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Can we forecast the implied volatility surface dynamics of equity options? Predictability and economic value tests

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ABSTRACT

We examine whether the dynamics of the implied volatility surface of individual equity options contains exploitable predictability patterns. Predictability in implied volatilities is expected due to the learning behavior of agents in option markets. In particular, we explore the possibility that the dynamics of the implied volatility surface of individual stocks may be associated with movements in the volatility surface of S&P 500 index options. We present evidence of strong predictable features in the cross-section of equity options and of dynamic linkages between the volatility surfaces of equity and S&P 500 index options. Moreover, time-variation in stock option volatility surfaces is best predicted by incorporating information from the dynamics in the surface of S&P 500 options. We analyze the economic value of such dynamic patterns using strategies that trade straddle and delta-hedged portfolios, and find that before transaction costs such strategies produce abnormal risk-adjusted returns.

1. Introduction

Contrary to the constant volatility assumption of Black and Scholes' (1973) model (henceforth, BS), the volatilities implicit in option contracts written on the same underlying asset differ across strike prices and time-to-maturities. This phenomenon is known as the implied volatility surface (henceforth, *IVS*).[1] In addition, there is abundant empirical evidence of predictable movements of the *IVS* (e.g., Dumas et al., 1998; Cont and Fonseca, 2002; Gonçalves and Guidolin, 2006; Fengler et al., 2007). These studies show that the shape of the *IVS* in its two key dimensions, moneyness and time-to-maturity, evolves over time in ways that can be forecasted using simple models. However, the financial literature has focused its attention mainly on the predictability of the *IVS* of index options, such as S&P 500 options. As a result, the existence of similar dynamics involving the *IVS* of individual equity options has remained relatively under-researched. Moreover, the existence of potential dynamic relationships between the *IVS* of options written on equities and the *IVS* of index options has not been investigated, even though it may be of great practical importance. For instance, the dynamics in the *IVS* of index options could help traders and hedgers anticipate movements in the *IVS* of individual equity options, which may be highly valuable for the design of either speculative or hedging strategies. The objective of our paper is therefore to fill these gaps by studying firstly the unexplored predictable dynamics in the *IVS* of equity options, and secondly, their relationships with movements in the volatility surface implicit in index option contracts.

There are both strong academic and practical reasons to pursue a systematic investigation of the *IVS* dynamics in individual equity options. From an academic perspective, Gonçalves and Guidolin (2006) have analyzed how predictable the S&P 500 *IVS* has been over a 1992–1998 sample. They find that predictability of the S&P 500 *IVS* is strong, but fail to find compelling evidence that such predictable movements may easily translate in positive risk-adjusted profits net of sensible trading costs. Therefore, they conclude that their findings fail to represent first-order evidence that contradicts the efficient market hypothesis. On the one hand,

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[1] See, e.g., Rubinstein (1985), Campa and Chang (1995), and Das and Sundaram (1999).

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this result provides a motivation to investigate whether alternative segments of the equity options market can be isolated in which *IVS* predictability may not only hold as a statistical fact, but also signal the existence of important pockets of market inefficiency. In fact, we would expect that such pockets of inefficiency may exist exactly with reference to options that are less liquid than S&P 500 index options. On the other hand, especially if the efficient market hypothesis is imposed so that any *IVS* predictability is traced back to either micro-structural imperfections or to unobserved and hard-to-estimate time-varying risk premia, financial economists might have a lot to learn from a careful study of the cross-sectional differences and/or economic value "scores" caused by *IVS* predictability.[2]

Understanding the *IVS* dynamics of equity options is not only crucial to participants in option markets such as market makers, option traders, or investors who aim at hedging equity option positions. Knowledge of the dynamic process of the *IVS* is also relevant for investment decisions in other markets, because options have been commonly used to obtain forward-looking market information. Forward-looking analyses based on option market information rely on the assumption that option prices should reveal agents' expectations about prospective economic scenarios, where the horizons of investors' forecasts correspond to the expiry dates of traded option contracts.[3] In practice, trading desks are often interested in estimating the dynamic process followed by the *IVS* of individual equity options, with the objective of taking positions to hedge existing portfolios or other over-the-counter exotic derivatives offered to institutional customers. However, because trading volume may often be lumpy in individual equity option markets, it is at least doubtful that real-time updates of the entire equity option *IVS* may be feasible in practice. In fact, a non-negligible portion of all existing equity options may be classified as infrequently traded securities. Therefore, given that investors are eager to learn any new information relevant to predict an equity option *IVS* in real time, they are likely to be ready to avail themselves also of information revealed by transactions involving more liquid but related contracts, such as those typically written on major market indices.[4] Consequently, in this paper we also test whether there is any forecasting power in movements in the S&P 500 index *IVS* for subsequent dynamics in the *IVS* of individual stock options. In this context, it is surprising that empirical research on derivatives has remained scarce when it comes to investigating the relationships between the *IVS* of equity options and the *IVS* of market index.[5] This may also be seen as an additional and novel contribution of our paper: in the same way that all students of finance apply the simple CAPM in their analyses, by which individual stock volatility moves proportionally with market volatility (e.g., as represented by the S&P 500 index), in our paper we test whether such relationship may also hold for the *IV* surfaces of equity and index options.[6]

