VERSITY
KE
UNIVERSITEIT
BRABANT

POSTBOX 90153
5000 LE TILBURG
THE NETHERLANDS

[redacted]

DEPARTMENT OF ECONOMICS

RESEARCH MEMORANDUM

THE USE OF THE IMPLIED STANDARD DEVIATION AS A PREDICTOR OF FUTURE STOCK PRICE VARIABILITY: A REVIEW OF EMPIRICAL TESTS

Drs. C.H. Veld

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INHOUDSOPGAVE

THE USE OF THE IMPLIED STANDARD DEVIATION AS A PREDICTOR OF FUTURE STOCK PRICE VARIABILITY: A REVIEW OF EMPIRICAL TESTS.

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1. Introduction.

In this paper we will discuss the use of implied standard deviations (ISDs) as predictors of future stock price variability. The ISD is the standard deviation that results if the market price of the option is equated to its model price. We have made two limitations. First we only consider ISDs derived from the Black and Scholesmodel or a dividend-adjusted version of this model. For a discussion of ISDs derived from other models we refer to Rubinstein (1985). The second limitation is that we only consider ISDs derived from call-option prices. The reader interested in ISDs derived from put option prices is referred to Brennan and Schwartz (1977).

This paper is organized as follows: in section 2 the Black and Scholesmodel will be discussed. Hereafter, in section 3, the concept of the ISD will be considered. In section 4, a number of empirical tests on the ISD will be overviewed. In section 5 we shall discuss the problems attached to the use of the ISD and, using the empirical tests discussed, we shall see how each of these problems can be dealt with. This paper will be finished with a summary and some conclusions.

2. The model of Black and Scholes.

In 1973 Black and Scholes published their well-known option pricing model. This model gives the price of a European call-option 1) that would be obtained in a perfect capital market

when no dividends are expected to be paid on the underlying stock during the life of the option.
The inputs to the model consist of four observable variables: the price of the underlying stock (S); the exercise price (E); the time to maturity (T); and the riskless interest rate (r), and one variable that is not observable, the standard deviation of the stock's distribution of rates of return (σ) 2). The latter will hence be referred to as the standard deviation. The model price C is:

$$C = S\,N(d1) - Ee^{-rT}\,N(d2) \qquad (1)$$

where:

$$d1 = \frac{\ln(S/E) + (r + \sigma^2/2)T}{\sigma\sqrt{T}}; \qquad (1a)$$

$$d2 = d1 - \sigma\sqrt{T}; \qquad (1b)$$

N(.) = cumulative standard normal distribution.

From now on this model will be referred to as the B/S-model. The assumptions needed to derive this model are: (1) there is a perfect capital market characterized by an absence of taxes and commissions, free access to all available information, and divisibility of all financial assets (in addition, borrowing and short selling as well as free use of all proceeds are permitted to all investors); (2) the short-term interest rate and the standard deviation of the stock's rate of return are known and constant; and (3) the stock price is lognormally distributed at the end of any finite interval.

The dividend problem.

We have already mentioned the fact that the original B/S-model assumes no dividend payments on the stock over the life of the option. Merton (1973) has relaxed this assumption for a rather special dividend policy, dividends are paid continuously so that the dividend yield is constant. This dividend yield can be represented as:

$$g = D/S \tag{2}$$

where:
g = the dividend yield;
D = dividend payment per subperiod;
S = stock price.

If the Black and Scholesmodel is corrected for a continuous dividend payment, the following equation results:

$$C = Se^{-gT} N(d1') - Ee^{-rT} N(d2') \tag{3}$$

where:

$$d1' = \frac{\ln(S/E) + (r - g + \sigma^2/2)T}{\sigma\sqrt{T}}; \tag{3a}$$

$$d2' = d1' - \sigma\sqrt{T}; \tag{3b}$$

This is the solution to the European call option problem when the underlying stock pays dividends continuously at the rate: g. We will refer to this model as the Merton Model. However, Merton (1973) has shown that the B/S-formula does not work for an American call-option on a stock that pays dividends, because it may pay to exercise the option just before the ex-dividend date. An intuitively easy understandable solution for this problem is the use of the binominal model. Verboven (1989) has shown that the possibility of an early exercise of the call-option resulting from a dividend payment can be included in the binominal model. An important disadvantage of this model is that it can only be solved numerically.
Another model that includes both discrete dividend payments and early exercise is the model developed by Geske (1979). An

important disadvantage of this model is its complexity, because it includes the valuation of compound options 3). Besides, Galai (1983) concludes that the Geske model does not yield consistently better predictions of actual prices than the B/S-model.

3. The implied standard deviation.

The traditional way to estimate the risk of common stocks is to calculate a historical standard deviation by using statistics based on a time series of realized rates of return. The implicit assumption is that past experience will repeat itself and that the ex post (historical) standard deviation is a good estimate of the future one.
Latané and Rendleman (1976) 4) have suggested to estimate the ex ante standard deviation from option prices by using the B/S-model. It is assumed that the B/S-model is valid, as are the required assumptions for its derivation, and that stock- and option markets are efficient. Under such conditions, by equating the model's value of an option to its market price, the implied standard deviation (ISD) can be calculated.

