Loss Aversion and Insider Trading

SAMUEL OUZAN*

[Preliminary version. Please do not quote]

First version, April 26th 2014

ABSTRACT

This study analyses equilibrium trading strategies and market quality in an economy with information asymmetry and in which speculators display loss aversion. A closed form characterisation of the equilibrium price is presented. The model successfully disentangles the effect of loss aversion on optimal informed trading strategy and equilibrium price. This paper studies the impact of loss aversion on asset prices, market depth, informed trading volume and prices volatility. The model predicts nonlinear market depth. Consistent with empirical observations, the model finds that important price movements may occur after small shocks in the intermediate price region and regardless of the value of the underlying asset.

I. Introduction

The phenomenon of loss aversion was discovered by Kahnemann and Tversky (1979), and since has received a considerable amount of empirical attention from economics and other disciplines such as cognitive psychology and sociology. Evidence that agents consider gains and losses differently has been found in experimental markets as the endowment effect[1] (Kahneman, Knetsch, and Thaler (1990)) and the disposition effect[2] (Weber and Camerer 1998). Odean (1998) also finds evidence of loss aversion in the trades of individual investors who are reluctant to realize losses and Genesove and Mayer

* Department of Finance, HEC Montréal, 3000, chemin de la Côte-Sainte-Catherine Montréal, Québec, H3T 2A7, Canada, samuel.ouzan@hec.ca. I particularly thank my advisor Martin Boyer and also Pierre Chaigneau for helpful comments and suggestions. Any errors are mine.

[1] Thaler (1980) defines the endowment effect as a discrepancy between buying and selling prices.

[2] The disposition effect is the tendency to sell assets that have gained value (‘winners’) and keep assets that have lost value (‘losers’).

(2001) finds such evidence in the behavior of house sellers who are unwilling to sell below buying price.

Gomes (2005) and Berkelaar et al. (2004) apply loss aversion to portfolio choice and find that loss averse investors abstain from holding stocks unless they expect the equity premium to be quite high. In the study of asset prices, arguably, one of the most important applications of the concept of loss aversion is the theoretical explanation of the equity premium puzzle (Benartzi and Thaler (1995)). In a related breakthrough article, Barberis, Huang and Santos (2001) find that in economy where investors are loss averse about the fluctuations in the value of their financial wealth, asset prices exhibit phenomena very similar to what have been observed in historical data. In particular they find that stock returns have a high mean, are excessively volatile and are significantly predictable in the time series.

On the other hand, while models of financial markets with asymmetric information have been often extended to economies in which traders hold mistaken distributional beliefs about the payoff of the risky asset, and in particular, to economies in which traders are overconfident, models of financial markets with loss averse traders where private information is acquired have been little discussed in the literature. Only, a very recent work of Pasquariello (2014) studies the effect of prospect theory in general and the effect of loss aversion in particular on market quality.

In line with Grossman and Stieglitz (1980), Kyle (1985) and Vives (1995), we propose a noisy rational expectation equilibrium model where competitive price taking speculators endowed with private information, exhibit loss aversion. The proposed economy is populated with informed traders, liquidity traders and a risk neutral market maker. Our model is a modified version of the model of Pasquariello (2014). While in his original model asset choice is based on the mean variance approach to rational investment and the equilibrium is intractable, the agents in our model maximize their expected utility and the proposed nonlinear rational expectation equilibrium is analytically tractable[3].

The speculators' preferences in our model disentangle loss aversion and risk aversion. This phenomenon yields to an optimal trading strategy that is a state dependant linear function of the private signal and that makes the inference problem for the equilibrium price tractable. The proposed model successfully disentangles the impact of loss aversion on optimal informed trading strategy and equilibrium price. The presence of loss averse better informed trader lowers equilibrium price volatility and expected informed trading volume. Loss aversion induces also the speculator to trade less for sufficiently large signals in absolute value and not at all for very low signal. We show that since speculators preferences successfully disentangle loss aversion and risk aversion, the trading intensity within the trading region remains unchanged in comparison to risk averse only speculators.

The difficulty for the market maker to assess the trading region of the informed can create in our simple model large market price movement in the intermediate price region. Our model outlines how small trigger shocks can create meltdowns as well as upward price movements. These large market price movements may appear when the absolute value of the aggregate order flow is low. In that situation, price adjustment to signal and noise trading shocks appear to be highly non linear, and a certain confusion by the market

[3] We successfully achieve this task because manly that the utility shape of the informed traders disentangle loss aversion and risk aversion.

maker about the trading status of the informed is very likely to happen. Crisis in the model are not indeed tailed-end event and large price movements support the evidence that crashes as well as market bubbles may appear without any preceding public news. This study show that market depth is non linear and that large price movements appear also when the market depth is low. Our model does not predict however asymmetrical price movement often reported in the literature[4].

II. The Model of Trading with Loss Aversion

Since the introduction of Allais paradox (1953), several violations of the basic expected utility theory have been documented. According to Starmer's (2000) review of the literature, one specifically persistent empirical finding in experiments is a greater sensitivity of losses than to gains of similar size. This idea that people are loss averse over changes in wealth is a central feature of prospect theory (Khaneman and Tversky (1979)). Recently, von Gaudecker et al (2011) analyse risk preferences using an experiment with real incentives in a representative sample of 1,422 respondents. They find that utility curvature and loss aversion are the key determinants of individuals' choices under risk. We adopt von Gaudecker et al's (2011) utility specification to model speculators' preferences. We describe a noisy rational expectation equilibrium model of sequential trading in the presence of better informed, loss averse speculators. In the same spirit of Grossman and Stiglitz (1980), Diamond and Verrecchia (1981) and Vives (1995), we assume that speculators of the model are competitive and submit limit orders instead of market order. Allowing for perfect competition, informed limit orders, and loss

[4]See Pindyk (1984) French, Schwert, and Stambaugh (1987), and Bekaert and Wu (2000)), and Yuan (2005).

aversion, our model is similar to the model of Pasquariello (2014) who study market quality with prospect theory driven preferences' speculators. However, while in Pasquariello (2014) equilibrium quantities are intractable and approximate using a numerical approach via OLS, the equilibrium developed in this study is analytically tractable.

The basic economy

We describe a noisy equilibrium model of sequential trading in the presence of better informed speculators, who are competitive and submit limit orders. The economy is populated with informed traders, liquidity ("noise") traders who share demands are exogenous and who trade for idiosyncratic life-cycle or liquidity reason, and a risk-neutral competitive market maker. Informed traders are competitive and form a continuum with measure one. The model includes two dates, time 0 and time 1. At time 0, investors trade competitively in the market based on their private information. At time 1, payoffs from the assets are realized and consumption occurs.

There are one risk-free asset and one risky asset. The risk-free asset is a claim to one unit, and the risky asset pays $\tilde{v}$ units of the single consumption good. While taking the risk free asset to be the numeraire, we let P be the price for the risky asset. Prior to trading, informed investors receive private information related to the payoff of the risky asset. The signal $\tilde{s}$ is a noisy signal of the asset final payoff $\tilde{v}$, given as follows: $s = v + \varepsilon$. We assume that all the informed investors receive the same private signal s[5]. The random variables v and ε are assumed to be mutually independent and normally

[5] We assume that speculators observe identical signals and possess identical preference. A model with diverse signal and/or diverse preferences is much more complicated and does not permit to derive tractable equilibrium.

distributed with mean zero[6] and variance σ_v^2 and σ_ε^2. Liquidity ("noise") traders produce a random, normally distributed demand z with mean zero and variance σ_z^2. Moving first, liquidity traders submit market orders and speculators submit demand schedules or generalized limit orders contingent on their information to the market maker, before equilibrium set price P has been set. When speculators optimize their demand, they take into consideration the relation between equilibrium functional price and the random variables in the economy. Then, competitive risk neutral market maker set the price efficiently given the observed aggregate order flow. It is well known that in large market, competitive noisy rational equilibrium are implementable allowing agents to use demand schedule as strategies. As in Vives (1995) and Pasquariello (2014) we denote a speculator demand schedule by $x_i(s,.)$; thus when the price is P, the desired position of the informed trader is then $x_i(s,P)$. We assume that the speculator perceives the investment of all her wealth in the risk free asset as the *reference point*, and any other outcomes as changes or profits with respect to this reference point. So the profits from speculator *i*, are given by $\pi_i = x_i(v-P)$.

Loss Averse Speculators

The CARA-normal model is popular in the study of financial market with asymmetric information. For various settings it admits linear equilibria. Helwing (1980), Grossman and Stiglietz (1980), Diamond and Verrecchia (1981), Admati (1985) and Vives (1995) all analyses competitive rational expectation models with asymmetric information with constant absolute risk aversion (CARA) and normally distributed random variables.

---

[6] We assume in order to save on notation that the mean of v is zero. However, for general value of $E[v]$ the derivation remains the same for $v-E[v]$.