In our paper, we use daily data from individual equity and S&P 500 index options traded on the U.S. markets over the period 1996–2006. The choice of a sample that stops at the end of 2006 is intended to provide evidence on the cross-sectional predictability dynamics in equity option *IVS* that is free from the effects of the recent U.S. financial turmoil of 2007–2009. Our modelling strategy is simple (one may argue, so simple to be tempting to many trading desks) and based on a two-stage econometric approach. First, we characterize the *IVS* of equity options and the *IVS* of S&P 500 index options by fitting on daily basis a straightforward deterministic *IVS* model. In this deterministic *IVS* model the dependent variable is implied volatility (henceforth, also shortened as *IV*), and the explanatory variables are factors related to key observable option contract features such as strike prices and time-to-maturities. Second, for each equity option we estimate a second-stage VARX predictive model in which the endogenous variables are the time series coefficients estimated from the deterministic *IVS* models concerning each stock option in the first stage; while the exogenous variables are the time series coefficients estimated from deterministic *IVS* models for S&P 500 index options. In the following, we often refer to such VARX model as the 'dynamic equity-SPX *IVS* model'. Finally, the dynamic equity-SPX *IVS* model is used to recursively compute *H*-day-ahead forecasts for the *IVS* of individual equity options, where *H* is set to be 1, 3, 5, 7, and 9 days. The goal of our paper consists of assessing whether such a recursive, two-stage approach yields *IV* and option price forecasts that display adequate statistical accuracy (relative to benchmarks) and/or that may support valuable trading strategies.

We find evidence of strong cross-sectional relationships between the implied volatility surfaces of individual equity and S&P 500 index options. Moreover, we show that a remarkable amount of the variation in the *IVS* of stock options can be predicted using past dynamics in the *IVS* of S&P 500 index options. Firstly, we compare our VARX-type model (the dynamic equity-SPX *IVS* model) with a simpler VAR-type dynamic equity *IVS* model. This VAR-type dynamic equity *IVS* model follows a similar two-stage procedure as the dynamic equity-SPX *IVS* model describe above, but this benchmark model does not take into account the information from the *IVS* of S&P 500 index options. In particular, when we compare both models we find that the predictable dynamics in the *IVS* of stock options are better characterized by the VARX model that use the information in recent movements in the S&P 500 index *IVS*. The dynamic equity-SPX *IVS* model yields a superior one-day-ahead forecasting performance in comparison to the VAR-type framework that only includes information from past movements of the *IVS* of stock options. The intuition for this result comes from the slow updating process of the equity option *IVS* caused by the often modest trading frequency of a large fraction of stock option contracts. As a result, when such an updating is allowed to include information revealed by recent movements in the S&P 500 index *IVS*, the resulting forecasts out-perform the VAR-type model and other benchmarks, such as an *ad-hoc* 'Strawman' random walk model for the first-stage deterministic *IVS* equity option coefficients (which is also used in Dumas et al. (1998), and Christoffersen and Jacobs (2004) and an option-GARCH model for American-style option contracts (see Duan and Simonato, 2001).

Furthermore, we also investigate the economic value of the predictable dynamics uncovered in the cross-section of the stock option *IVS*. We build a number of trading strategies that exploit

[2] Examples of predictability "scores" are the root mean-squared prediction error or the mean absolute prediction error for *h*-step ahead BS implied volatilities. Examples of economic value "scores" are average trading profits or realized Sharpe ratios from trading strategies built from a given *IVS* dynamic model. Section 4 provides details on all the criteria used in our paper to measure predictability and its economic value.

[3] Option prices have been recently used on many occasions to capture forward-looking information on the dynamic process of asset returns (e.g., Xing et al., 2010; Bakshi et al., 2011), their realized volatilities (e.g., Christensen and Prabhala, 1998; Busch et al., 2011), risk premiums (e.g., Duan and Zhang, 2010), betas (e.g., Siegel, 1995; Chang et al., 2009), correlation coefficients (e.g., Driessen et al., 2009), and to solve forward-looking asset allocation problems (e.g., Kostakis et al., 2011).

[4] In Section 2 we report market statistics concerning the trading activity levels on equity and index options. These statistics confirm, as one would expect, that index options are much more actively traded than even the most liquid individual equity options.

[5] See also Dennis and Mayhew (2002) and Dennis et al. (2006), although they do not directly explore the association of shape characteristics of equity option and the index *IVS*. Dennis and Mayhew (2002) find that the skew of the risk neutral density implied by equity options is more negative when there is a high at-the-money implied volatility of S&P 500 index options; Dennis et al. (2006) use a relationship similar to the CAPM for implied volatilities (using at-the-money short-term contracts) and find an implied idiosyncratic volatility in equity options.

[6] Equity options and S&P 500 index options are also known as stock options and SPX options, respectively. In what follows, we will use any of these expressions/acronyms interchangeably, without any special or technical meaning.