The following example derived from Van der Hilst (1982) will clarify the idea of the implied standard deviation:
Consider a call-option written on the firm Akzo, having an exercise price (E) of ƒ 32,50, an underlying stock price (S) of ƒ 31,10 and a maturity of 0,25 years. By assuming a riskless interest rate of 10% and by calculating a historical standard deviation, based on daily returns from 1978 of 0,333, the value according to the B/S-model is ƒ 1,80. The market price of this option was ƒ 1,40. If however a standard deviation of 0,272 would have been assumed, the model price would have equated the market price. Therefore the standard deviation of 0,272 is referred to as "the implied standard deviation".

Van der Hilst (1982) has argued that in some cases the ISD is impossible to calculate because the option's price falls below that which is consistent with the theory. Assuming no dividend payments, the minimum option price is:

$$C = \max\,(0,\ S - Ee^{-rT}) \tag{4}$$

The B/S-model assumes that no dividends are being paid, therefore if the call-option price falls below the minimum option price no ISD can be found.
In the Merton model continuous dividend payments are assumed, in that case the minimum option value becomes:

$$C = \max\,(0,\ Se^{-gT} - Ee^{-rT}) \tag{5}$$

This leads to a lower minimum option price, therefore the Merton model may calculate ISDs in case the B/S-model does not provide a solution. Van der Hilst (1981) has calculated ISDs for 2433 Akzo options. In 103 cases no ISD was found for the B/S-model, while in only 30 cases no ISD was found for the Merton model.

Van der Hilst (1989) argues that the ISD can be used in order to:

1) determine the distribution of future stock price variability and therefore the distribution of future stock prices;
2) trace the expectations of market participants;
3) test option pricing models;
4) test the efficiency of the option's exchange.

In the introduction we have already mentioned the fact that this paper concentrates on the ISD as a measure of future stock price variability, or in other words as a means to calculate the future standard deviation. For the use of ISDs as a way to test model- and market efficiency we refer to

Kemna (1988). In the next paragraph we will summarize some papers that have tested the ISD as a predictor of the future standard deviation.

4. The use of implied standard deviations as predictors of future stock price variability.

4.1. Introduction.

In this paragraph we will discuss the suitability of ISD to predict future stock price variability. If this suitability is tested then implicitly the ability of investors to make estimates of return variability from common stock is tested. This is due to the fact that ISD, as we already mentioned in paragraph 3.2., is the investor's ability to make good estimates of return variability from common stocks.
We will also discuss the relation between standard deviations calculated using historical data (ex post standard deviations) and future stock price variability, or in other words the suitability of historical standard deviations to predict future stock price variability.
If ISDs are calculated for options written on the same stock, but having other exercise prices and maturities, theoretically no differences would be expected. This is due to the assumptions of model validity and market efficiency.
Latané and Rendleman (1976) argue that this will as a practical matter not be the case because some options are more dependent upon a precise specification of the standard deviation than others. They argue that for options such as those which are in the money with little time to maturity, an exact specification of the standard deviation hardly matters 5). However, for other types of options it may be very important. Therefore Latané and Rendleman (1976) argue that some kind of weighing scheme for individual ISDs must be developed in order to come to a weighted ISD (WISD). All authors agree with Latané and Rendleman that a weighing

scheme is necessary. However, different opinions exist over the form of the weighing scheme to be used. We will discuss the studies that have been made in order to test the ISD as a predictor of future stock price variability, and we will pay specific attention to the weighing schemes that have been used.

4.2. The Latané and Rendleman study

Latané and Rendleman (1976) have calculated ISDs for individual options using the original B/S-model, without taking a dividend correction into account.
Because of the earlier mentioned fact that not all options are equally sensitive to an exact specification of the standard deviation, Latané and Rendleman have weighted the individual standard deviations by the partial derivative of the B/S-equation with respect to each single standard deviation. According to Cox and Rubinstein (1985) this derivative can be represented as:

$$\frac{\delta C}{\delta \sigma} = SN'(d1)\sqrt{(T)} \qquad (6)$$

where:

$$N'(d1) = \frac{1}{\sqrt{(2\pi)}} e^{-d1^2/2} \qquad (6a)$$

In table 1 we have computed this derivative for the earlier mentioned Akzo options. The underlying stock price was ƒ 31,10 and the interest rate was assumed to be 10%. From table 1 we can conclude that, as we expected, the procedure tends to give little weight to options with short remaining lives and to options that are far into the money; the weights of options with the shortest maturity (lines 1 till 5) are lower than the weights of options with longer maturities (lines 11 till 13); options that are at the money (lines 3 and 4) have

Table 1: Implied standard deviations and the partial derivatives of the B/S-equation with respect to each single ISD for the earlier mentioned Akzo example.

