The Role of Public and Private Information in a Laboratory Financial Market

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Abstract

The theoretical approach in dealing with the aggregation of information in markets in general and financial markets in particular considers information as an exogenous element to the system, focusing just on conditions and consequences of the efficient incorporation of information into prices. The production and acquisition of the information is, therefore, not a major focus of the theoretical as well as the empirical analysis. We take the position that the composition of the spectrum of information sources affects the behavior of the traders in the information gathering process. In this paper we will study experimentally the information aggregation process in a market as a function of the access to different sources of information, namely an imperfect, public and costless signal into a market where the participants have access to costly and imperfect private information. In order to investigate the impact of the access to information on the efficiency of the markets and the behavior of the traders.We observe that the release of public information reduces the traders' information demand, it keeps constant market informativeness, but significantly reduces price efficiency in aggregating information. In particular we show that traders overweight public information that dominates the market dynamics. As a policy advise we recommend that eventual reforms on the regulation of financial institutions (for instance the credit rating agencies) should account for the complex interplay between private and public information that we have identified in our experiments and give incentives to the investors (institutional and/or private) to search for alternative sources of information.

Keywords: *Experiments, financial markets, private and public information, rating agencies.*

JEL Classification: *C92, D82, G14.*

1 Introduction

After the recent financial turmoil, academics and regulators started a debate on the role that the main rating agencies played in the global diffusion of financial instability. It seems that their optimistic recommendations have been followed by the vast majority of investors, while revealing being misleading. However, why have financial investors passively followed recommendations of rating agencies? Did they search for independent and alternative sources of information in evaluating financial products? Might it be that the information provided by the rating agencies has produced a reduction in the information gathering activity of investors?.

Inspired by the recent debate on which role have played rating agencies in the current financial crisis, in our paper we use laboratory experiments to investigate the impact of releasing introduction of an imperfect, public and costless signal into a financial market where traders have access to (independent sources of) costly and imperfect private information about the future prospect of a financial asset. The main focus of the paper is, on the one hand, the analysis of the efficiency of prices in aggregating and disseminating information, studying in particular whether and under which conditions the contemporaneous presence of private and public information enhances or reduces market efficiency. On the other hand, we study the demand for information as a function of the relative precision of the public signal with respect to the noisiness of private information. In a market with these characteristics, using the words of Morris (2002) "public and private information (might) end up being substitute rather than being cumulative". More precisely, Morris (2002) show that in a game-theoretical beauty contest, this substitution effect can significantly decrease the information content in the system that, depending on the noisiness of public information might result in a welfare loss.[1] They demonstrate that public information might be considered a double edged-instrument, i.e. it conveys information on the fundamentals of a financial asset, but, at the same time, it serves as a focal point in coordinating the traders' activity in a market. They conclude that the noisiness of public information can be enhanced in the market due to the overreaction of the traders to the disclosure of a public signal. Following the theoretical work of Morris and Shin in a beauty-contest environment, in our paper we want to analyze whether we can observe in a laboratory financial market the complex interaction between public and private information described by Morris

[1] Given this double edged nature of public information, other authors have addressed the issue of transparency of public information. For example Amato and Shin (2004), Angeletos and Pavan (2004) or Hellwig (2005),

and Shin. The experimental literature on laboratory financial markets has paid no attention to such interplay and to the double edged role of public information in the experimental markets, outside the p-beauty context.

Taking into account the experimental literature, we can categorize previous studies on financial markets in a laboratory into two broad groups[2], on the one hand those studies where information is exogenously given to the traders at no cost. On the other hand, those settings where exists an information market that runs parallel to the asset market. As a representative example of the first category, we can mention the seminal paper of Plott (1982), where they study under which conditions *perfect* information is efficiently incorporated into prices. They address the issue of dissemination of information from a group of fully informed agents (i.e. insiders) to a group of uninformed agents and conclude that with replication and experience (even uniformed) traders are able to decipher the true state of the world by simply observing market price.[3] The review of different experimental studies on information aggregation and dissemination in a setting where *imperfect* information is distributed at no cost suggests that aggregation depends crucially on market features such as common knowledge, information distribution or subjects' experience.[4] One important finding is that, even under the best circumstances, information aggregation and/or dissemination (when occurs) is not instantaneous, since traders need some time to observe the market activity, form conjectures, test them and modify their strategies. Therefore, there is an incentive for costly information creation due to the noisy revelation of information in asset markets.[5]

As an example of the second category is the paper of Sunder (1992), who studied experimentally the impact of the contemporaneous presence of an information market and an asset market. In a first setting, the price of information is endogenous whereas the number of perfectly informed traders in fixed (i.e. a given number of perfect signals where auctioned off). In a second experimental setting, the price of information is fixed, whereas the number of informed traders is endogenous (and

[2]See Plott (2002) and Sunder (1995) for a thoughtful survey on experimental asset markets.

[3]Watts (1993) replicates the Plott and Sunder's experiments where the presence of insiders is random, and finds that the price convergence to the rational expectations equilibrium worsens.

[4]See Sunder (1995) for an detailed survey on this issue.

[5]See Grossman (1980)

not known by traders). A series of experimental studies using different settings inspired by Sunder (1992) conclude that when the distribution of (perfectly) informed traders is not common knowledge in the market, it is harder for the prices to reveal information.[6]

However, in all the previous experiments informed subjects are *insiders*, since the information received is always perfect or certain. Within this framework Hey (2004) develop a very simple experimental setting where heterogeneous and imperfectly informed agents have to trade a risky asset whose dividend depends on two equiprobable states of the world. In their setting, each trader can buy, at any moment during the trading period, as many signals as (s)he wants. Their results suggest that the aggregation process improves when the quality and quantity of information in the market are higher.[7]

Typically, as we have seen, the experimental literature focuses on the problem of market efficiency in aggregating private information into prices. Whereas, it has not been experimentally investigated so far, the impact of a public signal, for example the rating agencies' recommendations or a central bank disclosure on traders' behavior and/or market efficiency.

Contrary to the experimental literature, in the empirical literature, several papers deal with the market impact of the rating agencies. Among these contributions, Millon (1985) demonstrate that information gathering agencies may arise in a world of informational asymmetries and moral hazard. According to them, in a setting in which true firms' values are certified by screening agents whose payoffs depend on noisy ex-post monitors of information quality, the formation of information gathering agencies is justified because it: (i) enables screening agents to diversify their risky payoffs, and (ii) allows for information sharing.[8] Still on theoretical grounds, referring to a multiple equilibria set up, Boot et al. (2006) show that the rating is a coordinating mechanism, providing a "focal point" for firms and investors. However, Carlson and Hale (2006) reach opposite conclusions. Using a game theoretic model,

[6]See Copeland (1991, 1992) or y K. Weigelt (1991), among others.

[7]For a recent survey on financial markets in the laboratory see Noussair and Tucker (2013).

[8]However, Millon (1985) assume perfect knowledge by the information gathering agency about the underlying risk of the borrower.

they predict that introducing a rating agency to a market that otherwise would have the unique equilibrium, can bring about multiple equilibria.

Taking stock of all these contributions on the role that public and private information might have in a financial market, our paper aims at contributing to this debate by experimentally analyzing which role public information (e.g. information provided by a rating agency or a central bank) plays in the aggregation process of private information in a financial market. In particular, do subjects demand less private information if they have access to public information? Additionally, does public information play a role in the aggregation of available information into prices? If yes, is it detrimental or beneficial for market efficiency?

2 The Experimental Design and Procedure

In this section we will describe the main characteristics of the experimental design as well as procedure. Each market populated by 15 subjects. At the beginning of each trading period, each subject is endowed with $M = 1000$ units of experimental currency (EU)[9] and $m = 10$ units of an asset that pays a dividend D at the end of the trading period. Apart from the dividend paid out at the end of each trading period, assets are worthless. The value of the dividend depends on two equally likely states of the world: H and L. If the state of the world is H the dividend D is equal to 10, whereas in L the dividend D is equal to 0. At the beginning of each trading period the true state of the world is randomly determined by the experimenter, but not revealed to the subjects until the end, when the period payoff is determined.

At any moment within a given trading period, subjects can buy a private signal paying a cost $c = 4$ per signal. Additionally, only in those treatments with public information, subjects have access to a public signal, that has no cost to them and it is common to all subjects in the market. Such signal is made public before the trading period starts. Both (private and public) signals are partially but not totally informative as to the true state of the world, and are presented to the subjects taking the value 1 or 0 depending on the true dividend value. The subjects are explained

[9] Earnings, as well as asset value and dividend, during the experiments were designated in experimental units (EU) and converted into € at the end of the session.

that the probability of getting a public signal 1 (0) is P if the state of the world is H (L) and the probability of getting a public signal of 1 (0) is $1-P$ if the state of the world is L (H). This means that, if a subject observes a public signal equal to 1 (0), he/she can infer that the asset dividend at the end of the trading period will be 10 (0) with probability P and 0 (10) with probability $1-P$. Following the same reasoning regarding the private signal, the probability of getting a private signal 1 (0) is p if the true state of the world is H (L) and the probability of getting a private signal 1 (0) is $1-p$ if the state of the world is L (H). In this way, if a subject purchases a signal that results to be 1 (0), he can infer that the dividend at the end of the trading period is expected to be 10 (0) with probability p and 0 (10) with probability $1-p$. Both, the value of p and P is known by the subjects.

In most respects this experimental design is similar to Hey (2004), though it differs in the crucial point that in some treatments subjects receive public information. This is an important element of our setting, since it allows us to study whether the presence of public information may act as a sort of disciplining mechanism in the market, promoting the aggregation of noisy information. Additionally we can analyze in which way the demand for private information is affected by the release of public information into the market.

The different treatments implemented as well as the parameters used and the number of sessions conducted are displayed in table 1:

Treatment	p	P	♯ of sessions
1	0.6	-	2
2	0.8	-	1
3	0.6	0.8	2
4	0.8	0.8	1

Common to all treatments:
$M = 1000$, $m = 10$, $c = 4$,
♯ of subjects=15,
♯ of markets per session=10

Table 1: The experimental design and parameters.

