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An Analysis of the Covered Warrants listed on the Athens Exchange

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Abstract

The particular study is the first academic attempt to review a new financial instrument, the covered warrants, which were listed for trading in the Athens Exchange within the framework of the recapitalization of the three systematic Greek banks (Alpha Bank, National Bank of Greece and Piraeus Bank) in the summer of 2013. In particular, we discuss the basic characteristics of these instruments and we examine their pricing efficiency during the fifteen months of their listing. The empirical results suggest that the Greek warrants market is inefficient as the three listed contracts are systematically underpriced compared to their theoretical value based on the historic realized volatility of the underlying shares. Furthermore, a dynamic delta-hedged warrant portfolio yields significant cumulated gains that exceed the risk-free rate.

JEL classification numbers: G13, G23
Keywords: Warrants, Cox-Ross-Rubinstein model, Greek banks, Implied volatility, Delta hedging

1 Introduction

The particular study investigates a new segment of the Greek equity market, the covered warrants which were issued within the framework of the recapitalization of the Greek banks. The Hellenic Financial Stability Fund (HFSF) issued warrants for the ordinary shares of the three systematic banks (Alpha Bank, National Bank of Greece and Piraeus Bank) which it acquired in the share capital increases of 2013. The warrants were allocated at no cost to all private investors who participated in the recapitalization share capital increase (pro rata to their participation in the capital increase), in order to give them the opportunity to regain the control of the banks in the future.
The Greek banking sector was severely hit over the past six years by the combined effects of deposit withdrawals, which could not be recouped by the international capital markets, the credit loss projections of their loan portfolios and the restructuring of the Greek sovereign debt through the Private Sector Involvement (PSI). These factors put pressure

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on the liquidity and the capital base of Greek banks, which were required to raise new capital (Bank of Greece, 2012). In order to contribute to the maintenance of the stability of the Greek banking system, for the sake of public interest in July 2010 the Hellenic Financial Stability Fund (HFSF) was founded under Law 3864/2010. The HFSF has an initial duration until 30 June 2017, with a potential of a three-year extension if the Minister of Finance decides that this is necessary for fulfilment of its scope[3].In March 2012, the Bank of Greece carried out a conservative assessment of the capital needs of the Greek banking sector and published a relevant report entitled "Recapitalization and Restructuring of the Greek Banking Sector". The strategic assessment identified four systematic (core) banks, namely Alpha Bank, Eurobank, National Bank of Greece and Piraeus Bank, which were considered suitable candidates for recapitalization using government funds. In November 2012 the ministerial Cabinet Act 38 determined the terms of the recapitalization framework and during the summer of 2013 the four systematic Greek banks were able to raise over €28 billion for their capital and liquidity needs. Almost 700,000 shareholders of the three banks[4]participated in the capital increases covering around 12% to 15% of the total recapitalization needs. The rest of funds were invested by the HFSF, but since the minimum capital (10%) to be paid by private investors was achieved, covered warrants were issued. Each warrant incorporated the right of its holder to buy from the HFSF a pre-determined number of ordinary shares that the HFSF has acquired by participating in the capital increase of each bank.

This is the first academic attempt to discuss the basic characteristics of these warrants and investigate their pricing efficiency during the first 15 months of trading in Athens Exchange (ATHEX). In particular, we examine their market value compared to their theoretical value based on the historic realized volatility of the underlying shares and we investigate the performance of a dynamic delta-hedged warrant portfolio.

The rest of the paper proceeds as follows: in the next section we concisely analyze the basic characteristics of the Greek warrants market, while the third section includes a discussion of the warrant valuation models and the concept of implied volatility. In section four, we empirically analyze the first year of trading for the warrants and we examine the relationship of realized volatility of the underlying shares and the volatility implied by warrants prices. The fifth section investigates the performance of a delta-hedged warrant portfolio, while the last section includes the concluding remarks.

2 Greek covered Warrants Specifications[5]

Warrants are transferable securities listed on the Athens Exchange that were issued within the framework of the recapitalization of the Greek banks according to the special provisions of the Ministerial Council Act N.38. Each warrant gives its holder the right (but not the obligation) to buy a fixed number of underlying shares of the bank (owned by the HFSF), at a predetermined price (the strike price), on specific dates (exercise dates), until a predetermined time in the future (4.5 years or 54 months from the issue date of the warrants). The warrants are covered by the shares already held by the HFSF (acquired

[3]Source: Hellenic Financial Stability Fund website (www.hfsf.gr).

[4]The fourth systematic Greek bank, Eurobank, was fully capitalized by HFSF funds and thus, no warrants were written.

[5]Table 1 includes the basic specifications of the 3 listed Greek warrants.

during the share capital increase in 2013). This means that no new shares of the underlying banks are issued at each exercise, but already existing shares are used and hence, there is no dilution of existing shareholders as a result of exercise, since the total number of the bank's shares outstanding remains unchanged. Thus, the particular warrants are Bermudan covered call options.

Warrants holders can exercise their right to buy every six months, starting from the date which falls six months from the warrants issue date until the date which falls 4.5years from the warrants issue date, which is also the final expiration date (9 exercise periods in total). Warrants not exercised within this period will lapse and will be cancelled. The exercise price of the warrants is equal to the price that the HFSF paid for acquiring each of the banks' shares at the recapitalization process, plus accrued interest, which is calculated by applying an annual interest rate of 3% increased by a spread of 1% for the first year, 2% for the second year, 3% for the third year, 4% for the fourth year and 5% for the remaining time. The Multiplier ratio is the number of shares (that HFSF owns) corresponding to one warrant which the holder may acquire upon exercise. This ratio was determined by the contribution of the private sector in the recapitalization offering for each bank and ranges from 4.47 ordinary shares per warrant (for Piraeus Bank) to 8.23 ordinary shares per warrant (for National Bank of Greece).

For a period of thirty-six months from the warrants issue date, the HFSF is not allowed to transfer the shares underlying the warrants to a third party (the only transfer allowed relates to the exercise of a warrant). After this period and until the expiration of the warrants, the HFSF provides a right of first refusal to warrant holders and if they choose not to acquire such shares, then the HFSF shall be entitled to transfer the underlying ordinary shares without being obliged to indemnify the warrant holders.

