INFORMED OPTION TRADING STRATEGIES:
THE IMPACT ON THE UNDERLYING PRICE PROCESS

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Abstract	We use a sequential trade model to clarify two mechanisms following the introduction of an option that may lead to increased efficiency in the underlying. On the one hand, market makers learn from trades in the option market and set more accurate prices. On the other hand, the proportion of informed traders in the stock market may be altered depending on the informed traders' strategies. If insiders trade a larger fraction than uninformed traders in the stock, for example because the immediate profits in the stock are larger, spreads in the stock widen, and price errors may increase. This reduces the efficiency increase from the 'learning' effect, possibly to the extent that overall efficiency deteriorates. We use simulations to analyze the resulting impact in a dynamic setting. For realistic parameter values we find that option trading leads to lower price errors in the underlying. The more popular options are, the more quickly information is incorporated in the underlying prices. However, uninformed traders do not necessarily benefit from this speedier convergence. Their stock performance crucially depends on the insider's trading strategy and the fraction of informed trading.	
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Informed option trading strategies:

the impact on the underlying price process

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We use a sequential trade model to clarify two mechanisms following the introduction of an option that may lead to increased efficiency in the underlying. On the one hand, market makers learn from trades in the option market and set more accurate prices. On the other hand, the proportion of informed traders in the stock market may be altered depending on the informed traders' strategies. If insiders trade a larger fraction than uninformed traders in the stock, for example because the immediate profits in the stock are larger, spreads in the stock widen, and price errors may increase. This reduces the efficiency increase from the 'learning' effect, possibly to the extent that overall efficiency deteriorates. We use simulations to analyze the resulting impact in a dynamic setting. For realistic parameter values we find that option trading leads to lower price errors in the underlying. The more popular options are, the more quickly information is incorporated in the underlying prices. However, uninformed traders do not necessarily benefit from this speedier convergence. Their stock performance crucially depends on the insider's trading strategy and the fraction of informed trading.

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1. Introduction

There exists a large body of empirical work on the impact of option trading on the time-series properties of the underlying. Of the comparatively small number of theoretical papers, at least two use a sequential trade model in the spirit of Glosten and Milgrom (1985): Easley, O'Hara and Srinivas (1998; further referred to as Easley et al), and a working paper by John, Koticha, Narayanan and Subrahmanyam (2000; further referred to as John et al). Both models are developed in an asymmetric information setting in which informed traders may trade in stock or option markets. Easley et al (1998) study whether option markets attract informed trading and whether they incorporate information more quickly than stock markets. They derive that under certain conditions options are attractive to traders with superior information and find empirical support for the phenomenon that properly defined bullish and bearish option volume has predictive power for the price process of the underlying. John et al (2000) focus on the impact of option trading on the efficiency of the underlying price process, and the role of margin requirements. Depending on the criterion used, they find that options increase or decrease efficiency.

We start from the viewpoint that as long as some informed traders use options, option trades convey information about the underlying. Similar to John et al (2000) this paper's central theme is the impact of option trading on various efficiency criteria of the underlying security. Contrary to their analysis however, we derive the criteria in a dynamic setting and analyze them for different reasonable insider strategies.

First, we elaborate on a model similar to theirs, and show that the model is inherently dynamic. Expectations are updated after every trade, which allows us to study a sequence of trades and analyze new and more precise criteria. We will show that the focus on only first trades, leads to the use of inaccurate efficiency criteria. Our analysis indicates that an option may serve as an extra source from which information can be inferred, which speeds up convergence. However, we also find that uninformed traders do not necessarily benefit from this speedier convergence, especially when there are few informed traders.

In the initial design the dealer maximizes profits on every individual trade. This is realistic if there is strong competition among informed traders, but we believe this might not always be the case in practice. We show that other strategies are preferable when the insider is concerned about the effect of his trades on future profit opportunities, or when he has limited investment resources. In general, in other strategies the insider directs more trading from the stock to the option market, which might make it harder to identify him among the other traders. When the insider (temporarily) has a monopolistic position, he will choose a strategy that resembles the uninformed traders' randomization across stock and option markets in order to hide his information. This dynamic strategy leads to a slower convergence, but also smaller spreads in the stock market. When the insider has limited resources to invest, or when the insider can trade at a larger size in the option, more informed trades will be directed to the option market, and underlying spreads decrease even more.

2. The model

We develop a sequential trade model that is similar in nature to that of Easley et al (1998) and John et al (2000). These two papers add one or two plain-vanilla options to the model of Glosten and Milgrom (1985). In our model, trading takes place in two assets, a stock and a call option on that stock. Results are qualitatively the same if a put instead of a call option, or both, would be included. We include only one option type to facilitate the derivations and the insights in the most import mechanisms.

The model is a standard adverse selection model in market microstructure. It explains how market mechanisms lead prices to efficient values when some traders have information superior to others. For a discussion of the different assumptions and the resemblance with real world markets, we especially refer to the papers by Glosten and Milgrom (1985) and Easley and O'Hara (1987). The market is quote driven, which means that buyers and sellers trade with a market maker (also referred to as dealer or specialist), who is responsible for providing bid and ask quotes. We assume market makers are profit maximizing and risk-neutral. Trading takes place for one unit of one asset at a time. Liquidity and inside traders initiate trades. The liquidity traders trade for reasons of liquidity, such as portfolio rebalancing and time-varying consumption and income. We do not further specify their reasons for trading, but assume their demand and supply is completely inelastic, so independent of the outstanding quotes. This excludes the possibility of a market breakdown. The informed traders get private and perfect signals regarding the true asset value. They are completely free to engage in trades and will do so in the pursuit of profits.

The random variable S represents the intrinsic value of the stock, and the random variable C the intrinsic value of the option. The true asset value may be regarded as a value that every market participant agrees upon after all information has become public. The stock value can either take on a low value X-v or a high value X+v. These stock values occur with respective probabilities of d_L and d_H, whose sum equals unity. The option has an exercise price of X and its value can directly be derived from the value of the stock: C = Max[0, S-X].

