Price transmission dynamics between informationally linked securities

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Keywords: International equities; price transmission; dominant satellite relationship

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Abstract

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1. Introduction

The objective of the study is to examine the price dynamics of informationally linked securities and in particular, whether the location of trade has an effect on their pricing. Chowdhry and Nanda (1991) show theoretically that a market may emerge as the dominant one if most of the trading volume is concentrated in that market when trading occurs simultaneously in the markets. We investigate the issue by looking at the relationship between prices of shares listed on the Athens Stock Exchange (ASE) and the two German Stock Exchanges, Berlin and Frankfurt (thereafter BSE and FSE respectively). In effect, such an investigation explores the possibilities of arbitrage between home and foreign prices and between foreign prices themselves with implications for market efficiency.

The work, which has dominated the literature on the importance of location of trade for the pricing of securities focused on the cross-listing of non-US securities on the US exchanges. For example, Werner and Kleidon (1996) examined the intraday patterns of US and UK trading of British cross listed stocks and compared the intraday trading pattern for each cross-listed stock with that of non-cross listed stocks and found that there was no difference, suggesting that traders take a much less global view on trading. Froot and Dabora (1999) arrived at a similar conclusion, when examining pairs of large "Siamese twin" companies around the world with different trading and ownership habitats. They regressed the twins' log return differential on the log return of markets they traded in and on the currency change and found that the relative price of twin stocks is highly correlated with the relative stock-market indexes of the countries where the twins' stocks were traded most actively, implying that location matters and that there is a certain degree of market segmentation.

On the other hand, Lieberman, Ben-Zion and Hauser (1999) studied the importance of the location of trade on the pricing of stocks by examining the price dynamics of internationally dually listed stocks by estimating error correction models (ECMs) and thus incorporating in the regression the long-run relationship between the prices of the listed stocks in different locations as recommended by Hasbrouck (1995). They studied the question of which market is the dominant one and which is a satellite by examining whether the adjustment of prices is asymmetric as suggested by Garbade and

Silber (1979). In particular, they investigated the relationship between prices of shares listed and traded both in the OTC in the US and in the Tel Aviv Stock Exchange (TASE) in Israel using daily data. They also included in the ECM the S&P500 return in the regression when the dependent variable was the stock return traded in the OTC in the US and the return of the Israeli stock market when the dependent variable was the stock return traded in TASE. When they included the "away" index in each of the regressions they found it to be statistically insignificant. Their results indicate that the stock returns listed in each market are affected much more by that market, than by the "away" market index. Furthermore, the beta coefficient was lower for the stocks listed in US than those listed in Tel Aviv, which together with the finding that they do most of the adjustment following a shock, was interpreted that the market in TASE is the dominant market, while the US market acts as a satellite. They did not, however, include in their analysis the dynamic effects of the exchange rate.

In contrast, Kim et al. (2000) include the exchange rate and the US market index as well as the underlying securities when examining the price discovery process for European ADRs in the US market.[1] Using daily data to estimate VAR models they find a significant independent role for the US market index and the exchange rate in pricing ADRs although the underlying shares appear to be the most influential factor. Grammig et el. (2003) using high frequency data and ECM for three German ADRs listed in New York and Eun and Sabherwal (2003) in their examination of US-listed Canadian Stocks arrived at similar conclusions.

The objective of the current paper is to examine the price dynamics of internationally listed securities by looking at the pricing factors of stocks listed on ASE and the two German stock exchanges. In doing so we want to find out whether the German markets play a role in the pricing of Greek stocks listed in those exchanges, i.e. whether location of trade matters, as it has been found to be the case in the studies for ADRs and foreign stocks listed in US Exchanges. As it has been noted above there is very little work or indeed any on the subject in relation to European stocks and their

[1] Bailey et al. (2000) have examined the impact of the arrival of exchange rate information on the pricing and trading volume of Mexican ADR prices in NYSE and Mexican closed-end funds prices and found that increases in the peso-dollar exchange rate caused a decline in the prices of both instruments.

listings on other European Exchanges. With the establishment of the European Monetary Union such studies will be helpful in the rationalisation of European capital markets.

Another objective is to investigate informational efficiency between the stocks traded in the German exchanges and ASE. For market efficiency there should be no arbitrage opportunities after transaction costs between exchanges. The scope of the investigation of this issue is broader compared to previous studies by examining not only arbitrage opportunities between the foreign market (in our case the German Exchanges) and the home market i.e. the ASE, but also arbitrage opportunities between the German Exchanges themselves and as such the study differs from previous work as it includes more sources of informative trades.[2]

Our econometric approach to investigate the above issues is as follows. We first test whether the observed prices on ASE and the two German markets are bound together through the use of cointegration, which also indicates whether there are unexploited long-term arbitrage opportunities. We proceed to apply ECM and augment it with the differences of German and Greek stock markets. We test whether location of trade matters in the pricing of Greek stocks listed in the German exchanges by studying the relative importance of the Greek and German markets in their pricing and whether they adjust to deviations from long-run equilibrium relationships. For the latter exercise, we use a simple measure of the contributions to price discovery that can be obtained directly from the estimated coefficients of the ECM as proposed by Schwarz and Szakmary (1994). In addition, we decompose the forecast error variance of each variable into components, which account for innovations in all variables, in order to estimate the degree of exogeneity of each variable. If the price of a stock is found to be exogenous, then it evolves independently of the shocks to the prices of stocks traded in other markets, and that implies that the price discovery process takes place in the market in which it is traded. Finally, we study the adjustment process to the long-run equilibrium between the stocks in the various exchanges by applying impulse response analysis, which gives the

[2] In an earlier study Harris et al. (1995) using data for IBM have investigated the contribution of New York, Pacific, and Midwest Stock Exchanges to the price discovery process. They found that equilibrium IBM prices are established by information revealed on all three exchanges.

response of each variable to a shock. This analysis is important in the case where there are more than one cointegrating vectors, which is the case in our study.

The remainder of the paper is structured as follows. In section 2, we present the methodology, which examines the price behaviour of the internationally listed securities and the econometric methodology used. In section 3, we describe the data and present the empirical analysis. In section 4, we discuss the price discovery process, while the final section offers some concluding remarks.

2. Methodological issues

2.1 Arbitrage with internationally listed securities

One should expect that the price of a security listed abroad (thereafter called the home security) will not deviate from the price of the asset traded in the home country and expressed in the home currency. If that is not the case an arbitrage opportunity exists and the investor can obtain a riskless profit provided that the price differential more than offsets the transaction costs involved. Therefore, arbitrage forces would keep the price of the security listed abroad in accordance with the price of the asset traded in the home country and adjusted by the exchange rate.

Our study involves two markets: the Greek and the German. The opening and closing hours of the exchanges are reported in Table 1. As we can see both the Greek and the German markets open at 8:00 Greenwich Mean Time (GMT) but close at different times. To be more precise, the Greek security market closes at 12:30 GMT while the German exchanges at 19:00 GMT. Thus, assuming constant exchange rates, and that markets are efficient an upward or a downward movement of the home security will be reflected on the security listed in the German exchanges within the same calendar day.