Warrants are listed in the same market that the bank ordinary shares are listed in, that is in the ATHEX Securities Market and are registered in the Dematerialized Securities System (DSS), the registry and settlement system of Hellenic Exchanges. The trades are executed automatically and continuously in the trading system from 10:15 until 17:20. The only difference in their trading method compared to ordinary shares is how the opening and the closing prices are determined; the opening price is considered to be the price of the first trade executed in the respective market, while the closing price is defined as the price of the last trade concluded therein during the trading session[6] (ATHEX Resolution No. 22).

3 Valuation Models

For the valuation of Bermudan warrants, there is no closed-form solution (as the Black-Scholes pricing formula for European options) and only approximation methodologies exist. According to the relevant information memorandum of the Athens Exchange there are four methodologies for the calculation of the theoretical price of a Bermudan-style covered warrant. In particular, the first and simplest method is the use of an analytical option pricing model (e.g. the Black-Scholes formula) for valuing a European-style call option (with maturity in 4.5 years and exercise price the last available strike price). In this case, the Bermudan warrant is priced as a European call option ignoring the interim exercise periods. The second approach involves again the use of a closed-form model

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[6]The opening and the closing prices of ordinary shares are determined by a call auction method.

(Black-Scholes) in order to value all nine European-style call options (with the respective exercise price and date) and then choose the highest estimated value, which will roughly correspond to the price of the Bermudan warrant. The third method is the use of algorithms that give an approximation to the option value[7]. Versendaal (2008) proposes the use as a benchmark for the lower bounds on a Bermudan call stock option the value of the corresponding European call option and as an upper bound benchmark the value of the corresponding look-back option. A look-back option allows its holder to pick the exercise moment at expiration, when all cash flows are known. Therefore the value of the look-back option should be higher than the value of the Bermudan option, which does not allow foreknowledge. Finally, the fourth approach is the use of a modified binomial model. This is the method we are going to follow in our empirical analysis, since according to Versendaal (2008) for a one-dimensional underlying process (as the stock prices follow) a binary tree model and numerical procedures can be employed without any problem.

3.1 Binomial or Cox, Ross και Rubinstein (CRR) Model

The binomial model is particularly useful for pricing both simple American-style options and complex exotic options numerically, since it can deal with the possibility of early exercise. This method is only a reasonable approximation as it cannot provide an exact analytical solution as the Black-Scholes formula does. The binomial tree model was first proposed by Cox, Ross and Rubinstein (1979) who show how the binomial pricing model arises from a discrete development of the geometric Brownian motion of the underlying asset. It is based on the assumption of risk neutrality according to which all investors require no compensation for risk. Under the risk neutrality assumption, the option can be simply priced as the expected value of its future payoff discounted by the risk free rate.

The CRR model breaks down the option's time to expiration into potentially very large number of time intervals, or steps. At any point of time (step) the price of the underlying asset S_t has only two possibilities to move: either the price moves up at a constant rate u and with probability p or the price moves down at a constant rate d and with probability 1-p. The up and down rates are calculated using the annualized volatility of the underlying asset and the time duration of a step (measured in years). At the final step (i.e. at expiration of the option) the option value is simply its intrinsic value. The option value is found recursively for each step, working backwards in time (for time n-1, n-2 etc.) as the present value of the expected value of its future payoffs.In particular the value of a call option C_t is given by the following formula:

$$C_t = e^{-r_{f,t}\tau_t} \sum_{i=0}^{n} \left(\frac{n!}{i!(n-i)!}\right) p^i (1-p)^{n-i} (S_t u^i d^{n-i} - K_t) \qquad (1)$$

The CRR model is a discrete version of the Black-Scholes model, but as the time interval tends to zero, the two processes converge. In the case of a Bermudan call warrant the above described methodology should be slightly modified. In particular, at each node the possibility of early exercise should be evaluated; when early exercise is allowed the value of the warrant is the maximum between the exercise value and the binomial (model

[7]For an extensive analysis see Versendaal (2008).

estimated) value, while when early exercise is not allowed, only the binomial value is relevant (Cox et al, 1979).

3.2 Implied Volatility: Definitions and Analogies

The value of an option depends on the following six variables: the spot price of the underlying share at the moment of valuation, the strike price, the dividend yield(if any), the risk-free rate, the remaining time until maturity and the volatility of the underlying asset over the life of the option. By attributing values to the above factors, the option valuation model results in an estimate of the option's theoretical fair value. Since options usually trade in an organized market, we could consider their market price as their fair price. In that case, and since all the other five variables (except volatility) are fairly objectively determined, we could use the pricing model in order to solve for volatility (instead of price). In that way, we can calculate the volatility of the underlying asset implied by the current market price, which can be considered as the market forecast/ estimate for the volatility of the underlying asset over the remaining life of the option.

An analogy between interest rates and implied volatility contributes in understanding the latter. There is a direct correspondence between the role of interest rate in bond pricing and the role of implied volatility in option pricing. Volatility can be viewed as one of the determinant factors of an option pricing model (e.g. Black-Scholes or CRR); as any bond has its specific yield-to-maturity (YTM), each option corresponds into a specific implied volatility level. Yield-to-maturity is the market implied yield of each bond. In the same way as a specific implied volatility level can be translated through an option pricing model into a specific option price, a specific YTM can be translated through the discounted cash flow equation into a specific bond price.

4 Empirical Analysis of the Greek Warrants Market

Our sample covers the whole period of warrants trading in the Athens Exchange (until October 2014). Particularly, the period under review for the warrant of Alpha Bank (ALPHAW) is June 11, 2013 until October 27, 2014 (345 observations), for the warrant of National Bank of Greece (NBGW) the period under review is from June 27,until October 27, 2014 (334 observations) and finally for the warrant of Bank of Piraeus (TPEIRW) the period under review starts on July 3, 2013 and ends on October 27, 2014 (330 observations).