All possible outcomes of a single transaction and their relative probabilities are depicted in figure 1. At the beginning of a period, the informed trader receives a signal indicating whether the stock value is high or low. Next, trading for that period begins. Dealers set quotes to buy or sell during the trading period, execute orders as they arrive, and then revise their quotes. Informed traders always buy when the stock value is high, sell when it is low. Liquidity traders on the other hand have an equal probability to buy or sell[1]. Informed and uninformed traders anonymously post trades at random intervals in both markets, making it for the dealers a priori impossible to determine whether they trade with an informed or uninformed trader. The probability that they trade with an informed trader is μ, with an uninformed trader $1-\mu$. Liquidity traders (LT) also randomize their trades across stock and option markets, with a propensity for the stock of β and for the option of $1-\beta$. To summarize their strategy:

$$\Pr[\text{LT buys S}] = \Pr[\text{LT sells S}] = \tfrac{1}{2}(1-\mu)\beta$$

$$\Pr[\text{LT buys C}] = \Pr[\text{LT sells C}] = \tfrac{1}{2}(1-\mu)(1-\beta)$$

It can be shown that the insider is better off not entering in unprofitable trades (see for example John et al (2000)). Although unprofitable trades may confuse dealers, the losses incurred can not be recouped sufficiently to justify such a strategy. If there is at least some probability of uninformed trader activity, the dealers' bids and asks in the stock are strictly in between their minimum and maximum theoretical values. Therefore, when the stock value is high, the insider can profitably buy both assets; when it is low, the insider can profitably sell both assets.

The insider always has two profitable trading opportunities, one in the stock and one in the option. From the outset it is unclear what trading strategy would be optimal. We explore three different strategies. In the first the insider maximizes profits at every individual trade, and is not concerned about the effect of trading on prices. This strategy could be justified by the presence of many other informed traders, who will cause available profits to vanish quickly. We denote the probability that an informed trader transacts in the stock by p (p_L for a low stock value, p_H for a high stock value). If one market offers a larger profit than the other, the insider employs a pure strategy, and only trades the more profitable asset. If both markets offer the same profit, the insider randomizes between stock and option with relative preferences such that profits in both markets are indeed equal, and the market is in equilibrium. This is the strategy explored in Easley et al (1998) and John et al (2000). As we will see later in the text, it leads to a relative preference for the stock market.

In the second strategy, the insider is concerned about the effect of trading on prices. One explanation is that the insider expects to destroy future trading profits if he trades too openly on his information. Alternatively, due to regulatory restrictions the insider might not be allowed to trade on inside information and tries to hide his trades. In order to disguise his superior information, the insider does not want to distinguish himself too much from the other traders, and will direct more trades to the option market than in the first strategy.

The third strategy also leads to an increased preference for the option, but motivated by the insider having limited investment resources. In that case, he will not primarily

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[1] Changing the latter assumption makes the derivation of results more cumbersome, but leaves the results qualitatively unchanged.

be concerned about absolute profits, but also in returns. Allowing trade size in the option to be larger than in the stock, as in Easley et al (1998) has the same effect. Although margin requirements in the option increase the required investment in the option, total investment for one unit of the option will always be lower than for one unit in the stock. This leverage effect improves the attractiveness of the option market.

A small remark applies to a difference in design with several other sequential trade models. In our model there is always someone in the market with inside information, although a random information event would be closer to real world markets, where no one might have an informational advantage. If inside information is known to exist, it is even common practice in real world markets to halt trading until it is publicly announced. However, the random occurrence of information in our setup has the same effect as a decrease in the possibility of an insider trade. To simplify the analysis, we therefore assume an information event always occurs.

3. Efficiency criteria

John et al (2000) study two different criteria to measure differences in efficiency, of which the first is the initial spread in the stock. If we define the bid in the stock at the time of the *t*'th transaction (either stock or option) as $B_{s,t}$, the corresponding ask as $A_{s,t}$, then the initial spread $\Delta_{s,1}$ equals:

$$\Delta_{s,1} := A_{s,1} - B_{s,1} \qquad \text{Initial stock spread} \qquad (1)$$

The authors call their second criterion "the amount of information revealed through trading". It is defined as the ratio of two stock variances: the numerator contains the variance of expectations after the first trade, the denominator the variance of intrinsic values:

$$\eta := Var(E_1[S]) / Var(S) \qquad \text{Variance ratio} \qquad (2)$$

The idea of the variance ratio is that the higher it is, the more information the first trade reveals, the more efficient the market. John et al (2000) find that the inclusion of an option market increases the initial spread (*de*creases efficiency), and increases the variance ratio (*in*creases efficiency). In the discussion of results they place more emphasis on the variance ratio and conclude that an option market improves overall efficiency.

The problem with using these two criteria for efficiency evaluation (and partly the reason for their conflicting outcomes) is that they completely rely on the first trade. This is problematic, since the introduction of an option market opens up the possibility that the first trade is not in the stock, but in the option instead. For the variance ratio, John et al (2000) 'solve' this problem by including the *expected* in stead of *realized* stock values in case there is an option trade. To our opinion, only transaction prices should be included, because expectations cannot be observed, are not realized and thus not relevant. Moreover, the static criteria ignore the most important dynamic mechanism, i.e. increased learning, that an option introduction is accompanied with. That's why we explore more direct methods to measure efficiency, which are solely based on realized trades in the stock.

We agree that an option market may improve efficiency (measured differently), but for a different reason. If an option trade precedes a stock trade, expectations are updated, and bids and asks in the stock are adjusted to the new information. This 'cross-learning' behavior is the main reason that we expect an option market to speed up convergence in the underlying. Ignoring this dynamic effect yields an underestimation of the option's beneficial influence. It should be noted that John et al (2000) were inspired by Kyle (1985) in the choice of their efficiency criteria. In that model however, the above problems do not arise, because every trade, and thus every first trade, takes place in the stock.

Let us now specify our first two dynamic efficiency criteria:

$$\Delta_s := A_s - B_s \quad \text{Realized stock spread} \tag{3}$$

$$PE_s \quad := | P_s - S | \qquad \text{Realized stock price error} \tag{4}$$

where P_s is the realized stock price.

We call these criteria dynamic, because they require the generation of a sequence of trades. The disadvantage of these dynamics is that the solutions can no longer be derived analytically, but need to be based on numerical simulations. That's why the statistics we report later in the text are the averages of the above statistics for a large number of simulations.