Until January 2001 when Greece joined the European Monetary Union, the securities listed in ASE were traded in Drachmas and those listed in the German Exchanges prior to EMU in Deutchmarks and subsequently in Euros. Thus, from January 2001, the securities in both countries were traded in Euros. Up to that time, however, the prices of the Greek stocks listed in Germany included an exchange rate risk. According to the efficient market hypothesis, even if the price of the home share does not change,

exchange rate fluctuations will signal an adjustment of the price of the foreign security in order to eliminate arbitrage profits. If the exchange rate is Drachmas per DM or Euro, then an appreciation of the Drachma should cause the stock in the foreign exchanges to rise, i.e. there is an inverse relationship between the two. The net effect of fluctuations in both, the home share price and the exchange rate on the foreign stock price, will depend on the direction of each movement. For example, an appreciation of the local currency accompanied with an upward movement in the underlying share price will put upward pressure on the foreign stock price and vice versa. In a similar way, opposite movements in the exchange rate and the price of the home share will influence the foreign stock price according to the magnitude of each factor. At the same time, exchange rate fluctuations will not have an effect on arbitrage activities between the two German Exchanges. Finally, given that daily trading finishes earlier in the Greek market, the efficient market hypothesis implies that news released to the German market where the Greek security is traded when the Greek market is closed will affect the stock price in both Berlin and Frankfurt during the same day, while the movement will be transmitted to the home share price in ASE the next calendar day.

2.2 Multivariate cointegration

We explore the above interrelationships through the application of cointegration in order to explore long-run convergence and subsequently error correction modelling, impulse response analysis and forecast error variance decomposition in order to study the price discovery process. The above arbitrage possibilities imply that there could be two long-run relationships amongst the price of the home security at ASE (P_{Athens}), the price of the listed security on BSE (P_{Berlin}), the price of the listed security on *FSE* (P_{Frank}) and the exchange rate (S). There could be one long-run relationship between P_{Berlin} and P_{Frank} with a cointegrating vector (1,-1), and another one between either of the foreign stock price, P_{Athens}, and S, with a cointegrating vector (1,-1, β_2). If unit proportionality is rejected in either of the cointegrating vectors, then that would imply possible long-run arbitrage opportunities. In implementing the tests for cointegration we use the likelihood ratio test due to Johansen (1988) and Johansen and Juselius (1990) and included $P_{Athens,}$ P_{Berlin}, $P_{Frank,}$ and S, in the cointegrating relationship

2.3 Error Correction Modelling

Having tested for cointegration we proceed to start our investigation into the dynamics, which characterise the price discovery process by estimating generalised error correction models, which include apart from lagged changes of prices, differences of the German stock market (P_{DAX}) and the Greek stock market (P_{ASE}) as exogenous variables. In this way we examine the possibility that investors may evaluate the systematic risk of foreign stock returns with reference to the market they are traded in i.e. the German market. For example, for the stock traded in FSE we have

$$\Delta P_{t,Frank} = \alpha_0^F + \alpha_1^F (P_{Frank} - P_{Athens} + \beta_2 S)_{t-1} + \alpha_2^F (P_{Frank} - P_{Berlin})_{t-1} + \alpha_3^F \Delta P_{t,DAX} + \alpha_4^F \Delta P_{t,ASE}$$
$$+ \alpha_5^F DUM1 + \alpha_6^F DUM2 + \sum_{i=1}^{k} \alpha_{6+i}^F \Delta P_{t-i,Frank} + \sum_{i=1}^{k} \alpha_{6+k+i}^F \Delta P_{t-i,Berlin} + \sum_{i=1}^{k} \alpha_{6+2k+i,}^F \Delta P_{t-i,Athens} + \sum_{i=1}^{k} \alpha_{6+3k+i,}^F \Delta S_{t-1} + \varepsilon_t, \quad (1)$$

and for the stock traded in BSE we have

$$\Delta P_{t,Berlin} = \alpha_0^B + \alpha_1^B (P_{Frank} - P_{Athens} + \beta_2 S)_{t-1} + \alpha_2^B (P_{Frank} - P_{Berlin})_{t-1} + \alpha_3^B \Delta P_{t,DAX} + \alpha_4^B \Delta P_{t,ASE}$$
$$+ \alpha_5^B DUM1 + \alpha_6^B DUM2 + \sum_{i=1}^{k} \alpha_{6+i}^B \Delta P_{t-i,Frank} + \sum_{i=1}^{k} \alpha_{6+k+i}^B \Delta P_{t-i,Berlin} + \sum_{i=1}^{k} \alpha_{6+2k+i}^B \Delta P_{t-i,Athens} + \sum_{i=1}^{k} \alpha_{6+3k+i,}^F \Delta S_{t-1} + \varepsilon_t. \quad (2)$$

For the home market, the stock return is given below

$$\Delta P_{t,Athens} = \alpha_0^A + \alpha_1^A (P_{Frank} - P_{Athens} + \beta_2 S)_{t-1} + \alpha_2^A (P_{Frank} - P_{Berlin})_{t-1} + \alpha_3^A \Delta P_{t,DAX} + \alpha_4^A \Delta P_{t,ASE} +$$
$$+ \alpha_5^A DUM1 + \alpha_6^A DUM2 + \sum_{i=1}^{k} \alpha_{6+i}^A \Delta P_{t-i,Frank} + \sum_{i=1}^{k} \alpha_{6+k+i}^A \Delta P_{t-i,Berlin} + \sum_{i=1}^{k} \alpha_{6+2k+i}^A \Delta P_{t-i,Athens} + \sum_{i=1}^{k} \alpha_{6+3k+i,}^F \Delta S_{t-1} + \varepsilon_t. \quad (3)$$

The coefficients α_1 and α_2 indicate how the specific stock price responds to deviations from the long-run equilibrium. The coefficients α_3 and α_4 are in effect the standard *beta* coefficients in the CAPM model.

The following are our expectations of these coefficients regarding on the one hand the importance of the location where the stock is traded for the pricing of the stock, and on the other hand, the issue of the dominant versus satellite market hypothesis. If the location matters one will expect to find $\alpha_3^F > \alpha_4^F$, $\alpha_3^B > \alpha_4^B$ and $\alpha_3^A < \alpha_4^A$. If the

domestic market is the dominant one, since most of the trading volume concentrates there, we will expect to find that most of the price discovery process takes place in the Greek market and the foreign stock does most of the adjustment compared to the home stock following a shock to the market. If the price in Frankfurt is higher than the price in Athens after adjusting for the exchange rate, then we would expect a negative price change in Frankfurt and /or a positive price change in Athens in order to maintain the long-run equilibrium between P_{Frank}, P_{Athens} and S. Thus, the error correction dynamics characterise the price discovery process, i.e. "the process whereby markets attempt to find equilibrium" (see Schreiber and Schwartz, 1986).[3] In addition, we will expect the price in Frankfurt to be doing most of the adjustment. We have also added two dummy variables, DUM1, which took the value of one when Greece joined the Euro in January 2001; and the multi-step dummy variable DUM2, which took values ranging from 0.3 to 0.6 and represented the security transaction tax on the seller.[4] Germany on the other hand, did not have any transaction taxes.

We proceed to quantify the contributions to the process of price discovery by using the simple measure, which can be obtained directly by the estimated coefficients α_1 in the various markets as suggested by Schwarz and Szakmary (1994). Schwarz and Szakmary propose the relative magnitude of the coefficients of α_1^F and α_1^A to assess the contributions of the two markets to price discovery.[5] They propose

$$\begin{aligned} (1-\Theta_1) &= \left(\left|\alpha_1^F\right|\right) / \left(\alpha_1^A + \left|\alpha_1^F\right|\right), \\ \Theta_1 &= \left(\alpha_1^A\right) / \left(\alpha_1^A + \left|\alpha_1^F\right|\right). \end{aligned} \tag{4}$$

[3] It should noted that the error correction dynamics do not involve innovations in stock prices of the specific company due to information revelations, all of which are contained in ε_t but only cross-market information flows revealed by adjustments to price differences across the three markets.