Under the Standard CARA-Normal model, given our basic economy, the speculator maximizes $E_0\left[-\exp(-\gamma\tilde{W}_{1,i})\right]=E\left[-\exp(-\gamma\tilde{W}_{1,i})|s\right]$ over the final wealth, where γ is the coefficient of absolute risk aversion. E_0 refers to the expectation operator, conditional on investor information at time 0, and $\tilde{W}_{1,i}$ is the final wealth of speculator *i*. It is well known that the optimization result does not depend on initial wealth, and it is equivalent to maximize $E_0\left[-\exp(-\gamma\pi_i)\right]$ over the speculator's profits.

We modify the standard model by adding loss aversion in the preference. As stated above, we assume that the speculator perceives the reference point as $W_{i,0}$, since it refers to an entirely risk free investment. We suppose that preferences are continuous and display a kink at a reference point. Relative to the reference point, losses hurt more individuals than comparable gains, and thus the slope of the utility function is steeper for losses than for gains. We assume that all speculators have the same utility function $U(\pi,\gamma,\lambda)$ and so we drop the subscripts *i*. Moreover, in line with the specification of Von Gaudecker et al (2011), we assume that the utility function is given by

$$U(\pi,\gamma,\lambda)=\begin{cases}-\dfrac{1}{\gamma}e^{-\gamma\pi} & \text{for } \pi\geq 0\\ \dfrac{\lambda-1}{\gamma}-\dfrac{\lambda}{\gamma}e^{-\gamma\pi} & \text{for } \pi<0\end{cases} \tag{1}$$

where λ represents the degree of loss aversion. This functional form plotted in Fig. 1 allows disentangling preference parameters for utility curvature (risk aversion) and loss aversion. This functional form departs from the original utility function. While prospect theory's original utility function is concave over gains and convex over losses, equation 1 assumes the same type of curvatures over gains and losses. Although modeling speculators with prospect theory preferences makes the problem intractable in our setting, some recent empirical evidence challenges prospect theory's original utility function for mixed gamble (Baltussen, Post, and Pim van Vielt 2006). Moreover, Gaudecker et al (2011) show in their study that changing the assumption curvature to prospect theory-type preferences does not substantially affect their main estimates.

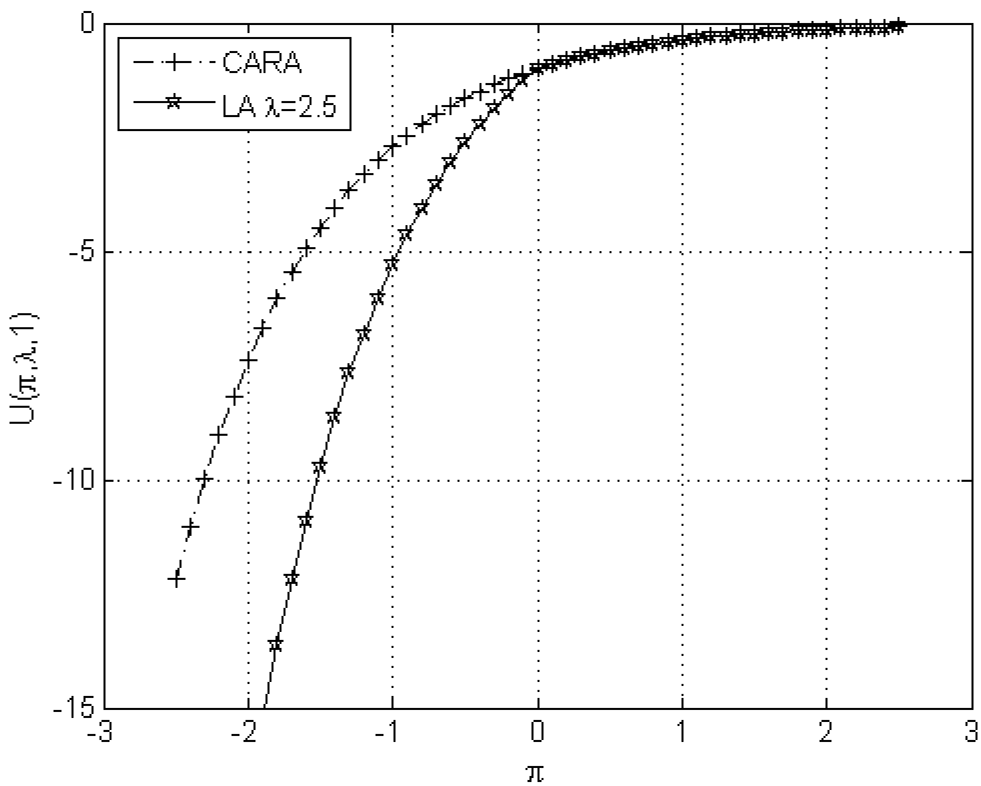

Figure 1. Utility function. This function in line with loss aversion exhibits a kink at the origin. The stared line is for loss aversion parameter of $\lambda = 2.25$ and the crossed line represents a particular case where $\lambda = 0$, (CARA preferences).The risk aversion parameter is $\gamma = 1$.

The Optimal Demand of the Informed Trader

$x(s,.)$ represents the demand schedule for the risky asset of the informed trader when she received the private signal. When the price realization is *P*, the demand function is then $x(s,P)$. The only available information of the informed trader at time 0 is the noisy signal *s*. According to Vives (1995) and Pasquariello (2014), speculators neither learn from market price nor internalize the impact on their trades on market prices. Thus the demand of the informed submitted at time 0, is given by the maximization of the expected utility

$$E\big(U(\pi,\gamma,\lambda)\big|s\big)=\begin{cases}-\dfrac{1}{\gamma}\left[\begin{array}{l}e^{-\gamma x(\mu_{v/s}-P)+\frac{\gamma^2x^2\sigma_{v/s}}{2}}\left[1+(\lambda-1)\Phi(\dfrac{x\gamma^2\sigma_{v/s}^2\text{-}\gamma(\mu_{v/s}-P)}{\gamma\sigma_{v/s}})\right]\\ \text{-}(\lambda-1)\Phi(\dfrac{\mu_{v/s}-P}{\sigma_{v/s}})\end{array}\right] & \text{for } x>0\\ -\dfrac{1}{\gamma}\left[\begin{array}{l}e^{-\gamma x(\mu_{v/s}-P)+\frac{\gamma^2x^2\sigma_{v/s}}{2}}\left[1+(\lambda-1)\Phi(\text{-}\dfrac{x\gamma^2\sigma_{v/s}^2\text{-}\gamma(\mu_{v/s}-P)}{\gamma\sigma_{v/s}})\right]\\ \text{-}(\lambda-1)\Phi(\text{-}\dfrac{\mu_{v/s}-P}{\sigma_{v/s}})\end{array}\right] & \text{for } x\le 0\end{cases} \tag{2}$$

where $\mu_{v/s}=\rho^2\tilde{s}$ and $\sigma_{v/s}^2=\sigma_v\sqrt{1-\rho^2}$ is the conditional mean and variance of the random risky payoff *v* given the private signal received by each speculator and where $\rho=\dfrac{\sigma_v}{\sqrt{\sigma_v^2+\sigma_\varepsilon^2}}$, and $\Phi(.)$ refers to the cumulative distribution function of the standard normal distribution. The derivation of (2) and the conditional mean and variance are presented in Appendix A.

Equation (2) admits for each region only one bonded maximum value since as we will see in the ensuing analysis, the first order condition of equation (2) is solved for at most one unique value in each region and for unbounded values of *x* in each region the objective function is equal to minus infinity.

Taking the first order condition of equation (1) with respect to *x*, yields for $x>0$

$$e^{-\gamma x(\mu_{v/s}-P)+\frac{\gamma^2 x^2\sigma_{v/s}^2}{2}}\left[\begin{array}{l}\dfrac{(\lambda-1)\gamma\sigma_{v/s}}{\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{x\gamma^2\sigma_{v/s}^2-\gamma(\mu_{v/s}-P)}{\gamma\sigma_{v/s}}\right)^2}\\+\left(1+(\lambda-1)\Phi(\dfrac{x\gamma^2\sigma_{v/s}^2-\gamma(\mu_{v/s}-P)}{\gamma\sigma_{v/s}})\right)\left(x\gamma^2\sigma_{v/s}^2-\gamma(\mu_{v/s}-P)\right)\end{array}\right]=0 \qquad (3a)$$

and for $x\leq 0$

$$e^{-\gamma x_i(\mu_{v/s}-P)+\frac{\gamma^2 x^2\sigma_{v/s}^2}{2}}\left[\begin{array}{l}-\dfrac{(\lambda-1)\gamma\sigma_{v/s}}{\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{x\gamma^2\sigma_{v/s}^2-\gamma(\mu_{v/s}-P)}{\gamma\sigma_{v/s}}\right)^2}\\+\left(1+(\lambda-1)\Phi(-\dfrac{x\gamma^2\sigma_{v/s}^2-\gamma(\mu_{v/s}-P)}{\gamma\sigma_{v/s}})\right)\left(x\gamma^2\sigma_{v/s}^2-\gamma(\mu_{v/s}-P)\right)\end{array}\right]=0 \qquad (3b)$$