A logical way to calculate the above statistics would be at the first stock trade, which may occur after a sequence of option trades. An alternative is to analyze the above statistics only at the first *liquidity* trade in the stock. This can be justified by the notion that new entrants to a market will normally have no specific knowledge about fundamental values. For example, they won't directly bother about the average price errors faced by an insider, at least not beyond the effect it has on their own trades and their own profitability. In order to define the attractiveness of a market, the focus should be on uninformed trades. Furthermore, a market may be classified as efficient if differences in inside information do not have too much of an impact on trading performance. Since the average losses of uninformed traders equal half the realized spread, we are able to calculate uninformed traders' losses by calculating their realized spreads. Because the definition of efficiency can still be a matter of taste, where it is informative we report efficiency both from the viewpoint of an outsider and of all traders (including informed).

Another statistic of interest is the volatility of prices or returns. A large body of empirical work is devoted to the influence of option trading on volatility in the underlying. Numerous studies find that option listing causes a decrease in volatility, although in several other studies the results are mixed or insignificant.[2] However, as Skinner points out, the results should be interpreted with care, because ….

[2] The following find a decrease in volatility: CBOE (1975 and 1976), Trennepohl and Dukes (1979), Skinner (1989), Conrad (1989), Detemple and Jorion (1990), Damodaran and Lim (1991), Kumar, Sarin and Shastri (1998). In the following the results are mixed or insignificant: Klemkosky and Maness (1980), Whiteside, Dukes and Dunne (1983), Fedenia and Grammatikos (1992), Fleming and Ostdiek (1999).

For a given intrinsic value we calculate volatility as the standard deviation of (first) realized stock prices over a large number of simulations. The larger the number of noise traders, the more transactions are in both directions (buy and sell). Although uninformed traders generally favor little variation in prices, we are inclined not to define volatility as an exact criterion of efficiency. For convenience however, we report it with the other efficiency criteria.

$$Vol_s := \sigma(P_s) \qquad \text{Standard deviation } (\sigma(.)) \text{ of realised stock price} \qquad (5)$$

4. Results

Before we can present the results, we first have to derive the equilibrium dealer quotes for a given insider strategy. Dealers set bids and ask such that they make zero profits on average.

4.1 Equilibrium quotes

The dealers are uninformed and thus lose on every transaction with a better-informed trader. Uninformed liquidity traders are necessary in this design for the dealers to break even on average. Dealers' quoted bid-ask spread gives them a relative advantage over the liquidity traders, who lose on average.

The zero-profit assumption of dealers can be motivated by the presence of competing dealers or zero entrance costs for new competitive dealers. Therefore, the dealer sets a bid price that equals the stock value conditional on receiving a sales order (Q = -S). If he trades with the insider (probability µ), he knows that the insider sells when the stock value is low (X-v, probability d_L) and when the insider chooses to trade the stock instead of the option (probability p_L). If the dealer trades with a liquidity trader (probability 1-µ), he knows this trader sells the stock with probability ½ß, independent of the true stock value. Using Bayesian inference we obtain:

$$B_S = E[S|Q = -S] = X - v \cdot \frac{2m \cdot d_L \cdot p_L - (1-m) \cdot b \cdot (d_H - d_L)}{2m \cdot d_L \cdot p_L + (1-m) \cdot b} \tag{6}$$

Similarly, the dealer sets an ask price that equals the stock value conditional on receiving a purchase order (Q = +S):

$$A_S = E[S|Q = +S] = X + v \cdot \frac{2m \cdot d_H \cdot p_H + (1-m) \cdot b \cdot (d_H - d_L)}{2m \cdot d_H \cdot p_H + (1-m) \cdot b} \tag{7}$$

The bid and the ask for the option can be derived likewise, keeping in mind that the option value is zero if the stock value is low or in the middle:

$$B_C = E[C|Q = -C] = v \cdot \frac{(1-m) \cdot (1-b) \cdot d_H}{2m \cdot d_L \cdot (1-p_L) + (1-m) \cdot (1-b)} \tag{8}$$

$$A_C = E[C|Q = +C] = v \cdot \frac{2m \cdot d_H \cdot (1-p_H) + (1-m) \cdot (1-b) \cdot d_H}{2m \cdot d_H \cdot (1-p_H) + (1-m) \cdot (1-b)} \tag{9}$$

4.2 Insiders maximize profits at every trade

In the first part of our analysis we follow Easley et al (1998) and John et al (2000), who assume that informed traders maximize profits at every individual trade, and are thus not concerned about their effect on prices. Later we will see that this may not be the optimal strategy if an insider is able to execute more than one trade. The insider's single-trade-strategy is of the following form.

Insider strategy A:

If he receives signal L, then:

$p_L = 0$	if B_S - X + v < B_C	always sell the option
$p_L = 1$	if B_S - X + v > B_C	always sell the stock
$0 < p_L < 1$	if B_S - X + v = B_C	randomize between stock and option

If he receives signal H, then:

$p_H = 0$	if A_S - X > A_C	always buy the option
$p_H = 1$	if A_S - X < A_C	always buy the stock
$0 < p_H < 1$	if A_S - X = A_C	randomize between stock and option

We now have to determine under what conditions each of the above situations hold.

Suppose the insider receives the signal L and suppose further that the profit of selling the stock equals that of selling the option. Equating both profits and using the expressions for the bid in stock (6) and call (8), we can derive that he transacts the stock with probability p_L and the option with probability 1- p_L, both between zero and one:

$$p_L = \frac{b}{2m \cdot d_L} \cdot \frac{4m \cdot d_L + (1-m)\cdot(1-b)}{1+b} \tag{10}$$

If the insider receives the signal H, and the available profits in both markets are equal, the probability of buying the stock is:

$$p_H = \frac{b}{2m \cdot d_H} \cdot \frac{4m \cdot d_H + (1-m)\cdot(1-b)}{(1+b)} \tag{11}$$

It can be shown that the above p's exceed ß, so the insider has a larger preference for the stock than the liquidity traders have. Please note that if the insider increases his relative preference for the stock (p_H or p_L), the stock quotes narrow and the option quotes widen. This makes it easy to see that if one of the above formulae exceeds one, and so the actual p equals one, the profit of trading the stock is higher than of trading the option. It is also easy to see that the above expressions never equal zero (except for some boundary values) and so the insider will never only trade the option. This is intuitive, because the stock has a larger variability (is more 'information sensitive') and hence cannot offer lower absolute profits than the option.

