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Did Option Prices Predict the ERM Crises?

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Abstract:

Option prices seem to behave in ways inconsistent with the Black-Scholes model. Implied volatility varies with the strike price in a parabolic shape that is often called the volatility “smile.” My objective in this paper is to identify implied probability distributions that might explain this anomaly.

I develop a simulated method of moments estimation procedure. I parameterize the underlying exchange rate process as a mixture of log-normals, price the options using Monte Carlo methods, and compare these simulated price “moments” to the market data. This process switching model appears to be quite promising in explaining the volatility smile.

Applying this to the ERM data, I find that the probability of a devaluation in the British Pound almost doubled before it withdrew from the ERM. This risk becomes statistically significant on September 15, 1992, only one day prior to the crisis though. The French Franc crisis of July-August 1993 appears to have been better anticipated. By July 20, 1993, the model predicts with 95% confidence that the Franc is going to be devalued.

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A basic insight of financial economics is that asset prices should reflect views about the future. For this reason, many economists will defer to the market when asked to make predictions. Derivative securities like futures or options are effective for this purpose because they are agreements to buy and sell at a future date. Options can be particularly useful because they incorporate information about the entire probability distribution of future events.

Numerous papers have looked at whether this faith in the market is justified. The literature on market efficiency is vast, and the evidence, though often not supportive of purely rational expectations, has not shaken belief in the basic insight.

On occasion, events of unusual magnitude take place that provide a short-lived laboratory for testing informational efficiency. The global stock market crash of October 1987 is one such example. Bates (1991) uses option prices to examine whether the market anticipated the extreme decline in stock prices.

This paper examines currency option prices prior to the exchange rate crises of September 1992 and July-August 1993. In the first episode, the British Pound (BP) and Italian Lira withdrew from the Exchange Rate Mechanism (ERM) of the European Monetary System. The Pound had traded in a narrow range against the German Deutschemark (DM) for almost two years and the Lira for more than five. The crisis threw the entire plan for European economic and financial integration into turmoil. The French Franc (FF) remained in the mechanism, but speculative pressures against it remained strong. In the second crisis I examine, the Franc, in August 1993, had to abandon its very close link with the DM (the “Franc fort.”)

I utilize a new method for analyzing the options data; simple pricing models like the Black-Scholes require inappropriate distributional assumptions. The leptokurtosis in exchange rates is well documented (see e.g. Hsieh (1988)), and the possibility of devaluations might imply some asymmetry. I use a mixture of log-normals density that can capture both of these features.

I cannot obtain closed form solutions for this density, so I simulate option values with Monte Carlo methods. The options are functions of the population moments, and I can estimate the parameters of the density using Duffie and Singleton's (1989) simulated moments estimator.

The estimation procedure provides a complete characterization of the implied probability density for the exchange rate at any point in the future. I examine the probability of depreciation in the BP and FF prior to the ERM crises. The model estimates reveal that the market anticipated both events. The devaluation risk with the Pound becomes significant only one day before it withdrew from the mechanism. With the Franc, the model signals a significant risk 12 days in advance of the crisis.

The paper begins with some discussion of the ERM. Section 2 describes some stylized features of the currency options, and the deviations of the data from the standard models. Section 3 develops the simulated moments estimation procedure. In Section 4, I present estimates of the implied devaluation probabilities. Section 5 concludes and suggests some directions for future research.

1. The ERM

The ERM began in 1979 with seven member countries.¹ The mechanism is a grid of fixed exchange rates with European Currency Unit (ECU) central parities and fluctuation bands. Prior to the crises, the FF had a target zone of $\pm 2.25\%$ and the BP $\pm 6\%$. Maintaining the parities requires policy coordination with the Bundesbank, and when necessary, intervention.

By the Spring of 1992, the momenta towards a single European currency seemed irreversible. Spain had joined the ERM in June of 1989. Great Britain finally overcame its resistance in October 1990. Portugal joined in April 1992 bringing the total membership to ten. In addition, Finland and Sweden had been following indicative DM targets. All the major European currencies, save the Swiss Franc, were incorporated in a system of stable

¹ Belgium, Denmark, France, Germany, Italy, Ireland, and the Netherlands.

exchange rate bands. Almost five years had passed without devaluations.² The financial sector seemed poised for integration, the next logical step in the blueprint of the Maastricht treaty signed on December 10, 1991.

A swift sequence of events left the idea of currency union almost irretrievably damaged. The Danes rejected the Maastricht treaty in June of 1992. The Finnish Markkaa and the Swedish Krona faced devaluation pressures in August which the Bank of Finland and the Riksbank actively resisted. The Markkaa was allowed to float on September 8th, and it quickly devalued 15% against the DM. The Riksbank raised their marginal lending rate to 500% on September 16th.

Then some of the core ERM currencies came under speculative attack. The Bank of England briefly raised their base lending rates, but the British chose to withdraw from the ERM on September 16th rather than expending additional reserves.³ The Lira devalued by 7% on September 13th and withdrew from the mechanism on September 17.

A number of additional devaluations followed. The Krona was allowed to float on November 19th. The Spanish Peseta (in September and November 1992), the Portuguese Escudo (in November 1992), and then the Irish Punt (in February 1993) subsequently adopted new parities. The ERM remained in turmoil into the summer. France faced continued pressure and went through a de facto devaluation when the ERM bands were widened to $\pm 15\%$ on August 2, 1993.⁴

In retrospect, the origins of these crises were evident. The Finnish and Swedish economies were weakened by recession and the collapse of the Soviet Union. Britain had probably overvalued the Pound when it entered the ERM. The Lira had appreciated 30% in real terms against the DM since 1987. Germany had raised interest rates to fight off inflationary pressures from unification, weakening the entire European economy in the process.

The folklore of this period suggests that some market participants anticipated the crisis, and may even have precipitated it. The hedge fund trader George Soros is rumored to have

² There was a small devaluation of the Italian Lira when it moved to narrow bands in January 1990.

³ The Bundesbank is reported to have spent DM92bn defending the Pound and Lira during this crisis.

⁴ The Guilder maintained the narrow bands.

made some US\$1 billion speculating against the Pound and the Lira in 1992.