Figure 1 depicts the price development of the three pairs under examination. It is obvious that the share and the respective warrant prices move in tandem. The correlation coefficient of the returns of the stock and the warrant is statistically significant in all three cases and hovers around 64% for Alpha Bank, 61% for National Bank of Greece and 59% for Bank of Piraeus. Figure 2 portrays the relative performance of the stock versus the respective warrant. The initial base price for the warrant is neither the initial price of each warrant (whichwasatheoreticalpricecalculatedbytheexchangebasedoncertainassumptions[8]) at which no actual transaction took place, nor the opening or the closing price of the first

[8]The initial price of each warrant was set according to ATHEX Resolution No. 33 following the modified Cox-Ross-Rubinstein (CRR) model.

day of trading. Furthermore, in order to calculate the relative performance for each pair, we exclude the first month of trading, since warrants were new and unknown financial instruments for the Greek market. The warrant written on Alpha Bank is the only one over- performing the underlying stock, while NBGW and TPEIRW performed worse compared to their respective ordinary shares.

Finally, Figure 3 shows the relationship between the stock price and the volatility implied by each warrant (in inverted scale). The link between these two measures seems stronger (compared to link between share and warrant prices). This is also confirmed by the correlation coefficients between the daily stock returns and the daily changes in implied volatility for each warrant, which are higher compared to respective coefficients of stock and warrant returns. In particular, the correlations are over -68% for Alpha, over -85% for NBG and around -64% for Bank of Piraeus. The correlation coefficient for NBGW is remarkable and it can be potentially explained by the fact that the particular warrant was the only one that was consistently out-of –money (with very exception over this 15-month period) and thus it only had time value, as its intrinsic value was zero.

4.1 Implied and Realized Volatility

Figure 4 shows the volatility implied by the market price of each warrant and the respective historic 20-day annualized realized volatility for each bank. It is obvious that implied volatility is significantly lower than realized volatility in all three cases. In the case of Bank of Piraeus, the realized volatility is significantly lower in all 330 days under review. A similar difference is recorded for the case of National Bank of Greece, while in the case of Alpha Bank the difference between the two volatility measures is slightly lower. In particular, for the period under review the difference between realized and implied volatility is 11.6% in the case of Alpha, 31.5% in the case of National Bank of Greece and 27.5% in the case of Bank of Piraeus. In order to examine the significance of this difference we run an equality test of the means; the t statistic suggests that the null hypothesis (of equality) is rejected at the 99% confidence level in all three cases. Table 2 includes the descriptive statistics of implied and 20-day realized volatility for the three banks. The median prices do not differ substantially from the average values, while the standard deviation difference confirms the well documented fact that implied volatility is a smoothed expectation of future realized volatility, as it exhibits lower variations. In concluding the preliminary analysis, it is also worth analyzing the number of observations for each series; particularly, for Alpha Bank, we were able to calculate an implied volatility measure only for 219 out of the total 345 trading days. The reason for this inability is that during these 126 trading days, ALPHAW was trading below its intrinsic value, thus it was not possible to derive an implied volatility estimate. For the other two warrants the mispricing was much more limited; only 4 out of the total 334 trading days for NBGW and 11 out of 330 for the warrant of Bank of Piraeus.

Therefore, in terms of volatility all three warrants under review are significantly undervalued. The particular finding is in contrast to Chang *et al* (2013) who find that the market prices of warrants in the Chinese market are much higher systematically than the Black-Scholes prices with historical volatility. Warrants' mispricing in the Greek market can be possibly explained by the absence of institutional investors, who either don't invest in Athens Exchange due to its limited size and liquidity, or they are not allowed to invest in derivative instruments. Another possible explanation relates to the limitations of short selling in the Greek stock exchange (as it is generally difficult and expensive to borrow

shares); short selling would have been the market mechanism that would adjust the price relationship between warrants and underlying stocks, as market participants need to buy the undervalued warrant and short-sell the ordinary shares. A third explanation doesn't relate to the characteristics of the Greek equity market, but has to do with the well-documented mean reversion property of volatility. Several academic papers (indicatively Poterba and Summers, 1988) have shown that periods of high (low) volatility are generally ensued by periods of average/ normal volatility. Therefore, long-term forecast/ estimates of volatility embed its mean reversion property and assume that sooner or later volatility will revert back to a normal level. Of course, even though the mean reversion property is indisputable, market participants do not necessarily agree on what the level of the normal volatility should be, since market conditions are dynamic.
Now, regarding the realized volatility of the three banks under review, examining the historic volatility of their ordinary share returns for a longer period of time we can potential reconcile the warrants mispricing. In particular, we calculate the annualized 20-day realized volatility over the last decade (from 01/01/2004 until 10/27/2014). The first outright observation is the striking similarity of the estimated measures. The average historic volatility hovers around 55% for all three banks (this happens to be the realized volatility of NBG and Bank of Piraeus for the warrants' trading period as well). We should note however, that the average volatility of the decade is biased from the elevated uncertainty that followed the fiscal and credit crisis that started in 2010. For the period 2010-2014 the average realized volatilities reach almost 80% for the three banks. The average historic volatility is significantly lower during the period 2004-2010 (and it is even lower if we also exclude the 2008-2009 period). Specifically, for the period 2004-2010 the average historic 20-day volatility for the three banks hovers around 35%; this level is closer to the volatility implied by the warrant prices on average during the last 15 months. Hence, we could conclude that market participants expect that future realized volatility of the Greek banking sector will lower and revert back to more normal levels.
Since all three warrants under review appear to be undervalued in terms of volatility, investors could open a combined position in the ordinary shares and the warrants of the three banks in order to take advantage of this mispricing. In particular, investors should sell the underlying shares and buy warrants. In the next section we are going to investigate the potential profits of a dynamic delta neutral position in ordinary shares and warrants.

5 Delta-hedged Warrant Portfolio

The delta of the option is the first derivative of the options price with respect to the underlying price. The delta of the underlying equals unity. Assuming that an investor holds a short position in a stock option (contract size one share) and at the same time buys delta shares of the underlying stock, then his/ her combined position is completely hedged (at least for small move in the underlying price). According to the Black and Scholes assumptions, the dynamic rebalancing of the portfolio as the price of the underlying moves in order to keep the total delta of the position equal to zero will result in a fully-protected portfolio which should result in a return equal to the risk-free rate. In case though the option is not fairly valued (if for example the volatility parameter used for the option pricing is higher or lower than it should be), then the delta neutral position will yield higher returns. Thus, if an investor thinks that the implied volatility of an option is higher than the expected realized volatility of the underlying asset during the life of the option, then he/ she should short the option and hedge by buying the underlying stock. The opposite is true in case the option's implied volatility is lower than the expected realized volatility.