[4] Greece imposed 0.3% tax on all stocks sales on 2.19.98. It was raised to 0.6% on 10.7.99 before being reduced again to 0.3% on 1.01.01.

[5] The same relationship applies to α_1^B and α_1^A.

If the price discovery takes place exclusively in the German markets $\Theta_1 = 1$; and if the price discovery process takes place exclusively in the Greek market $\Theta_1 = 0$.[6] A similar relationship will apply to the price discovery process between Frankfurt and Berlin,

$$\begin{aligned}(1-\Theta_2) &= \left(\left|\alpha_2^F\right|\right) \Big/ \left(\alpha_2^B + \left|\alpha_2^F\right|\right), \\ \Theta_2 &= \left(\alpha_2^B\right) \Big/ \left(\alpha_2^B + \left|\alpha_2^F\right|\right).\end{aligned} \tag{5}$$

If the price discovery process takes place exclusively in Frankfurt $\Theta_2 = 1$; and if it takes place in Berlin $\Theta_2 = 0$.[7]

2.4 Impulse response analysis and forecast error variance decomposition

In order to examine further the price dynamics of internationally listed securities and to explore the price discovery process we calculate the impulse response function of the cointegrated VAR system for each stock.[8] The impulse response function traces the impact of a shock (which can take the form of one standard error of each variable) in each of the stock prices and exchange rate on the entire time paths of $P_{Athens}, P_{Berlin}, P_{Frank}$ and S. If, however, the shocks are contemporaneously correlated, it implies that shock in one variables may also have an effect through the contemporaneous correlations of shocks of other variables and the impulse responses will depend on the ordering of the variables in the VAR. In order to avoid this problem we apply the generalised impulse response function proposed by Koop et al. (1996), which examines the shock in one of the variables, and integrates the effects of other shocks using an assumed or historically

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[6] In the case of the price discovery process between Berlin and Athens, we substitute α_1^A with α_1^B.

[7] It should be noted that the contributions to the price discovery as proposed by Schwarz and Szakmary (1994) are equal to the weights with which the time series enters the common long memory component identified by Gonzalo and Granger (1995) and used by Harris et al. (2000) to estimate the parameters of price discovery in cointegrating systems (see Theissen, 2002). In addition, Theissen shows that the common factor weights and the information shares of Hasbrouck (1995) leads to qualitatively similar conclusions on the price discovery issue as Schwarz and Szakmary (1994).

[8] See Lutkepohl and Reimers (1992), who show that innovation accounting can be used to obtain information concerning the interactions among the variables.

observed distribution of the errors. Thus, through the impulse response analysis we will examine the speed of transmission of information between the different markets.

We also decompose the forecast error variance of each variable from the VAR system of each stock into the proportion due to its "own" shocks and the proportion due to the shocks to the other three variables. If own shocks can explain fully the forecast error variance of the variable in question at all forecast horizons then the variable is exogenous, i.e. it evolves independently of the shocks to the other variables.

3. Empirical Results

3.1 Data

Our sample consists of seven companies: Alpha Credit Bank (ACB), Bank of Piraeus (BOP), Commercial Bank of Greece (CBG), Ergasias Bank (ERG), Hellenic Petroleum (HEP), National Bank of Greece (NBG), Hellenic Telecommunications (OTE) and Viohalco (VIO). These were the companies, with the highest capital market capitalisation and the earliest listing on the German Exchanges. For our analysis, we use daily closing prices of a logarithmic form, which were provided by the ASE. When there is a stock split or a dividend payment the closing prices are adjusted. Table 2 provides information on the sample periods of each of the stocks. The ASE Composite Share Price Index has also been provided by ASE.

Finally, the spot exchange rates of the Greek drachma against the DM and the Euro as well as the closing prices of the DAX 30 Performance Index were taken from Datastream.

3.2 Cointegration tests

Before testing for cointegration we tested for unit roots in all our variables. The results are not presented but can be made available by the authors. We used the Augmented Dickey Fuller test with and without trend and found that the null hypothesis of a unit root for the first difference can be rejected for all our variables. On the other hand, the null hypothesis of a unit root in levels was accepted in all cases. Thus, like most financial series, these stock prices and the exchange rate I(1), which means that first differencing is required to achieve stationarity.

We proceeded to test for cointegration. We use the Johansen trace statistic as Cheung and Lai (1993) have shown that it is more robust to non-normality of errors compared to the maximal eigenvalue. The lag length is chosen by applying the Schwarz information criterion (SIC) on the undifferenced VAR. Reimers (1992) finds that the SIC does well in selecting the lag length. The results are shown in Table 3. Using a 5% significance level, the hypothesis that there are at most two cointegrating vectors (H_0: r ≤ 2) cannot be rejected in any of the cases. On the basis of possible arbitrage opportunities we normalised on P_{Frank} and assumed that an investor will be facing the choice of investing in either of the two German stock exchanges and thus comparing P_{Berlin} and P_{Frank}, or of investing either in Germany or at ASE, and comparing P_{Frank} and P_{ASE}.[9] The two cointegrating vectors, CV1 and CV2, are

$$CV1: \quad P_{Frank} = \beta_1 P_{Athens} + \beta_2 S$$
$$CV2: \quad P_{Frank} = \beta_3 P_{Berlin} + \beta_4 S.$$

The maximum likelihood estimates of the cointegrating vectors with asymptotic standard errors in brackets are presented in Table 4.

The first point that can be noted is that β_1 in CV1 and β_3 in CV2 are very close to one. Secondly, β_4 in CV2 is statistically insignificant. We proceeded then to perform a likelihood ratio test for the hypotheses that $\beta_1, \beta_3 = 1$ and $\beta_4 = 0$ (see last column of Table 4). The results indicate that the null hypothesis cannot be rejected at the 5% level of significance for any of the countries considered, apart from OTE and HEP, which is rejected at the 1% level of significance. Thus, the results show that there are no long-run arbitrage profits.

3.3 Error Correction Modelling

Given these findings we turn to the estimation of error correction models, which incorporate these long-run relationships, as given in equations (1) to (3). In Table 5 we present the results. Various points can be made. First, in all the cases we find α_4 to be statistically significant and greater than α_3. In fact in some cases α_3 is statistically

[9] Results were not different when normalisation was on P_{Athens}.

insignificant. This is particularly the case for the stocks traded in Athens, where only in NBG α_3 is significant at the 10% level. These results imply that the location where the stock is traded is not important for the pricing of the stock. The stocks in the German markets are priced with reference to the Greek stock market.[10]

Secondly, the error correction terms are of the expected sign when they are statistically significant. Thirdly, concentrating on the adjustment to a shock in CV1, we find α_1^A to be high and statistically significant for all the stocks traded in Athens, while α_1^F and α_1^B are low and in most of the cases statistically insignificant for the stocks traded in the German stock exchanges. The value of Θ_1 ranges from 0.476 to 0.925 for the stocks traded in BSE and from 0.765 to 0.919 for the stocks traded in FSE. Only in one case it is below 0.5, indicating that the price discovery process takes place in the German markets. In other words, P_{Frank} and P_{Berlin} react less than P_{Athens} to price differentials implying that they are "weakly exogenous".