The term in the bracket of equation (3a) and equation (3b) should be equal to zero since the exponential function $e^{-\gamma x_i(\mu_{v/s}-P)+\frac{\gamma^2 x^2\sigma_{v/s}^2}{2}}$ is bounded below by a positive number. Dividing both sides of equation (3a) and equation (3b) by $\gamma\sigma_{v/s}$ and defining $\Lambda=\dfrac{x\gamma^2\sigma_{v/s}^2-\gamma(\mu_{v/s}-P)}{\gamma\sigma_{v/s}}$ we get for $x>0$

$$\Lambda\left(1+(\lambda-1)\Phi(\Lambda)\right)+\frac{(\lambda-1)}{\sqrt{2\pi}}e^{-\frac{1}{2}\Lambda^2}=0 \qquad (4a)$$

and equivalently for $x\leq 0$

$$\Lambda\left(1+(\lambda-1)\Phi(-\Lambda)\right)-\frac{(\lambda-1)}{\sqrt{2\pi}}e^{-\frac{1}{2}\Lambda^2}=0 \qquad (4b)$$

For any degree of loss aversion λ one can solve numerically equation (4a) and (4b). Empirically estimates of loss aversion are typically in the neighborhood of 2.5. For example if we set $\lambda = 2$ we find that $\Lambda = -0.276$ for positive value of *x* and $\Lambda = 0.276$ for negative value of *x*. Thus, the optimal positive demand is $x = \frac{(\mu_{v/s} - P)}{\gamma\sigma_{v/s}^2} - \frac{0.276}{\gamma\sigma_{v/s}}$ and the optimal negative demand is $x = \frac{(\mu_{v/s} - P)}{\gamma\sigma_{v/s}^2} + \frac{0.276}{\gamma\sigma_{v/s}}$. We notice however that a positive or negative demand will depend on the magnitude and the precision of the private signal. In order to push demand to positive ranges, the signal should be relatively high. i.e $s \geq \frac{P + 0.276\sigma_{v/s}}{\rho^2}$ and inversely to push the demand to the negative range the signal should be relatively low i.e. $s \leq \frac{P - 0.276\sigma_{v/s}}{\rho^2}$. Outside this range, in the interval $\left|\mu_{v/s} - P\right| \leq 0.276\sigma_{v/s}$ we note that neither the objective function for positive value of *x* nor for negative value of *x* admits local minimum in their respective ranges. Thus $x = 0$ maximize the expected utility in the range $\left|\mu_{v/s} - P\right| \leq 0.276\sigma_{v/s}$.

We can generalize to any value of λ. Thus the solution of equation (4a) and (4b) may be expressed as a function of λ, $\Lambda = \Lambda(\lambda)$.

Result 1: *The optimal demand for the informed trader is given by*

$$x_{LA}^* = \begin{cases} \dfrac{\rho^2 s - P}{\gamma\sigma_v^2\left(1-\rho^2\right)} - \dfrac{\Lambda(\lambda)}{\gamma\sigma_v\sqrt{1-\rho^2}} & \text{for } s > \dfrac{P + \Lambda(\lambda)\sigma_v\sqrt{1-\rho^2}}{\rho^2} \\ 0 & \text{elsewhere} \\ \dfrac{\rho^2 s - P}{\gamma\sigma_v^2\left(1-\rho^2\right)} + \dfrac{\Lambda(\lambda)}{\gamma\sigma_v\sqrt{1-\rho^2}} & \text{for } s \leq \dfrac{P - \Lambda(\lambda)\sigma_v\sqrt{1-\rho^2}}{\rho^2} \end{cases} \tag{5}$$

where $\Lambda = \Lambda(\lambda)$ solves $\Lambda\left(1+(\lambda-1)\Phi(-\Lambda)\right) - \frac{(\lambda-1)}{\sqrt{2\pi}} e^{-\frac{1}{2}\Lambda^2} = 0$.

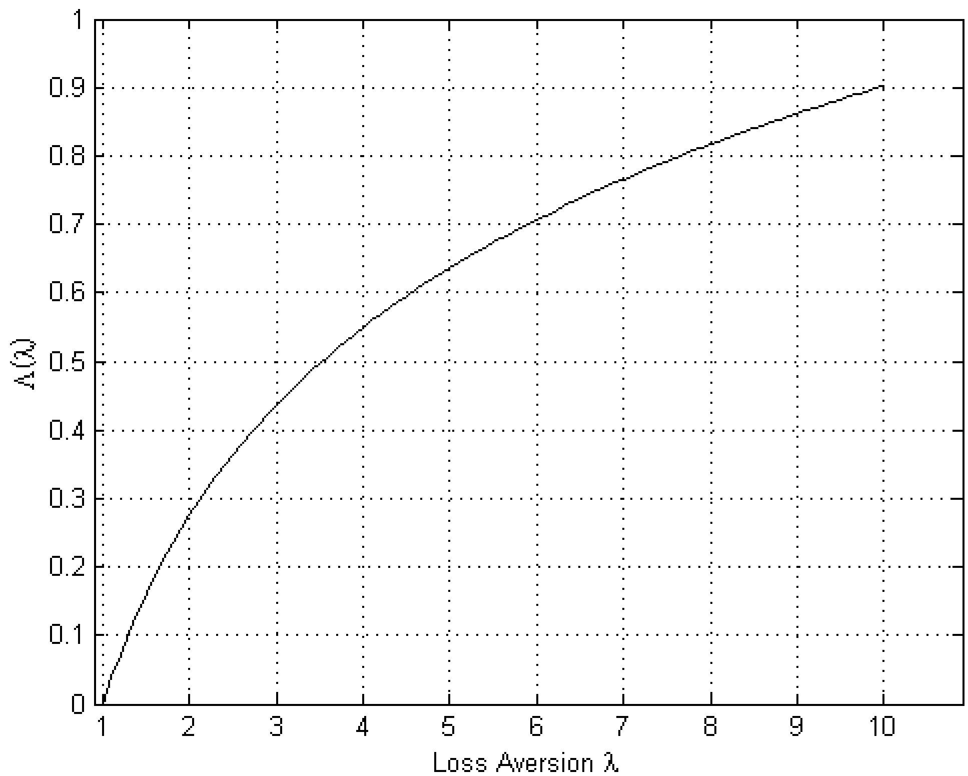

Figure 2. The effect of loss aversion on optimal demand: $\Lambda(\lambda)$**.** The graph plots the solution of equation $\Lambda\left(1+(\lambda-1)\Phi(-\Lambda)\right) - \frac{(\lambda-1)}{\sqrt{2\pi}} e^{-\frac{1}{2}\Lambda^2} = 0$ as a function of λ.

Figure 2 plots the functional form $\Lambda(\lambda)$ for loss aversion parameters in the range [1, 10]. From figure 2 we see that $\Lambda(\lambda)$ is concave and increases with λ. We notice that for $\lambda = 1$, $\Lambda(\lambda) = 0$ and the optimal demand reduces to the optimal generalized limit order under the regular CARA-Normal model with negative exponential utility (Vives (1995) and, Grossman and Stieglitz (1980)).

$$x_{MV} = \frac{\mu_{v/s} - P}{\gamma\sigma_{v/s}^2} = \frac{\rho^2 s - P}{\gamma\sigma_v^2\left(1-\rho^2\right)} \tag{6}$$

We find that loss aversion have additional effects on speculator trading strategies. As for the standard CARA-Normal setting, the proposed model predicts that informed traders submit cautious limit orders. The optimal demand is a state-dependant linear function of the private signal and the equilibrium price. Increasing loss aversion or increasing risk aversion, increases the cautiousness of the trade. The losses induced by trading which obviously hurts more the more loss averse is the speculator, is translated by a reduction of optimal trading activity comparing to risk averse speculators only. According to the intensity of the private signal, it is translated either by lesser trading or no trading at all.

The trading intensity (Vives, 1995) is defined by the sensitivity of speculators' demand function to information shocks $\zeta = \frac{\partial x}{\partial s}$. In our model the trading intensity is

$$\zeta = \begin{cases} 0 & \text{for } \left|s-\Delta\right| \le \frac{P}{\rho^2} \\ \frac{1}{\gamma\sigma_\varepsilon^2} & \text{for } \left|s-\Delta\right| \le \frac{P}{\rho^2} \end{cases}. \tag{7}$$

where $\Delta\left(\lambda,\sigma_v,\sigma_\varepsilon\right) = \frac{\Lambda\left(\lambda\right)\sigma_v\sqrt{\left(1-\rho^2\right)}}{\rho^2}$. Outside the no-trade interval, this measure of trading aggressiveness is the same as for the standard CARA-normal model and depends solely on the precision of the private signal and on risk tolerance. In our model indeed, since the speculators' preferences disentangle risk aversion and loss aversion, loss aversion does not affect the trading intensity for sufficiently large signals. Intuitively, while trading more with a better signal implies to risk more that does not increase the likelihood to lose more in expectation and thus the trading intensity is not affected by loss aversion.