Following Bakshi and Kapadia (2003) we calculate the cumulative profits of the delta-neutral position as follows:

$$\pi(t) = W_t - W_0 - \sum_{n=0}^{t} \Delta_{t-1}(S_t - S_{t-1}) + \sum_{n=0}^{t} r(\Delta_{t-1}S_{t-1} - W_{t-1})\frac{1}{360} \qquad (2)$$

In which, W_t is the price of warrant on day t (W_0 is the warrant price on the first day of the hedge[9]), $S_t$is the price of the underlying bank share, is the risk-free rate and$\Delta_t$is the delta of the warrant[10]. Therefore, delta profits consist of the capital gains/ losses from the warrant position, the capital gains/ losses from the stock position and the daily interest received. We calculate the cumulative profits in euros for a hypothetical position of 100 warrants.

Figure 6 includes the cumulative profits of the three delta-neutral positions. The conclusion is not inclusive, but it seems that there is a potential of accumulating profits by opening a long position in the warrants market and hedging it by selling the underlying stock. The cumulative profits are positive, but they are not statistically significant in the daily level. However, we believe that an investor can accumulate higher profits if he/ she follows a delta-neutral hedging based on the level of the implied volatility of the warrant and not just hold a continuous delta-neutral position. Furthermore, the delta estimate can be improved either by using alternative models (indicatively Baksi *et al*, 1997) or by modifying the Black and Scholes delta (following Derman *et al*, 1996 andColemanetal, 2001). According to Vähämaa (2004) and the references herein, although time-varying volatility option pricing models definitely outperform the Black and Scholes model in terms of pricing, they do not necessarily result in better hedging performance.

6 Conclusion

Within the framework of the recapitalization of the Greek banks during the summer of 2013, new securities were issued and started trading in the Athens Exchange, covered warrants. The current article is the first academic attempt to analyze the characteristics of this new market, which consists of the warrants of the three systematic Greek banks (Alpha Bank, National Bank of Greece and Bank of Piraeus).

The three warrants under review appear to be undervalued in terms of volatility, as their implied volatility is significantly lower than the historic realized volatility of the underlying ordinary shares for the most part of their trading history. The average volatility

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[9]The first day of the delta-neutral hedging is not the actual first day of trading, but one month after the first listing (although the results are not significantly different in any case.

[10]In order to calculate Δ, we employ the Black and Scholes model using the following assumptions: the strike price and the exercise date is the following exercise allowed by the terms of the warrant (and not the final one) and the volatility input is set equal to 35% (average historic realized volatility of the last decade).

implied by the warrant of Alpha Bank is30.4% (while the historic 20-day realized volatility of shares of Alpha during the same period is 42%), the implied volatility of NBGW is 22.6% (while the respective realized volatility is 54.1%) and the volatility implied by the Bank of Piraeus warrant is 27.5% (realized volatility equal to 55%).This divergence can be reconciled by a combination of factors which relate to both the characteristics of the Greek equity market (e.g. absence of large institutional investors or limited availability of shares to be borrowed in order to be short-sold) and the mean reversion property of volatility. The realized volatility during the last years (due to the Greek fiscal crisis) is extremely elevated compared to the historical average and thus, it is likely that market participants are currently pricing into warrants (which have long maturity) a reversion back to normal volatility levels.

In concluding, future relevant research could involve, among other, the pricing of the particular Bermudan warrants with dynamic volatility pricing models, the investigation of the relationship between moneyness and implied volatility and the construction of more advanced delta-neutral strategies (e.g. using several threshold levels). Finally, an attempt to improve the delta hedging performance by adjusting the Black and Scholes derived delta could be applied in the Greek market.

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APPENDIX

Table A1: Warrants' Specifications

Underlying asset	**Alpha Bank**	**National Bank of Greece**	**Piraeus Bank**
Warrant type	Covered Bermudan Call	Covered Bermudan Call	Covered Bermudan Call
Total warrants issued	1,143,803,533	245,748,459	843,640,590
Issue Date	Jun 10, 2013	Jun 26, 2013	Jul 2, 2013
Initial price[1] (€/warrant)	€1.45	€6.83	€0.899
Date of maturity	Dec 10, 2017	Dec 26, 2017	Jan 2, 2018
Settlement method	Physical Delivery	Physical Delivery	Physical Delivery
Multiplier ratio[2]	7.40868307 shares	8,22923881005499 shares	4.47577327722 shares

	Exercise Date	**Strike Price**	**Exercise Date**	**Strike Price**	**Exercise Date**	**Strike Price**
Exercise Prices and Dates	Dec 10, 2013	0.4488	Dec 26, 2013	4.3758	Jan 2, 2013	1.734
	Jun 10, 2014	0.4576	Jun 26, 2014	4.4616	Jul 2, 2014	1.768
	Dec 10, 2014	0.4686	Dec 26, 2014	4.56885	Jan 2, 2015	1.8105
	Jun 10, 2015	0.4796	Jun 26, 2015	4,6761	Jul 2, 2015	1.853
	Dec 10, 2015	0.4928	Dec 26, 2015	4.8048	Jan 2, 2016	1.904
	Jun 10, 2016	0.5060	Jun 26, 2016	4.9335	Jul 2, 2016	1.955
	Dec 10, 2016	0.5214	Dec 26, 2016	5.08365	Jan 2, 2017	2.0145
	Jun 10, 2017	0.5368	Jun 26, 2017	5.2338	Jul 2, 2017	2.074
	Dec 10, 2017	0.5544	Dec 26, 2017	5.4054	Jan 2, 2018	2.142

[1]The initial price of each warrant was set according to ATHEX Resolution No. 33
[2] The number of underlying shares corresponding to 1 warrant, if exercised.