In our experiment we assume that the institution behind the release of the public signal has no strategic role in the market. The presence of an objective function, e.g.

maximization of profits (in the case of rating agencies) or control of macroeconomic variables (central banks), can in principle distort the process of releasing the public information. In our experimental setting, on the contrary, we aim at studying whether the mere presence of a public signal can impact the market. Therefore, we do not provide the institution releasing the public signal with any payoff or target function.

Regarding the quality of the public signal, from table 1 we see that the public signal (when available) is at least as good as a single private signal. We assume that the public information (signal) released into the market results from aggregating different (independent) pieces of information. However, each individual trader can buy several private signals in a way that his/her aggregate private information might be more accurate than the single public signal, since all private signals are independent realizations of a given distribution.

The experiment was programmed using the Z-Tree software (Fischbacher (2007)). When the subjects arrived to the laboratory the instructions were distributed and explained aloud using a Power Point presentation and questions where answered. This was followed by 3 practice auction periods for subjects to get familiar with the software and the trading mechanism. The briefing period lasted some 40 minutes. An example of the instructions distributed to the subjects and screen-shots of the asset and information markets are included in Appendix **??**.

Each subject could only participate in one session. Each session consisted of 10 independent trading periods (markets) lasting 3 minutes each. At the beginning of each trading period the dividend was randomly determined by the experimenter and paid out at the end of the period.[10] During each trading period subjects were free both to introduce their bids and asks for assets or directly accept any other trader's outstanding bid or ask. Every bid, ask, or transaction concerned only one asset, but every subject could handle so much as desired as long as he had enough cash or assets (no short sale was allowed). Parallel to the asset market, we implemented an information market where subjects could purchase at a given price (perfectly elastic supply) as many private signals as he/she wanted during a given trading period, as

[10]The true dividend value was unknown to the subjects until the end of the trading period.

long as he had enough cash.

After each trading period, dividends were paid out and the subject profit was computed as the difference between their initial money endowment ($M = 1000$) and the money held at the end of the trading period, thus the net profit is computed as: (dividend received per asset hold) + (price received per asset sold) - (price paid per asset bought) - (price paid per private signal purchased). The subjects' final payoff was computed as the accumulated profit in the 10 trading periods, and paid to them in cash at the end of the session.[11] The average payoff was about 20 € and each session lasted around 90 minutes.[12]

3 Efficient Market Benchmark

Using the Bayesian inference, we can compute the probability that the true state of the world corresponds to the case of the dividend equal to 10 ECU conditioned on the series of signals purchased by all subjects up to an instant of time T, which we denote as $I_T = \{i_1, i_2, ...i_t, ..., i_T\}$.[13]; we refer to I_T as the market information set. The variable i_t takes the value -1, when the signal suggests that the dividend is worth 0 ECU, or 1, if it suggests that the dividend is worth 10 ECU. In the following, we omit the currency unit where not necessary.

3.1 Bayesian Inference with private information

If traders have access only to private information, we denote as $Pr(D = 10|I_T)$ is the probability of observing the dividend equal to 10 conditioned on the market information set available at time T:

$$Pr(D = 10|I_T) = \frac{Pr(I_T|D = 10) \cdot Pr(D = 10)}{Pr(I_T)} \,. \tag{1}$$

$D = 10$ refers to the case of the dividend equal to 10.

[11] One experimental currency unit is equivalent to 2 cents of euro.

[12] Note that subjects can make losses. To avoid some of the problems associated with subjects making real losses in experiments, we endowed all agents with a participation fee of 5 €, which could be used to offset losses. No subject earned a negative final payoff in any session.

[13] Note that here we do not specify the identity of the subject who purchases the signals but just their sequential order

$Pr(I_T)$ is the marginal probability computed as:

$$Pr(I_T) = Pr(I_T|D = 10) \cdot Pr(D = 10) + Pr(I_T|D = 0) \cdot Pr(D = 0). \qquad (2)$$

where $Pr(D = 10)$ is the prior probability of the event $D = 10$ without information or, equivalently, conditioned on I_0. *Mutatis mutandis*, it is possible to compute the probability that the dividend is worth 0 ECU, or we can equivalently use the following relation:

$$Pr(D = 0|I_T) = 1 - Pr(D = 10|I_T) \ , \qquad (3)$$

since we have just two possible states of the world.

Let us now assign the values to the different terms of eq. (1) as a function of:

- p is the probability that a single private signal is correct;
- $q = 1 - p$ is the probability that a single private signal is incorrect;
- N_T is the number of signals in the information set available up to time T;
- n_T is the number of 1s (or correct signals) and $N_T - n_T$ is the number of -1s (or incorrect signals) in the information set.[14]

In the following, when not necessary, we will omit the time variable T from the variables n_T and N_T. The first term of eq. (1) is given by:

$$Pr(I_T|D = 10) = p^n \cdot q^{N-n} \ , \qquad (4)$$

which is the probability of observing a given sequence of signals I_T. Given that the two states of the world are, by construction, equiprobable, the marginal probability in eq. (2) takes then form:

$$Pr(I_T) = \frac{1}{2} p^n \cdot q^{N-n} + \frac{1}{2} p^{N-n} \cdot q^n \ . \qquad (5)$$

[14]Since we compute the probability $Pr(D = 10|I_T)$, the signals -1s and 1s refer to the true state of the world $D = 10$. In other words, the case $i_t = 1$ suggests that the dividend is 10, on the contrary, the case $i_t = -1$ suggests an asset worths zero.

Combining eqs. (1), (4), (**??**) and (5), we obtain:

$$Pr(D=10|I_T) = \frac{p^n \cdot q^{N-n}}{p^n \cdot q^{N-n} + p^{N-n} \cdot q^n} = \frac{1}{1+\left(\frac{q}{p}\right)^{2n-N}} \ . \tag{6}$$

The term $2n - N$ is the difference of 1s and -1s signals in I_T. If we define:

$$\eta_T = \sum_{t=1}^{T} i_t = 2n_T - N_T \ , \tag{7}$$

as the aggregate net private signal available at time T, eq. (6) takes the form:

$$Pr(D=10|I_T) = \left[1+\left(\frac{q}{p}\right)^{\eta_T}\right]^{-1} \ , \tag{8}$$

and

$$Pr(D=0|I_T) = 1 - Pr(D=10|I_T) = \left[1+\left(\frac{p}{q}\right)^{\eta_T}\right]^{-1} \ . \tag{9}$$

According to eq. (8), we can identify several interesting cases:

- If $p = 1$ and therefore $q = 0$, $Pr(D = 10|I_T) = 1$, which is independent of N_T, when not zero. It is the case of fully informative signals.
- If $q = p = 0.5$ then $Pr(D = 10|I_T) = 0.5$. Purchasing signals does not provide any new information compared to the starting condition of equiprobability of the two states of the world.
- If $\eta_T = 0$, i.e. an equal number of 1s and -1s, $Pr(D = 10|I_T) = 0.5$. This is obviously the case at the beginning of the trading period when there are no signals in the market, and also might arise by chance during the experiment.

3.2 Bayesian inference with private and public information

The previous Bayesian inference equations are based on the condition of constant quality of signals, i.e. p is invariant across the signals. We can easily generalize the previous formulas to a setting with signals of heterogenous quality. In our experimental setting, in fact, we have several treatments with the contemporaneous presence of private signals of quality p and a single public signal of quality $P \geq p$.[15] In order to account for the impact of the public signal in the Bayesian inference, let us define as P the probability that the public signal is correct and $Q = 1 - P$, the probability that the public signal is incorrect. The variable S will take then the value 1 if the public signal suggests a dividend equal to 10 EU or -1 if it suggests a worthless dividend. Eq. (4) is then modified as follows:

$$Pr(I_T, S = 1 | D = 10) = P \cdot \left[p^n \cdot q^{N-n} \right] \ , \tag{10}$$

and

$$Pr(I_T, S = -1 | D = 10) = Q \cdot \left[p^n \cdot q^{N-n} \right] \ . \tag{11}$$

Using eqs. (10) and (11), we can easily modify eq. (8) in order to take into account the public signal:

$$Pr(D = 10 | I_T, S) = \left[1 + \left(\frac{Q}{P} \right)^S \left(\frac{q}{p} \right)^{\eta_T} \right]^{-1} \ . \tag{12}$$

In order to illustrate eq. (12), let us focus on a simple example. Considering the values of $P = 0.8$ and $Q = 0.2$ of our experimental setting, let us assume that there are no private signals in the market up to time T and that the only available information is the public signal. Therefore, $\eta_T = \eta_0 = 0$ and $Pr(D = 10 | I_T, S = 1) = 0.8$ or $Pr(D = 10 | I_T, S = -1) = 0.2$ depending on the value of the public signal being 1 or -1, respectively. Therefore, the subjects at the beginning of the trading period are not ignorant about the future state of the world, i.e. $Pr(D = 10) = Pr(D = 0) = 0.5$, but they are biased in favor of one of them, induced by the presence of the public signal.

3.3 Efficient market price

A market is efficient if all available and relevant information is incorporated into the price of the asset at each instant of time. In our simple experimental setting, this means that the the information set used by traders includes all information pur-

[15] The quality of a signal is defined as the probability of being correct.

chased by the traders, I_T. The equilibrium price, under risk neutrality assumption, is given by:

$$B_t = 10 \cdot Pr(D = 10|I_T) + 0 \cdot Pr(D = 0|I_T) = 10 \left[1 + \left(\frac{q}{p}\right)^{\eta_T}\right]^{-1}. \qquad (13)$$

In the presence of a public signal S eq. (13) can be re-written as:

$$B_t = 10 \cdot Pr(D = 10|I_T, S) + 0 \cdot Pr(D = 0|I_T, S) = 10 \left[1 + \left(\frac{Q}{P}\right)^{S} \left(\frac{q}{p}\right)^{\eta_T}\right]^{-1}. \qquad (14)$$

The net signal in the market can be thought as $\eta_T = \sum_{j=1}^{J} \eta_{j,T}$, i.e. the sum of the net signals over all subjects. Eqs. (13) and (14) represent a situation where, when a subject buys a signal, this information is incorporated into the price correctly and instantaneously as if such information would be available to all subjects in the market.