Thirdly, looking at the adjustment to a shock in the CV2, we find both α_2^F and α_2^B to be statistically significant and of the expected sign, i.e. $\alpha_2^F < 0$ and $\alpha_2^B > 0$. That is if the price in Frankfurt is greater than the price in Berlin, then there is a downward adjustment in the price in Frankfurt and an upward adjustment in Berlin. We have also computed Θ_2 and find it to be higher than 0.5 in three of the seven cases implying mixed results as in which market the price discovery process takes place.

The above comments do not take account of the cross effects, thus we will proceed on the one hand to explore further the degree of exogeneity of P_{Frank}, P_{Berlin} and P_{Athens} by examining the forecast error variance decomposition of the VAR model of each of the 7 stocks and on the other hand the adjustment process through

[10] The regression coefficients might be slightly biased as the stocks are included in the ASE composite price index. The bias should be however minor as the stocks comprise a small part of the index capitalisation, with perhaps the possible exception of OTE and NBG. It should be noted that for the rest of the stocks α_4 is much bigger than in those two stocks implying that our conclusions are valid. In addition, we checked the correlation between $\Delta P_{t,DAX}$ and $\Delta P_{t,ASE}$ and found it to be low, thus indicating that multicolinearity does not present a problem.

impulse response analysis. Before doing so however it is worth noting that DUM2 was found to be statistically significant either at the 5% or 10% level in many cases in the 3 ECMs. The coefficient was negative for equations (1) and (2) with one exception, implying that the tax reduced the return of the stocks traded in BSE and FSE, and positive in equation (3) implying that the tax increased the return of the stock traded in ASE. Thus, the incidence of taxation is shared in the two markets.

3.4 Impulse response functions

We subject our cointegrated VAR to impulse response analysis and we select the lag structure using SIC (the same criterion used in the cointegration exercise). It is well known that SIC is a strongly consistent lag order selection criterion suited for the analysis of finite-lag order VAR models. The impulse response function traces the effect and persistence of one market's shock to other markets, which tells us how fast information transmits across the markets. We would like to explore on the one hand, how long the adjustment takes as that will indicate the degree of the efficiency in processing information, and on the other hand, which price does most of the adjustment for that will shed more light on which market is the dominant one. As it has been mentioned the dominant market is the one where most of the price discovery process takes place. If the Greek market is the dominant one since most of the trading takes place there, then P_{Berlin} will be expected to do most of the adjustment following a shock. Figures 1 and 2 present the impulse responses for OTE and NBG. Similar results were obtained for the other stocks.

We will examine first the responses of P_{Berlin} and P_{Frank} to a standard deviation shock of P_{Athens} (see diagram 3 in each Figure). In most of the stocks there is a positive impact effect as expected because on a given calendar day the German markets are the last ones to close. Most of the responses take place in day 1 and the responses are almost complete by day 2.

In contrast, there is no impact effect on P_{Athens} when there is a standard deviation shock in either P_{Berlin} or P_{Frank} (see diagrams 1 and 2 in each Figure). This is to be expected since the Greek market closes before the German markets. Most of the

responses are completed by day 2. It is also interesting to note that P_{Athens} does most of the adjustment irrespective of the market that the shock has come from.

Concentrating now on how the two German markets react to each other we examine how P_{Frank} reacts to a shock in P_{Berlin} and vice versa (see diagrams 1 and 2 in each Figure). There is a substantial positive impact as expected since both markets trade at the same time. Most of the responses are completed within day 1. The adjustment is thus faster than the responses of P_{Athens} to shocks, implying that these markets are more efficient in processing information.

Diagram 4 in each Figure allows us to examine the response of P_{Berlin} and P_{Frank} to a currency shock. We note that most of the responses are completed by day 2, although there are some differences in the responses of P_{Berlin} and P_{Frank} in day 1. The mixed results might be due to the uncertainty of information content due to the small changes of the exchange rate as a result of the impending joining of EMU by Greece.

Thus, the impulse response analysis has shown that P_{Berlin} and P_{Frank} adjust less and faster than the P_{Athens} implying that price discovery process takes place in the German markets. Responses take up to two days to be completed raising doubts regarding market efficiency and implying the possibility of short-run arbitrage profits.

3.5 Forecast Error Variance Decomposition

The forecast error variance of each variable is decomposed into components, which account for innovations in all the variables. The more exogenous a variable is the less its forecast error variance is explained by innovations in the other variables. These results are reported in Table 6. Each entry in the table gives the 5-day ahead average forecast error variance of the left-hand side variable explained by innovations in the variable on the top.

The most exogenous variables in the VAR system for each of the stocks are S and P_{Berlin}.[11] For example, the S innovations account for between 95.10% and 99.04% of its own variance, while innovations in other variables do not go above 4.5%. A similar

finding was reported in Grammig et al. (2003). In the case of P_{Berlin}, while own innovations account for as much as in S, a substantial proportion of its own forecast error variance is explained by innovations in P_{Frank}. Similarly, a substantial proportion of P_{Frank} forecast error variance is explained by innovations in P_{Berlin}. In contrast, innovations in P_{Athens} account for a very small proportion of the forecast error variance of either P_{Berlin} or P_{Frank}. These are different to those of Kim et al. (2000), where they have found the innovations from the underlying shares to explain a substantial portion of innovations in the corresponding ADRs.

In neither of the forecast error variances of P_{Berlin} and P_{Frank} innovations of the exchange rate are important. Thus, investors in stocks traded in BSE and FSE do not realise any gains or losses on their shares due to variations in the exchange rate. This to some extent was to be expected since the exchange rate did not vary much in anticipation of Greece's entry in EMU.

The least exogenous variables is P_{Athens}. Own innovations account between 50.76% and 69.62%. Innovations in both P_{Berlin} and P_{Frank} account for almost similar amounts.

Thus, the results from forecast error variance decomposition confirm those of the error correction models. That is, P_{Berlin} and P_{Frank} are more exogenous than P_{Athens}.

4. Price discovery and trading systems

In our study we have found two conflicting results. We have found that the prices of stocks in the German markets are priced with reference to the Greek market, implying that the location of trade does not matter. At the same time, we have found overwhelming evidence that P_{Frank} and P_{Berlin} adjust much less than P_{Athens} to long-run equilibrium implying that the price discovery process takes place in the German markets, although most of the trading volume is concentrated in the Greek market. This result is

[11] It should be noted that when one applies generalised forecast error variance decomposition, the components might not add up to 100%.

rather puzzling. We give below various explanations including the different trading systems in the Greek and German Markets.

One possible explanation might lie with the differences in the conclusion of daily trading in the Greek and German markets. As noted in Section 2.1, the Greek market closes at 12.30 GMT, while the German markets close at 19.00 GMT.[12] Thus, it could be that news coming into the market after 12.30 GMT are absorbed into P_{Frank} and P_{Berlin} on the same day, while the Greek market responds the following day explaining the greater adjustment by P_{Athens} observed in our various tests.