	Time to expiration (in years)	Exercise price	Call-option price	Squared Implied standard deviation	Squared-Individual weight
	(T)	(E)	(Cjt)	$(\sigma jt)^2$	$(\delta Cjt/\delta\sigma jt)^2$
(1)	(2)	(3)	(4)	(5)	(6)
1	0,25	ƒ 25,--	ƒ 7,--	0,161	6.859
2	0,25	ƒ 27,50	ƒ 4,80	0,119	15,777
3	0,25	ƒ 30,--	ƒ 2,90	0,096	30,769
4	0,25	ƒ 32,50	ƒ 1,40	0,074	38,291
5	0,25	ƒ 35,--	ƒ 0,90	0,104	30,592
6	0,50	ƒ 25,--	ƒ 8,40	0,227	30,393
7	0,50	ƒ 27,50	ƒ 6,--	0,130	40,221
8	0,50	ƒ 30,--	ƒ 4,--	0,091	59,321
9	0,50	ƒ 32,50	ƒ 2,50	0,077	75,673
10	0,50	ƒ 35,--	ƒ 1,60	0,080	72,727
11	0,75	ƒ 30,--	ƒ 5,60	0,138	89,340
12	0,75	ƒ 32,50	ƒ 3,90	0,105	108,368
13	0,75	ƒ 35,--	ƒ 3,--	0,112	115,455

higher weights than options that are far in the money (line 1); unfortunately our example does not include options that are far out of the money.
In their paper Latané and Rendleman used the following weighing scheme 6):

$$WISDt = \frac{\sqrt{\left[\sum_{j=1}^{N} ISDjt^2 \times (\delta Cjt/\delta \sigma jt)^2\right]}}{\sqrt{\left[\sum_{j=1}^{N} (\delta Cjt/\delta \sigma jt)^2\right]}} \tag{7}$$

where:

N = total number of options written on a given stock;

WISDt = weighted average implied standard deviation in period t;

ISDjt = implied standard deviation for option j in period t;

$(\delta Cjt/\delta\sigma jt)^2$ = partial derivation of the price of option j in period t with respect to its implied standard deviation using the B/S-model, this can be calculated using equation (6).

Using equation (7) a weighted average implied standard deviation (WISD) can be calculated, in which the ISDs for all options on a given stock are weighted by the partial derivative of the B/S-equation with respect to each implied standard deviation. For our Akzo example a WISD of 0,330 can be calculated using equation (7).
Latané and Rendleman have calculated WISDs on a weekly basis for 24 companies whose options were traded on the Chicage Board Options Exchange (CBOE). Their calculations were made for the 38 weeks (39 weekly observations) beginning October 5, 1973 and ending June 28, 1974. They tested the relationship between the WISDs, standard deviations based on

historical data and actual standard deviations by running correlations on the following series of standard deviation measures:

1) the WISD averaged over the 38 week sample period (39 observations) for each of the 24 companies;
2) the standard deviation of monthly log price relative returns calculated over the four-year period ending September 30, 1973 for each company (historical standard deviations);
3) the standard deviation of weekly log price relative returns calculated over the 38 week sample period time adjusted to a monthly basis for each of the 24 companies;
4) the standard deviation of monthly log price relatives for each of the 24 companies calculated over the two year period ending March 31, 1975.

Series 3 represented actual standard deviations calculated over the sample period. Series 4 consisted of standard deviations calculated over the sample period and into the future 7). They found the highest correlation between the WISDs and series 4, which indicated that the ISDs are highly correlated with series of actual standard deviations which were calculated partially into the future. Both series 3 and 4 were more positively correlated with WISDs than with ex post (historical) standard deviations.

Latané and Rendleman concluded that during their sample period WISDs were better estimators of future return variability than ex post standard deviations which were calculated from historical data.

4.3. The Schmalensee and Trippi study.

Schmalensee and Trippi (1978) tested the relationship between ISDs and ex post time series (historical) standard deviations. The ISDs were calculated using the original, not dividend corrected, B/S-model.

Schmalensee and Trippi selected a sample of weekly closing price data for each of the 56 weeks in the period April 29, 1974 through May 23, 1975. This sample consisted of CBOE options which were written on stocks that had low dividend yields. Schmalensee and Trippi excluded all options that were either far out or far in the money and/or were having short maturities from the data set 8).

For each stock and each week, Schmalensee and Trippi calculated the arithmetic (unweighted) average of the remaining options. They did not find it necessary to weigh the option prices because they already eliminated options that were not dependent upon a precise specification of the standard deviation. Schmalensee and Trippi tested the hypothesis that a relationship would exist between changes in the ISD and changes in the historical standard deviation. Surprisingly they found that market expectations, embodied in the average ISD, were not influenced at all by historical standard deviations.

Schmalensee and Trippi have acknowledged that a relationship might have been found, if better data had been used (e.g. daily closing prices instead of weekly closing prices).