4 Results

Hey (2004) show, using backward induction, that in absence of public information the absence of activity in the market is the only possible equilibrium. Note that absence of activity refers to both, information and asset market. This means that any trader would not post bids, asks or buy any private signal. Ferri and Morone (2008) generalize this result to the case of simultaneous presence of private and public information.

Figures from 7 through 12, included in the Appendix, display the trading activity in all markets for all treatments. Each panel of these figures refers to one particular market. A simple inspection of the market activity shows that the "do nothing" equilibrium is not a meaningful description of the trading behavior of the subjects in any of the implemented treatments, since subjects purchase private information as well as post bids and asks in the market. Actually, there is not a single trader who did not do at least an action.

In the following we will present our results focusing on two main aspects: the information demand and how efficiently information is incorporated into prices. In particular, we are interested in describing how the access to public information impacts the information market as well as the asset market price efficiency.

4.1 Analysis of Information Market

A crucial aspect of our experimental design is that the quantity of information available in the market (the market informativeness) is endogenous, since subjects can buy as many signals as they want at a fixed price.

We analyze whether or under which conditions the information available to the traders in the market is sufficient to discover the true state of the world. We will focus attention on the role that the private information quality and the availability of public information have on the information acquisition process.

4.1.1 Information demand

As a first step, we analyze the demand for private information as a function of its quality. Figure 1 shows the distribution of the private signals purchased per capita across markets per treatment showing that an increase in the quality of the private signal increases the traders' demand for private information and, as a consequence, traders possess not only more accurate information but also more information. Indeed, the number of purchased signals is *significantly* higher in Treatment 2 ($p = 0.8$) as compared to Treatment 1 ($p = 0.6$).[16] This picture does not change with the introduction of a public signal, since the same pattern is confirmed, as shown in Figure 1, when comparing Treatments 3 ($P = 0.8$, $p = 0.6$) and 4 ($P = 0.8$, $p = 0.8$).[17] We conclude then that the demand for private signals increases with their quality, independently of the presence of public information. This finding confirms the results of Hey (2004) and generalizes them in a setting with public information.

[16] A Mann-Whitney test rejects the null hypothesis of equal mean at a 1% significance level.
[17] A Mann-Whitney test rejects the null hypothesis at a 1% significance level.

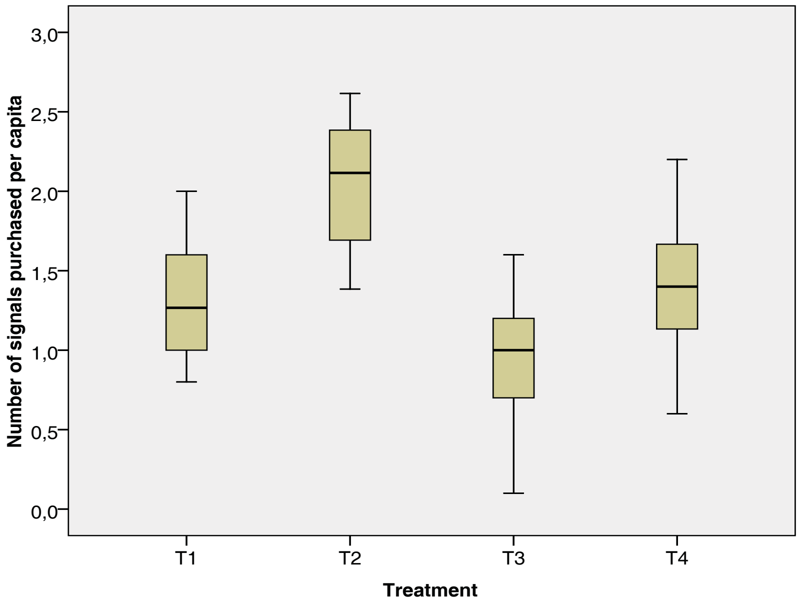


Figure 1: Number of private signals purchased per capita.

Our experimental setting allows to quantify the impact of the introduction of a public signal on traders' demand for private information. Fixing the quality of the private signal, we observe that the introduction of a public signal *significantly* reduces the demand for private information[18], see Figure 1. This phenomenon is observed for both, low and high quality private information. Therefore, we demonstrate that the release of public information into a financial market provokes a *crowding-out* effect on the demand for private information, i.e. a substitution of part of market information provided by several private signals with a single public signal. To our knowledge this is the first time that such *crowding-out* effect is observed.

When evaluating the effect of introducing public information into a financial market it is not only important to evaluate the impact on the aggregate demand for private information, but it is extremely important to determine the impact on the proportion of uninformed traders participating in the market. Bloomfield et al. (2009) use economic experiments to show that uninformed traders provide liquidity to the market, increasing market volume, as well as reduce the market informational

[18]A Mann-Whitney test rejects the null hypothesis of equal mean at a 1% significance level.

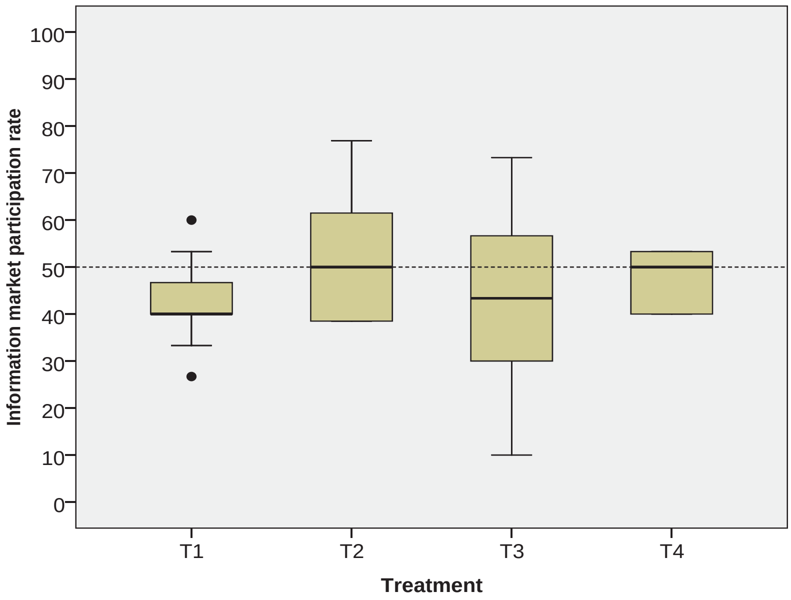


Figure 2: Information market participation rate per treatment.

efficiency.[19] In order to account for such impact, in our asset markets, we introduce the information market participation rate, defined as the number of traders purchasing at least one signal over the total number of traders in the asset market. The crowding-out effect is the sum of two effects: (i) a reduction on the information market participation rate, and (ii)a reduction in the per capita demand of the information market participants. In order two disentangle the two possible adjustments, Figure 2 presents the distribution of the information market participation rate per treatment. It clearly illustrates that the release of public information essentially does not affect the information market participation rate, but significantly reduces the per capita information demand of information market participants.

We can summarize our findings as follows:

Result 1: *The release of public information creates a crowding-out effect on the aggregate information market demand: whereas it leaves unaffected information market participation rate, it significantly reduces the individual demand for private*

[19]In their experimental setting the information is exogenously distributed among the market participants.

information.

4.1.2 The Market Informativeness

It remains an open question whether the presence of a public signal compensates for the reduction in the demand for private information due to the crowding-out effect and how public information affects the aggregation of information into prices. In other words, is the introduction of a public information neutral, beneficial or detrimental for the overall market informativeness?

In order to address this question let us quantify how close the traders were to discover the true value of the dividend, i.e the market informativeness. We rely then on the Bayesian price (B_t) computed in eqs. (13) or (14) that assumes the information set I_T being efficiently used. The efficient market hypothesis is based on the idea that the traders make an optimal use of all the available information.[20] Let us introduce the following measure of market informativeness:

$$E_{BD} = \frac{1}{60} \sum_{t=120}^{180} \frac{|B_t - D|}{10} , \tag{15}$$

where B_t is the Bayesian price given in eq. (14), D is the dividend and t denotes the seconds in a trading period.[21]

Using eq. (15) we can evaluate whether the introduction of a public signal is beneficial or detrimental for the overall market informativeness.

Figure 3 shows the distribution of E_{BD} across the different markets per treatment. A Kolmogorov-Smirnov test cannot reject the null hypothesis that the distribution of E_{BD} is not affected by the release of a public signal, i.e. comparing T1 (T2) to T3 (T4). This means that the introduction of a public signal does not alter the

[20]This might probably be a strong (behavioral) assumption. However, such an assumption allows us not to consider any *ad hoc* behavioral rules in describing the trading activity of the subjects. Moreover, the efficient market benchmark can be thought as the upper bound of the efficiency in the utilization of the market information.

[21]The choice of averaging over the last trading minute is a compromise between having good statistics for E_{BD} and analyzing the last part of the trading activity, where the number of purchased private signals is very low (between zero and few signals depending on the market) and therefore the Bayesian price is almost constant over time. The results are robust with respect to the considered time interval for the average if one chooses around one minute or less. We divided by 10 in order to normalize all prices to be between 0 and 1 from now on.