The question I ask here then is how well diffused was this information. Did the market anticipate these events and were the risks priced into exchange rate options. I begin to address these issues with some stylized facts about options markets.

2. The smile in ERM exchange rates

2.1 The volatility smile

Option prices can provide a great deal of information about the market's perceptions of asset movements. Under fairly general assumptions, the variation of an option price with the strike provides information about the cumulative distribution of the underlying asset. In the Black-Scholes framework, the distribution function is assumed to be log normal with the mean centered at the risk free rate. Implied volatility is a sufficient statistic, and it should not vary with the strike price.

Market data seems to be inconsistent with the Black-Scholes assumptions. Implied volatility tends to change across strike prices. Because this variation generally has a parabolic shape, it is often called the volatility "smile." Beginning with Shastri and Wethyavivorn (1987), researchers have recognized that non-normality in asset returns can contribute to the smile. The literature on time varying volatility, which includes contributions by Wiggins (1987), Hull and White (1987), Stein and Stein (1991) and Heston (1993), has also been motivated by this anomaly. This line of research has also been pursued by Rubinstein (1994) in his presidential address to the American Finance Association, and by numerous practitioners including Shimko (1993) and Derman and Kani (1994).

The approach taken by Bates (1991), though very different from mine, is the most similar in spirit. Bates uses a variant of Merton's (1976) jump diffusion model to detect a skewness premium in stock options prior to the 1987 market crash.

2.2 Data and Stylized Facts

The majority of the intra-ERM derivatives trading is in the over-the-counter markets, and the data is not available to non-traders. The best publicly available data is for US dollar (US\$) exchange rates which are traded in Philadelphia. I focus on the US Dollar/British Pound (US\$/BP) and Dollar/French Franc (US\$/FF) contracts. I have data for the years 1992 and 1993, which encompass both major ERM realignments.

The US\$ appears to be an adequate proxy for the DM. During September 1992, the DM depreciated by -1.47% against the US\$, while the BP depreciated -11.51%. From July 1 to August 5, 1993, the DM was similarly stable, depreciating -0.83%, while the Franc devalued by -3.59% against the US\$.

Both American and European options are traded. The BP options are for 31,250 Pounds and the FF options are for 250,000 Francs. I use daily closing option prices that are quoted in cents. Spot exchange rates are expressed as US\$ per unit foreign and are recorded contemporaneous with the closing trade. Foreign currency appreciation (depreciation) will increase the moneyness of a call (put) option.

I utilize the more frequently traded American style options.⁵ I transform the data into calls using put-call parity. Interest rates are the Eurodeposit rates closest in maturity to the term of the option.

To obtain a rough idea about the implied volatility pattern in the currency options, I look at sample averages. For scaling, I sort the data into bins according to how much they were in or out of the money. Let S denote the spot price and K the strike price, then moneyness is given by

$$\%M = 100 \times (S - K)/S.$$

In Figures 1 and 2, I plot the data for all of 1992 and 1993, for the BP and FF, respectively.

⁵ Currency options may be thought of as options on a dividend paying stock where the dividend is equal to the foreign risk free rate. Early exercise is relevant for call options where the foreign risk free rate is high because this indicates that the currency is likely to devalue. The risk of devaluation will then be priced into American options of all maturities. For empirical comparisons on using European pricing formulas on American options, see Shastri and Tandon (1986).

Both appear to display the characteristic pattern, with the minima of the implied volatility at the money, and with higher implied volatilities in the two tails.

For estimation purposes, I excluded options that were more than 10% in or out of the money and with volumes less than 5 contracts. This seemed to eliminate most data points with unreasonably high implied volatilities. For the Pound, I looked at options from 5 to 75 days to maturity. Because the data were thinner with the Franc, I utilized all maturities greater than 5 days.

Given that the volatility smile is present in the data sample, I must turn to methods more general than the Black-Scholes for inference about the \$/ERM options. I will also try to infer whether changes in the smile signalled an impending crisis in the ERM.

3. Implied probability distributions

3.1 Risk neutral pricing

It is a well-known result that options can be priced as if investors were risk neutral. A call option is just a function of how likely the spot price will exceed the strike price at the time of exercise. Let $C(t, K)$ be the value of a European call at time t struck at K . The value of the call is given by

$$C(t, K) = e^{-r\tau} \int_K^\infty (\tilde{S}_T - K) f(t, \tilde{S}_T) d\tilde{S}_T, \quad (3.1)$$

where $f(t, \tilde{S}_T)$ is the probability density of the terminal spot process, \tilde{S}_T . The tilde denotes that this distribution is with respect to the *risk neutral measure*. For currency options, this implies that the mean of the underlying distribution has been re-centered at the risk free interest differential.

Breeden and Litzenberger (1978) first showed that the partial derivatives of C with respect to the strike price reveal important information about the underlying distribution. The first derivative is a function of the cumulative distribution,

$$\partial C(t, K) / \partial K = -e^{-r\tau} \left(1 - F(t, \tilde{S}_T, K) \right). \quad (3.2)$$

where τ is the time to expiration, r is the risk free rate of interest, and $F(t, \tilde{S}_T, K) = \int_K^\infty (\tilde{S}_T - K) f(t, \tilde{S}_T) d\tilde{S}_T$. The second derivative then extracts the density,

$$\partial^2 C(t, K) / \partial K^2 = -e^{-r\tau} f(t, \tilde{S}_T). \quad (3.3)$$

If you could observe a continuous range of strike prices, it would be straightforward to trace out the underlying distribution. In most markets though, the range of strikes is too coarse. A number of techniques have emerged for overcoming this. Shimko (1993) fits a parabola to the data scatter on implied volatility. Rubinstein (1994) and Derman and Kani (1994) use binomial trees. Each of these methods has limitations that are discussed at greater length in a companion piece to this paper, Mizrach (1996a).

The approach I take here has three parts. I first parameterize a data generating mechanism for the exchange rate series. I then price options using Monte Carlo methods. Simulated method of moments estimation is used to fit the observed data. I discuss each of these steps in turn.