Another explanation might relate to the different trading systems in the two markets. Although ASE has an Automated Exchange Trade system where the speed with which orders enter the electronic system, the immediacy with which orders are executed and the greater transparency of the market might make the price discovery faster than the floor market of BSE and FSE, the high volatility of the Greek market and the lower liquidity of the stocks compared to that of the German market might render the floor trading system of the German markets more advantageous in processing new information. Martens (1998) in his study of the Bund Futures contract in LIFFE, which uses a floor trading system, and Deutsche Terminborse (DTB), which employs an electronic screen based system, found that in volatile periods, the share in the volume of LIFFE decreased, but the share in the price discovery process increased. According to Glosten (1994) in periods with much new information the danger of adverse selection costs increases and that makes risk-averse traders reduce their limit orders in the order book or shorten the average time span for the display of an order in the order book reducing thus the information content of the order book and the advantages of the electronic based system. Furthermore, the advantages of the floor system increase as observation of other traders becomes more informative. On the basis of that, it is possible that because of the high volatility of the Greek market compared to the developed markets, such as the German one,[13] the electronic trading system of the Greek market might have offered less signals for predicting market developments than observation of traders on the floor in the

[12] Trading hours for both markets changed during the sample period but it has always been the case that the German market closed later in the day.

German markets. This would explain the higher share of the German markets in the price discovery process.

In addition, Thiessen (2002), who has analysed the price discovery in floor-based and electronic exchanges using data from a fully electronic trading system (XETRA) in Germany, which operates in parallel to the FSE, found the adverse selection costs are higher for less liquid stocks and thus the advantages of the electronic systems less pronounced for such stocks. Stocks in the less mature Greek market compared to the other European markets are less liquid in terms of total value of share trading and market capitalisation and the electronic based system might have less advantages in processing new information.[14]

There could also be another explanation to the German markets contributing more to the price discovery process. The local market is dominated by private investors as opposed to institutional investors. For example, in 2001, the participation of the local institutional investors were only 19% of the current value of the market portfolio compared to 35% of the private investors and 24% of legal entities. It is believed that the reverse is true in the German markets. The higher participation of institutional investors implies better and cheaper access to information. Thus, although the volume traded in the German markets is small, there could be greater amount of informed trading taking place.

5. Conclusion

We have set out in this paper to examine the price dynamics of Greek securities, which are traded in three exchanges, ASE, BSE and FSE. We have used daily data for the period mid 1998 to March 2001 and applied on the one hand cointegration analysis to capture the possibility of long-run arbitrage profits and on the other hand, ECM and innovation accounting, in particular forecast variance error decomposition and impulse response analysis, to investigate the possibility of short-run arbitrage profits and the price discovery process. The three listings provide various opportunities for potential arbitrage

[13] The volatility in the Greek market was 42% over the period 1987 to 1996 compared to 15% to 25% for most developed markets (see Solnik, 2000, pp 307).

[14] For example, the value of share trading/market capitalisation was 0.43 in ASE in 2001 compared to 1.29 in Germany.

profits. Investors can switch from shares at BSE to shares at FSE. They can also switch from shares at BSE to shares at ASE if allowing for transaction costs they can see an arbitrage opportunity. Since the stocks traded at BSE and FSE were denominated in Euros while at ASE in Drachmas for most of the period, the stocks in the German Exchanges should also incorporate fluctuations in the exchange rate.

The following are some of our main findings. First, the three share prices converge in the long run so that there are no long-run arbitrage profits to be made. Second, the ECM has shown that the stocks in the German markets are priced with reference to the Greek market implying that the location where the stock is traded is not important. Although Froot and Dabora (1999) and Werner and Kleidon (1996) arrived at different conclusions for ADRs and foreign stocks listed in US exchanges, Bacidore and Sofianos (2002) in their detailed analysis of specialist behaviour in the ADR market find that in the case of most ADRs price discovery takes place in the home market and NYSE market participants take those prices as given.

Third, we have found that the price discovery process takes place in the German markets implying that they are the dominant markets and the Greek market is the satellite one although most of the trading volume is concentrated in the Greek market. This is not in agreement with Chowdhry and Nanda (1991) who showed in their theoretical analysis that the dominant market is the one where most of the trading volume is concentrated when trading occurs simultaneously in two markets. A possible explanation might lie with the trading systems in the different markets. We argue that the floor system of the German markets might impound new information faster into prices as stocks in the Greek market are not as liquid as those of other European markets and are in addition more volatile. Another explanation could relate to the differences in the conclusion of daily trading in the Greek and the German markets.

Finally, our results with respect to market efficiency are mixed. Most adjustment seems to take place within the same calendar day, but there are instances, when adjustment takes longer implying the possibility of short-run profits. This, however, could reflect the existence of substantial trading costs. We also found the securities transaction tax to affect the short-run dynamics and this is worth exploring more in future research.

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Table 1
Trading hours of Greek and German securities exchanges

Market	Hours of trading (GMT)
Athens Stock Exchange	
1.01.98 - 14.01.99	8.45 - 11.30
15.01.99 - 6.10.99	8.30 - 12.15
7.10.99 - 5.12.99	8.45 - 11.30
6.12.99 - 16.09.01	8.00 - 12.30
Berlin Stock Exchange	
Frankfurt Stock Exchange	
1.04.98 - 19.09.99	7.30 - 16.00
20.09.99 - 1.06.00	8.00 - 16.30
2.06.00 - 16.09.01	8.00 - 19.00

Table 2
Stocks and their sample periods

Stocks	Sample period
Alpha Credit Bank	01/09/98-29/03/01
Commercial Bank of Greece	04/09/98-12/03/01
Ergasias Bank	07/09/98-23/08/00
Hellenic Petroleum	03/08/99-29/03/01
Hellenic Bottling	19/06/98-12/03/01
National Bank of Greece	15/09/98-12/03/01
Hellenic Telecommunications	04/09/98-29/03/01
Viohalco	05/02/99-12/03/01

Table 3

Multivariate cointegration tests

Companies	Johansen trace statistics			
	H_0: r = 0	H_0: r ≤ 1	H_0: r ≤ 2	H_0: r ≤ 3
OTE	546.88**	230.04**	11.68	0.88
NBG	402.75**	153.89**	15.73	4.57
CBG	349.75**	73.24**	14.81	7.03
ACB	276.89**	242.60**	9.65	7.11
ERG	346.28**	138.73**	15.51	5.27
HEP	332.41**	105.73**	17.86	0.79
VIO	348.66**	145.08**	4.08	0.25

If r denotes the number of significant vectors, then the Johansen trace statistics test the hypotheses of at most three, two, one and zero cointegrating vectors, respectively. The critical values introduced by Osterwalt-Lenum (1992) were used.
** Denotes significance at the 5% level.

Table 4

Maximum likelihood estimates of the cointegrating vectors where

$$CV1: \quad P_{Frank} = \beta_1 P_{Athens} + \beta_2 S$$
$$CV2: \quad P_{Frank} = \beta_3 P_{Berlin} + \beta_4 S.$$

Companies	Cointegrating parameters of the following variables			
	P_{Athens}	P_{Berlin}	S	LR test $\beta_1 = 1$ $\beta_3 = 1$ $\beta_4 = 0$
OTE				
CV1	-0.97(-0.01)		1.10(0.10)	9.63
CV2		-0.99(-0.008)	-0.10(0.082)	
NBG				
CV1	1.01(0.015)		-1.02(-0.268)	1.37
CV2		0.99(0.013)	0.03(0.241)	
CBG				
CV1	0.97(0.033)		-2.09(-0.625)	1.92
CV2		0.97(0.033)	-0.87(-0.666)	
ACB				
CV1	0.98(-0.016)		-0.86(-0.288)	3.22
CV2		0.99(0.012)	-0.034(-0.207)	
ERG				
CV1	1.03(0.026)		-0.68(-0.434)	2.41
CV2		1.01(0.023)	-0.002(-0.417)	
HEP				
CV1	1.02(0.020)		-0.90(-0.251)	9.77
CV2		0.98(0.023)	-0.63(-0.325)	
VIO				
CV1	-0.99(-0.007)		-0.93(-0.259)	6.12
CV2		0.98(0.005)	-0.07(-0.187)	

The numbers in brackets are asymptotic standard errors.