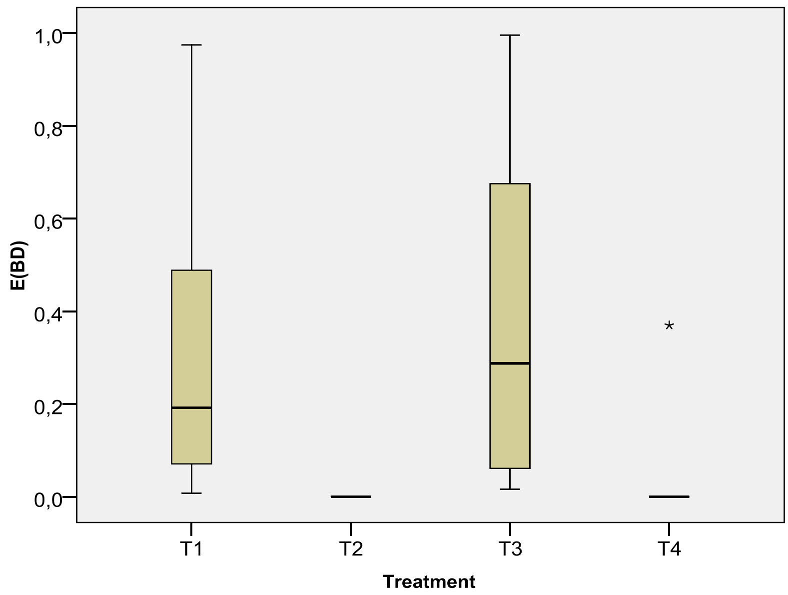


Figure 3: Market informativeness per treatment.

market potential to discover the true dividend value. We can conclude then that the presence of public signal entirely compensates for the crowding-out effect, i.e. the additional information provided by the public signal is sufficient to counterbalance the reduction in the number of private signals present in the market, under the assumption of an efficient aggregation of the information into market prices.

Result 2: *The information conveyed by the public signal compensates for the crowding-out effect on the private information: the release of public information does not affect market informativeness.*

With results 1 and 2 we conclude that public and private information result to be *perfect substitutes*, since the reduction in the demand for private signals is fully compensated by the public information, keeping the market informativeness constant. The implication of our findings could be relevant for policy makers. The release of public information might not increase the overall market informativeness, since the intervention of the public institutions reduces traders' effort to gather private information. Therefore, when introducing a new public information source in a market one should consider its complex interaction with the information already present.

4.2 Analysis of Price Efficiency

Result 2 shows that the introduction of a public signal of good quality compensates for the crowding-out effect on the private signals leaving invariant market informativeness. Our previous analysis, however, is based on the strong assumption of perfect aggregation of information into market prices and, therefore, we use the Bayesian market price as benchmark. However, in this section, we analyze the convergence of the *market price* to the Bayesian benchmark. In other words, we would like to know *what the traders have done* as a function on what *they could have done.* As a measure of *price efficiency* we use:

$$E_{BPR} = \frac{1}{60} \sum_{t=120}^{180} \frac{|B_t - PR_t|}{10} , \qquad (16)$$

where B_t is the Bayesian price given in eq. (14), PR_t is the market price and t denotes the seconds in a trading period (See footnote 21). Using E_{BPR} we can easily quantify the deviation of the observed market prices from what the traders could have achieved using efficiently all available information. In order to discriminate whether the market reached price efficiency we set a 10% threshold, i.e. $E_{BPR} < 0.1$.[22]

4.2.1 Quality of the private signal

Figure 4 shows the distribution of E_{BPR} across the different treatments. If we compare T1 to T2, there is a striking difference in price efficiency, being such difference statistically *significant.* The same pattern is observed when comparing T3 and T4. Therefore we can conclude that the treatments where the private signal has a higher quality turn out to be more efficient in incorporating information into prices. Price efficiency increases with the quality (and quantity, taking into account the results

[22]We could have chosen a more conservative level. However, given the noisy nature of the experimental data, such a level seems to be appropriate, see for example Levitt and List (2007). Qualitatively the results remain unchanged with smaller confidence levels.

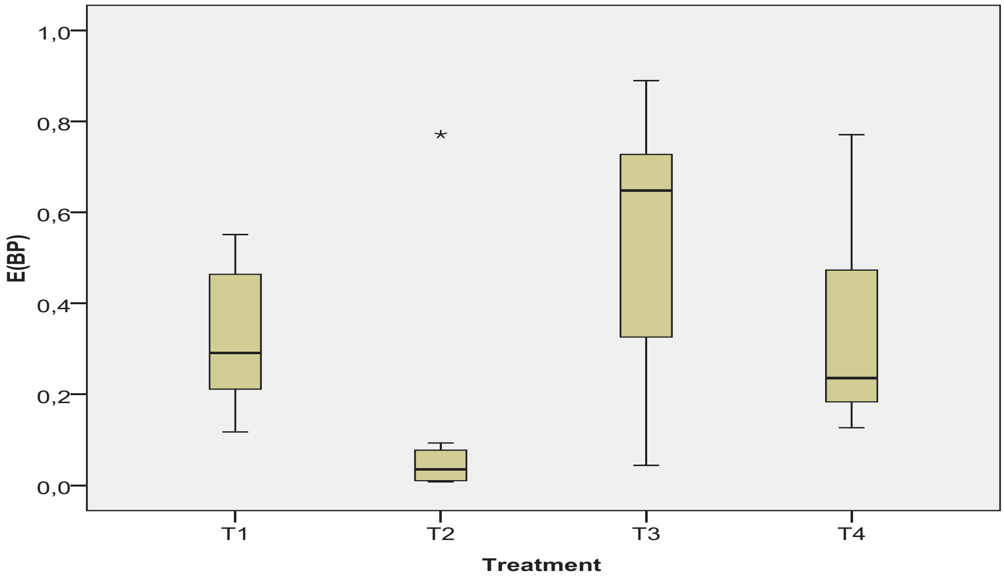


Figure 4: Time average of absolute difference between Bayesian and market price.

shown in Figure 1) of the private information available to the traders in the market, that is, an increase in market informativeness leads to an increase in price efficiency which is in line with previous experimental results of Hey (2004). Therefore we can conclude that the higher the quality of private information the higher the market price efficiency.

4.2.2 The availability of a public signal

Recall that Result 2 shows that releasing a public signal does not affect market informativeness. From Figure 4 when comparing those treatments with and without public information, i.e. T1 (T2) to T3 (T4), we observe that the introduction of a public signal *significantly*[23] reduces price efficiency and increases the dispersion of the price efficiency measure. One might then assume that the presence of public information worsens price efficiency.

Result 3: *The introduction of a public signal keeps constant market informativeness but worsens price efficiency.*

If market informativeness remains constant after releasing a public signal, why

[23] A Mann-Whitney test rejects the null hypothesis at a 1% significance level.

price efficiency worsens? Does the release of a public signal play a role in the aggregation of the available information into prices?

4.2.3 Overweighting of public information

Morris (2002) characterize public information as a *double-edged* instrument, since it not only conveys fundamental information to the traders but also constitutes a focal point for the coordination of their expectations. They suggest that traders might then overreact to the presence of a noisy public signal, which is then amplified when incorporated into market prices. Since our experimental setting possesses all the main building blocks of the model of Morris and Shin, namely, beauty contest type interaction[24] and the contemporaneous presence of noisy public and private information, we expect that also in our setting traders over-rely on the public signal. This would explain why the release of public information worsens price efficiency, even when market informativeness remains unaffected by the release of public information (See Result 2).

We define the public information benchmark as the expected price conditional on the value of the public signal:[25]

$$B_S = 10 \cdot Pr(D = 10|I_0, S) + 0 \cdot Pr(D = 0|I_0, S) = 10 \left[1 + \left(\frac{Q}{P}\right)^S\right]^{-1} . \quad (17)$$

Analogously to eq. (4.2) we introduce a measure of how close market prices are from the public signal as:

$$E_{SPR} = \frac{1}{60} \sum_{t=120}^{180} \frac{|B_S - PR_t|}{10} . \quad (18)$$

Under the hypothesis that traders overweight the public signal we expect the value for E_{SPR} is systematically lower than the value for E_{BPR}. This means that,

[24]In strict sense we do not introduce any explicit beauty contest in our experiment. However, asset markets have been described by Keynes using the metaphor of a beauty contest.

[25]See eq. (12).

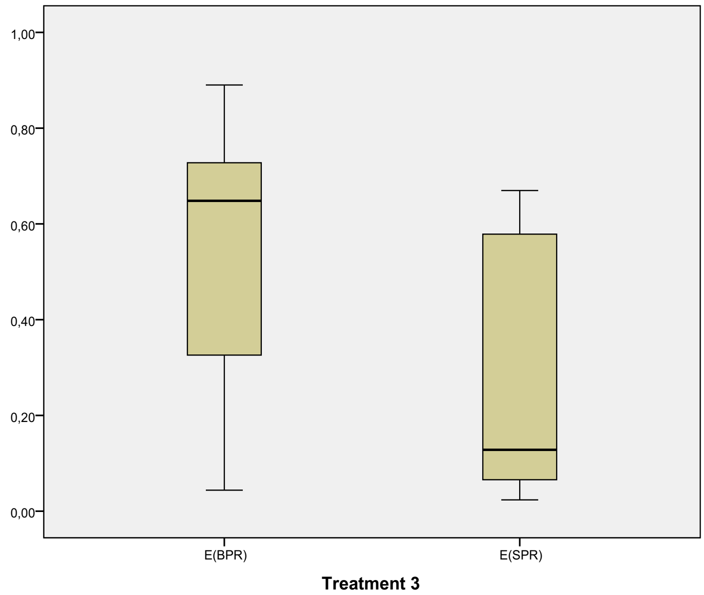
when public information in released, market prices tend to follow the public signal rather than the efficient market benchmark that includes all information present in the market, private and public. Our hypothesis is confirmed by Figure 5.Considering the median of the distribution as a proxy for the market aggregate behavior, note that the maximum, minimum and mean of the distribution of E_{SPR} is lower than the respective values of the distribution of E_{BPR} in T3 and T4.[26]

Result 4: *Traders overweight public information.*

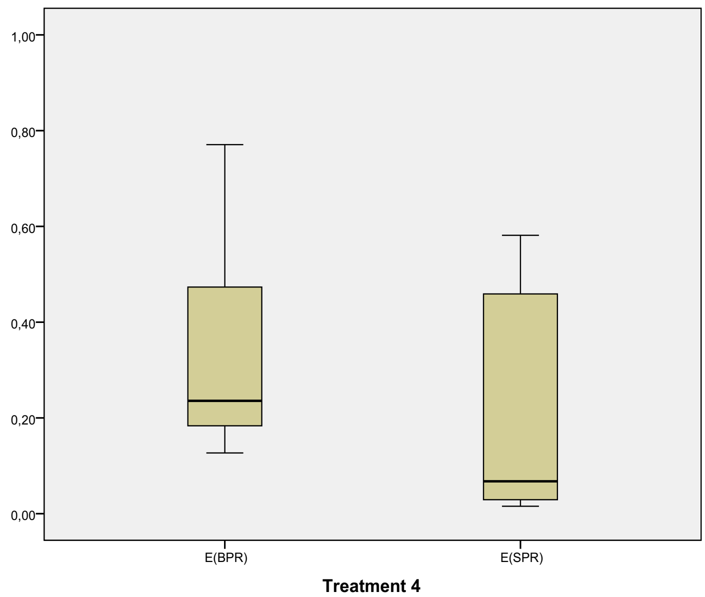
This result confirms the intuition of Morris and Shin in defining public information as a double edged instrument. On the one hand it helps the market in aggregating information and driving market prices towards the correct fundamentals, when correct. On the other hand, the public signal acts as a coordination device for the traders' expectations and, when incorrect, might drive the market towards the wrong state of the world, even when the market informativeness is sufficient to discover the true state of the world as occurred in many markets in T4.