3.2 The data generating mechanism

I assume that the exchange rate process is a draw a diffusion process,

$$dS = \mu S dt + \sigma S dz \quad (3.4)$$

where μ is the mean, σ is the standard deviation, and z is a standard Brownian motion. It follows from Ito's lemma that the logged exchange rate process is

$$d \ln S = (\mu - \sigma^2/2) dt + \sigma dz. \quad (3.5)$$

For a European call, the spot rate at the time of expiration, S_T , determines the value. (3.5) implies that the terminal value is distributed log normally,

$$f(\ln S_T) = N(\ln S + (\mu - \sigma^2/2)\tau, \sigma\sqrt{\tau}), \quad (3.6)$$

with $\tau = T - t$. For discussion purposes, I will ignore the Ito terms and simply call this an $N(\mu, \sigma)$ distribution.

The Black-Scholes analysis assumes a single diffusion with μ equal to the risk free interest

differential. This diffusion is called the *pseudo price process*. Karatzas and Shreve (1991) show that we obtain the identical call values using (3.6) or by evaluating the option in the risk neutral measure (3.1). I suppress the tilde in the remaining discussion and work with the pseudo price process.

I utilize three log normal distributions with four free parameters. Two additional parameters define the probabilities of drawing from each log normal, for a total of six parameters b_1, \dots, b_6 . The first distribution, $N(\mu, b_4)$, has only the standard deviation as a free parameter. The mean is tied to the interest differential, the U.S. rate less the foreign rate, $r - r_f$. Covered interest parity implies that the τ -period ahead forward rate, $F^{(\tau)}$, is given by

$$F^{(\tau)} = S \exp^{\mu\tau}. \quad (3.7)$$

The two other log normal distributions have symmetric means, $b_3 > 0 > -b_3$, centered around μ , but both have their own standard deviations, b_5 and b_6 . The next parameter b_1 is the probability of drawing from the left tail of the mixture, $N(\mu - b_3, b_5)$. The exchange rate is expressed as US\$ per unit foreign so an increase in b_1 represents an increased probability of Pound or Franc *depreciation*. The probability of drawing from the right tail distribution, $N(\mu + b_3, b_6)$, is b_2 .

In the baseline simulations, I show that this data generating mechanism can match a wide range of shapes for the volatility smile. I turn next to Monte Carlo procedures that will enable me to price options from this process.

3.3 Monte Carlo pricing

In the case of a European call, we are concerned with only a single realization, the terminal spot price,

$$C(t, K) = e^{-r\tau} E h(S_T - K). \quad (3.8)$$

where $h = \max[0, S_T - K]$. With some exotic options, the call price may depend on the entire time path,

$$C(t, K) = e^{-r\tau} E h(S_0, \dots, S_T, K).$$

In the case of an Asian option, for example, h would be the max over the average of the S' s.

A Monte Carlo estimate \hat{C} replaces this expectation with a sample average. We use N replications for a price process of sample size n ,

$$\hat{C}(t, K) = e^{-r\tau} \frac{1}{N} \sum_{i=1}^N \sum_{j=1}^n h(S_{j,T}^i) \quad (3.9)$$

where $\{S_{1,T}^i, \dots, S_{n,T}^i\}$ is the i th set of terminal realizations for the exchange rate. In the simulations, I set $N = 500$ and $n = 250$.

3.4 Baseline examples

To calibrate our Monte Carlo estimates, I begin with a baseline normal example with a standard deviation of 15%, $b_4 = 0.15$, and the other parameters set equal to zero. If I form Monte Carlo estimates of European call options with the spot rate log normally distributed, I simply recover the flat Black-Scholes profile (not shown).

I then use a mixture of log normals model to generate both a smile and the left and right “smirks”. In the left (right) smirk, only the left (right) tails shows an increase in implied volatility.

The smile in Figure 3 requires leptokurtosis. I set the standard deviations of the two tail densities to 30% per annum, $b_5 = b_6 = 0.3$, and lower the central standard deviation to 10%, $b_4 = 0.1$. I assume a balanced switching probability, $b_1 = b_2 = 0.1$ which makes the tail mixture mean $b_3 = 0.1$ essentially irrelevant.

The smirks require asymmetry. I generate the left smirk in Figure 4 by assuming a larger probability of foreign currency *appreciation*, $b_2 = 0.2$, and $b_1 = 0.1$, with a jump of 10%, $b_3 = 0.1$. The standard deviations don’t play a role here. All are set equal to the baseline, $b_4 = b_5 = b_6 = 0.15$. The possibility of appreciation raises the value of all the calls above the baseline 15% represented by the dashed line. The options already in the money gain the most, and lead to an even larger increase in implied volatility in that tail.

The right smirk in Figure 5 represents a scenario in which the foreign currency is more likely to *depreciate*, $b_1 = 0.2$, and $b_2 = 0.1$. All the other parameters are the same as in the

left smirk. These events lower the value of the in the money options to the greatest extent. The implied volatility falls below the baseline for all options, but the in the money calls are hurt disproportionately.

These shapes are of course only of secondary interest to this exercise. The six parameters fully describe the underlying distribution and will enable me to evaluate how likely the foreign currency is to depreciate against the US\$ and the DM. I turn to estimation of these parameters next.

3.5 Simulated method of moments estimation

Duffie and Singleton (1989) have provided a framework for using the method of moments estimator in the context where no population moments are known. This will prove highly valuable to us in trying to fit densities to observed options prices.

$f(t, S_T)$ is the object I am trying to estimate, and I have assumed in section 3.2, that it is a mixture of log normals,

$$f(t, S_T) = \left\{ \begin{array}{ll} N(\mu - b_3, b_5), & \text{with } \Pr(b_1) \\ N(\mu + b_3, b_6), & \text{with } \Pr(b_2) \\ N(\mu, b_5), & \text{with } \Pr(1 - b_1 - b_2) \end{array} \right\}. \quad (3.10)$$

μ is set equal to the risk free interest differential.

The density is not directly observable, and the call option is a function of the cumulative distribution. Even in the case of the normal density, analytic expressions are quite complicated. I have little choice other than to simulate a population.