Equilibrium

We now characterize equilibrium prices and trading behavior in the model. We denote the aggregate order flow by $\omega = x + z$, which refers to the noisy limit-order book schedule observed by the market maker. The market maker earns zero expected profit conditional of the order flow. The market clearing price P set by the market maker satisfies

$$P(\omega) = E\left[v \middle| \omega\right]. \tag{8}$$

Risk neutrality and dealership competition imply the semi-strong market efficiency rule expressed by equation (8)[7].

From equation (5), this implies that the optimal demand schedule x^*_{LA} depends on risk aversion, loss aversion, market clearing price and the intensity of the private signal. For a given intensity of the private signal at a given equilibrium price, speculators optimal demand falls either within no-trade interval or trading interval. Thus, the market maker has to conjecture speculators' trading status. Following Pasquariello (2014), and in the

[7] Similar condition is found for instance in Kyle (1995), Hirshleifer, Subramanyahm, and Titman (1994), Vives (1995), and Pasquariello (2014). According indeed to Vives (1995), this condition can be justified with Bertrand competition among risk neutral market makers who observe the limit order book and have symmetric information. It can be also explain by a situation where there is a continuum of risk neutral market makers who submit limit order to a central mechanism jointly with informed traders where prices are set by a Walsarian auctioneer to equate the aggregate excess demand from all the model's market participants to zero. In this case, in equilibrium equation (8) is necessarily verified since otherwise market makers would like to take unbounded positions.

same spirit of Yuan (2005) the risk neutral market maker inference problem can be expressed as

$$
\begin{aligned}
P = {} & E\left[v \,\middle|\, \omega, s \geq \frac{P}{\rho^2} + \Delta \right] \Pr\left[s \geq \frac{P}{\rho^2} + \Delta \right] + E\left[v \,\middle|\, \omega, s \leq \frac{P}{\rho^2} - \Delta \right] \Pr\left[s \leq \frac{P}{\rho^2} - \Delta \right] \\
& + E\left[v \,\middle|\, \omega, \left| s - \Delta \right| \leq \frac{P}{\rho^2} \right] \Pr\left[\left| s - \Delta \right| \leq \frac{P}{\rho^2} \right]
\end{aligned} \tag{9}
$$

Where $\Pr\left[s \leq \frac{P}{\rho^2} - \Delta \right]$, $\Pr\left[s \geq \frac{P}{\rho^2} + \Delta \right]$ are the probability that order flow being informative while $\Pr\left[\left| s - \Delta \right| \leq \frac{P}{\rho^2} \right]$ is the probability that the order flow is uninformative about the risky payoff *v*.

Since the optimal demand schedule x_{LA}^{*} of equation (5) makes ω a linear function of *P* and of the private signal *s* and since the boundaries are not functions of the received private signal s (i.e. Δ does not depend on s), the inference problem of equation (9) is analytically tractable and it is described in Appendix B.

Result 2: *The rational expectations equilibrium price function of the model is the unique fixed point of the implicit function*

$$
\begin{aligned}
P_{LA}^{*} = {} & \frac{\gamma \sigma_v^2 \sigma_\varepsilon^2}{\sigma_v^2 + \sigma_\varepsilon^2 \left(1 + \gamma^2 \sigma_\varepsilon^2 \sigma_z^2\right)} \left(\frac{s}{\gamma \sigma_\varepsilon^2} + z \right) \left[1 - \Phi\left(\frac{\frac{P}{\rho^2} + \Delta}{\sqrt{\sigma_v^2 + \sigma_\varepsilon^2}} \right) + \Phi\left(\frac{\frac{P}{\rho^2} - \Delta}{\sqrt{\sigma_v^2 + \sigma_\varepsilon^2}} \right) \right] \\
& + \sigma_v \rho \left(1 - \sqrt{\frac{\gamma^2 \sigma_z^2 \sigma_\varepsilon^4}{\sigma_v^2 + \sigma_\varepsilon^2 \left(1 + \gamma^2 \sigma_\varepsilon^2 \sigma_z^2\right)}} \right) \left[\psi\left(\frac{\frac{P}{\rho^2} - \Delta}{\sqrt{\sigma_v^2 + \sigma_\varepsilon^2}} \right) - \psi\left(\frac{\frac{P}{\rho^2} + \Delta}{\sqrt{\sigma_v^2 + \sigma_\varepsilon^2}} \right) \right]
\end{aligned} \tag{10}
$$

Proof: Given $g(P) = f(P) - P$, where $f(P)$ represents the right side of equation (9), and since $\lim_{x\to\infty}\Phi(x) = 0$, $\lim_{x\to-\infty}\Phi(x) = 1$, and $\lim_{x\to\pm\infty}\psi(x) = 0$ [8], it is immediate that $\lim_{P\to\infty} g(P) < 0$ and $\lim_{P\to-\infty} g(P) > 0$. By the Intermediate Value Theorem, at least one solution to $g(P) = 0$ exists. As $g(P)$ is a decreasing function, the solution to $g(P) = 0$ is therefore unique. Hence P exists and is unique. Q.E.D.

If speculators do not exhibit loss aversion (i.e. $\lambda = 1$, $\Delta(\lambda) = 0$), the rational equilibrium price function of equation (9) is reduced to equilibrium price when speculators have CARA preferences

$$P^*_{CARA} = \frac{\gamma\sigma_v^2\sigma_\varepsilon^2}{\sigma_v^2 + \sigma_\varepsilon^2\left(1+\gamma^2\sigma_\varepsilon^2\sigma_z^2\right)}\left(\frac{s}{\gamma\sigma_\varepsilon^2} + z\right). \tag{11}$$

Equation (10) is identical to the mean variance preferences, equilibrium price found by Pasquariello (2014) and in particular is a special case of the linear equilibrium in Vives (2008, Proposition 1.11) when a continuum risk averse speculators receive identical noisy signals of the asset payoff.

In equilibrium informed agent *i*, buy or sells according to whether *s*, the private estimate of *v* is larger than $\frac{P}{\rho^2} + \Delta$ or smaller than $\frac{P}{\rho^2} - \Delta$, and do not trade otherwise. In their trading region, informed agents trade more intensively if risk aversion (γ) is lower, and if the precision of the signal $\left(1/\sigma_\varepsilon^2\right)$ is higher. Moreover, in our model, the precision of the signal $\left(1/\sigma_\varepsilon^2\right)$ also shorten the no-trade region (2Δ), while γ have no impact on the

[8] $\psi(x)$ refers to the probability density function of the standard normal distribution.

determination of that region. As in the CARA model trading intensity is independent of the amount of noise trading.

There is a trade in this type of model because of the presence of noise trader and because of the information advantage that informed agents hold on the market maker. The asymmetric information between speculators and market maker creates typically two opposite effects, namely the selection effect and the information (efficiency) effect. While private signal of higher quality encourages informed agent to trade more and more aggressively and thus exploiting more efficiently their information premium, they also typically reveal to the market maker more private information increasing the precision of the equilibrium market price. The information advantage of insiders always holds but it could diminish or increase depending on risk aversion, the quality of private signal and the noise. In that sense the camouflage which conceals informed agents' trading from market maker varies with the parameters of the economy.

In our model, another dimension is added to the efficiency effect or equivalently to the information process by which the private information is revealed to the market maker. The degree of uncertainty regarding informed investor trading region plays indeed a crucial role in the inference process of the market maker. Intuitively, when the magnitude of the aggregate order flow in very low, the market maker conjectures with a relatively high (depending primarily on the degree of loss aversion) probability that the informed traders did not submitted any limited order, inferring that the information advantage held by insiders is not exploited due to their loss aversion. However, conversely, when the magnitude of the order flow is very high, the market maker conjectures with high probability that the insiders exploit although cautiously (equation (5)) their information advantage. Since in case of informative aggregate order flow, the trading intensity (ζ) is similar outside the no trade region to the CARA model, the information content of the price should be close to that given by the CARA model and thus the price should be as well very close.

To illustrate our main intuition, and to clarify the effect of loss aversion on information sharing and on equilibrium price formation process, we conduct a numerical analysis of an economy with typical market-specific calibration where the parameters are chosen to equate the expected return on the risky asset to 6% and the standard deviation to 20%. We follow Hirshleifer, Subrahmanyam, and Titman (1994) and we set $\gamma = 2.5$, $\sigma_\varepsilon^2 = 8, \sigma_v^2 = 1$, and $\sigma_z^2 = .4$[9]. Figure 3 illustrates an example of equilibrium price $P_{LA}^*(\Theta)$ where $\Theta = \frac{s}{\gamma\sigma_\varepsilon^2} + z$, as a function of the noisy demand and the intensity of the private signal scales by the risk tolerance and its precision which refer to the statistically relevant part of the informative aggregate order flow observed by the market maker. It is important to emphasize that the equilibrium price is a non linear function of the noisy demand and of the private signal intensity while for the CARA model, $P_{CARA}^*(\Theta)$ is linear in Θ. This non linearity arises because of the uncertainty regarding informed investor trading status. In the two extreme region (when $|\Theta|$ is high) there is very little uncertainty regarding informed trader status and thus the price is confounding with linear price function of the CARA-Model. However, in the region around the expected value of the payoff *v*, the equilibrium price exhibits the smallest variation with Θ. When Θ is around

[9] The value of risk aversion coefficient is consistent with historical estimates of the market risk premium. Our result is robust to other market specification calibrations proposed in the literature (Gennotte and Leland (1990), Leland (1992), and Yuan (2005)).

zero, the market maker perceives with the highest probability the informed investor no trade status. In the intermediate region small movement in Θ can create large asset price movements.