To facilitate the derivation of efficiency criteria we make the plausible assumption that from the outset the probability of an upward and downward move are equal, i.e. we assume that $d_L=d_H=½$.

Static criteria

The initial stock spread can be derived analytically, using the expressions for bid and ask (6 and 8), and the insider’s equilibrium strategy (10 and 11) :

If $p_L<1$ and $p_H<1$, then:

$$\Delta_{s,1} = \left(2m + (1-m)\cdot(1-b)\right)\cdot v \qquad (12)$$

The initial spread increases linearly in the probability of an informed trade (µ), and in the distance between the low and high signal (v), and decreases in the relative preference of the liquidity traders for the stock market (ß). If the insider's preference for trading the stock (p) hits its upper bound of one, the initial spread will be lower than the above expression, because the insider cannot trade the stock as much as he would have wanted. Most interesting is that the initial spread decreases in ß, so uninformed traders initially face a higher spread in the stock market the more they trade the option. We obtain a market with only stock trading by setting ß equal to its maximum value of one. Then the liquidity traders only trade the stock, and so does the insider. Using this static criterion we therefore find that the introduction of an option decreases the efficiency in the underlying.

The second static criterion is the variance ratio. The denominator of the variance ratio, the unconditional stock variance, equals v^2. The numerator, the variance in expected stock values after one trade, is more complicated. Following a transaction in the stock, the dealers have updated expectations of the stock value equal to the bid (6) or ask (7).

Following a trade in the option, the expected stock values are similar to expression (6) and (7), but with p replaced by 1-p, and ß replaced by 1- ß. If we weight these updated expectations with the probability of the respective trades, we can derive the analytical expression for the variance ratio (in a mixed strategy)

$$\begin{aligned}\eta &= \mu^2 \cdot \left(\frac{\pi^2}{\mu \cdot \pi + (1-\mu) \cdot \beta} + \frac{(1-\pi)^2}{\mu \cdot (1-\pi) + (1-\mu) \cdot (1-\beta)} \right) \\ &= \mu^2 + \tfrac{1}{2}(1-\mu)^2 \cdot \beta \cdot (1-\beta)\end{aligned} \tag{13}$$

The above expression is minimal for ß equal to zero and one, and has a unique maximum in between (recall that $\pi=\pi_L=\pi_H$ is a function of ß and μ). This implies that a market with only stock trading (ß=1) would be less efficient than a market with trading in both assets. However, it is not true that more option trading always makes the market more efficient. At some level of uninformed option trading, more option trading decreases the market's efficiency, at least according to this criterion.

Dynamic criteria

We have already explained why static criteria are inappropriate for evaluating the beneficial influence of an option. They are malspecified and ignore the fact that the stock dealers 'learn' from the trades in the option.

First, observe that the above results depend crucially on the assumption that the insider maximizes his profit at every single trade. For example, if he tries to mimic the uninformed traders by attaching the same preference to the stock market as the uninformed do ($p_L=p_H=$ß), then the initial spread and variance ratio are unaffected by the introduction of an option. We will show that this strategy is indeed more profitable in the long run, but first calculate the updated beliefs of the dealers after they observe a transaction.

If the dealers observe for example a stock purchase, they know an uninformed trader initiated it with probability 1-μ, and that it then does not contain any information about intrinsic values. However, they know that it could also have been an informed trade, and that the stock value must then be high. They update their beliefs according to the following scheme:

a. After a stock purchase: $$d_{H,+1} = d_H \cdot \frac{2m \cdot p_H + (1-m) \cdot b}{2m \cdot d_H \cdot p_H + (1-m) \cdot b} \qquad (14)$$

b. After a stock sale: $$d_{H,+1} = d_H \cdot \frac{(1-m) \cdot b}{2m \cdot d_L \cdot p_L + (1-m) \cdot b} \qquad (15)$$

c. After an option purchase: $$d_{H,+1} = d_H \cdot \frac{2m \cdot (1-p_H) + (1-m) \cdot (1-b)}{2m \cdot d_H \cdot (1-p_H) + (1-m) \cdot (1-b)} \qquad (16)$$

d. After an option sale: $$d_{H,+1} = d_H \cdot \frac{(1-m) \cdot (1-b)}{2m \cdot d_L \cdot (1-p_L) + (1-m) \cdot (1-b)} \qquad (17)$$

After a purchase in stock or option, the probability of a high stock value is revised upwards, and revised downwards after a sale. The larger the insider's preference for the stock (p_H), and the larger the proportion of informed traders (μ), the more a stock purchase signals a high stock value.

The updated beliefs form the basis to generate a sequence of trades. At every point in time, we randomly select a trade and trader type according to the different probabilities. Then we update beliefs and randomly select a new trade and trader type. We continue till we obtain a (liquidity) trade in the stock, either a purchase or a sale. Since there is an infinite number of possible sequences, and because the beliefs are updated differently in every sequence, we believe it is impossible to derive our dynamic efficiency statistics theoretically[3]. Therefore, we rely on a large number (one million) of simulations[4] to clarify the dynamics.

The parameters X and v are only necessary to scale the stock and option, but do not affect the insider's strategy or the updating of beliefs. Without loss of generality, we can therefore fix them, for example to 100 and 10 respectively. It is also reasonable

[3] If it is possible, we would appreciate to hear so.
[4] The simulation program (Visual Basic for Applications in an Excel file) is available on request.

that a priori there is no higher probability of an upward move than a downward move, so we keep d_H=d_L=½. The parameters ß and µ are more delicate, so we will carefully study various values. But first we assume there is an equal proportion of informed and uninformed traders (µ=½), and the uninformed trade as often in the stock as in the option (ß=½).

INSERT TABLE I APPROXIMATELY HERE

In this base case, the initial available profits in stock and option are equal (table I). That's why the insider starts with a mixed strategy, although he prefers the stock five times to the option. Initially, he faces a spread in the stock market of 12.50, in the option of 2.50. If a liquidity trader trades before him, and trades in the opposite direction of the correct value, he trades the stock even more intensively. However, if he or another trader trades in the direction of the correct value, he subsequently shifts more trading to the option. This happens, because his preference for the stock (π) decreases in the correct expectation. Spreads narrow after the first trade, irrespective of the trade type, because a trade directs the expectations into one direction (the stock distribution becomes skewed). Table I also shows that a stock trade is followed by a stronger update of beliefs than an option trade. This is due to the relatively higher preference for the stock of the insider than of the liquidity traders (π>ß).