It might be tempting to proceed by matching the simulated moments to time series data on exchange rates. This approach is not suitable because $f(t, S_T)$ is the risk neutral density. The only sample “moments” I observe are the option prices. Let $c(t, K_i)$ denote data on calls struck at K_i , $i = 1, \dots, k$, sorted from lowest to highest, $K_i > K_{i-1}$. Because the options are traded in implied volatility units, our intuition about the smile is in these terms. I transform all the data into implied standard deviations using the Black-Scholes formula,

$$\sigma(c(t, K_i) = \left\{ \sigma : S e^{-r_f \tau} N(d_1) - K_i e^{-r \tau} N(d_2) = c(t, K_i) \right\}, \quad (3.11)$$

where $N(\cdot)$ is the cumulative normal distribution,

$$d_1 = \frac{\ln(S/K_i) + (r - r_f + \sigma^2/2)\tau}{\sigma\sqrt{\tau}}$$

and $d_2 = d_1 - \sigma\sqrt{\tau}$. Let $\sigma(C(t, K_i))$ be the population analog.

In the case where the population includes draws from two distinct tails, $b_1 = b_2 \neq 0$, $b_3 > 0$, the cumulative distribution, $F(t, S_T, K_i)$ is a function of all six parameters for any K_i .⁶ Option prices will also be dependent. The value of the call at the highest strike value $C(t, K_k)$ helps to determine the value of the next strike,

$$C(t, K_{k-1}) = e^{-r\tau} \int_{K_{k-1}}^{K_k} (S_T - K_{k-1}) f(t, S_T) dS_T + C(t, K_k). \quad (3.12)$$

This implies that a single call will just identify the model, and that any additional data will require some criterion function for estimation.

I chose the percentage deviation between the standard deviations of the simulated call options and the market data,

$$g_k \equiv ([\sigma(C(t, K_i)) - \sigma(c(t, K_i))]/\sigma(c(t, K_i)))^{1/2}. \quad (3.13)$$

My simulated moment estimator (SME) chooses $\hat{b} = (\hat{b}_1, \dots, \hat{b}_6)$ so as to minimize

$$Q(b; \{c(t, K_i)\}_{i=1}^k) = G_k W_k G_k' \quad (3.14)$$

where

$$G_k = \underset{(1 \times k)}{[g_1 \ g_2 \ \cdots \ g_k]}, \quad (3.15)$$

and W_k is a $(k \times k)$ positive definite weighting matrix. Because of the computational complexity of the problem⁷, I have not, as of yet, attempted to choose W optimally. For the results reported here, I use the identity matrix which weights each option price equally.

Duffie and Singleton demonstrate that a discrete approximation to a diffusion satisfies all the technical assumptions for consistency and asymptotic normality of the SME. Nothing that I have added to their framework violates the regularity conditions. If the estimated density converges almost surely as the sample size and number of replications grows large,

⁶ The shape of the density to the left of K_i does not enter the call value. Nonetheless, for our process (3.5), the probability mass to the right of *any* K_i will depend upon draws from each of the log normal densities.

⁷ Each day's estimation takes approximately four hours on a Pentium 100.

$f(t, S_{j,T}^i) \rightarrow f(t, S_T)$, then the Monte Carlo estimates do as well, $\hat{C}(t, K) \rightarrow C(t, K)$. Because the implied volatility is just a smooth function of the call price, the remainder of the proof applies without modification.

4. Results

To obtain starting values for estimation, I performed a grid search over the first five parameters. I set the standard deviation of the central log normal distribution, b_6 , equal to the average of the implied volatility for that day. I then used the Davidon-Fletcher-Powell algorithm to obtain final parameter estimates.

I limited my sample to September 1 to 29, 1992 for the British Pound and for July 16, to August 5, 1993 for the Franc. This interval seems to bracket each crisis. I summarize the devaluation risk by evaluating the probability of a 3% or greater devaluation against the US\$ 30 days from the trading date. This is plotted in Figures 6 and 7.

I must re-emphasize that I am estimating the *risk neutral* density. The 3% decline is relative to the forward rate.⁸ The option prices will reflect information beyond that contained in the interest differentials.

Three things will raise devaluation risk: a general increase in implied volatility $b_4, b_5, b_6 \uparrow$, an increase in the probability of foreign currency depreciation, $b_1 \uparrow, b_2 \downarrow$, and an increase in the expected devaluation size, $b_3 \uparrow$.

To determine confidence bands, I took the upper and lower 2.5% fractiles of implied volatility for the three months preceding each crisis. I then simulated a standard log normal distribution with this implied volatility and evaluated the risk of a 3% or larger devaluation. For the Pound, the implied volatility interval was [9.60%, 15.46%] and the probability range was [13.69%, 25.39%]. The Franc traded in a wider probability zone. The implied volatility interval was [4.26%, 14.69%] with a probability range of [0.64%, 24.20%].

The Pound begins the month of September 1992 at a slightly below average risk of

⁸ The French-US one-month interest differential is 12.06% on July 30. This implies a jump of roughly $4\% \approx 3\% + 12.06/12$ relative to the spot rate.

18.59%. It begins to trend upward on September 4, but it does not exceed the 95% interval until September 15 when it hit 27.85%, only one day before it withdrew from the ERM. The spot rate was falling during this period. On September 14, the BP depreciated by -1.68% , and two days later, it fell another -3.29% . On September 17, the day the Lira withdrew from the ERM, the risk peaked at 30.03%. The devaluation risk remains significant until September 21 when it falls to 24.30%.

By the time of the July-August 1993 devaluation, the Franc had been subjected to periodic speculative attacks for almost a year. The average volatility of FF options was as high in January 1993 as in July-August. Nonetheless, the situation seemed to have quieted by early summer. At the beginning of July, the Bank of France was able to lower interest rates closer to German levels, and French commentators declared the FF to be an “anchor” currency of the ERM.

On July 16, the Franc risk was at only 13.58%. Over the next three days though, the risk rose 11.61% and exceeded the upper confidence band on July 20. This was a full 12 days before the crisis. The risk becomes significant again on July 29 at 24.53% as the crisis was underway. On August 2, the monetary authorities did not officially devalue the Franc. They weakened the link to the DM by widening the fluctuation bands to $\pm 15\%$. Surprisingly, after falling -3.59% in July, the Franc actually appreciated slightly against the Dollar by the end of the year.