At the aggregate level, the subjects in our experimental markets overweight public information with respect to private information as in the game theoretical framework proposed by Morris and Shin. Since we do not explicitly introduce a beauty contest, in some sense, our experimental setting generalizes the main conclusion of Morris and Shin showing that can be also applied in a market setting. It would be interesting then to investigate which are the minimal conditions for the emergence of such complex interplay between private and public information in financial markets.

[26]If we look at individual markets we observe that for 19 out of 20 (8 out of 10) markets in Treatment 3 (Treatment 4) the price is closer to the public information benchmark than to the efficient market benchmark. In fact, if we run a binomial test assuming that the two benchmarks are equally probable, the probability that 19 out of 20 (8 out of 10) markets follow the public information benchmark is $2 \cdot 10^{-6}$ (0.043).



(a) Price convergence in Treatment 3



(b) Price convergence in Treatment 4

Figure 5: Distribution of E_{BPR} and E_{SPR}.

4.3 Is it profitable for an individual trader to purchase information?

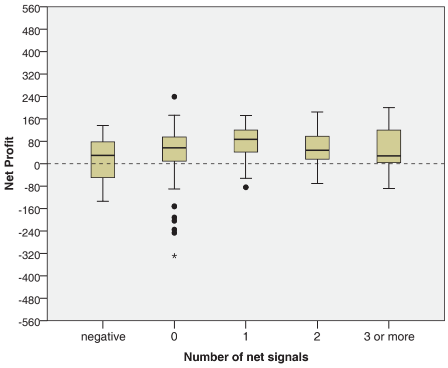
In the experimental literature on asset markets with costly information production[27] strongly supports that the information aggregation process in the market allows

[27]See Sunder (1995) or Noussair and Tucker (2013).

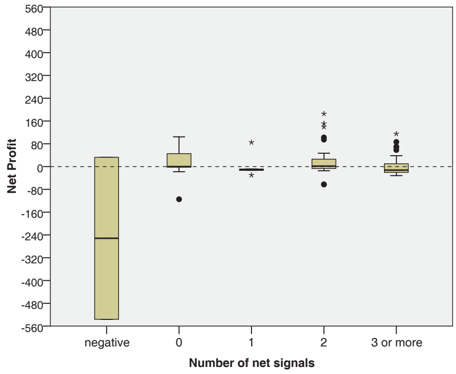
informed traders to recover the cost of information. However, the absence of common knowledge on the distribution of information among market participants might allow informed traders to obtain larger net profits. Our experimental setting allows then to analyze the economic consequences that the presence of public information might have on the profits of informed traders. From figure 1 we can see that the information market is strongly affected by the release of public information. More precisely, from Result 1 we conclude that the release of public information has an effect on the individual demand for private information rather than the information market participation rate. This means that the proportion of traders purchasing information is always around 50% whereas the individual demand for private information is significantly reduced.

Figure 6 report the distribution of traders' net profit depending on their net information. Regressing profit on the number of net signals hold by a subject we observe that it is not significant for any case but for the case where the public information results to be incorrect and private information is of low quality (T3I).

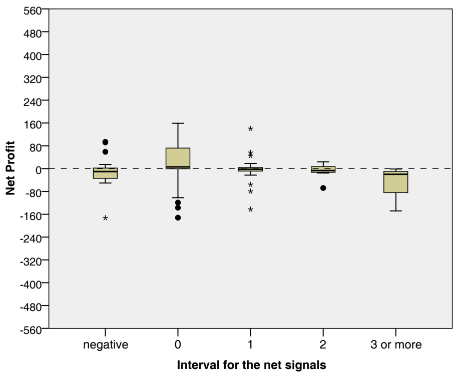
The non significance of the coefficient can be interpreted within the framework of non-arbitrage condition in a costly information environment *à la* Grossman (1980), meaning that informed and uninformed traders earn the same profit independently on their information demand, in line with the results observed in the experimental literature. However, this is not the case when private information has low quality and public information is incorrect. If we compare in Treatment 3 those cases where public information is correct to those where it is incorrect, we observe that in T3C the introduction of a correct public signal does not distort the net profit across subjects depending on their information level, whereas in T3I those subjects with a higher net private signal are able to earn a higher profit compared to those less informed. It seems that the public signal has a distortive effect. In this case the market does not correct the high level of informative asymmetry and this creates an asymmetry in the profit distribution across traders, given the low quality of the private signals.



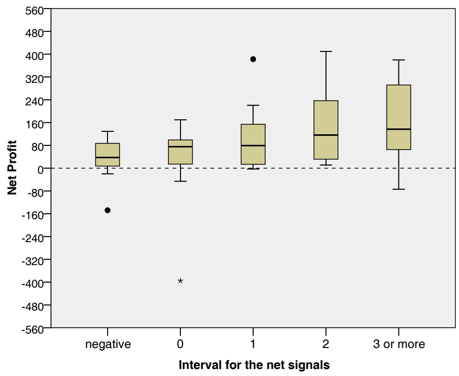
(a) T1: Private signal with $p = 0.6$.



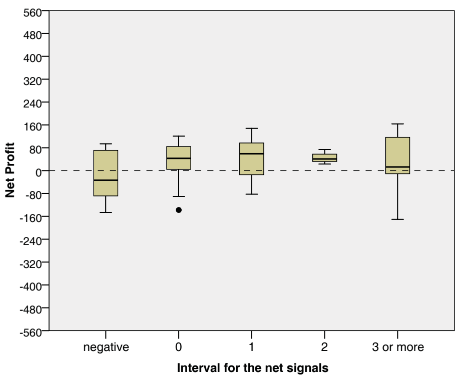
(b) T2: Private signal with $p = 0.8$.



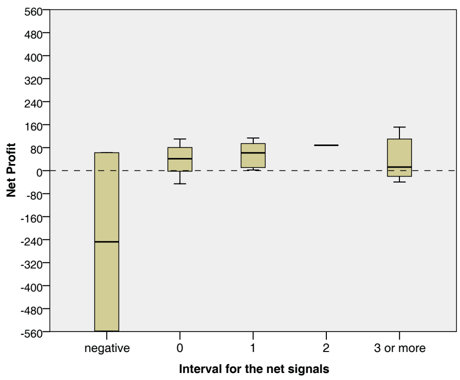
(c) T3C: Private signal with $p = 0.6$ and correct public signal.



(d) T3I: Private signal with $p = 0.6$ and incorrect public signal.



(e) T4C: Private signal with $p = 0.8$ and correct public signal.



(f) T4I: Private signal with $p = 0.8$ and incorrect public signal.

Figure 6: Public and Private Information: Distribution of subjects net profit depending on the net information.

By setting a threshold value on the measure of market informativeness introduced in eq. (15), we can compute the minimum net private signal (η_T in eq. (7)) sufficient to identify the true dividend value for a given confidence level.[28] In Table 2 we give

[28]Recall that the net private signal is defined as the number of correct private signals minus the number of incorrect private signals conditioned on the true dividend. In order to understand the

the minimum values for the net private signal that, if correctly aggregated, allows subjects to discover the true dividend value at 1% (10%) confidence level across the implemented treatments, that is, $E_{BD} \leq 0.01$ ($E_{BD} \leq 0.1$).[29]

	Minimum η_T with:		
	Only private signals	Correct public signal	Incorrect public signal
$p = 0.6$	12(6)	8(3)	15(9)
$p = 0.8$	4(2)	3(1)	5(3)

Table 2: Minimum net private signal η_T in order to identify the true dividend value in the different cases of our experimental setting, at 1% (10%) confidence level.

In T3C often (in 11 out 12 cases where public information is correct) the net information in the market (if aggregated) is enough to discover the true dividend value at a 10% confidence level.[30] In T3I the net information present in the market it is almost never enough (in 1 out 8 cases where public information is incorrect).[31] Furthermore, in T4, independently of the public signal being correct or not, the net information in the market is almost always sufficient for the market to discover the true dividend value at a 10% confidence level.[32] Then we can conclude that in those cases where the public information is incorrect and, on aggregate, there is not enough information to allow traders to discover the true dividend value the performance of informed traders improves, since uninformed traders cannot infer from the market the right state of the world and then correct the wrong signal provided by public information. Note moreover, that in Result 4 we show that traders overweight public information and in the case of an incorrect public signal and a reduction in the demand for private information might lead the market towards

computation, let us give some illustrative examples: the net private signal of market 1 in session 1 of Treatment 1 is +2; the net private signal of market 2 in session 1 of Treatment 1 is +2; the net private signal of market 3 in session 1 of Treatment 1 is −2.