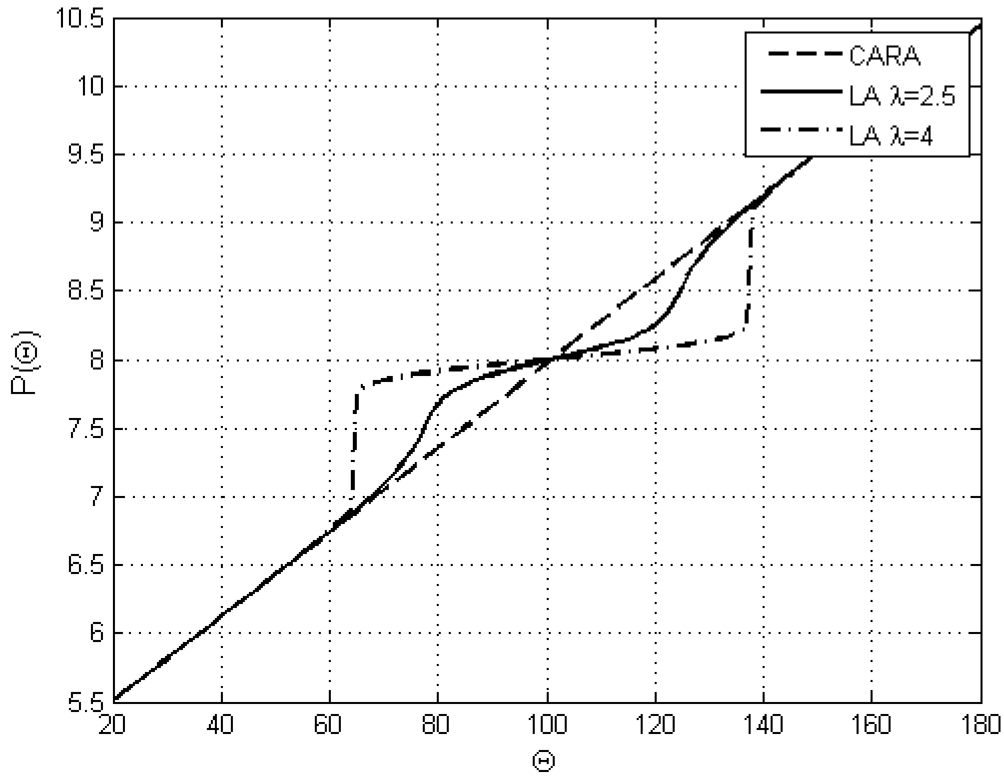

Figure 3. Equilibrium price. The dash line, and the solid line and the dash-dotted line, represent equilibrium price for risk averse speculators and loss averse speculators with coefficient of loss aversion of 2.5 and 4 respectively.

The unique interaction between loss aversion of the speculators and adverse selection between the informed traders and the market maker can indeed create in our simplified model market crisis as well as important upward market price movements. Figure 4 graphs the sensitivity of equilibrium price to signal and noise trading shocks for a simplest economy with asymmetric information and risk avesre informed agent (CARA-Normal) and for an economy populated by loss averse informed traders with private information. The equilibrium price becomes sensitive to shocks in the intermediate price region when it is more difficult for the market maker to infer the quality of the private signal and to conjecture about the trading status of informed traders. The magnitude of such sensitivity decreases with the degree of the precision of the private signal and increase with the level of speculators' loss aversion. Large market downturns or upturns in this model may occur regardless of the value of the underlying asset. Our simple model confirms empirical findings, reported by Culter, Poterba and Summers (1989) that important prices movement can occur without any particular news event.

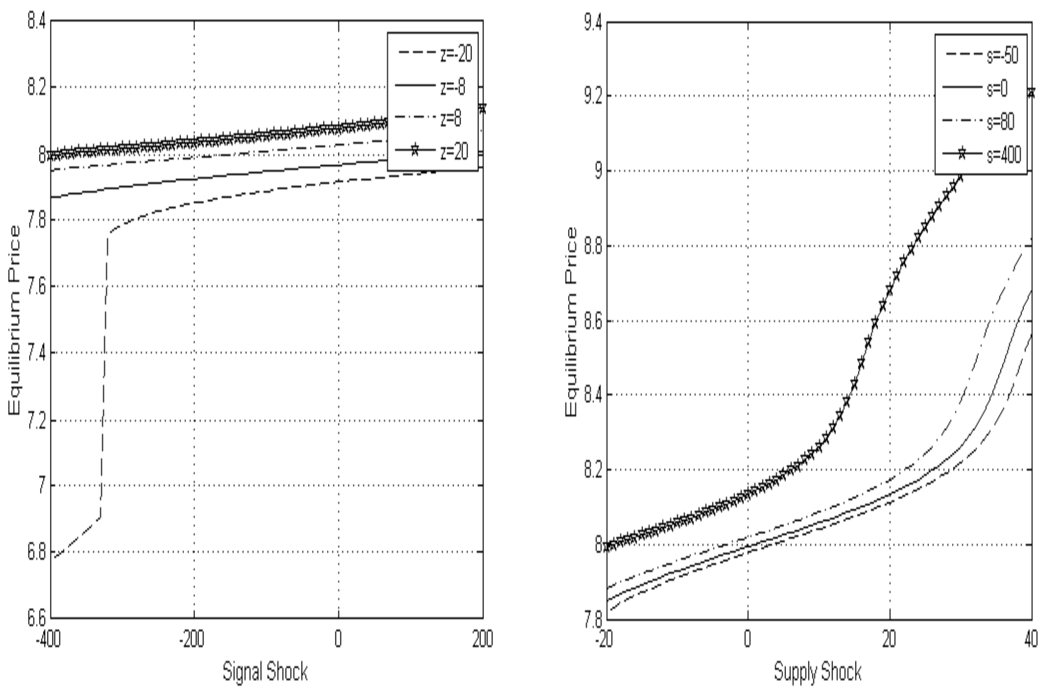

Figure 4. Price sensitivity to signal and supply shocks. The lines in the left graph represent equilibrium price as a function of the signal shock when the supply shock is -20,-8,20 and ,8, respectively. The lines in the right graph represent equilibrium price as a function of supply shock when the signal shock is -50,0,80, and 400.

Market Liquidity

All rational expectation equilibrium models have a particular property, equilibrium price have a dual effect, a substitution effect and an information effect. The market maker attempts to offset losses of the noise traders due to adverse selection of the speculators. As in Kyle (1985) we denote the market liquidity measure λ_{LA}^{-1} as the inverse of the *price impact* $\lambda_{LA} = \frac{\partial P}{\partial z}$ where the underscript LA refers to Loss Aversion preferences. By the Implicit Function Theorem, the equilibrium market liquidity is the inverse of

$$\lambda_{LA} = \frac{A\left[1-\Phi(H)+\Phi(L)\right]}{1+\frac{A}{\sigma_v \rho}\left(\frac{s}{\gamma\sigma_\varepsilon^2}+z\right)\left(\psi(H)-\psi(L)\right)+\left(1-\sqrt{B}\right)\left(L\psi(L)-H\psi(H)\right)} \tag{12}$$

where $A = \frac{\gamma\sigma_v^2\sigma_\varepsilon^2}{\sigma_v^2+\sigma_\varepsilon^2\left(1+\gamma^2\sigma_\varepsilon^2\sigma_z^2\right)}$, $B = \frac{\gamma^2\sigma_z^2\sigma_\varepsilon^4}{\sigma_v^2+\sigma_\varepsilon^2\left(1+\gamma^2\sigma_\varepsilon^2\sigma_z^2\right)}$, $H = \frac{\frac{P}{\rho^2}+\Delta}{\sqrt{\sigma_v^2+\sigma_\varepsilon^2}}$, and $L = \frac{\frac{P}{\rho^2}-\Delta}{\sqrt{\sigma_v^2+\sigma_\varepsilon^2}}$.

For $\lambda = 1, \Delta = 0$ as in Pasquariello (2014), the price impact is reduced to the equilibrium price impact of a risk averse speculator with constant absolute risk aversion

$$\lambda_{CARA} = A = \frac{\gamma\sigma_v^2\sigma_\varepsilon^2}{\sigma_v^2+\sigma_\varepsilon^2\left(1+\gamma^2\sigma_\varepsilon^2\sigma_z^2\right)}. \tag{13}$$

As in Kyle (1985) and Vives (1995), the equilibrium price impact for CARA speculators is positive $A > 0$ and increases in σ_v^2, highlighting the market maker's willingness to offset losses due to the speculator's adverse selection with profits to noise trading. Thus, the more uncertain the payoff, the more valuable is the private information and hence the less liquid in equilibrium become the market. However consistent with

Vives (1995) the depth of the market λ_{CARA}^{-1} is increasing in noise trading σ_z^2 and nonmonotonic in risk aversion (γ) and the precision of the signal $(1/\sigma_\varepsilon^2)$. In equilibrium, it is easy to show that if $\gamma < \frac{\sqrt{\sigma_\varepsilon^2 + \sigma_v^2}}{\sigma_\varepsilon^2 \sigma_z}$, the depth of the market increases in risk tolerance and if $\sigma_\varepsilon^2 < \frac{\sigma_v}{\gamma \sigma_z}$ the depth increases with the precision of the private signal. The reason is that although these changes tend to increase the adverse selection of speculators it increases likewise the trading intensity and the information revealed to the market maker.