5. Conclusion

Using simulated moments estimation, I have extracted implied devaluation probabilities for US\$/BP and US\$/FF exchange rates. I was able to relax the restrictive Black-Scholes assumptions and use a mixture of log-normals density to describe the devaluation risk. While this density is quite general and captures both skewness and leptokurtosis, virtually any data generating process could be used. The methods described in this paper should enable estimation of a broad class of option pricing models.

In previous work, Mizrach (1995), I fit a Markov switching specification with probit transition probabilities to a Bertola-Svensson (1993) target zone model. That model demonstrated that interest differentials could help predict realignments. This paper showed that option prices contain information not incorporated into the forward rate. The FF options also signal a realignment three days *before* the interest differentials.

The most important extension from a technical point of view is to model the early exercise provision. That will require using tree methods along the lines of Rubinstein (1994) and Derman and Kani (1994).

Advance notice about impending crises may sometimes help prevent them. Option prices are informative about the entire probability density, and may provide more sensitive inputs to policy makers. Central bankers may tolerate a fairly high rate of false signals as long as no actual crises are missed.⁹ Further research is needed to evaluate error rates from this model. The single day's warning for the September 1992 episode should also remind us that there are limits to market wisdom.

⁹ Some thoughts along these lines are developed in Mizrach (1996b).