[29]We are aware that the chosen confidence levels are quite arbitrary. As a partial justification of our choice, the 1% level is based on the granularity of the prices, i.e. the traders cannot post bids and asks under 1/10ECU. The level of 10% is somehow a less conservative choice and is below the precision of the public signal. Anyhow, we have run a sensitivity analysis to test the robustness of our results with respect to the choice of the confidence levels, showing that the conclusion of our analysis does not change.

[30]At a 1% confidence level only in 1 out of 12 cases.

[31]In no market at a 1% confidence level.

[32]In one market out of 7 where the public information was correct the net information was equal to 0. At a 1% confidence level in 1 out of 3 markets where the public information was incorrect the net information was lower than 5.

a price disconnected from fundamentals, giving room for a higher net profit for well informed traders. However, we do not observe such result when the information present in the market is enough to correct the error of the public information in Treatment 4.

5 Conclusion

The efficient market hypothesis states that all relevant and available information is correctly incorporated into prices. However, the efficient market hypothesis considers only the incorporation of information into prices, leaving out the way this information is generated and/or its origin. Taking stock of this idea, the main objective of the paper is the analysis of the aggregation of information in financial markets as a function of the access of the traders to different sources of information, namely costless public and costly private information.

The objective of regulatory institutions when releasing public information is essentially to discipline the market, reducing the potential negative effects of asymmetric information. Recently, Morris (2002) have pointed out the double-edged role of public information in both, conveying information on the fundamentals of a financial asset and coordinating traders' expectations in the market. Therefore, in the presence of a noisy public signal, the noisiness of public information might be enhanced in the market due to the overreliance of the traders on the disclosure of a public signal. The presence of a public signal, therefore, might have a distortive effect on the market price formation.

Following this line of reasoning and inspired by the debate on the role of rating agencies in the recent financial crisis, we study how the release of a noisy public signal affects the efficiency of prices in aggregating information in a laboratory financial market. In our experimental setting we implement an asset market where traders can exchange a risky asset and an information market that provides noisy and costly private signals on the future value of the asset. What we observe is that the introduction of a public signal in the market reduces the traders' information demand because of a crowding out of the public information on the private information. It is the first time that this crowding out effect is observed and measured, thanks also to the peculiarities of the experimental method in precisely control for the information available to each trader at each moment during their trading activity.

Despite the reduction in the private information (the crowding out effect), we observe an essentially unchanged level of informativeness in the market. It means that the reduction of private information is compensated by the presence of a public signal. In other words, public and private information become *perfect* substitutes. Surprisingly, even if market informativeness is not affected by the introduction of a public signal, there is a significant reduction in the efficiency of the market prices in incorporating the available information. We interpret our experimental results following the line of reasoning of Morris (2002), namely the public information as a double-edge instrument, coordinating trading activity and conveying fundamental information. We observe, in fact, that the public signal becomes a focal point, i.e. it seems that the prices follow the prediction based on just the public signal, disregarding partially the private information. As a conclusion of our experiment, we observe that if the private information is of poor quality, the public information dominates the market in the sense of driving the price. If this market regime might be beneficial in the case of correct release of public information, the case of an incorrect public signal might lead the market towards a price disconnected from fundamentals.

Some policy implications can be derived out of our simple experiment. Policy makers should be aware that a release of public information might have a distortive effect on the aggregation of information into prices. Far of be against the presence of public institutions in regulating financial markets, we stress the complex interaction between private and public information. We provide with a simple experimental setting in order to better understand such interplay for a more effective regulatory policy.

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A Appendix B: Information Purchased per Treatment

Market Session 1	N	n	$N-n$	D
1	15	9	7	10
2	16	7	9	0
3	19	11	8	0
4	27	10	17	0
5	22	17	5	10
6	16	7	9	10
7	14	4	10	0
8	24	14	10	10
9	25	6	19	0
10	19	7	12	0
Market Session 2	N	n	$N-n$	D
1	12	8	4	10
2	14	5	9	10
3	13	7	6	0
4	14	5	9	0
5	17	4	13	10
6	22	13	9	10
7	24	16	8	10
8	24	18	6	10
9	27	13	14	0
10	30	12	18	0

Table 3: Information purchased in Treatment 1. Note that N denotes the total number of signals purchased and n ($N-n$) the number of correct (incorrect) signals.

Market Session 1	N	n	$N-n$	D
1	34	8	26	0
2	33	10	23	0
3	31	8	23	0
4	29	6	23	0
5	29	21	8	10
6	22	5	17	0
7	26	19	7	10
8	23	5	18	0
9	21	3	18	0
10	18	3	15	0

Table 4: Information purchased in Treatment 2.

Market Session 1	N	n	$N-n$	D	Public signal
1	15	11	4	0	10
2	14	7	7	0	0
3	15	8	7	0	0
4	14	6	8	0	0
5	13	9	4	0	0
6	12	10	2	10	0
7	18	10	8	10	0
8	14	8	6	0	0
9	23	15	8	10	0
10	23	13	10	10	0
Market Session 2	N	n	$N-n$	D	Public signal
1	2	1	1	10	0
2	3	0	3	0	0
3	9	5	4	10	10
4	4	0	4	0	0
5	8	3	5	0	10
6	5	0	5	10	10
7	6	3	3	0	0
8	1	0	1	0	0
9	3	1	2	10	0
10	4	1	3	0	0

Table 5: Information purchased in Treatment 3.

Market	N	n	$N-n$	D	Public signal
1	9	9	0	10	10
2	25	4	21	0	0
3	20	17	3	10	0
4	23	6	17	0	0
5	16	3	13	0	10
6	19	14	5	10	10
7	24	2	22	0	0
8	32	3	29	0	0
9	18	8	10	0	10
10	12	10	2	10	10

Table 6: Information purchased in Treatment 4.

B Appendix C: Market Trading Activity per Treatment

On each panel the vertical axis shows the price at which the trade took place and the horizontal axis shows the time (in seconds) at which the trade took place. The solid line is the trading price, the bold solid line (either 10 or 0) above each market period shows the rue dividend (revealed to the participants just at the end of the trading period). The dotted line indicates the Bayesian price, i.e the price computed using eq. (13) or eq. (14), without or with a public signal, respectively. The squares indicate the public signal (either on 10 or 0), available to the subjects at the beginning of the trading period.

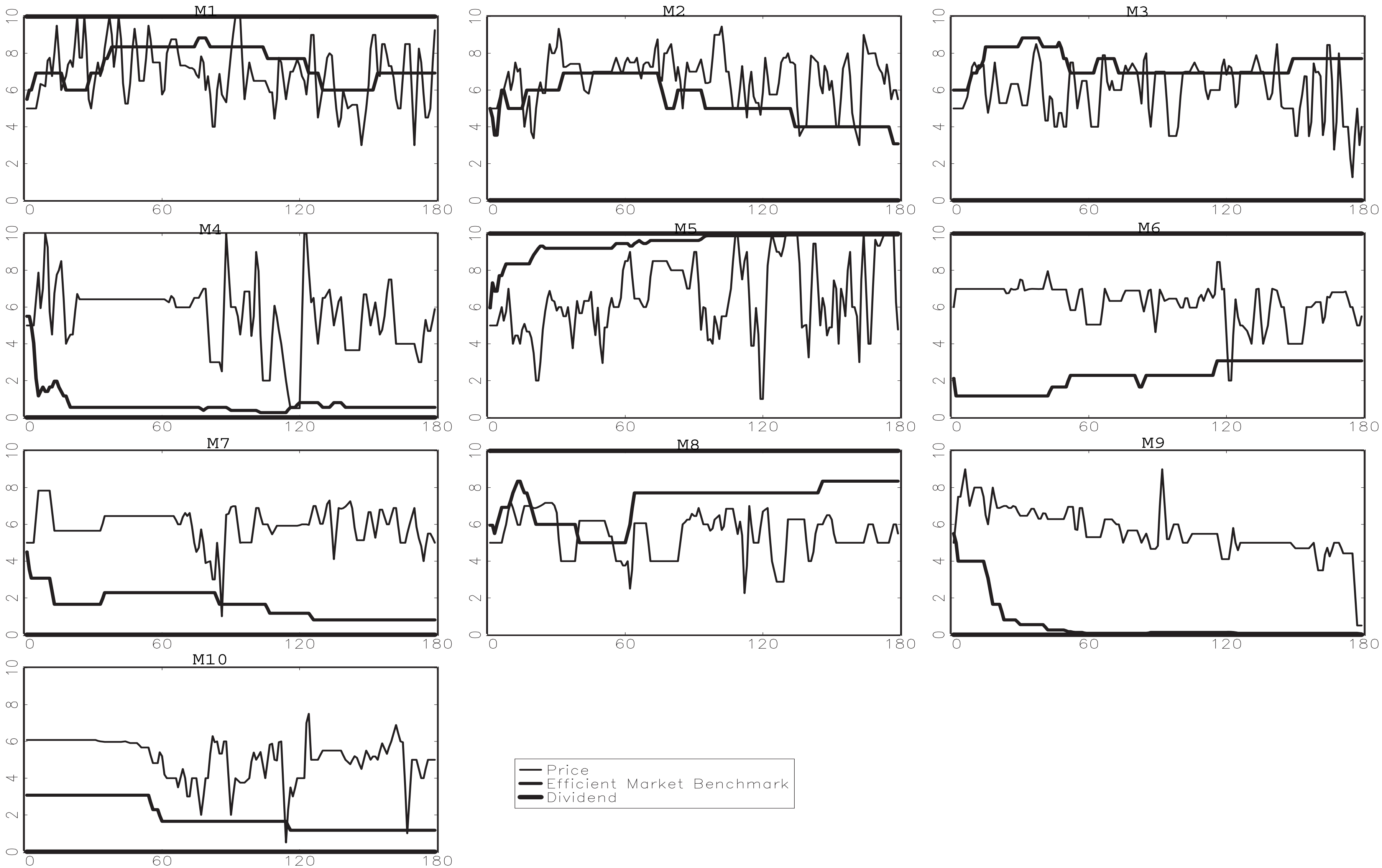

Figure 7: Markets Treatment 1 (Session 1: Private signal with $p = 0.6$.

