully and make good decisions, you may earn a considerable amount of money which will be paid to you in cash at the end of the experiment.

Please do not communicate with other participants during the experiment. If you have a question please raise your hand, and an experimenter will assist you.

In this experiment, you have the opportunity to buy or sell in a market. The money used in this market is 'Experimental Currency Units' (ECU). All trading will be done in terms of ECU. The cash payment to you at the end of the experiment will be in Danish kroner. The conversion rate will be **11 ECU to 1 krone**.

You will then be asked to complete a questionnaire, after which you will receive your payment. The entire experiment will last approximately two-and-a-half hours, including half an hour for instructions and practice.

## How to use the Computerized Market

On the top right of the screen you will see how much time is left in the current trading period. The items you can buy and sell in the market are called shares. In the center of your screen you will see the number of shares and the amount of money you currently have.

Period		1 of 1		Remaining Time [sec]: 2	
Money: 5000		Shares: 10			
Enter offer to sell	Offers To Sell	Transaction prices	Offers To Buy	Enter offer to buy	
<input type="text"/>				<input type="text"/>	
<input type="button" value="SUBMIT OFFER TO SELL"/>	<input type="button" value="BUY"/>		<input type="button" value="SELL"/>	<input type="button" value="SUBMIT OFFER TO BUY"/>	

The screen can be used to participate in the market in one of four ways.

*Making an offer to sell a share, by entering the price at which you would like to sell:*

To offer to sell a share, enter the price at which you would like to sell in the box labeled 'Enter offer to sell' on the left of the screen, then click on the button 'Submit offer to sell'.

The second column from left will show a list of offers to sell, each submitted by a different participant. The lowest offer-to-sell price will always be on the bottom of the list. Your own offer will appear in blue. Submitting a new offer will replace your previous one.

*Making an offer to buy a share, by entering the price at which you would like to buy:*

To offer to buy a share, enter the price at which you would like to buy in the box labeled 'Enter offer to buy' on the right of the screen, then click on the button 'Submit offer to buy'.

The second column from right will show a list of offers to buy, each submitted by a different participant. The highest offer-to-buy price will always be on the bottom of the list. Your own offer will appear in blue. Submitting a new offer will replace your previous one.

*Buying a share, by accepting an offer to sell:*

You can select an offer to sell in the second column from left by clicking on it. If you click the 'Buy' button at the bottom of this column, you will buy one share at the selected price. However you are not allowed to buy a share from yourself.

When you accept an offer to sell, it will disappear from the list. If you had also placed an offer to buy, it will disappear from the offers to buy list because you have just bought a share.

*Selling a share, by accepting an offer to buy:*

You can select an offer to buy in the second column from right by clicking on it. If you click the 'Sell' button at the bottom of this column, you will sell one share at the selected price. However you are not allowed to sell a share to yourself.

When you accept an offer to buy, it will disappear from the list. If you had also placed an offer to sell, it will disappear from the offers to sell list because you have just sold a share.

### ***Transaction prices***

When you buy a share your money decreases by the price of the purchase. You can only buy a share if you have enough money to pay for it.

When you sell a share your money increases by the price of the sale. You can only sell a share if you owned one to begin with.

In the middle column of the screen, labeled 'Transaction prices', you will see the prices at which shares have traded in the current period.

### ***Practice period***

You now have ten minutes to practice buying and selling shares. Your actions in this practice period will not influence your earnings or your position later in the experiment. The only goal is to master the use of the interface.

Please make sure that you successfully submit offers to buy and offers to sell. Also make sure that you successfully accept other people's offers to buy and sell shares.

If you have any questions, please raise your hand and an experimenter will assist you.

### **Specific Instructions for this Experiment<sup>21</sup>**

In each market there are ten participants. *Although there may be more than ten participants in the lab today, you will always be in the same market of ten participants, consisting of yourself and the same set of nine others.*

The market will consist of fifteen trading periods. In each period there will be four minutes during which you can trade shares in exchange for ECU.

At the beginning of the first trading period, your screen will display your initial holdings of money and/or shares. These will not necessarily be the same for all participants in the market.

Any trade that you make will change your holdings of money and shares. These holdings will carry over from one trading period to the next.

### ***Dividends***

Recall that the market consists of fifteen trading periods. Shares are assets with a life of fifteen periods. Each share will pay a dividend to its current owner at the end of each period.

The dividend is randomly determined by the computer, and will be the same for all shares. In particular, each share that you own at the end of a period will pay:

- a dividend of 0 ECU with probability 1/4;
- a dividend of 8 ECU with probability 1/4;
- a dividend of 28 ECU with probability 1/4; and
- a dividend of 60 ECU with probability 1/4.

Since each outcome is equally likely, the average dividend is  $(0+8+28+60) / 4 = 24$  ECU in every period.

Dividends will be added to your money balance automatically at the end of each period. After the dividend is paid at the end of the fifteenth trading period, all shares will be worthless and there will be no further earnings possible from them.

### **Average Holding Value Table**

You can use your AVERAGE HOLDING VALUE TABLE to help you make decisions.

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<sup>21</sup>Distributed after completion of the practice period.

The first column indicates the Ending Period of the market. The second column indicates the Current Period for which the average holding value is being calculated. The third column gives the Number of Holding Periods from the Current Period to the Ending Period.

The fourth column gives the Average Dividend per Period for each share that you hold. The fifth column gives the Average Holding Value per Share that you hold from the Current Period until the end of the market.

That is, for each share that you hold for the remainder of the market, you will earn on average the amount listed in column five. The value in column five is calculated by multiplying the values in columns three and four.

### AVERAGE HOLDING VALUE TABLE

Ending Period	Current Period	Number of Holding Periods	×	Average Dividend Per Period	=	Average Holding Value Per Share
15	1	15		24		360
15	2	14		24		336
15	3	13		24		312
15	4	12		24		288
15	5	11		24		264
15	6	10		24		240
15	7	9		24		216
15	8	8		24		192
15	9	7		24		168
15	10	6		24		144
15	11	5		24		120
15	12	4		24		96
15	13	3		24		72
15	14	2		24		48
15	15	1		24		24

### Your Earnings

At the end of the market, your earnings will equal the amount of money you have at the end of period fifteen, after the last dividend has been paid.

This amount of money will be equal to:

$$\begin{aligned}
 & \textit{Any money you had at the beginning of period one} \\
 & + \textit{Any money you received from sales of shares} \\
 & - \textit{Any money you spent on purchases of shares} \\
 & + \textit{Any dividends you received}
 \end{aligned}$$

At the conclusion of the experiment this amount will be converted into Danish kroner at the rate specified on page one of these instructions, and paid to you in cash.