4.4. The Beckers study.

4.4.1. Introduction.

Beckers (1981) extended the studies of Latané and Rendleman and Schmalensee and Trippi in three important ways:

1) he introduced a dividend-adjusted model;
2) three different weighing schemes were compared;
3) transaction data were considered as an alternative for closing price data.

We will discuss these extensions in three different subparagraphs.

4.4.2. The introduction of a dividend-adjusted model.

Because of the earlier discussed complexity of models that take discrete dividends into account, Beckers suggested the use of an ad hoc dividend correction. He argued that it can be shown that the boundary condition on the value of a call-option in case of a dividend payout before the maturity date of the option becomes:

$$C \geq \max\left(0,\ S - Ee^{-rt},\ S - Ee^{-rT} - De^{-rt}\right) \tag{8}$$

where:
D = dividend payment;
T = time to maturity;
t = time until ex-dividend date.

Beckers reported a study by Brealey (1971) who has argued that the stock price does not drop by the full amount of the dividend on the ex-dividend date. Empirical research by Brealey has pointed out that on the ex-dividend date, the price falls by approximately 85% of the gross value of the dividend 9). Therefore Beckers subtracted only the present value of 85 percent of the dividend on each day before the ex-dividend day. Because it is only optimal to exercise just before the ex-dividend date, an ad hoc way to take into account the possibility of premature exercise consists of calculating the ISD under two different conditions:

1) the option is assumed to be held to maturity and simultaneously 85 percent of all intermediate dividend payments will be subtracted from the current stock price;
2) the option is assumed to be exercised on the last ex-dividend day and simultaneously 85 percent of all previous dividend payments will be subtracted from the current stock price. In case only one dividend payment will be made, no correction will be necessary in this case.

Beckers has demonstrated that of these two values, the lower ISD is the one which is to be chosen.

4.4.3. The introduction of different weighing schemes.

Beckers employed three different weighing schemes, in order to weigh individual ISDs:

1) The first weighing scheme is the one that was introduced by Latané and Rendleman. Latané and Rendleman weighted all ISDs with the first derivative of the option price with respect to the standard deviation. In contrast with Latané and Rendleman, Beckers did not calculate a single WISD for all options on the same firm but only for those options that had the same maturity. Thus for the Akzo example mentioned before, Latané and Rendleman would have calculated one WISD, while Beckers would have calculated three WISD's, i.e. one for every maturity. We will refer to this weighted ISD as the WISD.
2) Beckers argued that ISDs for deep in the money, close to maturity options are usually extremely far out of line (up to ten times the ISD of the corresponding at the money option). Although the Latané and Rendleman weighing scheme tends to put less weight on these outliers, Beckers preferred the use of an alternative weighing scheme that concentrated mainly on the ISD for at the money options 10). This method resulted in a BISD. This BISD tended to put more weight on the options that were highly sensitive upon an exact specification of the standard deviation than the WISD did.
3) The third weighing scheme considered by Beckers, consisted of simply using the ISD for the most sensitive option. This was justified by the argument that all of the available information should be reflected in the at-the-money option and that all other options had too much noise to be of any additional relevance. Although the most sensitive option is usually the one which is slightly out of the money, Beckers referred to it as the at the money ISD, or AMISD.

Just as in the case of the WISD, the BISD and AMISD were calculated for options written on the same stock and having the same maturity.
Beckers tested the predictive power of WISD, BISD and AMISD in using a sample consisting of CBOE and NYSE daily closing prices observed over the 75 trading day interval between October 13, 1975 and January 23, 1976. He concluded that the BISD measure tended to outperform the WISD and that both were in term inferior to the AMISD.
Beckers concluded that the ISDs were extremely volatile over time. He argued that this could be due to an overestimation of the market in case new information became available or to the fact that a bid-ask spread exists on the options exchange. The reported closing price reflects the price at which the last trade has taken place. Due to the existence of a bid-ask spread, the last trade may have been executed at the bid price, the ask price or some price in between.
Taking into account these results Beckers argued that in order to eliminate the estimation errors that might exist for any single day, a five day arithmetic average ISD could be a better predictor. He calculated results for a larger sample and a longer time period. This sample existed of observation intervals of five days each. For each five day interval the following standard deviations were compared:

SSD = the actual standard deviation of stock price return over the remaining life of the option;

SSD-1 = the actual standard deviation of stock price return during the three month period preceding the interval (historical standard deviation);

$$BISD = \sum_{j=1}^{5} BISDj/5 \qquad (9)$$

$$AMISD = \sum_{j=1}^{5} AMISD/5 \qquad (10)$$

FBISD = Fischer Black's standard deviation. These estimates are sold by the Fisher Black's option pricing service to option traders. Besides information based on ISDs these estimates also include additional information.