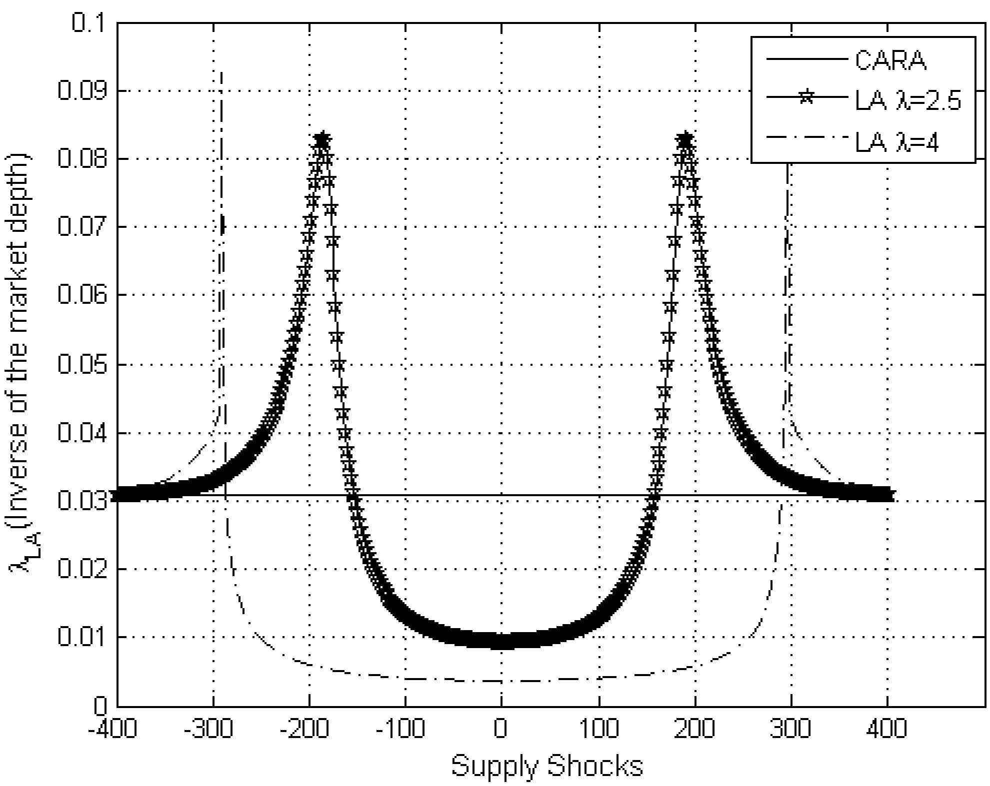

Figure 5. Price Impact. The graph above represents the price impact (Inverse measure of liquidity) in function of noise traders shocks where the private signal shock is 0. for risk averse speculators and loss averse speculators with coefficient of loss aversion of 2.5 and 4 respectively.

As stated above, the equilibrium price in our model is a non linear function of both signal intensity and the noise traders demand *z*. Thus, the price impact is not a constant. However in the extreme region of the equilibrium price, the price impact λ_{LA} of the implicit function is equal to the price impact in the presence of CARA speculators

$$\lim_{P \to \infty} \lambda_{LA} = A = \lambda_{CARA}. \tag{14}$$

For sufficiently large value of *P*, the relation between equilibrium market liquidity and all the parameters of the model (except loss aversion) is indeed the same as for the case of risk averse informed traders.

For intermediate price region, the market depth is highly nonlinear in noise trading demand. As for the CARA normal case, the price impact is nonnegative since the market maker attempt to offset losses due to the presumably adverse selection of the speculator with profits from noise trading. Figure 5 illustrates a numerical example of price impact for a given signal shock, with the specific calibration of the technology parameters discussed above, and for different degrees of loss aversion. We can separate the price impact into three distinct states corresponding to three different levels of inferred likelihoods of informed trading status by the market maker. When the price impact is close to zero the market maker conjectures with high probability that the insider did not trade and she does not need to cope with the adverse selection problem. However, when the price impact is constant the problem is reduced to the mean variance case since the trading intensity (ζ) for the trading region is equivalent to the trading intensity of mean variance speculator. Finally in between, the market depth emphasizes the difficulty for the market maker to infer the trading status and thus a small supply shock can have a huge effect, a priori not justified, on the equilibrium price while the market maker misinterpreted the trading status of the informed trader. The market maker cannot indeed, distinguishes between a shock in the private signal and a shock in the noisy demand. Our model supports recent empirical evidence suggesting that the relationship between orders and price adjustment may be nonlinear. Moreover, as reported by Farmer et al. (2004) large price fluctuations occur when the market depth is low in line with the presented comparative static analysis. It is also consistent with the empirical study conducted by Pastor and Stambaugh (2003) where the authors use a related measure of price sensitivities as measures of market liquidity. They find several episodes of extremely low aggregate liquidity, including the October-1987 crash and the LTCM crisis of September 1998.

Informed trading volume, and volatility

Based on the optimal demand schedule derived in equation (3), the expected trading intensity of loss averse speculators is lower than for mean variance speculators ($\sum_{k=1}^{3}\Pr\left(x\in I_k\right)\frac{\partial x_{LA}}{\partial s}\leq\frac{\partial x_{CARA}}{\partial s}$, where I_k refers to one of the three different trading regions), and it decreases with the degree of loss aversion. The expected informed trading volume is defined as $E\left[\left|x\right|\right]$ and the ex-ante price volatility as the variance of the equilibrium price. For mean variance speculator only, the equilibrium price P_{CARA} is normally distributed. Thus, the ex-ante price volatility is $\operatorname{var}\left(P_{CARA}\right)=\frac{\sigma_v^4}{\sigma_v^4+\sigma_\varepsilon^2\left(1+\gamma^2\sigma_\varepsilon^2\sigma_z^2\right)}$ and from the well known property of half normal distribution variance, $E\left[\left|x_{CARA}\right|\right]=\sqrt{\frac{2}{\pi}}\frac{\sigma_z\sqrt{\sigma_\varepsilon^2+\sigma_v^2}}{\sqrt{\sigma_\varepsilon^2\left(1+\gamma^2\sigma_\varepsilon^2\sigma_z^2\right)+\sigma_v^2}}$.

The intuition suggests that the presence of better informed loss adverse speculators should lower the expected trading volume as well as the ex-ante price volatility because the average trading intensity decreases with loss aversion. In order to confirm this intuition, we estimate the kernel of the price distribution and we compute empirically the expected trading volume for different calibration values. Similarly to the finding of Pasquariello (2014) for speculators with prospect theory preferences, we do find that the expected informed trading volume as well as ex-ante price volatility is lower in our model compare to the CARA-Normal benchmark and it decreases with loss aversion.

The effect of loss aversion on trading volume contradicts empirical evidence that trading volume is extremely large across all developed stock markets. However, the negative correlation between loss aversion and trading volume may support that trading volume appears to act as an indicator of investor sentiment (Hong and Stein (2007)). Let follow Barberis, Huang and Santos (2001). If allowing the pain of the loss to depend not only of the loss but also on investment performance prior to the loss, our simple model might explain why high-priced stocks with a long experience of prior gains tend to have higher volume than low priced value stocks.

III. Conclusion and Directions for Future Work

A closed-form characterisation of the equilibrium market price in the presence of loss averse better informed trader is presented in this paper. This work extends the actual literature on asymmetric information with prospect theory preferences. This study provides for the first time a tractable equilibrium solution in an economy with asymmetric information and loss aversion.

Moreover, we successfully disentangle the effect of loss aversion and risk aversion on equilibrium price and market depth. We show that loss aversion decreases the ex-ante price volatility and the informed trading volume.

In addition, the unique interaction between loss aversion and asymmetric information can produce in our simple model important price movements. Loss aversion, while affecting speculators willingness to trade, adds also another dimension to the difficulty for the market maker to infer the private information from the optimal demand schedule of the informed trader. When the aggregate order flow is low, the market maker is confusing about speculators' trading status and the equilibrium price as well as the market depth becomes highly non-linear. In that situation, a small adverse shock to the fundamentals can trigger a large drop in asset value.

Other generalization of the model could be quite interesting. Examining the impact of private information on insurance and hedging with loss aversion should allow us to study the welfare consequences of improvements in private information release with more realistic preferences.

