ARTICLE IN PRESS

North American Journal of Economics and Finance xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

North American Journal of Economics and Finance

journal homepage: www.elsevier.com/locate/najef

European quanto option pricing in presence of liquidity risk

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ARTICLE INFO

Keywords:
Quanto options
Option pricing
Market liquidity
Liquidity discount factor

ABSTRACT

In this paper, we study the pricing problems of the European quanto options in which the underlying foreign asset is in imperfectly liquid markets. First, we assume that the dynamics of the underlying foreign asset price are affected by market liquidity and propose a liquidity-adjusted quanto model. This allows for the effects of market liquidity on European quanto option pricing. And then we derive the analytical pricing formulas for four different types of European quanto options. Finally, we empirically investigate the pricing performance of our proposed model with a European quanto construction involving the SSE 50 ETF, as the underlying asset, and the CNY/HKD exchange rate. Empirical results demonstrate that the pricing accuracy of the proposed model is markedly superior to that of the Black-Scholes quanto model. In other words, allowing for liquidity risk in the framework of European quanto option pricing can make markedly improvements in fitting the real market data. Particularly, the improvement rate is high for medium-term and out-of-the-money options. Moreover, these results are robust for different liquidity measures.

1. Introduction

With the growth and deepening of globalization, the quanto options (currency translated foreign equity options) have gained wider popularity. Quanto option is a popular contingent claim whose payoff depending on the equity price in one currency but the payoff actually settled in another currency. This enables investors from different countries or regions to manage the multinational risk in their positions from global financial markets while the profit and loss are denominated in their own currencies.

So far there have been many modified Black-Scholes quanto models and valuation methods for pricing quanto options. Under the assumption that the dynamics of the foreign asset price and exchange rate are governed by the Black and Scholes (1973) model, i.e. geometric Brownian motion, the quanto option pricing has been studied by Baxter and Rennie (1996), Dai, Wong, and Kwok (2004), Dravid, Richardson, and Sun (1993), Kwok and Wong (2000), Reiner (1992), among others. Although the success of the Black-Scholes quanto model based on Brownian motion and normal distribution, some empirical phenomenons in foreign asset return and exchange rate cannot be explained by Black-Scholes quanto model, such as, jumps, heavy tails, skewness and mean-reverting. To incorporate these features in quanto option pricing, a variety of models have been proposed, including, among others, jump-diffusion processes, tempered stable processes, stochastic volatility, Lévy processes and GARCH models. For the applications of these alternative models in quanto option pricing, see, for example, Duan and Wei (1999), Fallahgoul, Kim, Fabozzi, and Park (2017), Huang and Hung (2005), Kim, Lee, Mittnik, and Park (2015), Sun and Xu (2015), Ulyah, Lin, and Miao (2018) and Xu, Wu, and Li (2011a, 2011b).

Moreover, because of regime-switching models provide a natural and convenient choice to model the structural changes in economic conditions, especially due to financial crises, this class of models will enjoy more and more popularity. In view of this, Chen, Chiang, Hsu, and Li (2014), Fan, Shen, Siu, and Wang (2014), and Ng, Li, and Chan (2013) discussed the quanto option pricing

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https://doi.org/10.1016/j.najef.2018.03.002
Received 16 December 2017; Received in revised form 12 March 2018; Accepted 19 March 2018
1062-9408/

Please cite this article as: Li, Z., North American Journal of Economics and Finance (2018), https://doi.org/10.1016/j.najef.2018.03.002

in presence of a Markovian regime-switching market. On the other hand, from the market data analysis reveals that financial quantities are correlated in a strongly nonlinear way and exhibited non-zero correlation risk premium. From this point of view, both Ma (2009) and Teng, Ehrhardt, and Günther (2015) investigated the pricing of quanto options under dynamic correlation models.

The previous literature mentioned above considers quanto options under the idealized assumptions, i.e. the financial markets are frictionless and the underlying assets are perfectly liquid. However, a large number of empirical studies indicate that the liquidity is an important and significant effect factor in many financial asset prices. It has been shown that the stock returns are influenced by liquidity risk and commonality in liquidity, and the expected returns are positive related to the level of stock illiquidity. Therefore, market liquidity has currently become an issue of high concern in asset pricing and financial risk management. Naturally, investors demand a premium for bearing the risk of illiquidity. The illiquidity premium was first documented for the stock market in Amihud and Mendelson (1986).[1] Soon afterwards, some researches began to focus on the effects of liquidity on option prices. By using a unique dataset that options are issued by a central bank and are not traded prior to maturity, Brenner, Eldor, and Hauser (2001) examined the effect of illiquidity on the price of currency options. Chou, Chung, Hsiao, and Wang (2011) illustrated the influence of both spot and option liquidity levels on option prices. Nordén and Xu (2012) investigated the dynamic relationship between the steepness of the volatility smirk and relative index option liquidity. Christoffersen, Goyenko, Jacobs, and Karoui (2018) presented a significant positive impact of option illiquidity on expected call option returns by utilizing portfolio sorts and cross-sectional regressions. Theoretically, stock illiquidity is positively related to option illiquidity and thus indirectly affects option prices.