Cost considerations prevented Beckers from calculating the WISD. After running some empirical tests Beckers concluded that, in general, the implied standard deviation is a better predictor of future stock price variability than past standard deviations. BISD and AMISD did better than SSD-1 in practically all cases. Beckers also concluded that generally AMISD had as least as much information content as BISD. This tended to confirm his earlier results that introducing additional options tended to worsen the predictive power of the AMISD.
Finally Beckers concluded that the FBISD was a better predictor than the BISD and the AMISD. The FBISD appeared to be the best predictor in periods when all predictors performed well, however it did not predict better in periods when the other measures performed poorly.

4.4.4. The use of transaction data.

Beckers argued that the use of transactions data might outperform the use of closing price data because of the problems of non-simultaneousness of stock- and option prices and of the existence of the bid-ask spread. He tested this for a small subsample of his data set. On the basis of this limited data he concluded that the ISD based on transactions data tended to outperform the ISD based on closing price data. However, he argued that a more extensive research would be necessary.

4.5. The Brenner and Galai approach.

Except for Beckers (1981), all empirical work upon ISDs derived from option prices discussed so far used weekly or daily closing prices. Latané and Rendleman (1976) and Schmalensee and Trippi (1978) used weekly closing prices and Beckers (1981) used daily closing prices.

Brenner and Galai (1984) have argued that the use of transaction data is in some cases superior to the use of last weekly or daily observations data. In order to calculate transaction data Brenner and Galai selected data from the Berkeley Options Data Base which contains CBOE data. In this data base, days are divided into intervals in which the price of the underlying stock remains constant. During such an interval the lowest and the highest option prices were observed and the volume traded at the low price, the high price, and the total volume. The prices that Brenner and Galai used, in order to calculate ISDs from transactions data, were selected by the relative volume traded. We will refer to this ISD as the AISD. The ISD derived from daily closing prices will be referred to as LISD. Brenner and Galai expected the AISD to be superior over the LISD in case:

1) closing prices are nonsynchronous;
2) institutional factors bias the closing prices;
3) errors in the measurement of variables are random.

Brenner and Galai selected data on IBM stock and options for 98 consecutive days starting from June 3, 1977 to October 21, 1977 in order to test the relationship between AISD and LISD. In order to account for dividend payments, Brenner and Galai used an approximation used by Black (1975). In this method the present value of all realized dividends paid before the option's maturity are subtracted from the stock price and this adjusted stock price is used in the B/S-formula. This approach has two problems: the first problem is that dividends are assumed to be certain. The second problem is that the model ignores the possibility of early exercise.

Brenner and Galai first tested if LISD was different from AISD. They came to the conclusion that in many cases not only statistically significant deviations existed but that the deviations were also large in absolute values.

Brenner and Galai argued that if AISD would be a better predictor of the "true" unobservable standard deviation of the stock's rate of return at time t, the "true" standard deviation should be better predicted by AISDt-1 than by LISDt-1. The results of a regression ran by Brenner and Galai gave results consistent with their expectations. Brenner and Galai concluded their paper by arguing that it seemed that AISD is a more reliable measure than LISD simply because it is based on more observations and gives very little weight to the last transaction of the day. They emphasized that these findings should be more pronounced using options on stock that are less actively traded and/or have lower prices.

4.6. The van der Hilst study.

4.6.1. Introduction.

Van der Hilst (1982) has extended the previously discussed studies in two ways:

1) he suggested to weigh the individual ISDs by the partial derivative from the option price to the variance instead of the partial derivative from the option price to the standard deviation;
2) he discussed the use of the Merton model as an alternative for the B/S-model.

4.6.2. The partial derivative from the option price to the variance versus the partial derivative from the option price to the standard deviation.

Van der Hilst calculated implied variances instead of implied standard deviations. He weighted these implied variances by the derivative for the option price to the variance. He did not give a reason for selecting the derivative from the option price over the derivative from the option price to the standard deviation. On theoretical grounds we do not find it possible to give preference to one of the derivatives over the other. For the B/S-model the derivative from the option price to the standard deviation can be represented as:

$$\frac{\delta C}{\delta \sigma^2} = Ee^{-rT} N'(d2) \frac{\sqrt{T}}{2\sigma} \qquad (11)$$

We have calculated the outcomes of this derivative for the Akzo example mentioned before. The results of this calculation have been compared with the outcomes of the squared derivative from the option price to the standard deviation. All outcomes are presented in table 2.
From table 2 we can conclude that the weighing scheme of Van der Hilst, who used the derivative from the option price to the variance (column 7), may be different from the weighing scheme of Latané and Rendleman, who have used the squared derivative from the option price to the standard deviation (column 6). This is especially true if we compare lines 10 and 11. The squared derivative from the option price to the standard deviation (column 6) gives relatively <u>more</u> weight to the option on line 11 (89,340) than to the option on line 10 (72,727). For the derivative from the option price to the variance (column 7) the weight given to the option on line 11 (12,743) is <u>lower</u> than the weight given to the option on line 10 (15,115).
These differences also exist if options having the same maturity are considered. This can be illustrated by comparing lines 12 and 13. The squared derivative from the option price to the standard deviation gives more weight to the option on line 13 (115,455) than to the option on line 12 (108,368). The derivative from the option price to the variance, on the other hand, gives more weight to the option on line 12 (16,090) than to the option on line 13 (16,080).
It is also possible to calculate a weighted implicit variance by weighing the individual implicit variances by

Table 2: Implied standard deviations and the derivatives of the B/S-equation from the option price to the standard deviation and from the option price to the variance for the earlier mentioned Akzo example.