Table II reports the static and dynamic efficiency statistics corresponding to this base case and various fractions of uninformed trading in the stock (ß). We first focus on the data corresponding to an equal proportion of informed and uninformed traders (µ=½). The statistics of panel A are based on the first trade in the stock, and those of panel C on the first *liquidity* trade in the stock. All reported values are independent of whether the true stock value is low (90) or high (110).

INSERT TABLE II APPROXIMATELY HERE

We can infer the following results from table II for increasing levels of uninformed trading in the option (decreasing ß).

Thanks to the coverage of the option market, the insider is able to execute more option trades before the first stock trade. This increase in trading activity makes it easier for dealers to form their opinion on the correct stock value, which in turn leads to lower realized price errors in the stock for all trader types.

The effect on stock price volatility is ambiguous: volatility is highest for intermediate levels of option trading. This can be explained by the phenomenon that realized stock prices depend on the number and direction of previous option trades, which vary most for intermediate levels of option trading.

The effect of increased option trading on stock spreads is ambiguous as well. From equation (12) we know that the initial quoted spread increases in the fraction of option trading, but this result does hold for realized spreads. Those may increase or decrease. Both insiders and liquidity traders may be faced by an increased spread, though the possible spread increase faced by uninformed traders is smaller than by informed traders. Liquidity traders face only somewhat larger stock spreads when they execute few trades in the option (ß=0.9) compared to when they only trade the stock (ß=1.0). Although the difference is very limited, it will harm their performance in the stock market.

To clarify the ambiguous results on realized spread and volatility, we restrict the fraction of informed traders to a more realistic 25% (table II). It is then easier to see that uninformed traders do not necessarily benefit in the stock market from their activity in the option market. In fact, if uninformed traders form a large proportion of the total population, realized stock spreads (and so stock losses) and volatility increase the more they trade the option. This phenomenon is due to the insider's strategy, which is aimed at maximizing profits at every individual trade. This strategy leads to a larger preference for the stock than the liquidity traders' preference for the stock. This in turn causes informed traders to reap a relatively large part of all stock trades. Mathematically (see equation 10 and 11), p/(p+ß) increases in the fraction of uninformed traders (1-µ) and the amount of uninformed option trading (1-ß).

If the insider maximizes profits at every individual trade, the following summarizes the effect of option trading on the price process of the underlying. First, option trading decreases price errors. Second, option trading has ambiguous consequences for volatility, realized spreads and losses of uninformed traders. In a market where informed traders form a large part of the population, volatility, spreads and losses may increase or decrease, depending on the exact intensity of uninformed option trading. In a market with few informed traders (which is likely to be true in real world markets), an option market increases volatility, spreads and liquidity traders' losses.

4.3 Other insider strategies

The above results depend crucially on the assumption that an insider maximizes profits at every individual trade. This strategy causes the insider to have a relative preference for the stock, and this preference increases for high levels of uninformed trading and for high levels of uninformed trading in the option. Yet this strategy may not be optimal for a number of reasons.

Mimicking the uninformed traders

A first reason to deviate from strategy A is that insiders are concerned about the effect of their trading on prices. This concern might be fuelled by regulatory restrictions to exploit inside information or by the fear to destroy future trading profits. Regulatory restrictions are hard to model and more likely to curb the number of trades than that they affect the insider’s preference for stock or call. The second concern however is more realistic and insightful to analyze, because it shows us whether the fear to destroy future trading profits justifies a deviation from the original trading strategy.

We will analyze a strategy B, in which the insider directs the same proportion of trades to the stock as the uninformed traders do in order to hide his superior information. Later we show that this indeed increases profits if the insider is able to execute several trades.

Insider strategy B:

$$p_L = p_H = b \qquad (18)$$

Strategy B is independent of the quoted bids and asks, the fraction of informed traders and the fraction of uninformed trades directed to the option. Let us start with the initial quoted spread and the variance ratio. Because the insider follows the same strategy as the uninformed traders, the probability that a trade in the stock is informed is independent of the uninformed intensity of option trading. Therefore, initial spread and variance ratio are independent of β and smaller than when the insider employs strategy A.

$$\Delta_{s,1} = m \cdot v \qquad (19)$$

$$h = m^2 \qquad (20)$$

▪▪

INSERT TABLE III APPROXIMATELY HERE

▪▪

In table III we present the dynamic efficiency statistics based on the first stock trade and first uninformed stock trade when the insider mimics the liquidity traders. Although the prices converge more slowly than with the previously analysed strategy, the stock market becomes more efficient the more options are traded, both from the viewpoint of all traders as from the viewpoint of uninformed traders. Since the insider and liquidity traders direct an equal proportion of trades to the stock market, this efficiency gain is solely due to the increased learning ability of the dealers. Strategy B thus separates the learning effect from the insider strategy effect.

Compared to strategy A, the average spreads, losses and volatility in the stock are lower, because the stock dealers do not fear the insiders so much. On the other hand, with this mimicking strategy prices converge more slowly, as is the aim of the insider. Dealers have now more difficulty to detect where the insider is trading. Their prices are less accurate and realized price errors larger (but lower than without options)[5].

Since the dealers break even on average, the lower liquidity trader losses in the stock imply lower insider profits in the stock. Yet overall the insider is better off, because the reduced profits in the stock are more than offset by larger profits in the option (table IV). This effect is independent of the intensity of insider trading (μ) or the intensity of uninformed trading in the stock (β). Therefore, the insider's new mimicking strategy outperforms the original strategy in terms of overall profits. Depending on the number of trades the insider is able to execute, he optimally chooses a strategy in between strategy A and B. The less the competition he faces with other informed traders, the more he will try to mimic the liquidity traders. He will shift trading to the option market even more if he has limited resources to invest, as will be shown next.