Additionally, there have been some theoretical researches on how to introduce liquidity effect into the framework of standard European option pricing. Cetin, Robert, and Protter (2004) developed a model for the inclusion of liquidity risk into arbitrage pricing theory by assuming that a stochastic supply curve for a security's price as a function of trade size.[2] Bakstein and Howison (2004) developed a parameterized model for liquidity effects arising from the traded assets, where the liquidity was defined by means of a combination of a trader's individual transaction cost and a price slippage impact. Based on this model, options can be priced and hedged under the risk-neutral world. In contrast to the standard framework and consistent with a market with imperfect liquidity, Liu and Yong (2005) examined the effect of stock liquidity on the replication of a European contingent claim under the assumption that the investors's trading had a direct impact on the stock price. As the liquidity was understood as a nonlinear transaction cost incurred as a function of rate of change of portfolio, Rogers and Singh (2010) proposed a model for the effects of illiquidity and explored some of its consequences for the hedging of European options in the model of Black and Scholes (1973). Working within a Markovian regime-switching setting, Ludkovski and Shen (2013) defined illiquidity as the inability to trade in a timely way and then studied the pricing and hedging problems of European options with liquidity shocks. Following the asset price dynamics proposed by Brunetti and Caldarera (2006), Feng, Hung, and Wang (2014, 2016) derived the corresponding pricing formulas for European options and investigated the importance of the stock liquidity on option pricing. Their empirical results provided strong evidence to support that incorporating a stock liquidity into the framework of option pricing can produce smaller pricing errors. Recently, within the framework of conic finance, Leippold and Schärer (2017) studied the discrete time option pricing with stochastic liquidity model, in which the liquidity measure was not directly defined by observable variables in the financial market such as bid-ask spreads or trading volume, but inferred from a comparison of market and model implied bid-ask spreads. To the best of our knowledge, until now there is no literature research on pricing European quanto options in which the foreign asset is in imperfectly liquid market. So the aim of this paper is to fill this gap.

Motivated by the above mentioned insights, we study the pricing problem of the European quanto options, where the foreign asset is in illiquid markets. That is to say, the foreign asset return is affected by the level of market liquidity. We first propose to price European quanto options under the assumption that the foreign asset price process is driven by the asset price model developed by Brunetti and Caldarera (2006), which contains the Black-Scholes economy as the limiting case (i.e., when the markets are perfectly liquid). It should be noted that this model had been used to price European options, see, for example, Feng et al. (2014, 2016). Suppose that the liquidity discount factor is connected to both market liquidity and the sensitivity of stock prices to market liquidity, we then derive the closed-form pricing formulas for the European quanto options based on standard risk-neutral valuation principle.[3] Finally, an empirical application to SSE 50 ETF options and the CNY/HKD exchange rate to illustrate the pricing performance of the proposed liquidity-adjusted quanto model compared with that of the Black-Scholes quanto model. Here, we suppose that an investor in Hong Kong wants to purchase the financial derivative traded at mainland China.

Turning to empirical results, we investigate the effects of the foreign equity market liquidity on the European quanto option pricing. In the present paper, the liquidity is defined as the ability of an asset to trade any amount of securities quickly at the market price without additional transaction cost and within a short of time. To show that the robustness of the pricing performance does not affected by the employed liquidity measure, we utilize three liquidity measures for empirical studies. The first liquidity measure is defined as the ratio of stock return to its RMB trading volume, which can be viewed as the modified liquidity measure of Amihud (2002). The other two are the absolute return divided by the trading volume and the absolute change in daily close price divided by the RMB trading volume, respectively. In addition, due to the shortage of readily available real market data of European quanto

[1] For more related studies on illiquidity premia in the stock market, see Amihud (2002), Acharya and Pedersen (2005), Amihud and Mendelson (1989), Bali, Peng, Shen, and Tang (2014), Brennan and Subrahmanyam (1996), Brunetti and Caldarera (2006), Datar, Naik, and Radcliffe (1998), Eleswarapu and Reinganum (1993), Hung, Chen, and Fang (2015), Kim and Na (2017), Lee (2011), Pastor and Stambaugh (2003), and Watanabe and Watanabe (2008).

[2] Following the framework of Cetin et al. (2004, 2006, 2010) studied the problems of option pricing and super-replication in an extended Black Scholes economy, where the underlying asset is imperfectly liquid.

[3] The liquidity discount factor successfully captures the effect of the liquidity on the asset price, such as in Chen (2012), Chen, Yang, and Yeh (2017), Longstaff, Mithal, and Neis (2005), Subramanian and Jarrow (2001).