Table A2: Summary statistics of Implied and 20-day Realized Volatility

	Alpha Bank		**National Bank**		**Piraeus Bank**	
	Implied	**Realized**	**Implied**	**Realized**	**Implied**	**Realized**
Mean	0.304	0.420	0.226	0.541	0.2751	0.550
Median	0.316	0.425	0.234	0.523	0.274	0.545
Maximum	0.470	0.594	0.358	0.953	0.431	0.807
Minimum	0.150	0.225	0.079	0.320	0.073	0.312
Std. Dev.	0.057	0.082	0.070	0.140	0.075	0.104
Skewness	-0.329	-0.173	-0.236	0.672	-0.234	0.136
Kurtosis	2.519	2.291	1.771	2.750	2.825	2.710
# Obs.	219	345	330	334	319	330

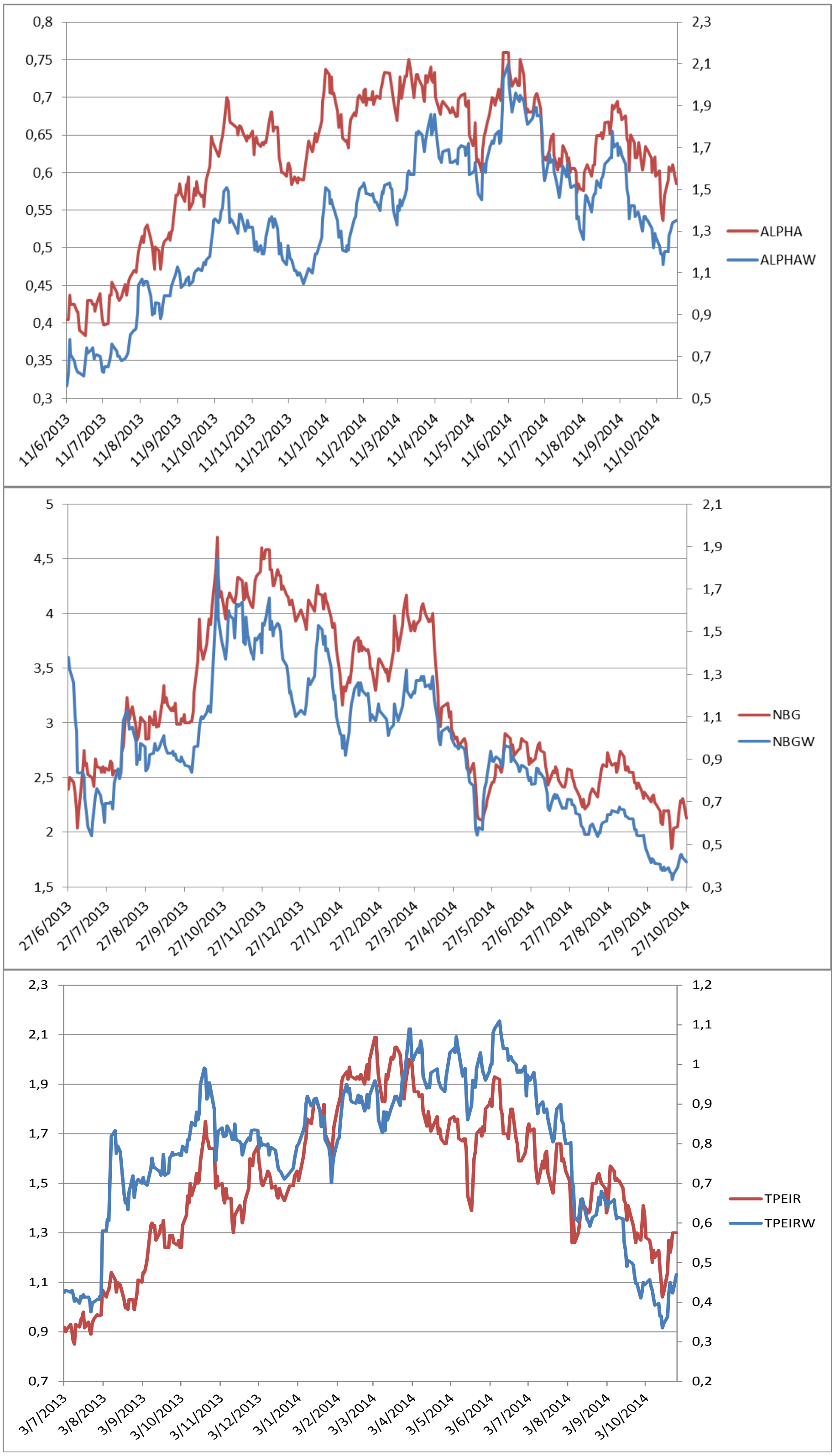