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Figure 7

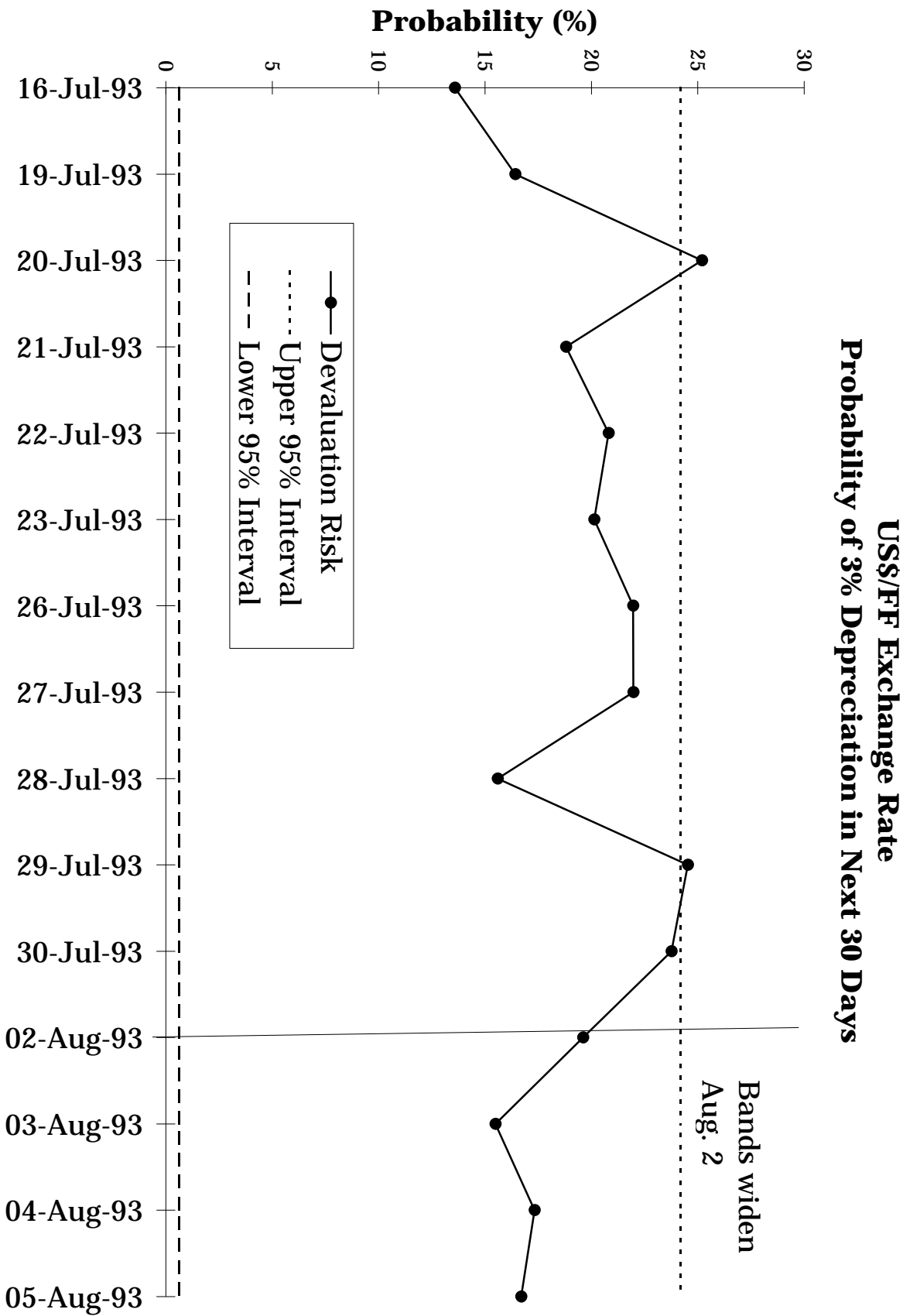


Figure 6