(1)	Time to expiration (years) (2)	Exercise price (3)	Call-option price (4)	Implied standard deviation (5)	Squared Individual weight $(\delta Cjt/\delta\sigma jt)^2$ (6)	Individual weight $(\delta Cjt/\delta\sigma jt^2)$ (7)
1	0,25	ƒ 25,--	ƒ 7,--	0,401	6,859	3,264
2	0,25	ƒ 27,50	ƒ 4,80	0,345	15,777	5.756
3	0,25	ƒ 30,--	ƒ 2,90	0,310	30,769	8,998
4	0,25	ƒ 32,50	ƒ 1,40	0,272	38,291	11,372
5	0,25	ƒ 35,--	ƒ 0,90	0,322	30,592	8,500
6	0,50	ƒ 25,--	ƒ 8,40	0,476	30,393	5,800
7	0,50	ƒ 27,50	ƒ 6,--	0,361	40,221	8,817
8	0,50	ƒ 30,--	ƒ 4,--	0,302	59,321	12,799
9	0,50	ƒ 32,50	ƒ 2,50	0,277	75,673	15,716
10	0,50	ƒ 35,--	ƒ 1,60	0,283	72,727	15,115
11	0,75	ƒ 30,--	ƒ 5,60	0,371	89,340	12,743
12	0,75	ƒ 32,50	ƒ 3,90	0,324	108,368	16,090
13	0,75	ƒ 35,--	ƒ 3,--	0,335	115,455	16,080

the derivative from the option price to the variance. If the square root from this weighted implicit variance is taken, a weighted implicit standard deviation results. If this procedure is applied to the Akzo example a WISD of 0,327 results. This WISD does not differ much from the WISD that resulted by weighing the individual implicit standard deviations by the derivative from the option price to the standard deviation (i.e. 0.330). Further research is necessary to prove if more important differences may exist in other cases.

If the option with the highest weight should be selected from all options (over different maturities), differences may exist between the different weighing schemes (compare lines 10 and 11). These differences may also exist if options having the same maturity are considered (compare lines 12 and 13). We have already mentioned the fact that on theoretical grounds it is not possible to give preference to one of the derivatives ($\delta C/\delta\sigma$ of $\delta C/\delta\sigma^2$) over the other.

4.6.3. The use of the Merton Model.

Van der Hilst (1982) has suggested the use of the Merton model instead of the B/S-model in order to calculate ISDs. The advantages of the Merton model over the B/S-model are:

1) it is a simple way of taking dividend payments into account;
2) as we have seen in paragraph 3.2. more ISDs can be calculated if the Merton model is used instead of the B/S-model.

The Merton model calculates lower option prices than the B/S-model, this is due to the fact that dividend payments are taken into account. Therefore the ISDs calculated using the Merton Model are lower than the ISDs calculated using the B/S-model. This difference increases if the dividend yield increases.

4.7. Some concluding remarks.

4.7.1. The "term structure of volatility".

In paragraph 4.4.3. we have already noticed that Latané and Rendleman calculated one WISD for all options that were traded on a specific date while Beckers argued that a WISD should be calculated for each maturity. Beckers stated that a distinction should be made between options written on the same stock but having different maturities since they have different time horizons. He argued that the market's perception of the stock's volatility over the remaining life of the option could therefore differ depending upon the time to maturity. Brenner and Subrahmanyam (1988) agree with Beckers that different perceptions exist on short-run versus long-run volatility. They call this "the term structure of volatility".

Kemna (1987) tested fourteen (European Options Exchange) options for three different maturities over the period from 13/08/1984 till 28/12/1984. She concluded that the near-term average ISD was always significantly different from the middle- and long-term average ISD and that the middle-term average ISD was in eleven out of fourteen cases significantly different from the long-term ISD. She also concluded for twelve out of fourteen cases that an increase in the time to maturity led to a decrease in the average ISD.

4.7.2. A simple formula to compute the ISD.

In practice the ISD is calculated using a numerical procedure such as the Newton-Rhapson method (Bjorck and Dahlquist (1974)). Brenner and Subrahmanyam (1988) have suggested a simple formula to calculate the ISD.