Allowing also for both overconfidence and loss aversion is very important to asses more realistically the impact of behavioral biases on financial markets. Indeed, a large number of papers that study the phenomenon of overconfidence on adverse selection in financial markets predict a higher trading volume and volatility in contradiction with our finding. However developing a model with both these two main apparently contradicting behavioral biases can broaden our understanding of financial market and can probably shed light on certain striking features such as the relation trading volume and turnover, under and overreaction and negative skewness of asset return.

Appendix A

Derivation of equation (2)

The utility function can be written as

$$U(\pi,\gamma,\lambda) = -\frac{1}{\gamma}e^{-\gamma\pi} - \frac{(\lambda-1)}{\gamma}\left(1+e^{-\gamma\pi}\right)1\{\pi>0\}\,. \tag{A1}$$

The conditional expectation is given by

$$E\left[U(\pi,\gamma,\lambda)\middle|s\right] = -\frac{1}{\gamma}E\left[e^{-\gamma\pi}\middle|s\right] - \frac{(\lambda-1)}{\gamma}\left(1+E\left[e^{-\gamma\pi}\middle|s,\ \pi>0\right]\right)\Pr\left(\pi>0\middle|s\right) \tag{A2}$$

where

$$E\left[e^{-\gamma\pi}\middle|s\right] = e^{-\gamma\left(\mu_{v/s}-P\right)x+\frac{\gamma^2x^2\sigma_{v/s}}{2}}\,. \tag{A3}$$

For $x>0$

$$\Pr\left(x(\tilde{v}-P)>0\middle|s\right) = \Phi\left(-\frac{\mu_{v/s}-P}{\sigma_{v/s}}\right)\,, \tag{A4}$$

and

$$E\left[e^{-\gamma\pi}\left|s,\ \pi>0\right.\right]=e^{\gamma P}E\left[e^{-\gamma v}\left|s,\ \tilde{v}>P\right.\right]=\frac{\int_P^{\infty}(2\pi)^{1/2}e^{-\gamma(z-P)x}e^{-\left(z-\mu_{v/s}\right)^2/2\sigma_{v/s}^2}dz}{\Phi\left(-\frac{\mu_{v/s}-P}{\sigma_{v/s}}\right)}$$

$$=e^{-\gamma(\mu_{v/s}-P)x+\frac{\gamma^2x^2\sigma_{v/s}}{2}}\frac{\int_P^{\infty}(2\pi)^{1/2}e^{-\frac{\left(z-\left(\mu_{v/s}-x\gamma\sigma_{v/s}^2\right)\right)^2}{2\sigma_{v/s}^2}}dz}{\Phi\left(-\frac{\mu_{v/s}-P}{\sigma_{v/s}}\right)}=\frac{e^{-\gamma(\mu_{v/s}-P)x+\frac{\gamma^2x^2\sigma_{v/s}}{2}}\Phi\left(-\frac{\mu_{v/s}-x\gamma\sigma_{v/s}^2-P}{\sigma_{v/s}}\right)}{\Phi\left(-\frac{\mu_{v/s}-P}{\sigma_{v/s}}\right)} \tag{A5}$$

and for $x\le 0$,

$$\Pr\left(x(\tilde{v}-P)>0\left|s\right.\right)=\Phi\left(\frac{\mu_{v/s}-P}{\sigma_{v/s}}\right), \tag{A6}$$

and

$$E\left[e^{-\gamma\pi}\left|s,\ \pi>0\right.\right]=e^{\gamma P}E\left[e^{-\gamma v}\left|s,\ \tilde{v}<P\right.\right]=\frac{e^{-\gamma(\mu_{v/s}-P)x+\frac{\gamma^2x^2\sigma_{v/s}}{2}}\Phi\left(\frac{\mu_{v/s}-x\gamma\sigma_{v/s}^2-P}{\sigma_{v/s}}\right)}{\Phi\left(\frac{\mu_{v/s}-P}{\sigma_{v/s}}\right)} \tag{A7}$$

Plugging (A3), (A4), (A5), (A6) into (A7) yield to equation (2)

Appendix B

Derivation of equation (9)

Each conditional expectation and probability of equation (10) is tractable in our setting. Since *z* and *v* are independent, for the no-trade region we have

$$E\left[v\left|\omega,\left|s-\Delta\right|\le\frac{P}{\rho^2}\right.\right]=E\left[v\left|z,\left|s-\Delta\right|\le\frac{P}{\rho^2}\right.\right]=E\left[v\left|\frac{P}{\rho^2}-\Delta\le s\le\frac{P}{\rho^2}+\Delta\right.\right] \tag{B1}$$

whereas for the informed trading region

$$E\left[v\middle|\omega, s \le \frac{P}{\rho^2}-\Delta\right] = E\left[v\middle|\omega_1 = \frac{\rho^2 s - P}{\gamma\sigma_v^2\left(1-\rho^2\right)} + \frac{\Lambda(\lambda)}{\gamma\sigma_v\sqrt{1-\rho^2}} + z, s \le \frac{P}{\rho^2}-\Delta\right] \qquad \text{(B2)}$$

and

$$E\left[v\middle|\omega, s > \frac{P}{\rho^2}+\Delta\right] = E\left[v\middle|\omega_2 = \frac{\rho^2 s - P}{\gamma\sigma_v^2\left(1-\rho^2\right)} - \frac{\Lambda(\lambda)}{\gamma\sigma_v\sqrt{1-\rho^2}} + z, s \ge \frac{P}{\rho^2}+\Delta\right] \qquad \text{(B3)}$$

We can express the conditional moments of the truncated normal variables in closed-formed (Greene (2002) (pp.781-782), and Madala (1986)).

$$E\left[v\middle|\frac{P}{\rho^2}-\Delta \le s \le \frac{P}{\rho^2}+\Delta\right] = \rho\sigma_v \frac{\phi\left(\dfrac{\frac{P}{\rho^2}+\Delta}{\sqrt{\sigma_v^2+\sigma_\varepsilon^2}}\right) - \phi\left(\dfrac{\frac{P}{\rho^2}-\Delta}{\sqrt{\sigma_v^2+\sigma_\varepsilon^2}}\right)}{\Phi\left(\dfrac{\frac{P}{\rho^2}+\Delta}{\sqrt{\sigma_v^2+\sigma_\varepsilon^2}}\right) - \Phi\left(\dfrac{\frac{P}{\rho^2}-\Delta}{\sqrt{\sigma_v^2+\sigma_\varepsilon^2}}\right)}. \qquad \text{(B4)}$$

While for the trading region we have

$$E\left[v\middle|\omega_1, s \le \frac{P}{\rho^2}-\Delta\right] = \mu_{v/\omega_1} - \frac{\rho^*\sigma_{v/\omega_1}\phi\left(\dfrac{\frac{P}{\rho^2}-\Delta}{\sqrt{\sigma_v^2+\sigma_\varepsilon^2}}\right)}{\Phi\left(\dfrac{\frac{P}{\rho^2}-\Delta}{\sqrt{\sigma_v^2+\sigma_\varepsilon^2}}\right)}, \qquad \text{(B5)}$$

and

$$E\left[v \middle| \omega_2, s > \frac{P}{\rho^2} + \Delta\right] = \mu_{v/\omega_2} + \frac{\rho^* \sigma_{v/\omega_2} \phi\left(\dfrac{\frac{P}{\rho^2} + \Delta}{\sqrt{\sigma_v^2 + \sigma_\varepsilon^2}}\right)}{1 - \Phi\left(\dfrac{\frac{P}{\rho^2} + \Delta}{\sqrt{\sigma_v^2 + \sigma_\varepsilon^2}}\right)}, \tag{B6}$$

where ρ^* refers to correlation coefficient of the conditional bivariate normal variable $v, s|\omega$.

The conditional expectation and standard deviation of normal random (Greene 26, p. 90) are

$$\mu_{v/\omega} = \frac{\operatorname{cov}(v,\omega)}{\operatorname{var}(\omega)}\left(\omega - E[\omega]\right) \quad \text{and} \quad \sigma_{v/\omega} = \sigma_v\left(1 - \frac{E[v\omega]}{\sigma_v \sigma_\omega}\right) \tag{B7}$$

where $w - E(\omega) = \frac{s}{\gamma \sigma_\varepsilon^2} + z$; $\operatorname{cov}(v,\omega) = \frac{\sigma_v^2}{\gamma \sigma_\varepsilon^2}$ and $\operatorname{var}(\omega) = \frac{1}{\gamma^2 \sigma_\varepsilon^2} + \frac{\sigma_v^2}{\gamma^2 \sigma_\varepsilon^2} + \sigma_z^2$. Equation (B8) is the same for the lower region $\omega_1 = \frac{\rho^2 s - P}{\gamma \sigma_v^2 \left(1 - \rho^2\right)} + \frac{\Lambda(\lambda)}{\gamma \sigma_v \sqrt{1 - \rho^2}} + z$ as well as for the upper region $\omega_2 = \frac{\rho^2 s - P}{\gamma \sigma_v^2 \left(1 - \rho^2\right)} - \frac{\Lambda(\lambda)}{\gamma \sigma_v \sqrt{1 - \rho^2}} + z$.