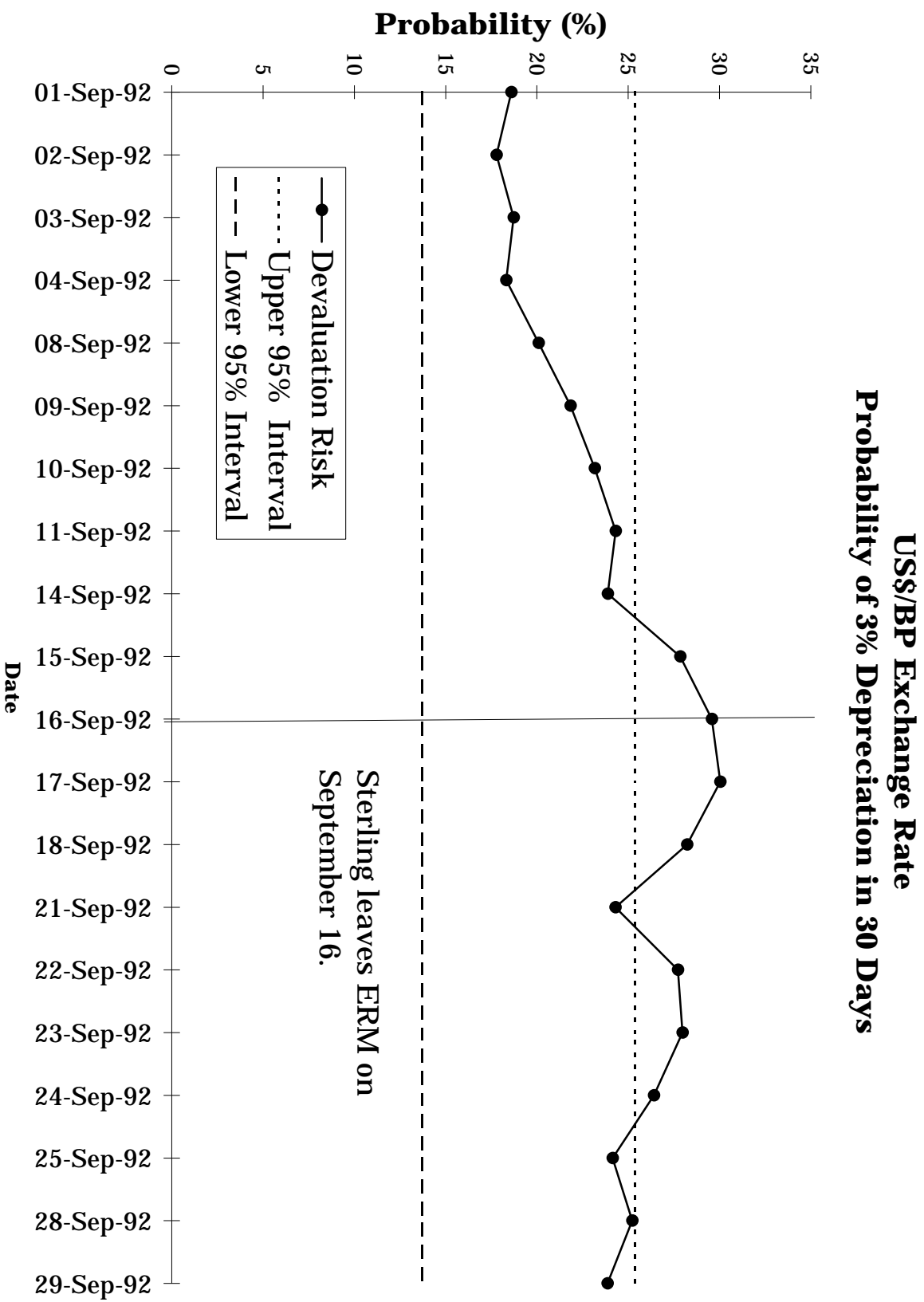


Figure 5

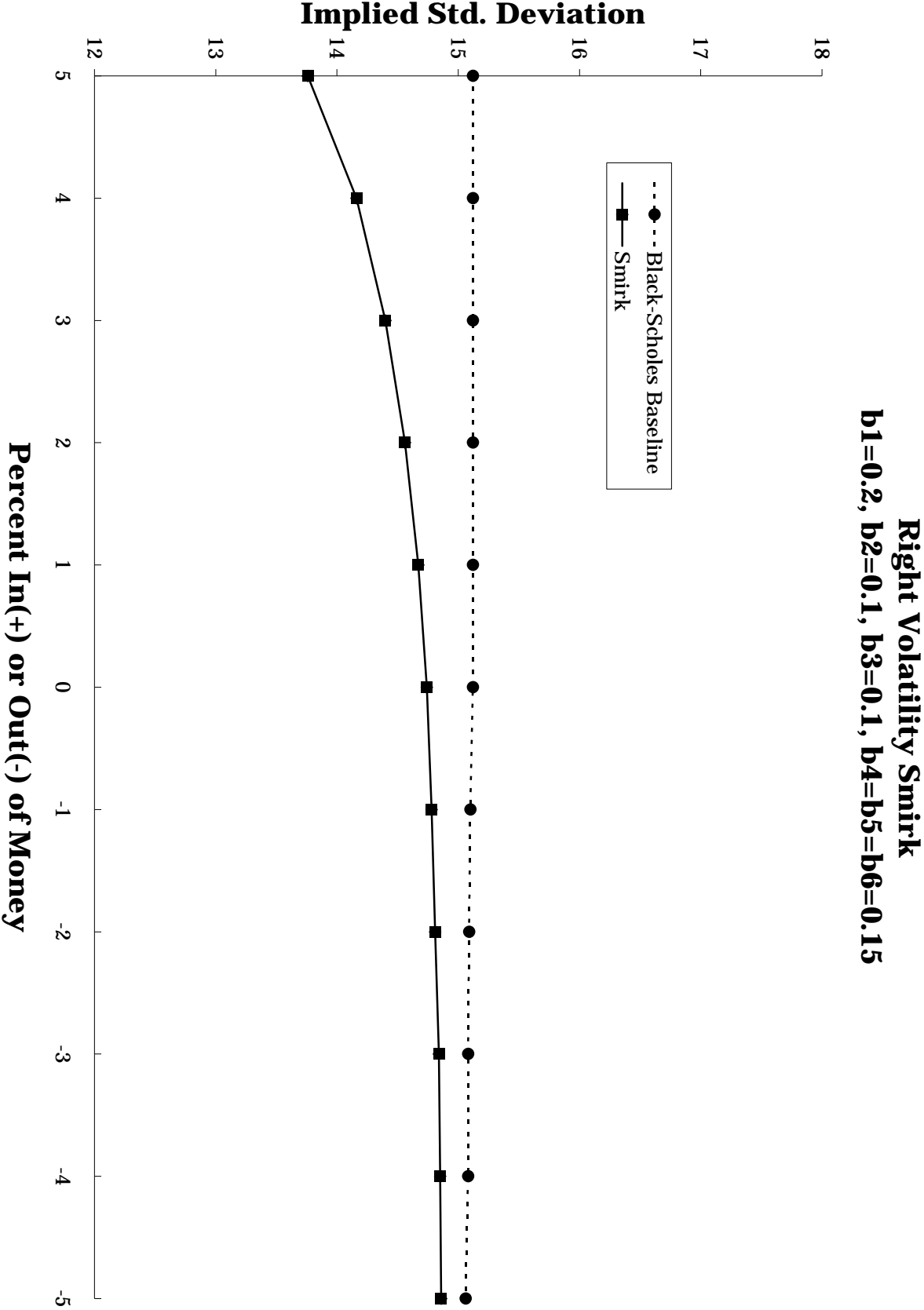


Figure 4

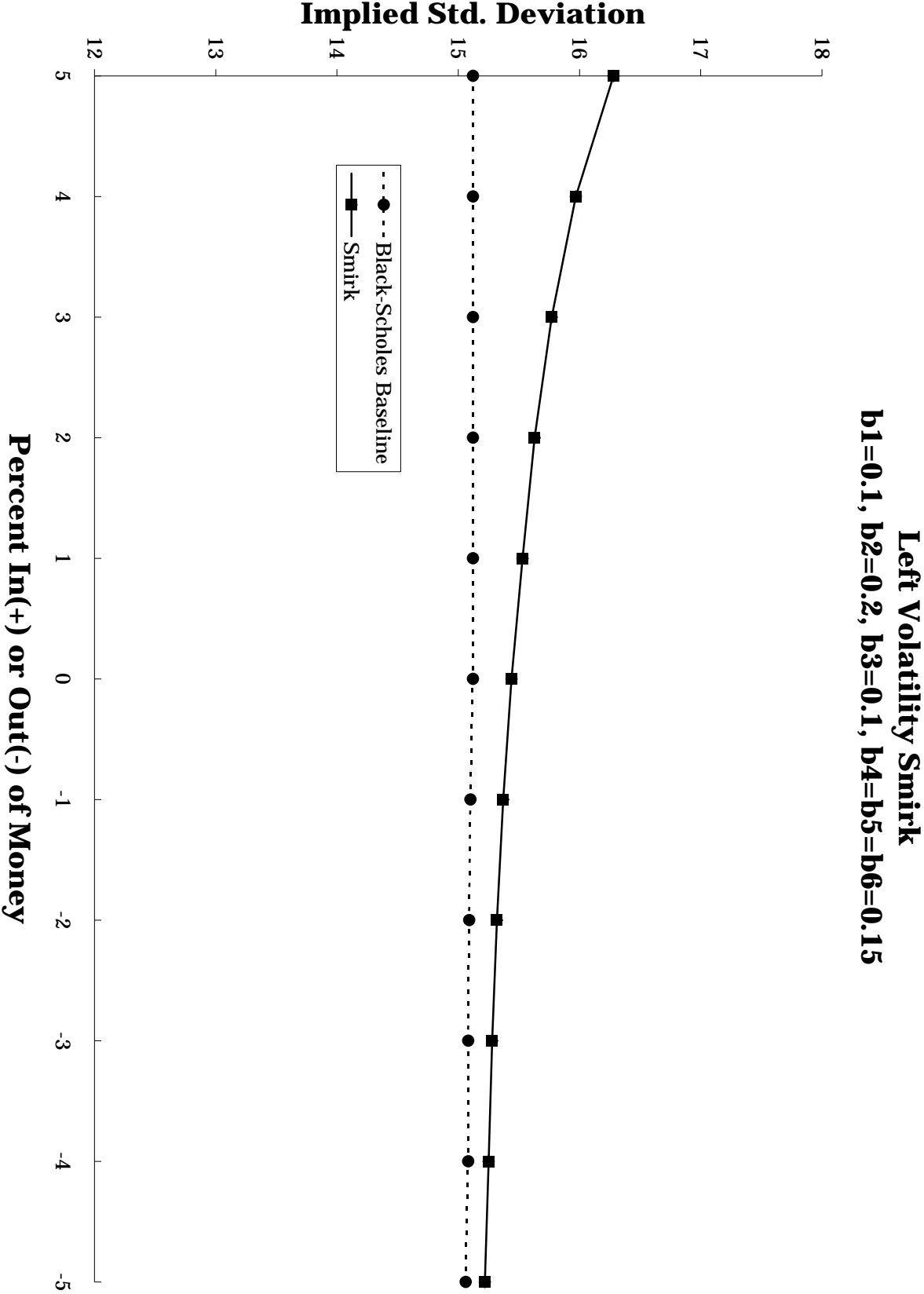