Figure A1: Stocks and Warrants Daily prices

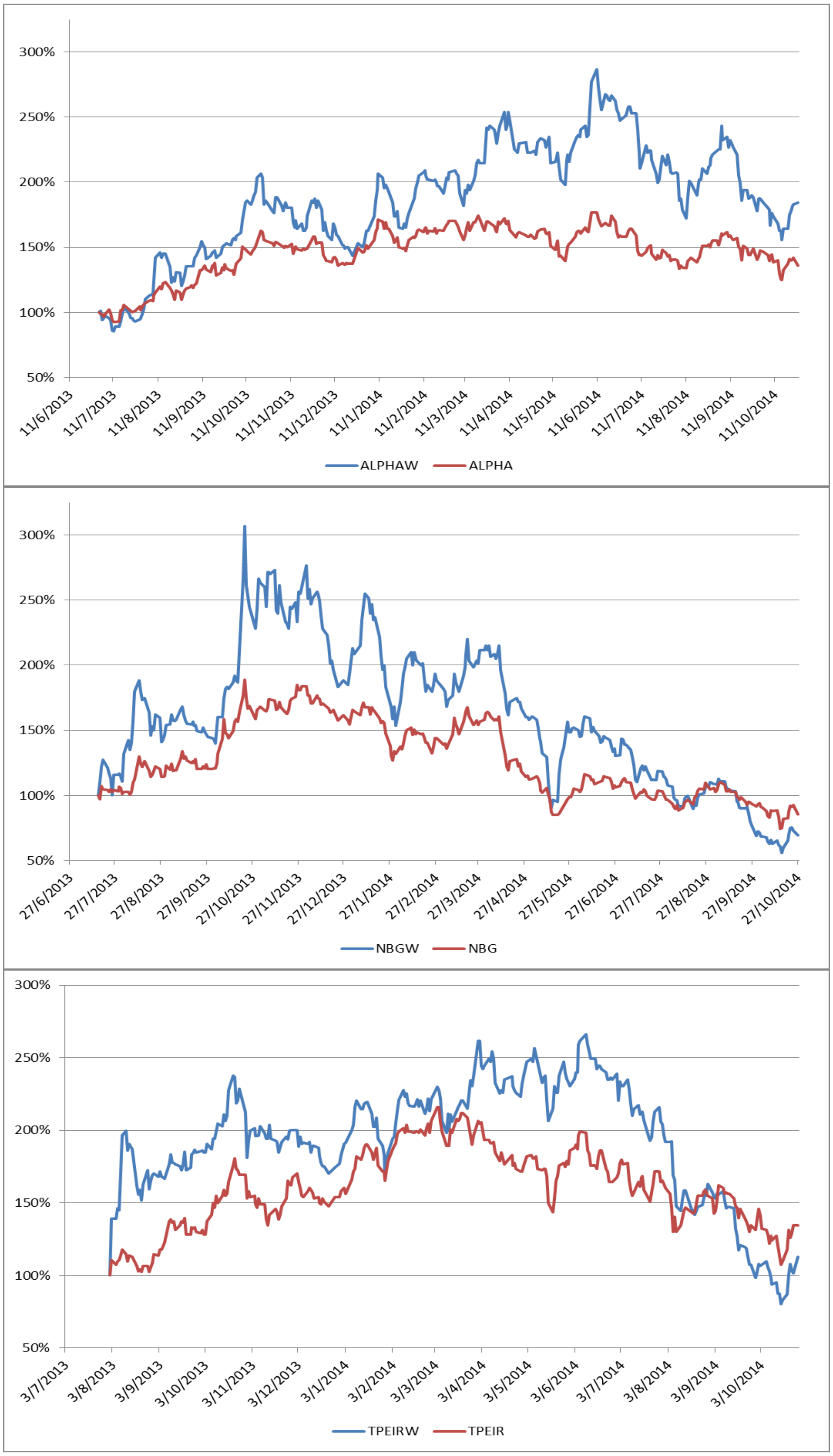

Figure A2: Stocks and Warrants Daily Returns

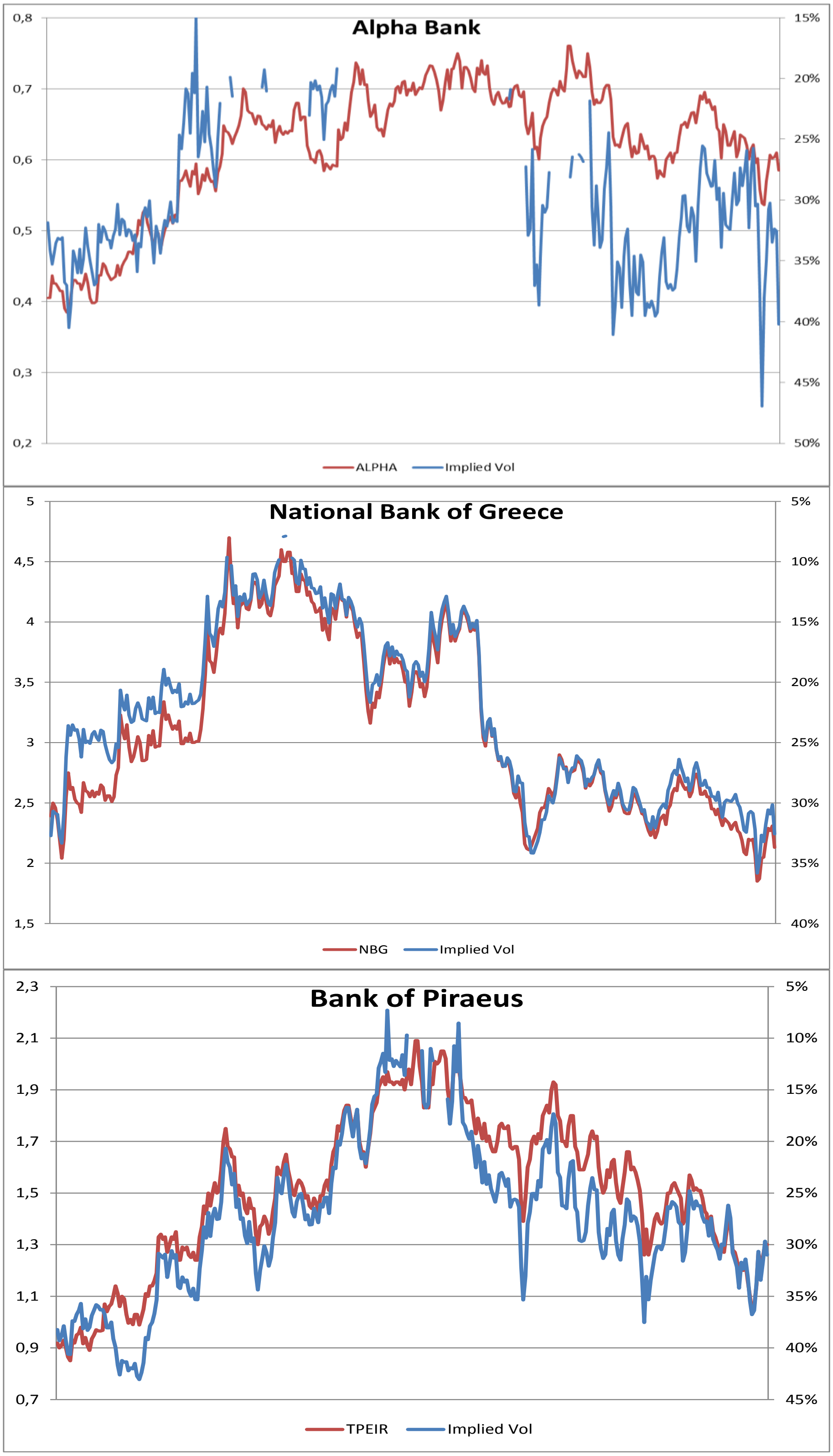

Figure A3: Stocks Daily prices and implied volatility

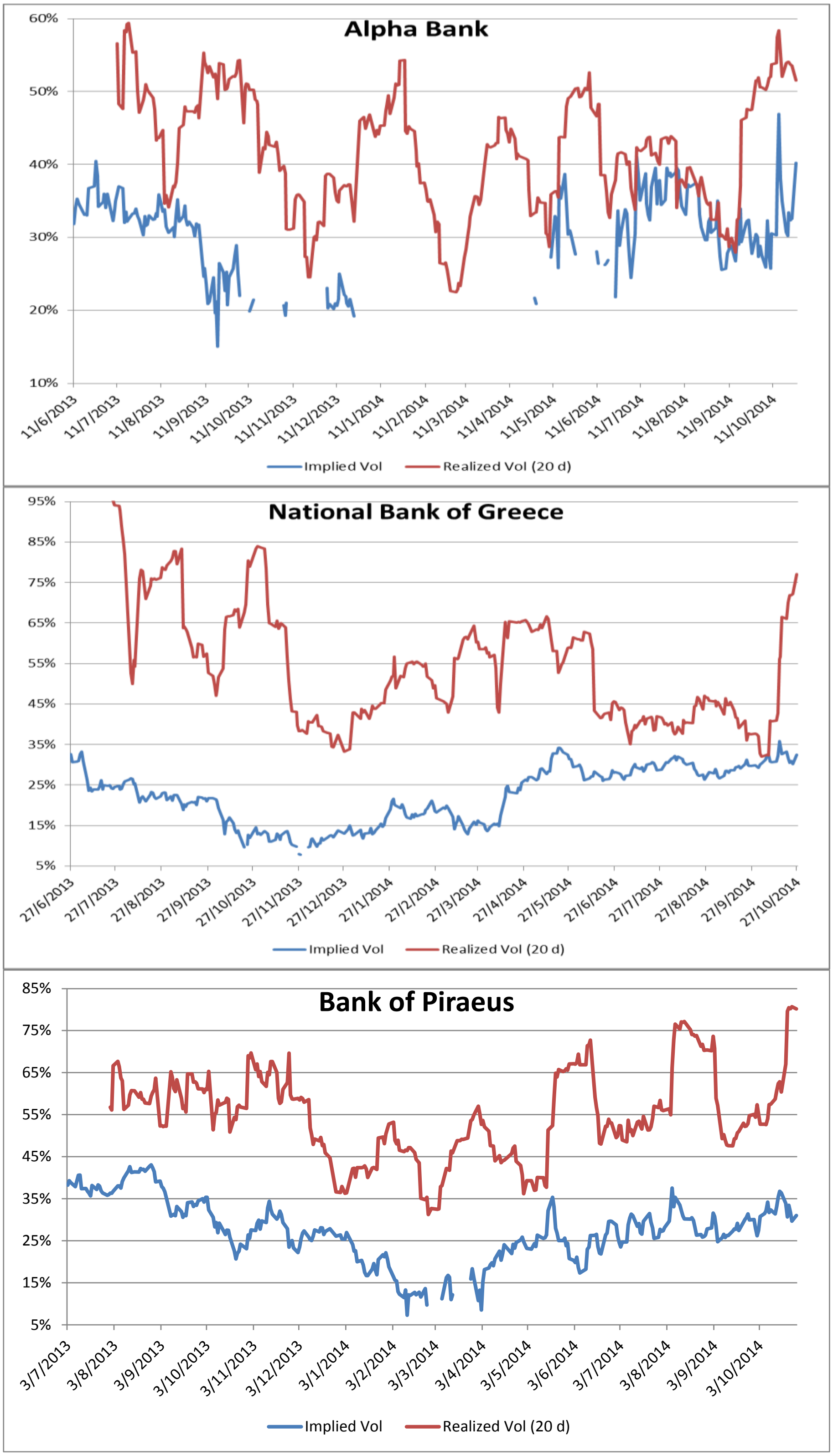

Figure A4: Implied and Realized Volatility (20d)