Brenner and Subrahmanyam argued that the best estimates for the volatility are obtained from at-the-money options. This was also recognized by Beckers (1981). In order to derive their formula Brenner and Subrahmanyam defined an at-the-money option is one which exercise price is given by:

$$E = \frac{S}{e^{-gT}} \tag{12}$$

Using equation (12) Brenner and Subrahmanyam derived the value of an at-the-money call-option (Cs) for the B/S-model:

$$Cs = 0.398\ S\ \sigma\ \sqrt{T} \tag{13}$$

The value of the ISD is given by:

$$\sigma = \frac{Cs}{0.398 S\sqrt{T}} \tag{14}$$

For example if:
S = ƒ 49,25;
E = ƒ 50,--;
T = 0,25 years;
r = 0,06;
Cs = ƒ 5,25.

Using equation (14) the ISD can be calculated as 0,54. Unfortunately not always an option exists that is exactly at the money. Consider the Akzo example:
S = ƒ 31,10;
E = ƒ 32,50;
T = 0,25 years;
r = 0,10;
Cs = ƒ 1,40.
If we calculate the ISD using equation (14), an ISD of 0,2262 results. Using a numerical procedure we have concluded that the true ISD must be 0,2724, in other words, if equation (14) is used a difference of 20% results. We find this difference unacceptable in order to make calculations, especially if we take the fact into account that some options (e.g. Nedlloyd,

Aegon) are less actively traded than Akzo, so that it is even more difficult to find an option that is (nearly) at the money. We conclude that the usefulness of the formula developed by Brenner and Subrahmanyam is quite limited.

5. Problems in the use of ISDs as predictors of future standard deviations.

5.1. Introduction.

According to Brenner and Galai (1982) implied standard deviations seem to suffer from the following shortcomings:

a) ISDs are rather unstable;
b) due to the non-synchronization of stock and option markets, the ISD does not have to give the correct volatility;
c) when ISDs are used, possible estimation biases in the measurement of other parameters can also lead to a bias in the volatility measure.

We will discuss each of these problems in separate sections.

5.2. The unstability of the ISD.

The ISD is calculated under the assumptions that the B/S-model is correct and that option and stock markets are efficient and synchronous. If all of these assumptions hold, than the ISD is stationary over time, across maturities and striking prices.
Latané and Rendleman (1976) already noticed that the ISDs derived from options written on the same stock differed over maturities and exercise prices. This led Beckers (1981) to note that there is a basic inconsistency in using the B/S-model to obtain predictions of the presumably non-stationary variance. However, he argued, the empirical results of Latané and Rendleman have indicated that their approach is valuable, at least from a pragmatic standpoint.

Kemna (1987) tested the stability of ISDs over time. With this aim she divided the data sample in two subsamples of each ten weeks. For each subsample an average ISD was calculated. In only two out of fourteen cases the ISD of the first ten weeks equated the ISD of the second ten weeks. Kemna also constructed a second test. In this test the data-sample was divided into fourteen periods of ten days each. This second test also revealed that the ISD was not constant over time. It is noteworthy, however, that the degree of change over time was different per stock.
Van der Hilst (1982) calculated a WISD for options, written on three different stocks, over four consecutive intervals. He calculated WISDs using the Merton model. His results are presented in table 3.
Van der Hilst concluded from this example that the ISD was especially unstable in the case of Royal Dutch.

Table 3: WISDs calculated using the Merton model.

	period 1 Jan-April	period 2 April-July	period 3 July-Oct	period 4 Oct-July
Akzo	0.369	0.326	0.333	0.361
Royal D.	0.077	0.100	0.152	0.211
Philips	0.241	0.266	0.255	0.259

Van der Hilst mentions the following factors that may be due to the instability of the ISDs:

1) the discrete price setting process;
2) the price setting on the Exchange is sometimes artificial in case only a few options are being traded; we notice that this may especially be relevant for less actively traded funds such as Aegon or Nedlloyd;
3) options are of the American type instead of the European type;

4) prices are rounded off at ten cents;
5) a constant interest rate of 10% has been assumed;
6) the existence of transaction costs;
7) the fact that there is no perfect synchronization between the price setting at the European Options Exchange (EOE) and the Amsterdam Stock Exchange.

The last mentioned problem will be discussed in the next section.

5.3. The non synchronization between stock and option markets.

In section 4.5. we have discussed the paper written by Brenner and Galai (1984). They have argued that the problem

of non-synchronization can be dealt with if transaction data are used instead of closing price data.

5.4. Estimation biases in the measurement of the other parameters.

Besides the volatility variable the following factors are needed as inputs for the B/S-model: the price of the underlying stock, the exercise price, the time to maturity and the riskless interest rate. The stock price, exercise price and maturity are directly observable. A somewhat difficult parameter to estimate is the riskless interest rate. A completely riskless interest rate does not exist. However, the yield on Dutch or (U.S.) treasury bonds is a good approximation. Besides that the B/S-formula is not very sensitive for an estimation error in the interest rate (Jarrow and Rudd (1983), page 117-121).