Figure 3

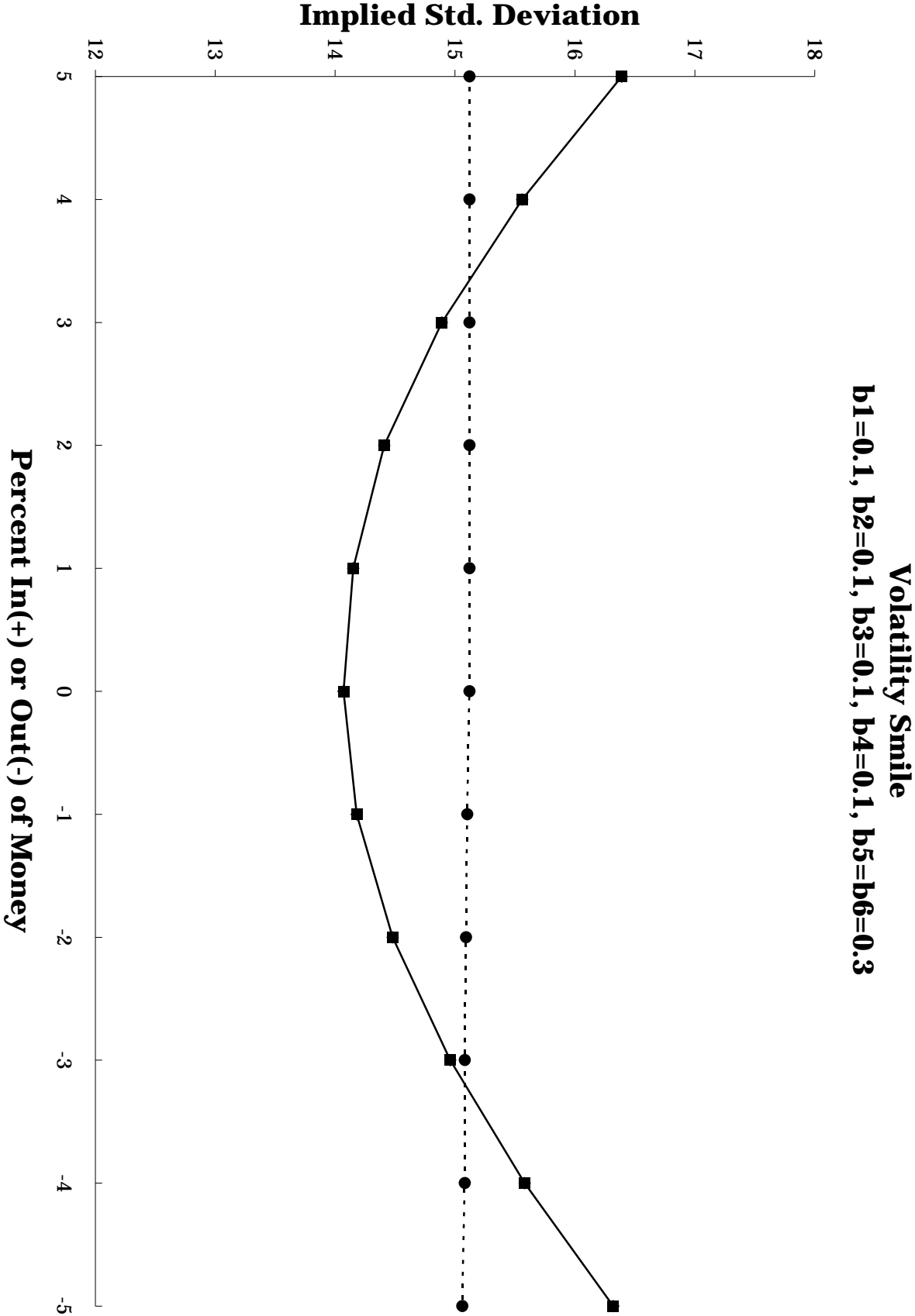


Figure 2

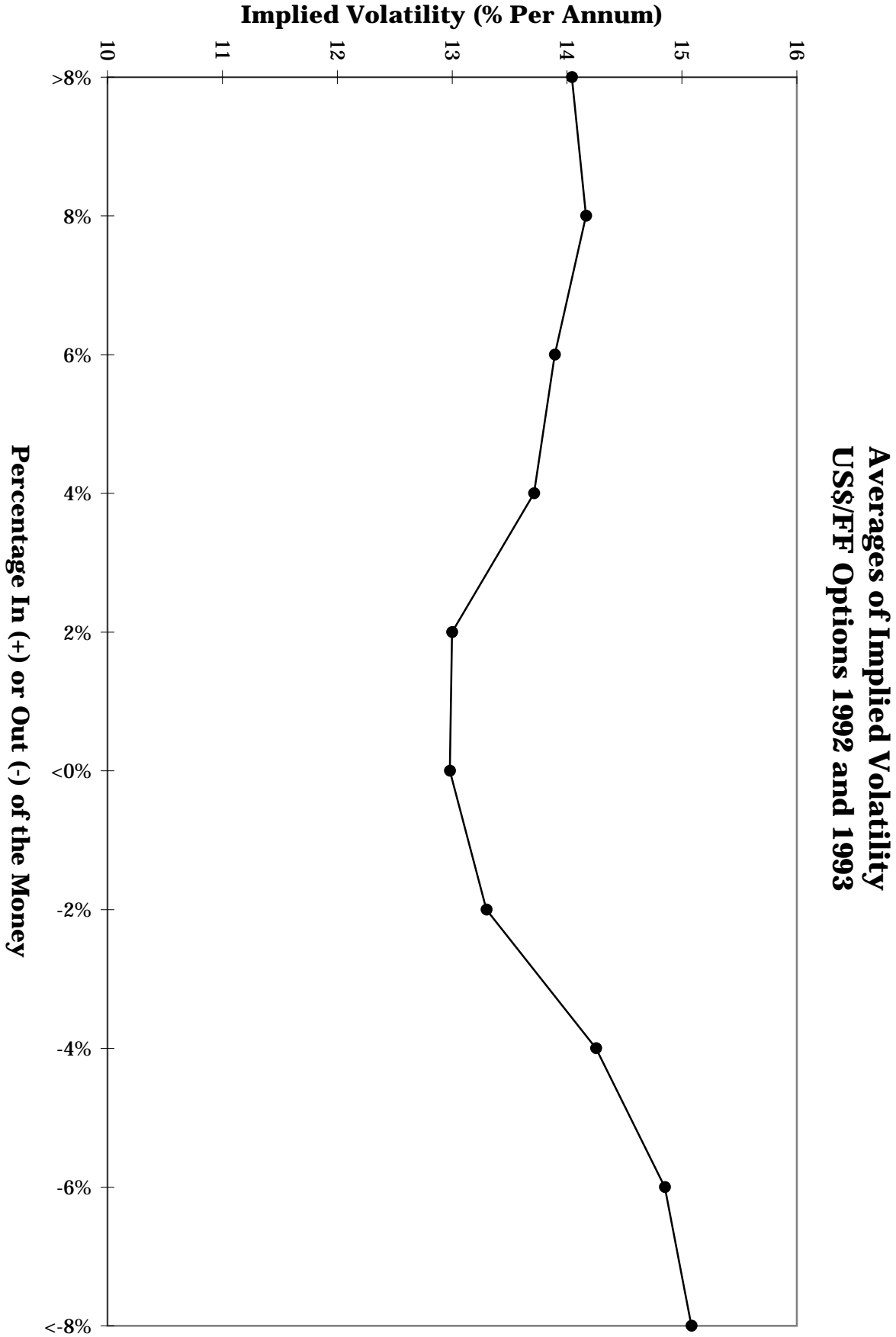


Figure 1