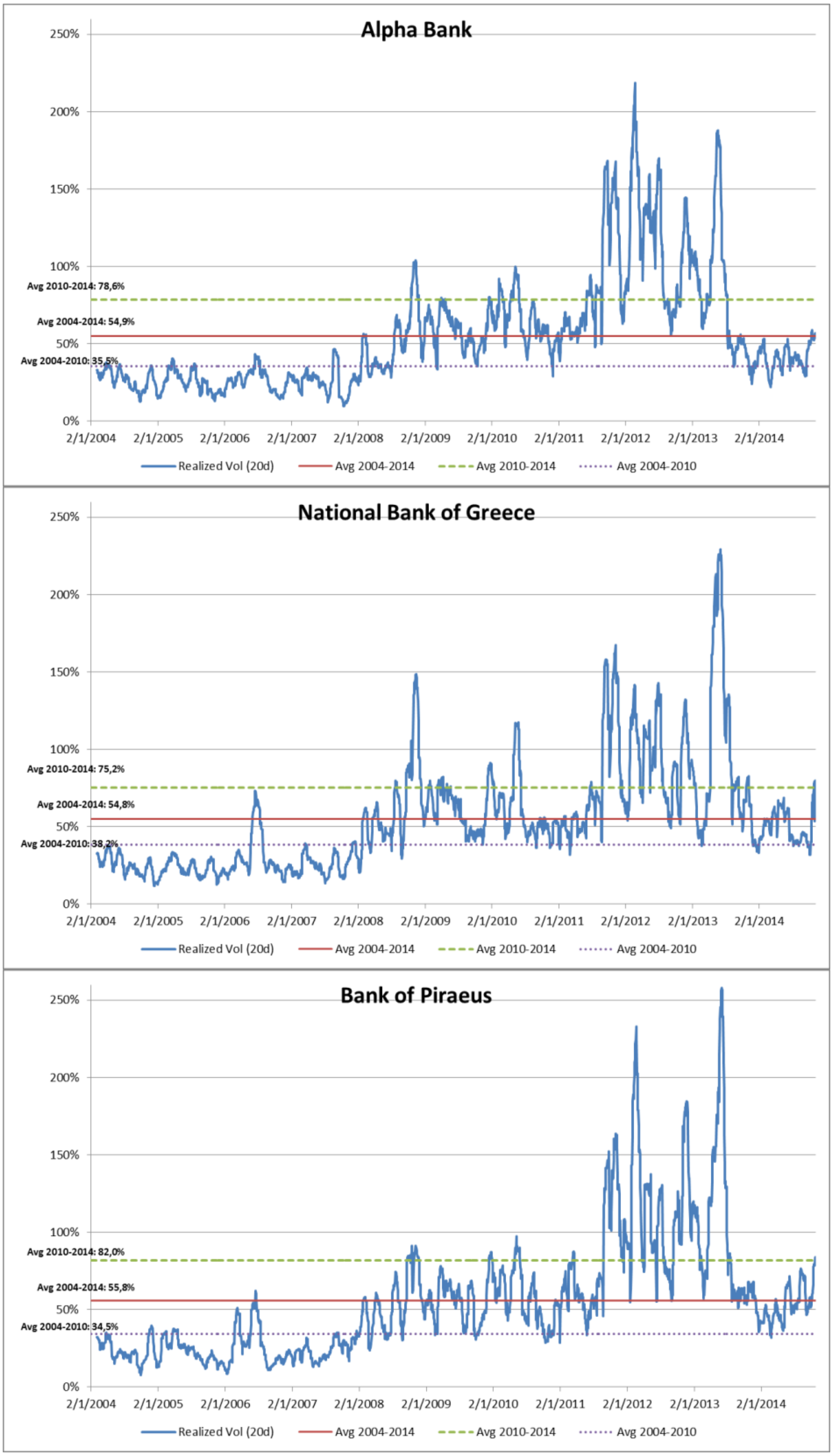

Figure A5: 20-day Realized Volatility (2004-2014)

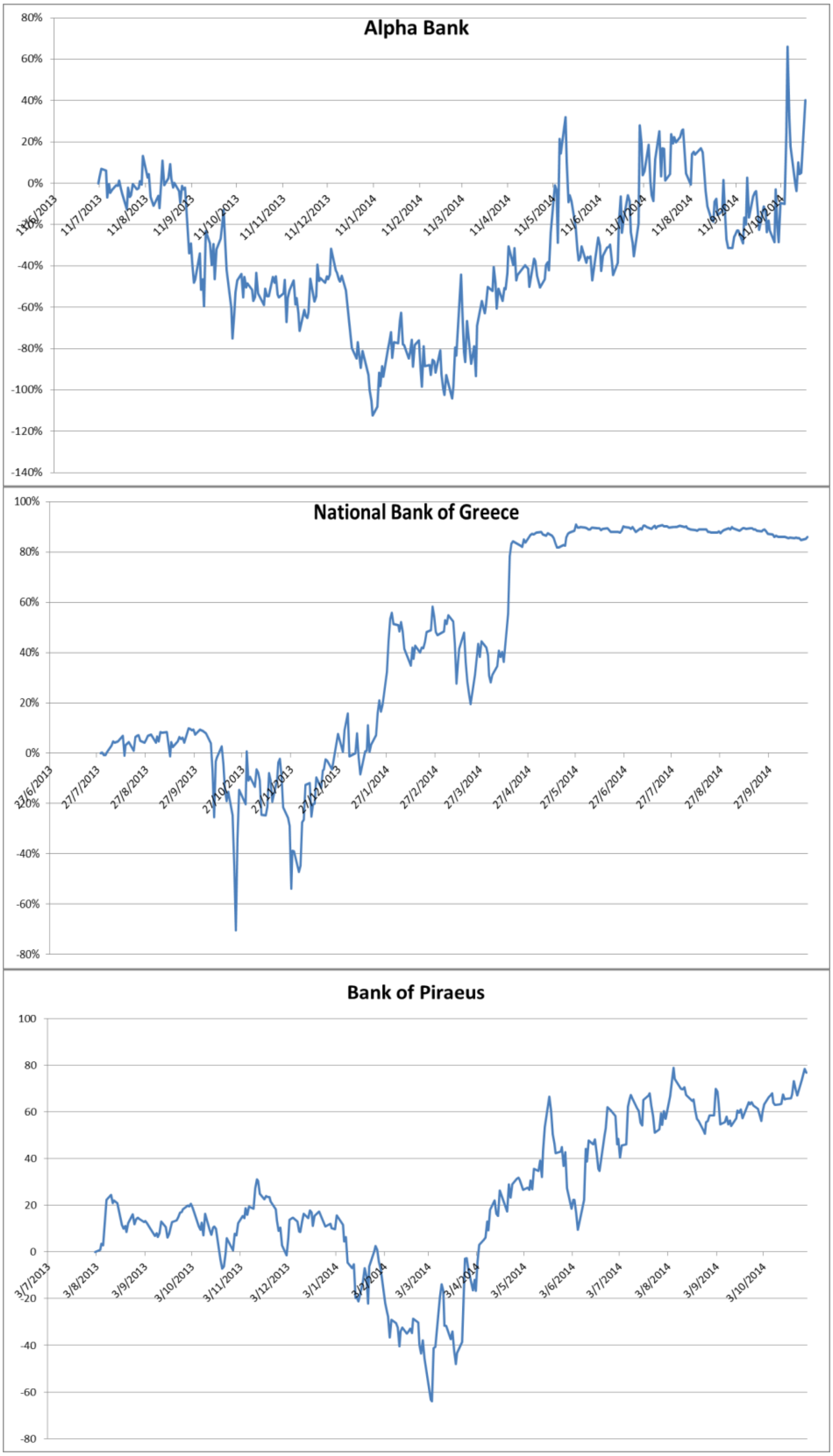

Figure A6: Dynamic Delta Hedging Cumulative profits