Therefore

$$\mu_{v/\omega_1} = \mu_{v/\omega_2} = \mu_{v/\omega} = \frac{\gamma \sigma_v^2 \sigma_\varepsilon^2}{\sigma_v^2 + \sigma_\varepsilon^2\left(1 + \gamma \sigma_\varepsilon^2 \sigma_z^2\right)}\left(\frac{s}{\gamma \sigma_\varepsilon^2} + z\right), \tag{B8}$$

and

$$\sigma_{v/\omega} = \sigma_{v/\omega_1} = \sigma_{v/\omega 2} = \sqrt{\frac{\sigma_v^2 \sigma_\varepsilon^2\left(1 + \sigma_z^2 \gamma^2 \sigma_\varepsilon^2\right)}{\sigma_v^2 + \sigma_\varepsilon^2\left(1 + \sigma_z^2 \gamma^2 \sigma_\varepsilon^2\right)}}. \tag{B9}$$

Using well known properties of conditional multivariate normal distribution (Rencher (2002) (pp. 88)), the variance covariance matrix and correlation coefficient bivariate normal variable $v, s|\omega$ are:

$$\Sigma^* = \begin{bmatrix} \dfrac{\sigma_v^2\sigma_\varepsilon^2\left(1+\sigma_z^2\gamma^2\sigma_\varepsilon^2\right)}{\sigma_v^2+\sigma_\varepsilon^2\left(1+\sigma_z^2\gamma^2\sigma_\varepsilon^2\right)} & \dfrac{\gamma^2\sigma_\varepsilon^4\sigma_z^2\sigma_v^2}{\sigma_v^2+\sigma_\varepsilon^2\left(1+\sigma_z^2\gamma^2\sigma_\varepsilon^2\right)} \\ \dfrac{\gamma^2\sigma_\varepsilon^4\sigma_z^2\sigma_v^2}{\sigma_v^2+\sigma_\varepsilon^2\left(1+\sigma_z^2\gamma^2\sigma_\varepsilon^2\right)} & \dfrac{\gamma^2\sigma_\varepsilon^4\left(\sigma_v^2+\sigma_\varepsilon^2\right)\sigma_z^2}{\sigma_v^2+\sigma_\varepsilon^2\left(1+\sigma_z^2\gamma^2\sigma_\varepsilon^2\right)} \end{bmatrix}, \tag{B10}$$

where Σ^* is the same for ω_1 as well as for ω_2 . From Σ^*, we find that

$$\rho^* = \frac{\rho\gamma\sigma_z\sigma_\varepsilon}{\sqrt{1+\gamma^2\sigma_\varepsilon^2\sigma_z^2}} \tag{B11}$$

The probabilities of equation (10) are given by

$$\Pr\left[\left|s-\Delta\right| \le \frac{P}{\rho^2}\right] = \Phi\left(\frac{\frac{P}{\rho^2}+\Delta}{\sqrt{\sigma_v^2+\sigma_\varepsilon^2}}\right) - \Phi\left(\frac{\frac{P}{\rho^2}-\Delta}{\sqrt{\sigma_v^2+\sigma_\varepsilon^2}}\right);\ \Pr\left[s \le \frac{P}{\rho^2}-\Delta\right] = \Phi\left(\frac{\frac{P}{\rho^2}-\Delta}{\sqrt{\sigma_v^2+\sigma_\varepsilon^2}}\right),$$

$$\text{and}\quad \Pr\left[s > \frac{P}{\rho^2}+\Delta\right] = 1-\Phi\left(\frac{\frac{P}{\rho^2}+\Delta}{\sqrt{\sigma_v^2+\sigma_\varepsilon^2}}\right) \tag{B12}$$

The equation (10) is then obtained by replacing (B8), (B9), and (B11) into (B6), (B5) and (B6) (B5) and (B12) into equation (9).

REFERENCES

Admati, Anat R., 1985, A noisy rational expectations equilibrium for multi-asset securities markets, *Econometrica* 53, 629-657.

Allais, Maurice, 1953, Le comportement de l'homme rationnel devant le risque : critique des postulats et axiomes de l'école américaine, *Econometrica* 21, 503-546.

Baltussen, Guido, Thierry Post, and Pim van Vliet, 2006, Violations of cumulative prospect theory in mixed gambles with moderate probabilities, *Management Science,* 52, 1288 - 1290.

Bekaert, Geert, and Guojun Wu, 2000, Asymmetric volatility and risk in equity markets, *Review of Financial Studies* 13, 1–42.

Benartzi, Shlomo, and Richard H. Thaler, 1995, Myopic loss aversion and the equity premium puzzle, *Quaterly Journal of Economics* 110, 73–92.

Berkelaar, Arjan, Roy Kouwenberg, and Thierry Post, 2004, Optimal portfolio choice under loss aversion, *The Review of Economics and Statistics* 86, 973–987.

Culter, David M., James M. Poterba, and Lawrence H. Summers, 1989, What moves stock prices, *Journal of Portfolio Management* 15, 4–12.

Diamond, Douglas, and Robert E. Verrecchia, 1981, Information aggregation in a noisy rational expectations economy, *Journal of Financial Economics* 9, 221–235.

J. Doyne Farmer, and Fabrizio Lillo, 2004, On the Origin of Power-Law Tails in Price Fluctuations**,** *Quantitative Finance* 4**,** C7–C10.

Francisco J. Gomes, 2005, Portfolio choice and trading volume with loss-averse investors, *Journal of Business* 78, 675–706.

French, Kenneth R., William G. Schwert, and Robert Stambaugh, 1987, Expected stock returns and volatility, *Journal of Financial Economics* 19, 3–29.

Genesove, David, and Christopher Mayer, 2001, Loss aversion and seller behavior: evidence from the housing market, *Quarterly Journal of Economics* 116, 1233–1260.

Genotte, Gerard and Leland, Hayne, 1990, Market liquidity, hedging and crashes, *American Economic Review* 80, 999-1021.

Greene, William H., 2002, *Econometric Analysis, 5th edition* (Prentice Hall: New York, NY).

Grossman, Sanford J., and Joseph E. Stiglitz, 1980, On the impossibility of informationally efficient markets, *American Economic Review* 70, 393–408.

Hellwig, Martin F., 1980, On the aggregation of information in competitive markets, Journal *of Economic Theory* 22, 477-498.

Hirshleifer, David, Avanidhar Subrahmanyam, and Sheridan Titman, 1994, Security analysis and trading patterns when some investors receive information before others, *Journal of Finance* 49, 1665-1698.

Hong, Harrison, Terence Lim, and Jeremy C. Stein, 2000, Bad news travels slowly: size, analyst coverage, and the profitability of momentum strategies, *The Journal of Finance* 55, 265-295.

Hong, Harrison, and Jeremy Stein, 2007, Disagreement and the stock market, *The Journal of Economic Perspective* 21, 109-128.

Kahneman, Daniel, Jack L. Knetsch, and Richard H. Thaler, 1990, Experimental tests of the endowment effect and the coase theorem, *Jounal of Political Economy,* 98, 1325–48.

Kahneman, Daniel, and Amos Tversky, 1979, Prospect theory: an analysis of decision under risk, *Econometrica* 47, 263–91.

Kyle, Albert S., 1985, Continuous auctions and insider trading, *Econometrica* 53, 1315–35.

Maddala, G. S., 1986, *Limited-dependent and qualitative variables in econometrics* (Cambridge University Press: Cambridge, UK).

Odean Terrance., 1998, Are investors reluctant to realize their losses? *The Journal of Finance* 53, 1775–1798.

Pasquariello Paolo, 2014, Prospect theory and market quality, *Journal of Economic Theory* 149, 276–310.

Pástor**,** Lubos, and Robert F. Stambaugh, 2003, Liquidity risk and expected stock returns, *Journal of Political Economy* 111, 642–68.

Pindyck, Robert S., 1984, Risk, inflation, and the stock market, *American Economic Review* 74, 334–351.

Rencher Alvin C., 2002, *Methods of Multivariate Analysis*. (John Wiley & Sons Inc.: New York).

Starmer, Chris, 2000, Developments in non-expected utility theory: The hunt for a descriptive theory of choice under risk, *Journal of Economic Literature* 38, 32–82.

Thaler, Richard. H., 1980. Toward a Positive Theory of Consumer Choice. *Journal of Economic Behavior and Organization* 1:1, 39–60.

Vives, Xavier, 1995, Short-term investment and the informational efficiency of the market, *Review of Financial Studies* 8, 125–160.

von Gaudecker, Hans-Martin, Arthur van Soest, and Erik Wengstrom, 2011, Heterogeneity in risky choice behavior in a broad population, *American Economic Review* 101, 666–694.

Weber, Martin and Colin F. Camerer, 1998, The disposition effect in securities trading: an experimental analysis, *Journal of Economic Behavior & Organization* 33, 167–184.

Yuan, Kathy, 2005, Asymmetric price movements and borrowing constraints: A REE model of crisis, contagion, and confusion, *Journal of Finance* 60, 379–411.