Table 5: Error Correction Modelling

$$\Delta P_{t,Frank} = \alpha_0^F + \alpha_1^F (P_{Frank} - P_{Athens} + \beta_2 S)_{t-1} + \alpha_2^F (P_{Frank} - P_{Berlin})_{t-1} + \alpha_3^F \Delta P_{t,DAX} + \alpha_4^F \Delta P_{t,ASE}$$
$$+ \alpha_5^F DUM1 + \alpha_6^F DUM2 + \sum_{i=1}^{k} \alpha_{6+i}^F \Delta P_{t-i,Frank} + \sum_{i=1}^{k} \alpha_{6+k+i}^F \Delta P_{t-i,Berlin} + \sum_{i=1}^{k} \alpha_{6+2k+i}^F \Delta P_{t-i,Athens} + \sum_{i=1}^{k} \alpha_{6+3k+i}^F \Delta S_{t-1} + \varepsilon_t .$$

Companies	α_1^F	α_2^F	α_3^F	α_4^F	α_5^F	α_6^F	$\bar{R}^2$	Θ_1	Θ_2
OTE	-0.072* (-1.601)	-0.577** (-8.857)	0.184** (2.581)	0.235** (3.513)	0.007 (1.392)	-0.013* (-1.817)	0.297	0.881	0.296
NBG	0.002 (0.047)	-0.401** (-5.015)	0.018 (0.299)	0.311** (4.445)	0.001 (0.455)	-0.012* (-1.830)	0.397	0.999	0.214
CBG	0.073* (1.627)	-0.153** (-3.177)	0.204** (2.647)	0.318** (4.456)	-0.019* (-1.876)	-0.065** (-2.030)	0.235	0.852	0.618
ACB	-0.089 (-2.019)	-0.449** (-4.992)	0.140** (2.014)	0.328** (3.128)	-0.006 (-1.497)	-0.026** (-3.339)	0.441	0.765	0.475
ERG	-0.030 (-0.594)	-0.184** (-3.049)	0.276** (2.988)	0.378** (5.196)		-0.013 (-1.412)	0.174	0.919	0.778
HEP	-0.048 (-0.776)	-0.218** (-3.671)	0.093 (0.976)	0.530** (5.588)	-0.005 (-0.558)	-0.039 (-1.215)	0.160	0.914	0.590
VIO	-0.061 (-1.241)	-0.472** (-7.309)	-0.036 (-0.412)	0.457** (7.872)	-0.001 (-0.370)	-0.008 (-0.865)	0.342	0.896	0.236

$$\Delta P_{t,Berlin} = \alpha_0^B + \alpha_1^B (P_{Frank} - P_{Athens} + \beta_2 S)_{t-1} + \alpha_2^B (P_{Frank} - P_{Berlin})_{t-1} + \alpha_3^B \Delta P_{t,DAX} + \alpha_4^B \Delta P_{t,ASE}$$
$$+ \alpha_5^B DUM1 + \alpha_6^B DUM2 + \sum_{i=1}^{k} \alpha_{6+i}^B \Delta P_{t-i,Frank} + \sum_{i=1}^{k} \alpha_{6+k+i}^B \Delta P_{t-i,Berlin} + \sum_{i=1}^{k} \alpha_{6+2k+i}^B \Delta P_{t-i,Athens} + \sum_{i=1}^{k} \alpha_{6+3k+i}^F \Delta S_{t-1} + \varepsilon_t .$$

Companies	α_1^B	α_2^B	α_3^B	α_4^B	α_5^B	α_6^B	$\bar{R}^2$	Θ_1
OTE	-0.077* (-1.698)	0.243** (3.561)	0.104 (1.324)	0.263** (3.929)	-0.002 (-0.379)	-0.002 (-0.286)	0.061	0.873
NBG	-0.062* (-1.694)	0.109** (2.282)	0.068 (0.914)	0.228** (3.811)	-0.004 (-0.916)	-0.014* (-1.792)	0.038	0.871
CBG	-0.147** (-4.550)	0.247** (6.771)	0.179** (2.292)	0.359** (5.331)	0.014** (2.024)	0.044** (2.389)	0.136	0.740
ACB	-0.317** (-2.269)	0.407** (3.343)	0.172* (1.884)	0.455** (4.688)	-0.014** (-2.277)	-0.030** (-2.005)	0.178	0.476
ERG	-0.194** (-2.751)	0.647** (9.497)	0.412** (2.202)	0.508** (3.392)		0.005 (0.023)	0.315	0.637
HEP	-0.041 (-0.644)	0.314** (5.003)	0.277** (2.293)	0.569** (5.728)	-0.034** (-3.339)	-0.086** (-2.773)	0.211	0.925
VIO	-0.088 (-1.088)	0.132 (1.517)	0.001 (0.128)	0.764** (9.630)	-0.009** (-2.953)	-0.021** (-2.065)	0.232	0.856

$$\Delta P_{t,Athens} = \alpha_0^A + \alpha_1^A (P_{Frank} - P_{Athens} + \beta_2 S)_{t-1} + \alpha_2^A (P_{Frank} - P_{Berlin})_{t-1} + \alpha_3^A \Delta P_{t,DAX} + \alpha_4^A \Delta P_{t,ASE} +$$

$$+ \alpha_5^A DUM1 + \alpha_6^A DUM2 + \sum_{i=1}^{k} \alpha_{6+i}^A \Delta P_{t-i,Frank} + \sum_{i=1}^{k} \alpha_{6+k+i}^A \Delta P_{t-i,Berlin} + \sum_{i=1}^{k} \alpha_{6+2k+i}^A \Delta P_{t-i,Athens} + \sum_{i=1}^{k} \alpha_{6+3k+i,}^F \Delta S_{t-1} + \varepsilon_t .$$

Companies	α_1^A	α_2^A	α_3^A	α_4^A	α_5^A	α_6^A	$\overline{R}^2$
OTE	0.533** (14.544)	-0.263** (-4.692)	-0.053 (-1.041)	0.110** (2.301)	0.006** (2.353)	0.027** (5.032)	0.439
NBG	0.417** (15.995)	-0.279** (-8.309)	-0.093* (-1.783)	0.238** (5.648)	0.002 (0.835)	0.018** (3.280)	0.439
CBG	0.419** (17.052)	-0.351** (-12.65)	-0.855 (-1.442)	0.225** (4.408)	0.013** (2.393)	0.040** (2.912)	0.416
ACB	0.289** (4.142)	-0.124* (-1.664)	-0.072 (-0.996)	0.227** (2.580)	0.003 (1.170)	0.025** (3.450)	0.395
ERG	0.340** (6.899)	-0.138 (-1.396)	-0.071 (-0.900)	0.247** (2.774)		0.002 (0.322)	0.350
HEP	0.513** (13.050)	-0.159** (-3.549)	0.022 (0.284)	0.204** (3.038)	0.011* (1.759)	0.029 (1.560)	0.441
VIO	0.523** (9.906)	-0.497** (-6.570)	0.013 (0.172)	0.299** (4.077)	0.002 (0.491)	-0.007 (-0.887)	0.400

Notes: The coefficients of lagged differences have been left out to save space. They can be made available by the authors.