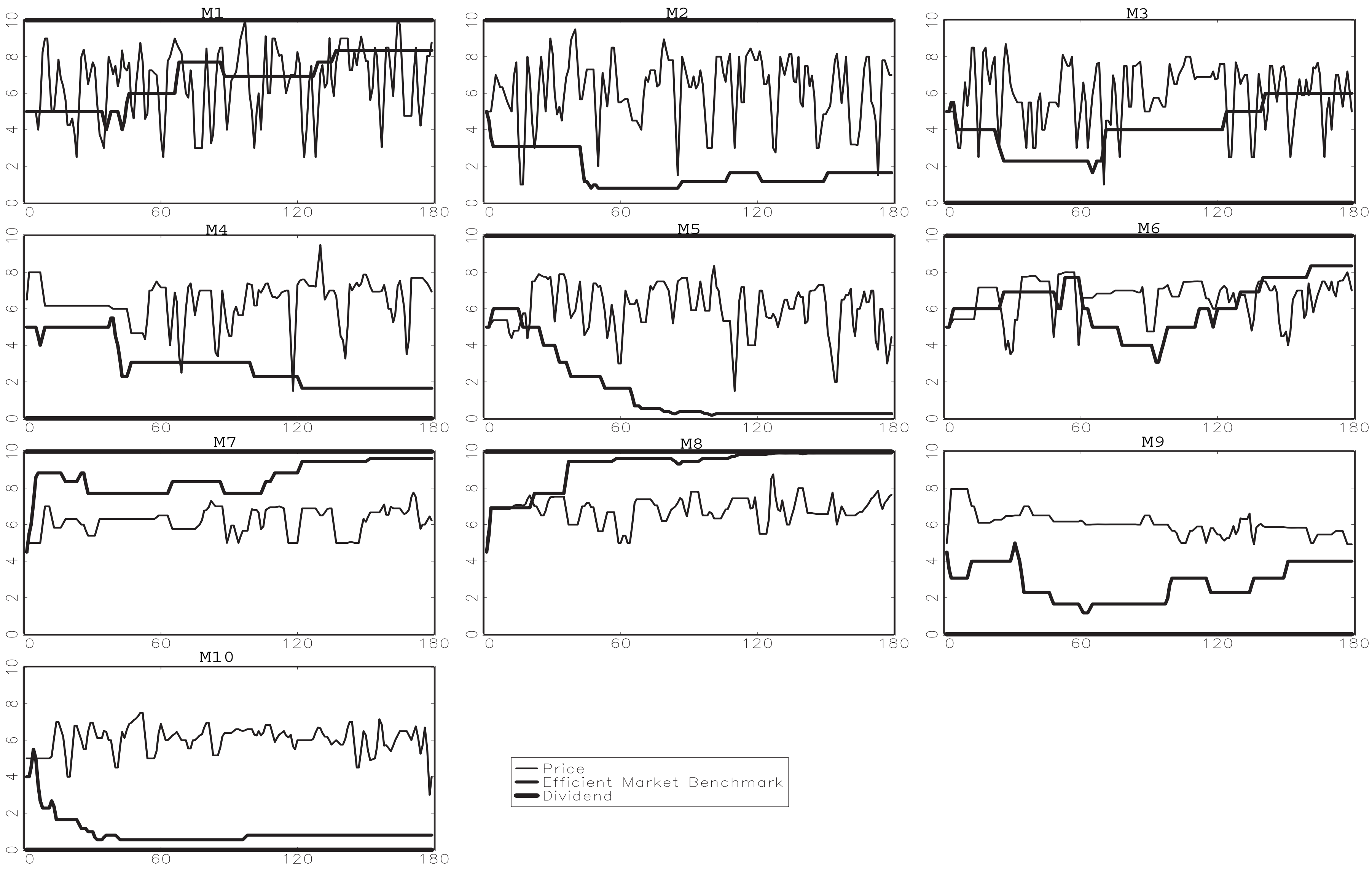

Figure 8: Markets Treatment 1 (Session 2): Private signal with $p = 0.6$.

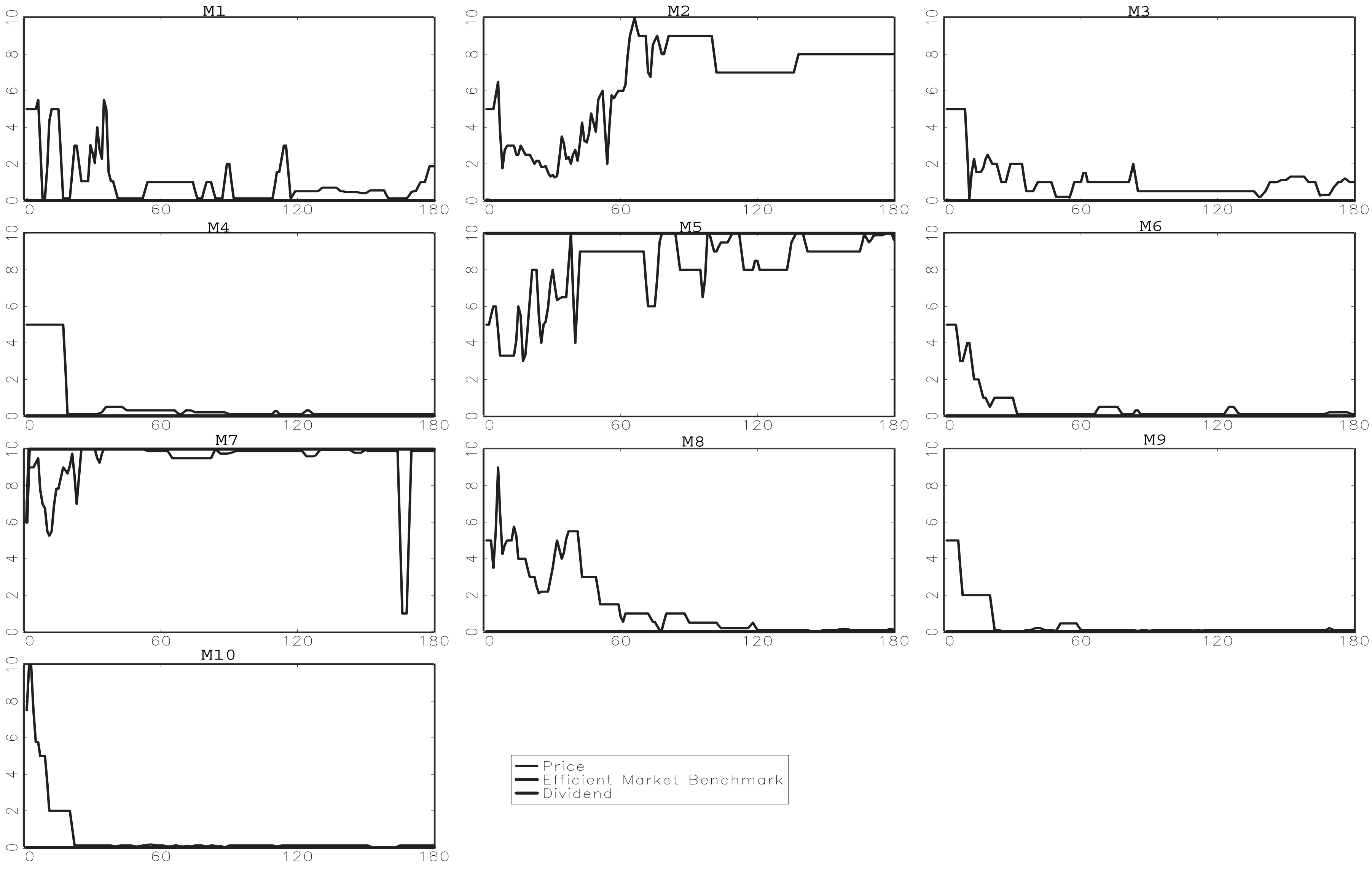

Figure 9: Markets Treatment 2: Private signal with $p = 0.8$.