A more important problem is the dividend estimation. The only simple dividend correction is the inclusion of continuous dividend payments (the Merton model). In this case the possibility of early exercise for American options cannot be included. Besides that the continuous dividend yield is difficult to estimate thus approximations will always be biased. Therefore if the ISD is to be estimated from the Merton model, the measure of ISD is likely to be biased because of a misspecification of the continuous dividend yield. A more precise dividend correction is necessary. This brings us to the binominal model or the Geske model. These models require, as we have already mentioned, numerical solution.

The problem remains, even using these models, that the future dividend payments will always be uncertain. Therefore the dividend estimation will always be biased, leading to a biased ISD.

6. Summary and conclusions.

In this paper we have discussed the implied standard deviation (ISD) as a predictor of future stock price variability. The implied standard deviation is the standard deviation that results if the market price of the option is equated to its model price.

Because not all options are equally sensitive to an exact specification of the standard deviation, some kind of a weighing scheme for individual ISDs must be developed in order to come to a weighted implied standard deviation. If all the individual standard deviations are weighted by the partial derivative of the Black and Scholes equation with respect to each single standard deviation, the WISD results. Latané and Rendleman (1976) concluded that this WISD is a better predictor of future standard deviations than historical standard deviations are. Besides that Latané and Rendleman concluded that no strong relationship existed between the WISD and historical standard deviations.

Beckers (1981) concluded that a weighted ISD that gave relatively more weight to at the money options, the so-called BISD, was a better predictor of future standard deviations than the WISD. This BISD was in term inferior to the ISD with the highest weight of the derivative from the option price to the standard deviation. Beckers explained this by the fact that this standard deviation reflected all available information and that the other options contained too much noise to be of any additional relevance.

Beckers also introduced the theory that only a weighted ISD should be calculated for options with the same maturity, because the market's perception of the stock's volatility over the remaining life of the options may differ upon the time to maturity. Evidence for this "time structure of volatility" was found by Kemna (1987).

Although much evidence has been found that a weighted ISD is a better predictor of future standard deviations than historical standard deviations are, some problems are attached to the use of the ISD. The following problems are mentioned by Brenner and Galai (1982):

1) due to the non-synchronization of stock and option markets, the ISD does not have to give the correct volatility;
2) ISD's are rather unstable;
3) when ISD's are used, possible estimation biases in the measurement of other parameters can also lead to a bias in the volatility measure.

The problem of non-synchronization of stock- and option markets can be resolved if transactions data are used instead of closing price data. Evidence has been found by Beckers (1981) and Brenner and Galai (1984).

The unstability of ISDs has been tested by Kemna (1987) and Van der Hilst (1982). Both concluded that the ISD was not constant over time, but that the degree of change over time was different per stock.

Possible estimation biases in the measurement of the discrete dividends to be paid in the future (in the binominal model or the Geske model) or the future continuous dividend yield (in the Merton model) will probably lead to a bias in the ISD.

We conclude this paper by arguing that the implied standard deviation is a better predictor of future standard deviations than historical standard deviations are, but that caution should be exercised in the calculation and interpretation of the implied standard deviations.

Footnotes:

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1) A European call-option is an option that can only be exercised at its maturity. An American call-option can be exercised at any time until its maturity.

2) The square of the standard deviation of the stock's distribution of rates of return is the variance of the stock's distribution of rates of return (σ^2).

3) A compound option is an option on an option. Geske (1979) argued that a call-option on the firm's stock is a compound option, because a firm's equity can be considered as a call-option on the firm.

4) According to Brenner and Subrahmanyam (1988) this approach was also suggested by R. Reback and W. Sharpe in a working paper titled: "Estimation of market uncertainty based on option prices". However this paper, written at the same time Latané and Rendleman (1976) wrote their paper, was never published.

5) At-the-money options are options with an exercise price close to the currently prevailing market price of the stock. In-the-money options have an exercise price which is lower than the stock price. Out-of-the money options have an exercise price which is higher than the stock price.

6) In their original paper their weighing scheme was reported in error in footnote 4. Therefore a rectification was placed in the Journal of Finance, 1979,

page 1083.

7) We notice that the actual (realized) standard deviations of series 3 and 4 could of course only be calculated ex post, while investors have to make calculations of standard deviations ex ante.

8) The following options were excluded by Schmalensee and Trippi (1978):
   a) options having prices less than $ 1,00;
   b) options having prices less than 1% of the price of the underlying stock (S);
   c) in case the exercise price of the option (E) was below the stock price (S), options having prices less than: 1,5(S-E);
   d) options having remaining lives less than three weeks.

9) Dorsman (1988) has examined this for the Dutch situation. He calculated that on the ex-dividend data, the price fell by approximately 73,5% of the gross value of the dividend.

10) Specifically, on any single observation day the following loss function was minimized:

$$f(ISD) = \frac{\sum_{j=1}^{N} dj\ [Cj - Cb/Sj\ (ISD)]^2}{\sum_{j=1}^{N} (\delta Cj/\delta\sigma j)} \qquad (15)$$

where:

C = market price of option j;

Cb/sj = B/S-option price as a function of the ISD;

N = total number of options on a given stock with the same maturity.

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