** Denotes significance at the 5% level
* Denotes significance at the 10% level

Table 6

Decomposition of 5-day ahead average forecast error variance

Company	Variables explained	By innovations in			
		P_{Berlin}	P_{Athens}	P_{Frank}	S
OTE	P_{Berlin}	97.46	2.36	38.48	0.28
	P_{Athens}	47.68	50.76	38.40	1.54
	P_{Frank}	73.76	2.97	75.64	0.26
	S	1.62	1.64	0.11	96.84
NBG	P_{Berlin}	98.64	0.98	16.54	0.42
	P_{Athens}	39.86	58.50	12.44	0.70
	P_{Frank}	62.92	0.76	63.00	0.22
	S	4.02	1.24	1.38	95.64
CBG	P_{Berlin}	94.00	3.06	25.86	0.10
	P_{Athens}	34.72	63.32	16.00	0.27
	P_{Frank}	39.72	0.80	88.02	0.30
	S	4.40	0.82	1.56	95.94
ACB	P_{Berlin}	88.48	17.14	23.98	0.05
	P_{Athens}	34.98	69.62	26.44	0.02
	P_{Frank}	56.70	11.2	64.96	0.05
	S	2.56	0.07	1.06	95.80
ERG	P_{Berlin}	88.78	3.88	32.52	0.36
	P_{Athens}	25.72	67.60	27.84	0.22
	P_{Frank}	36.98	2.84	90.66	0.72
	S	2.42	0.28	1.02	98.30
HEP	P_{Berlin}	90.64	0.74	50.16	0.74
	P_{Athens}	28.32	55.86	43.02	0.75
	P_{Frank}	46.60	2.44	93.62	1.78
	S	0.04	1.36	0.05	99.04
VIO	P_{Berlin}	98.68	27.08	37.14	0.42
	P_{Athens}	70.36	61.98	28.30	0.35
	P_{Frank}	74.52	21.02	70.02	0.09
	S	1.38	1.02	0.176	95.10