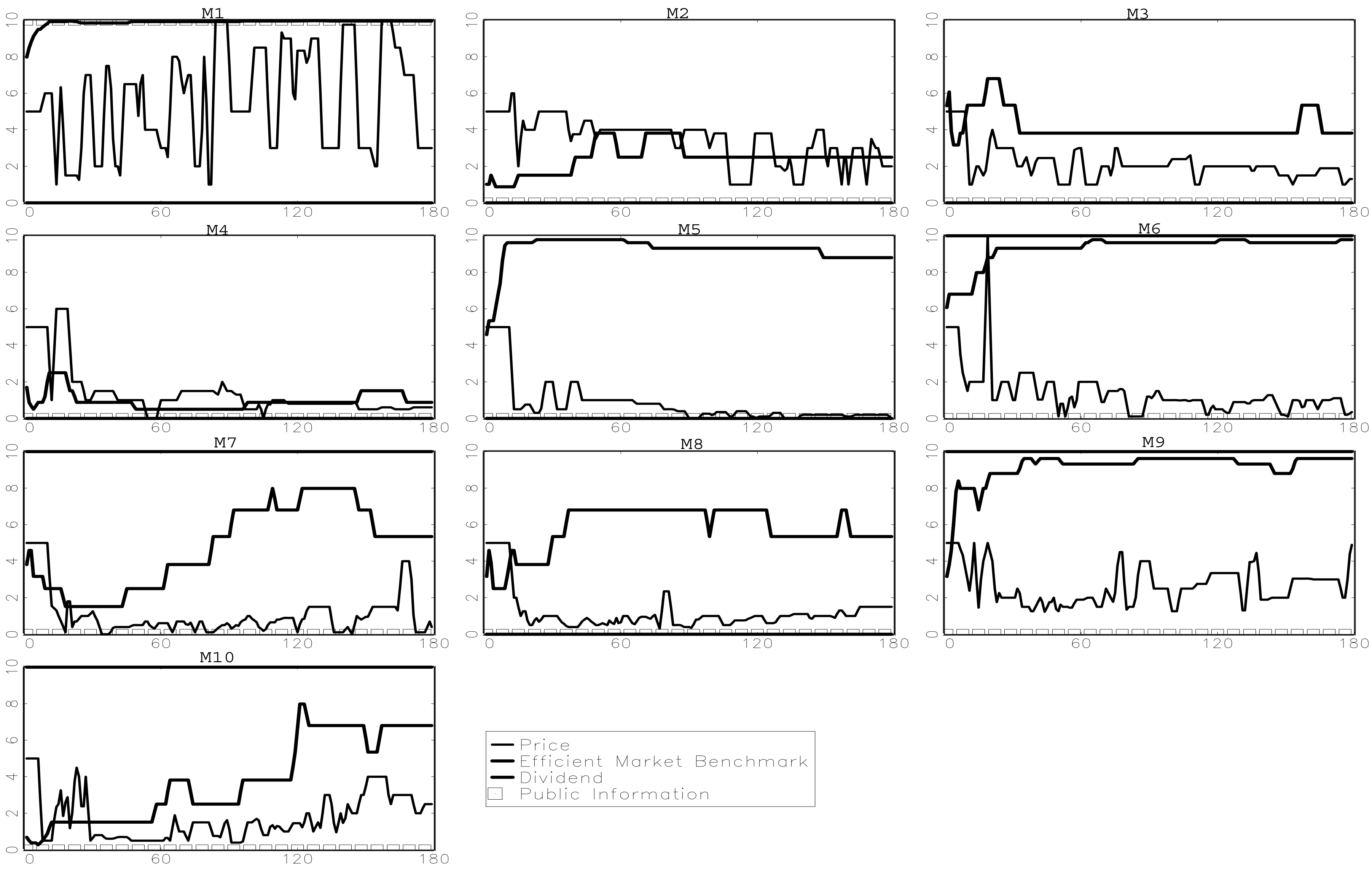

Figure 10: Markets Treatment 3 (Session 1): Private signal with $p = 0.6$ and public signal with $P = 0.8$.

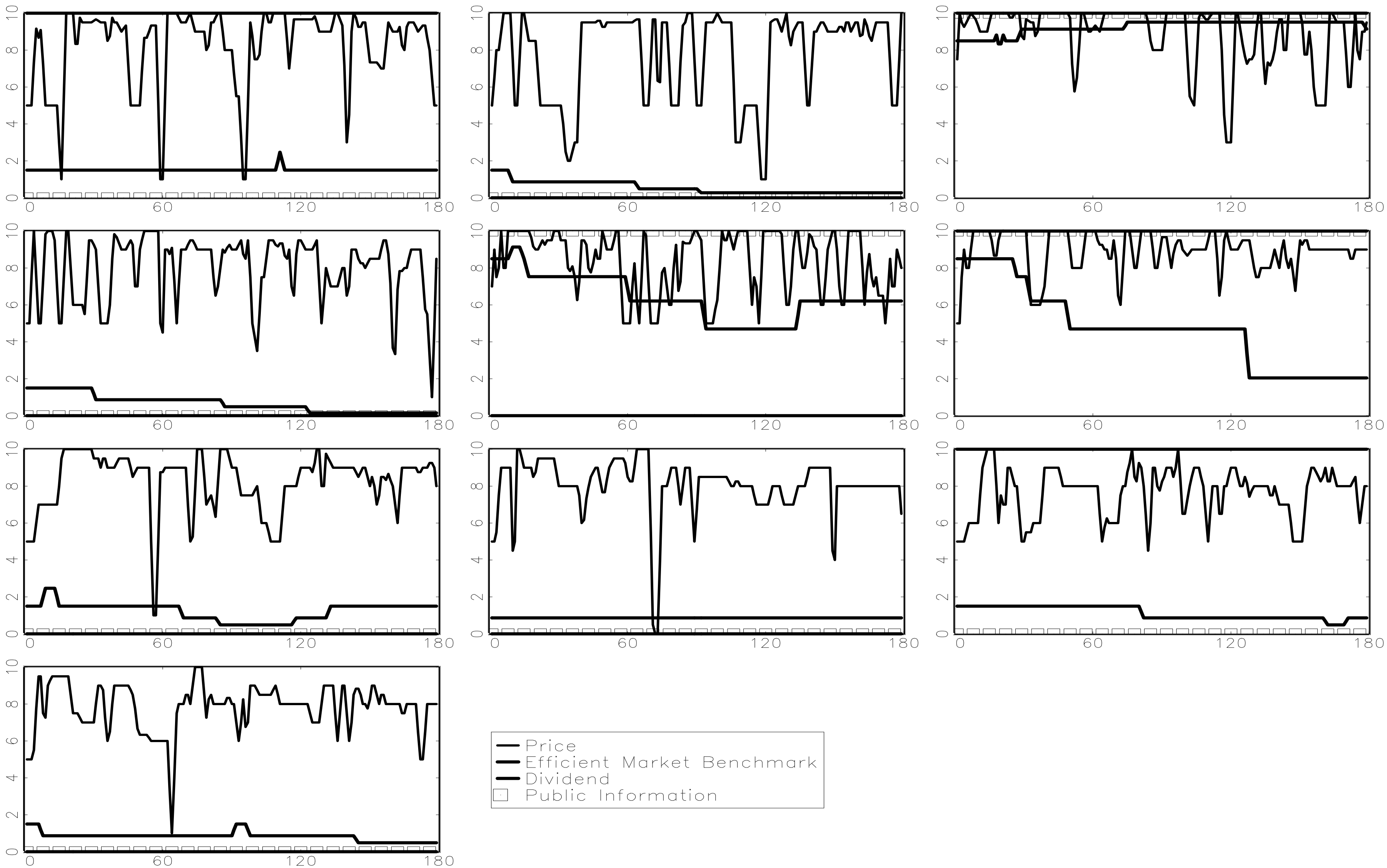

Figure 11: Markets Treatment 3 (Session 2): Private signal with $p = 0.6$ and public signal with $P = 0.8$.

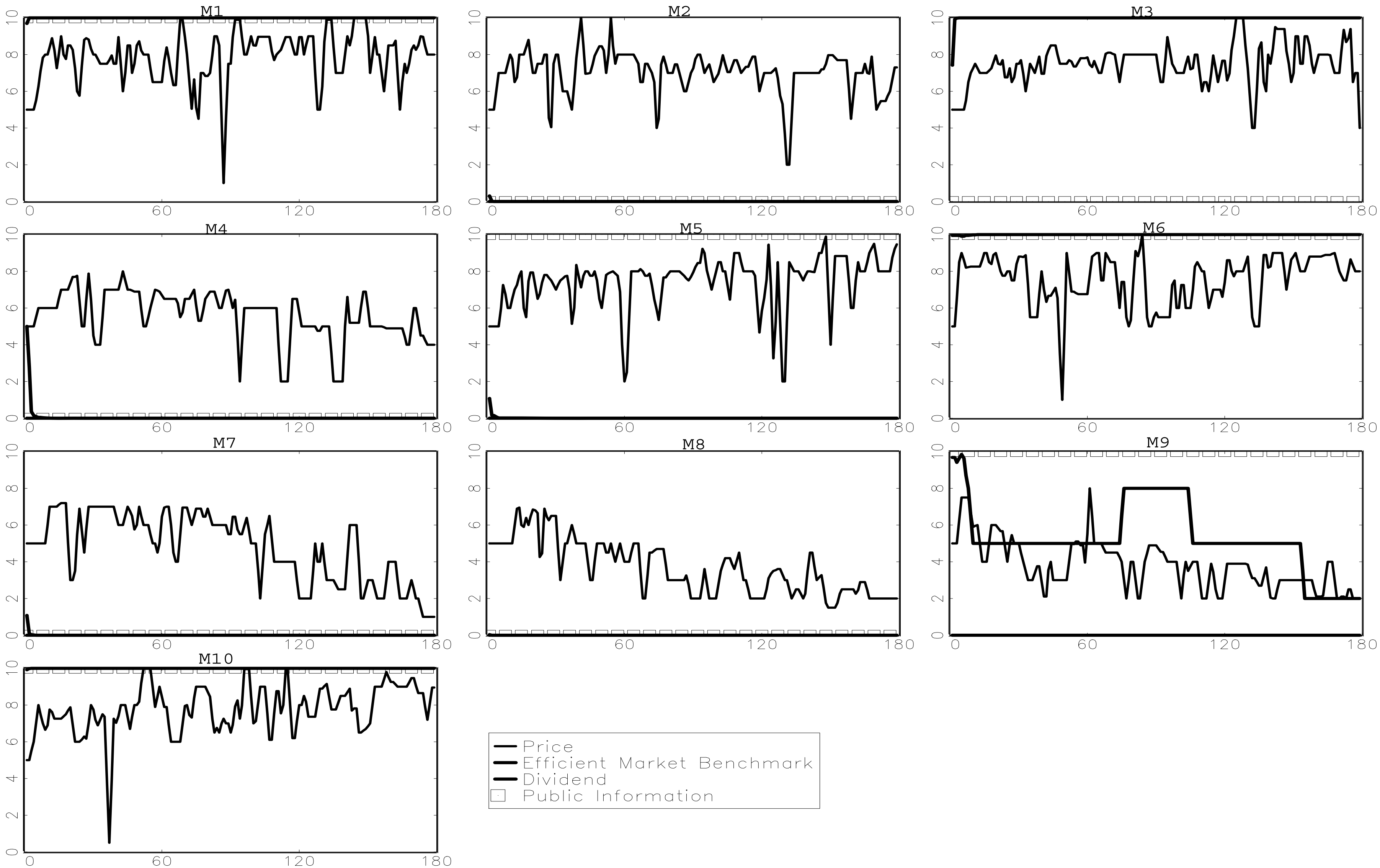

Figure 12: Markets Treatment 4: Private signal with $p = 0.8$ and public signal with $P = 0.8$.