Maximizing returns

A reason for insiders to forego immediate expected profits is that they have limited resources to invest, or that they are not so certain about their signal. In either case, they will be not so much concerned about maximizing profits, but rather about maximizing returns. Even though margin requirements increase option investments, the required investment in the option to achieve a certain leverage is lower than in the stock. John et al (2000) derive the insider's optimal trading strategy when the insider

[5] One small exception can be detected in tables II and III with respect to the smaller price errors. Additional analysis made clear that price errors are only smaller in strategy B compared to strategy A for a combination of unrealistically high proportions of insider trading and uninformed option trading.

maximizes returns and margin requirements are in place. They model margin requirements into detail. To arrive at a more tractable solution, we derive the insider's strategy without exactly specifying those requirements, which also has the advantage that there are no differences in margin requirements for going long and short. With only a traded call option namely, going short is harder than going long. This contrasts with real world markets, in which both call and put options are normally traded, and short and long positions require similar investments. We simply suppose the required dollar profit in the stock is ? times the dollar profit in the option. Then the insider's strategy is the same as when he maximizes dollar profits per trade, but with the following probabilities of trading the stock.

Insider strategy B:

$$p_L = \frac{b}{2m \cdot d_L} \cdot \frac{4m \cdot d_L + (2-g) \cdot (1-m) \cdot (1-b)}{g + (2-g) \cdot b}$$

$$p_H = \frac{b}{2m \cdot d_H} \cdot \frac{4m \cdot d_H + (2-g) \cdot (1-m) \cdot (1-b)}{g + (2-g) \cdot b}$$

We obtain the initial strategy A by equalizing the required dollar profit on stock and option (?=1). With the mimicking strategy B the available profit in the stock is always twice the profit in the option, so we obtain strategy B by setting ? equal to two. Again, if one of the above expressions exceeds one, the insider only trades the stock. It is now also possible for the above expressions to fall below zero (?>2). Then the insider only trades the option. Not surprisingly, the insider trades the stock less intensively when the required profit on the stock is larger than that on the option (?>1).

With this strategy C, and under the assumption that the insider randomizes between stock and option (0<p<1), the traders face an initial spread and variance ratio of:

$$\Delta_{s,1} = (2m + (2-g) \cdot (1-m) \cdot (1-b)) \cdot v$$

$$h = \frac{(2-g)^2}{2g} \cdot b \cdot (1-b) \cdot (1-m)^2 + m^2$$

The lower the required investments in the option relative to the stock, the heavier the insider trades the option and the smaller is the difference between bid and ask. The variance ratio is not strictly increasing or decreasing in ?, but attains a minimal value of μ^2 at ? = 2, when the insider has the same preference for stock and option as the liquidity traders.

In real world markets it can be expected that a stock position requires more than twice the investment of an equally levered position in the option. In table IV we analyze a market for which the difference is a factor four. Results are similar for other values of ?, as long as it exceeds two.

INSERT TABLE IV APPROXIMATELY HERE

The results indicate that option trading leads to smaller price errors and smaller realized spreads. Price errors are largest when the insider imitates the uninformed, so they are lower right now. Unfortunately, it is hard to predict the impact of option trading on volatility. The effect depends on the exact amount of option trading and the fraction of informed trading.

Information rewards

We haven't analysed yet whether the insider is indeed better off by foregoing immediate profits. Therefore, we calculate for the three different strategies the insider's earnings. Dealers earn nothing on average, so the insider profits simply equal the uninformed traders' losses. We calculate profits up to moment that vertually all information is in the market, and the insider has exploited nearly all his superior information. We establish this point when the expectation of the correct intrinsic stock value exceeds 99%. Apart from profits, we also present the required investments and returns for the different strategies (table V). Results are qualitatively unaltered when we change the fraction of insiders or the fraction of uninformed stock trades.

INSERT TABLE V APPROXIMATELY HERE

We use the fact that in real world markets, not only call options are traded, but put options as well. The required investments to go short are then comparable to those of going long. That's why we calculate the investments for a high stock value and assume that with a put option market the investments are similar for a low stock value. Consequently, the insider's investment in the stock is the current stock ask price, the investment in the option the current option ask price.

When the insider maximizes profits at every individual trade (strategy A), he hardly trades the option. Similarly, when the option yields leverage that is four times larger than the stock (strategy C), he hardly trades the stock. As a result, investments are considerably lower and realized returns higher than with strategy A.

The results clearly show that when the insider is in a monopolistic position and can fully exploit his superior information, he should revert to strategy B, and imitate the liquidity traders' randomization across stock and option. Compared to chasing immediate profits his stock trades are less profitable, but more than compensated by option trades.

Although strategy B yields the highest dollar profits, it does not yield the highest returns. An investment in the option is in the range of 0 to 10 dollars, whereas a stock investment is considerably larger, in the range of 90 to 110 dollars. Therefore, to maximize returns the insider should direct more, and often all, trades to the option market, as in strategy C.

5. Conclusion

This paper clarifies two mechanisms following the introduction of an option market that may lead to increased efficiency in the underlying. First, market makers learn from trades in the option market, set more accurate prices and thus increase efficiency. Second, the proportion of informed traders in the stock market may be altered. If informed traders have a relative preference for the option, for example because an option enables a leveraged position, the adverse selection component of the spread and price errors will decrease. If however insiders trade a larger fraction than uninformed traders in the stock, for example because the immediate profits in the stock are larger, spreads in the stock widen, and price errors increase. This reduces the efficiency increase from the 'learning' effect, possibly to the extent that overall efficiency deteriorates.

The current sequential trade literature with a derivative asset has been concentrated on initial quotes. Under the assumption that informed traders have a relative preference for the stock, spreads were found to increase, although trades reveal more information. Focus on just initial quoted spreads precludes the learning mechanism to take effect, since learning can only be observed in a sequence of trades. In a dynamic setting expectations concerning the true asset value are updated after every trade and a number of dynamic statistics can be calculated by simulation.

For realistic parameter values we find that that option trading leads to lower price errors in the underlying. The more popular options are, the more quickly the underlying prices converge to the true value. However, uninformed traders do not necessarily benefit from this speedier convergence. Their performance crucially depends on the insider's trading strategy and the fraction of informed trading. If insiders are concerned about their effect on prices and imitate the liquidity traders' preference for the stock relative to the option, realized spreads and volatility in the underlying decrease, which favors uninformed traders. If on the other hand insiders maximize profits at every individual trade, results are ambiguous. When there is a large proportion of informed traders, liquidity traders benefit in the stock from their trades in the option, but when there is a small proportion of informed traders, option trading harms liquidity traders' performance in the stock.