Figure 1 OTE

Diagram1

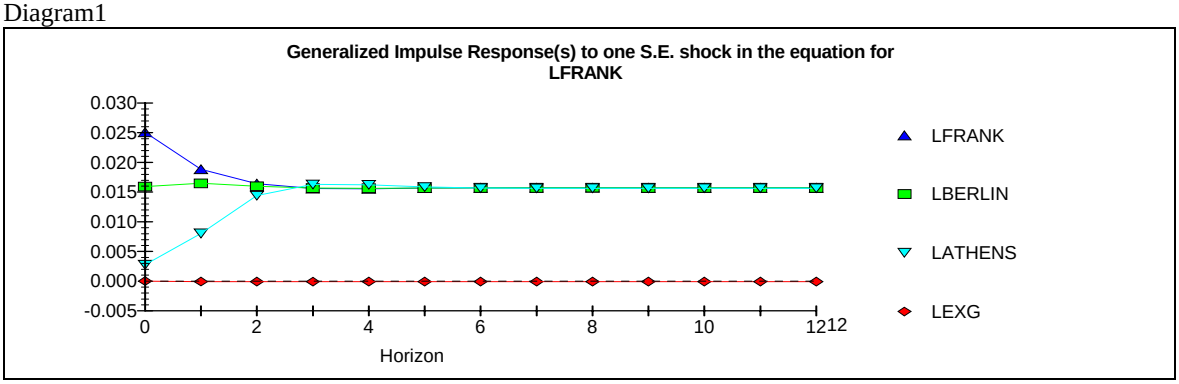

Diagram 2

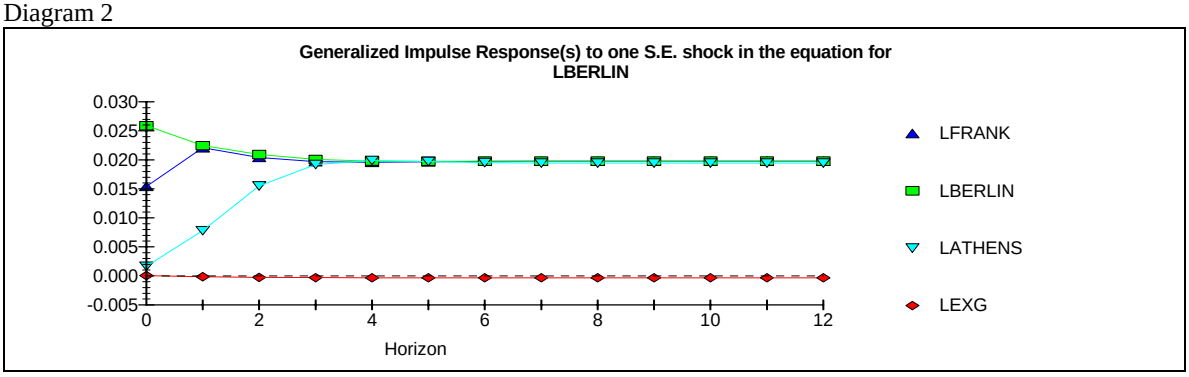

Diagram 3

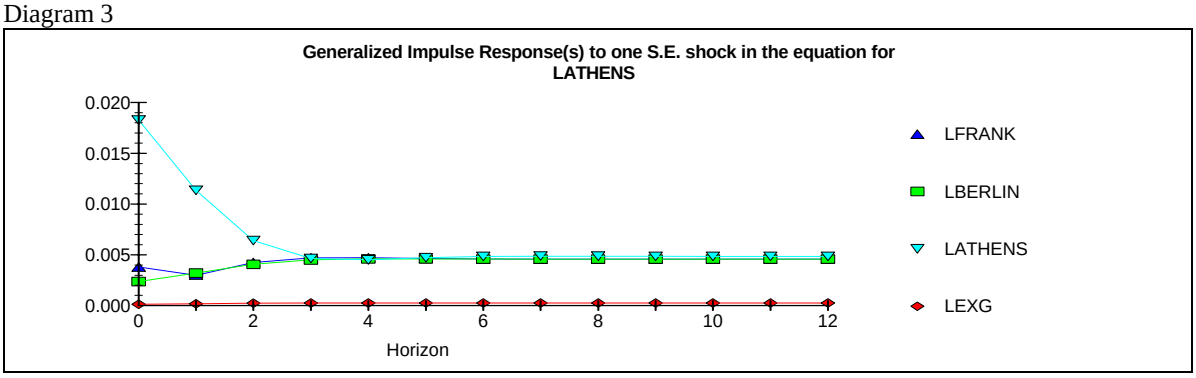

Diagram 4

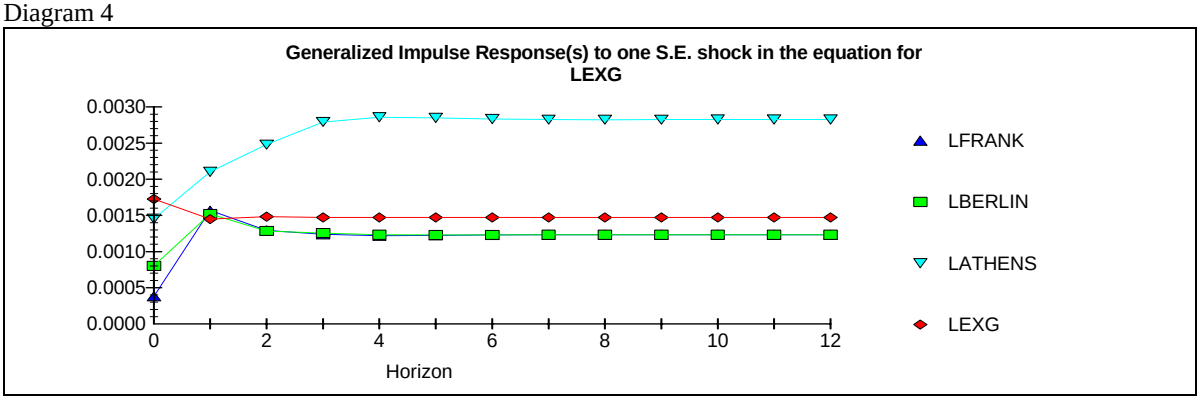

Figure 2 NBG
Diagram 1

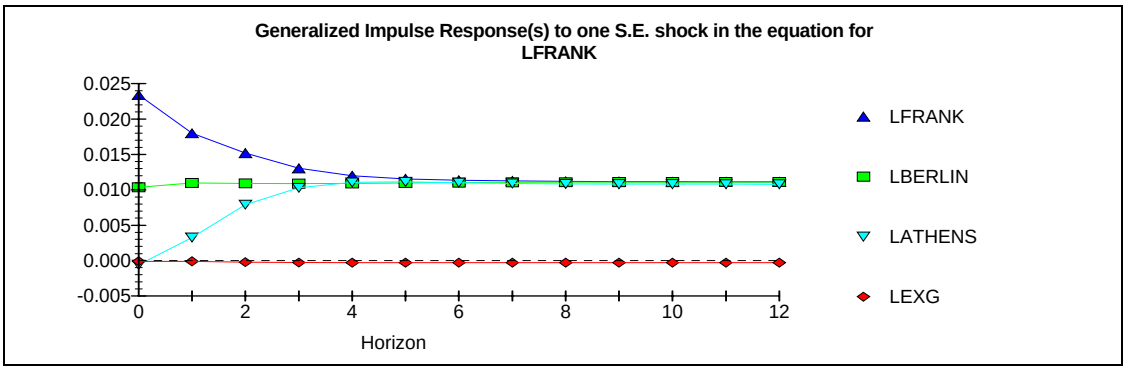

Diagram 2

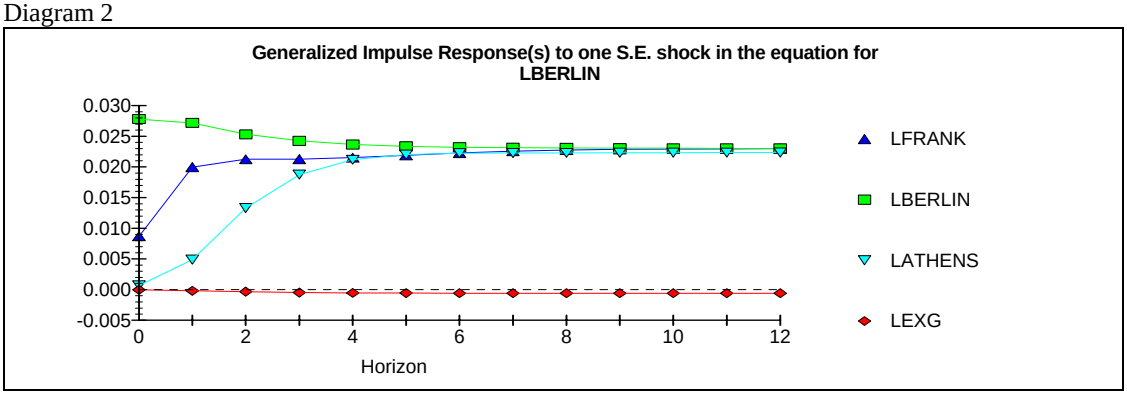

Diagram 3

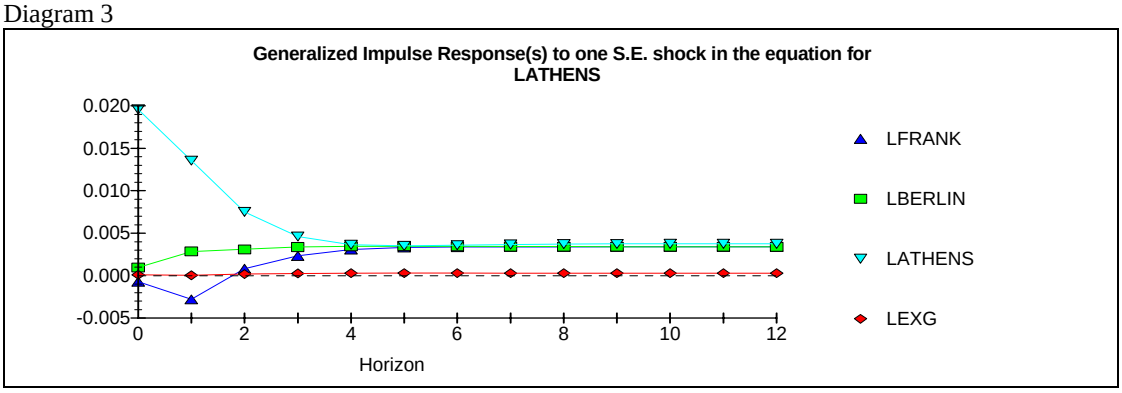
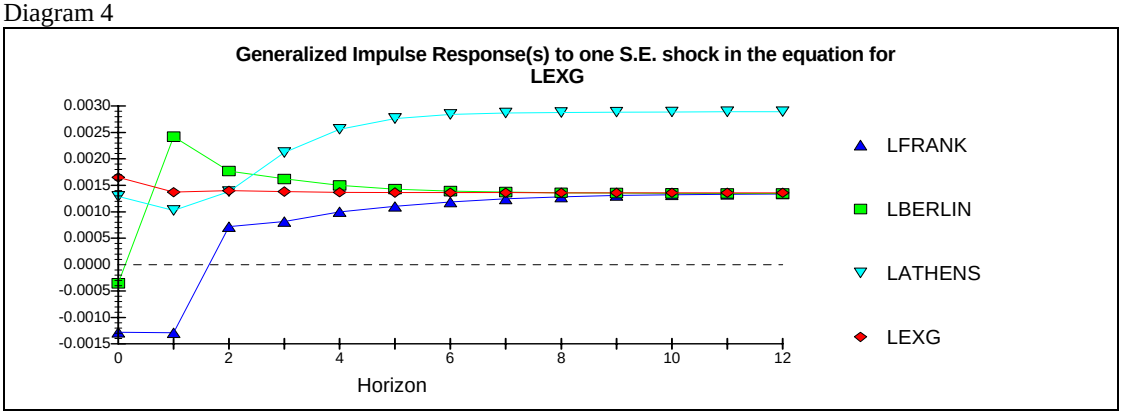
Diagram 4