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Figure 1
The structure of trading

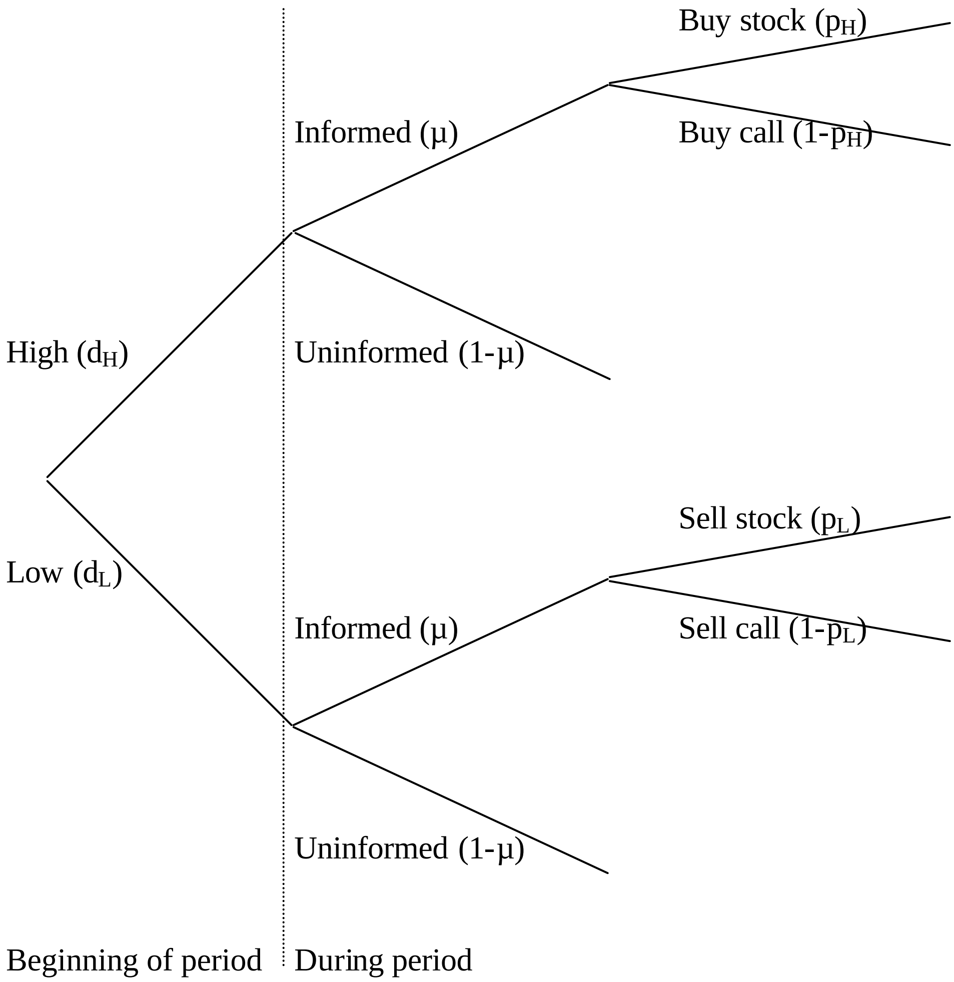

Table I
Updating of beliefs

This table reports updated beliefs, insider's trading strategy and dealer's quotes after a trade has been executed. There is trade in a stock and a call option on that stock. The stock can either be 110 (with probability d_H) or 90. The call option has an exercise price exactly in between the high and low value (100). Dealers provide quotes in both markets. They are fully competitive, risk-neutral and profit maximizing. Trades are initiated by an informed or uninformed trader with equal probability. Informed traders sell when the intrinsic stock value is low, buy when it is high. They maximize their profits at every individual trade by selecting the probability π with which they trade in the stock (strategy A). Uninformed traders have an equal probability to buy or sell, and to trade in the stock or call.

	Previous trade	$\mathbf{d_H}$	p	**Stock bid**	**Stock ask**	**Call bid**	**Call ask**
First period		0.50	0.83	93.75	106.25	3.75	6.25
Second period	Stock buy	0.81	0.77	99.29	108.93	8.13	8.93
	Stock sell	0.19	1.00	91.07	100.71	1.07	1.88
	Call buy	0.63	0.80	95.36	107.50	5.36	7.50
	Call sell	0.38	0.89	92.50	104.64	2.50	4.64

Table II
Efficiency with insider strategy A

This table reports several efficiency criteria for various levels of option trading. There is trade in a stock and a call option on that stock. The stock can either be 110 or 90 with equal probability. The call option has an exercise price exactly in between the high and low value (100). Dealers provide quotes in both markets. They are fully competitive, risk-neutral and profit maximizing. Trades are initiated by an informed trader with probability μ, by an uninformed trader with probability 1- μ. Informed traders sell when the intrinsic stock value is low, buy when it is high. They maximize their profits at every initial trade (strategy A). Uninformed traders have an equal probability to buy or sell. They trade with probability ß in the stock, otherwise in the option. The statistics in panel A apply to the first trade in the stock market, those in panel B to the first liquidity trade in the stock market. The statistics below are based on one million simulations. *Spread* measures the average difference between bid and ask; *price error* is the average absolute difference between the transaction price and intrinsic value; *volatility* is the standard deviation of the transaction price.

		ß = 0.10	ß = 0.25	ß = 0.50	ß = 0.75	ß = 0.90	ß = 1.00
Panel A: Dynamic criteria based on first stock trade							
μ = 0.50	Spread	9.82	12.28	12.26	11.23	10.50	10.00
	Price error	3.12	4.66	5.98	6.81	7.24	7.50
	Volatility	4.63	4.99	4.91	4.65	4.47	4.33
μ = 0.25	Spread	10.78	10.58	8.00	6.15	5.41	5.00
	Price error	5.88	7.12	8.42	9.05	9.26	9.37
	Volatility	4.92	4.51	3.68	2.93	2.60	2.42
Panel B: Dynamic criteria based on first uninformed stock trade							
μ = 0.50	Spread	3.63	5.73	7.20	7.67	7.71	7.67
	Price error	2.27	3.80	5.22	6.17	6.65	6.94
	Volatility	4.93	5.81	5.99	5.76	5.55	5.39
μ = 0.25	Spread	6.68	7.67	7.00	5.81	5.21	4.86
	Price error	5.02	6.55	8.01	8.82	9.12	9.24
	Volatility	5.89	5.58	4.53	3.52	3.08	2.83

Table III
Efficiency with insider strategy B

This table reports several efficiency criteria for various levels of option trading. There is trade in a stock and a call option on that stock. The stock can either be 110 or 90 with equal probability. The call option has an exercise price exactly in between the high and low value (100). Dealers provide quotes in both markets. They are fully competitive, risk-neutral and profit maximizing. Trades are initiated by an informed trader with probability µ, by an uninformed trader with probability 1- µ. Uninformed traders have an equal probability to buy or sell. They trade with probability ß in the stock, otherwise in the option. Informed traders sell when the intrinsic stock value is low, buy when it is high. They maximize profits over several trades by imitating the liquidity traders' preference for the stock relative to the option (strategy B). The statistics in panel A apply to the first trade in the stock market, those in panel B to the first liquidity trade in the stock market. The statistics below are based on one million simulations. *Spread* measures the average difference between bid and ask; *price error* is the average absolute difference between the transaction price and intrinsic value; *volatility* is the standard deviation of the transaction price.

		ß = 0.10	ß = 0.25	ß = 0.50	ß = 0.75	ß = 0.90	ß = 1.00
Panel A: Dynamic criteria based on first stock trade							
µ = 0.50	Spread	3.76	6.37	8.36	9.38	9.78	10.00
	Price error	2.81	4.77	6.27	7.03	7.34	7.50
	Volatility	4.49	4.99	4.83	4.56	4.42	4.33
µ = 0.25	Spread	3.42	4.30	4.73	4.91	4.97	5.00
	Price error	6.40	8.06	8.88	9.19	9.31	9.37
	Volatility	4.79	3.96	3.17	2.72	2.53	2.42
Panel B: Dynamic criteria based on first uninformed stock trade							
µ = 0.50	Spread	2.17	4.05	5.85	6.92	7.40	7.67
	Price error	2.13	3.91	5.49	6.36	6.74	6.95
	Volatility	4.39	5.33	5.58	5.51	5.44	5.39
µ = 0.25	Spread	3.02	3.97	4.50	4.73	4.82	4.86
	Price error	5.93	7.70	8.65	9.03	9.17	9.25
	Volatility	5.05	4.37	3.60	3.15	2.95	2.83

Table IV
Efficiency with insider strategy C

This table reports several efficiency criteria for various levels of option trading. There is trade in a stock and a call option on that stock. The stock can either be 110 or 90 with equal probability. The call option has an exercise price exactly in between the high and low value (100). Dealers provide quotes in both markets. They are fully competitive, risk-neutral and profit maximizing. Trades are initiated by an informed trader with probability µ, by an uninformed trader with probability 1- µ. Uninformed traders have an equal probability to buy or sell. They trade with probability ß in the stock, otherwise in the option. Informed traders sell when the intrinsic stock value is low, buy when it is high. They maximize returns at every individual trade, taking into account that a stock investment is four times as large (? = 4) as an option investment (strategy C). The statistics in panel A apply to the first trade in the stock market, those in panel B to the first liquidity trade in the stock market. The statistics below are based on one million simulations. *Spread* measures the average difference between bid and ask; *price error* is the average absolute difference between the transaction price and intrinsic value; *volatility* is the standard deviation of the transaction price.

		ß = 0.10	ß = 0.25	ß = 0.50	ß = 0.75	ß = 0.90	ß = 1.00
Panel A: Dynamic criteria based on first stock trade							
µ = 0.50	Spread	0.30	0.93	2.54	5.43	8.05	10.00
	Price error	2.00	3.70	5.33	6.52	7.18	7.49
	Volatility	4.00	4.82	4.99	4.76	4.49	4.32
µ = 0.25	Spread	0.00	0.00	0.02	1.05	3.17	5.00
	Price error	5.73	7.37	8.06	8.43	8.98	9.37
	Volatility	4.94	4.40	3.95	3.64	3.02	2.42
Panel B: Dynamic criteria based on first uninformed stock trade							
µ = 0.50	Spread	0.27	0.82	2.13	4.24	6.11	7.67
	Price error	1.89	3.46	4.86	5.84	6.48	6.95
	Volatility	3.99	4.88	5.24	5.37	5.41	5.39
µ = 0.25	Spread	0.00	0.00	0.02	1.04	3.05	4.86
	Price error	5.73	7.37	8.07	8.35	8.82	9.25
	Volatility	4.94	4.40	3.96	3.75	3.32	2.83

Table V
Insider profits and returns

This table reports profits and investments of insider trading. There is trade in a stock and a call option on that stock. The stock can either be 110 or 90 with equal probability. The call option has an exercise price exactly in between the high and low value (100). Dealers provide quotes in both markets. They are fully competitive, risk-neutral and profit maximizing. Trades are initiated by an informed trader with probability μ, by an uninformed trader with probability 1- μ. Uninformed traders have an equal probability to buy or sell and to trade the stock or option. Informed traders sell when the intrinsic stock value is low, buy when it is high. In strategy A they maximize profits at every individual trade. In strategy B they maximize profits over several trades by imitating the liquidity traders' preference for the stock relative to the option. In strategy C they maximize returns at every individual trade, taking into account that a stock investment is four times as large (? = 4) as an option investment. Trade continues till the correct expectation about the intrinsic stock value exceeds 99%. The statistics below are based on one million simulations and an intrinsic stock value of 110. *Stock, Option and Total profits* measure the total dollar profits the insider obtains in a trading period in the respective markets; *total investments* are the sum of all insider's purchase prices; *total return (%)* equal total profits divided by total investments.

		Strategy A	B	C
μ = 0.50	Stock profits	7.81	6.96	1.94
	Option profits	0.98	4.48	3.90
	Total profits	8.79	10.44	5.84
	Total investments	382.66	319.49	128.31
	Total return (%)	2.30	3.27	4.55
μ = 0.25	Stock profits	20.81	20.14	0.25
	Option profits	0.12	10.09	10.39
	Total profits	20.93	30.23	10.63
	Total investments	660.14	524.59	76.53
	Total return (%)	3.17	5.76	13.89

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