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Cet article étudie les liens existant entre le marché des actions suisses et les cinq plus grands marchés mondiaux (Etats-Unis, Japon, Grande-Bretagne, Allemagne et France) en terme de rentabilité et de volatilité. Nous trouvons que chaque marché présente de l'hétéroscédasticité conditionnelle et que la volatilité conditionnelle réagit de façon asymétrique aux chocs passés. Afin de prendre en compte ces phénomènes de façon appropriée nous modélisons les relations entre marchés à l'aide de modèles GARCH bivariés asymétriques. Les résultats de nos estimations montrent que le marché américain a la plus forte influence sur le marché helvétique en terme de rentabilité et de volatilité. Les liens avec les autres marchés en termes de rentabilité sont relativement faibles. Les marchés anglais et allemand ont également une forte influence sur le marché suisse en terme de volatilité. Enfin, nous trouvons que l'influence du marché suisse sur les autres marchés est relativement faible.

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On the dynamic interdependence of international stock markets: A Swiss perspective[‡]

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Abstract:

This paper studies the links existing between the Swiss stock market and the five largest stock markets in the world (USA, Japan, United Kingdom, Germany and France) in terms of return and volatility. We find that conditional heteroskedasticity is present in every market and also that conditional volatility responds asymmetrically to past shocks. In order to properly take account of these phenomena we estimate a series of bivariate asymmetric AR(1)-GARCH(1,1) models to measure the links existing between the Swiss stock market and the five other stock markets. The results indicate that the US market has the strongest influence on the Swiss market in terms of returns and volatility. Links with other markets in terms of returns are relatively weak. The German and British markets strongly influence the volatility of the Swiss market. On the other hand, we find that the Swiss market has a statistically significant but economically weak influence on the foreign markets.

Résumé:

Cet article étudie les liens existant entre le marché des actions suisses et les cinq plus grands marchés mondiaux (Etats-Unis, Japon, Grande-Bretagne, Allemagne et France) en terme de rentabilité et de volatilité. Nous trouvons que chaque marché présente de l'hétéroscédasticité conditionnelle et que la volatilité conditionnelle réagit de façon asymétrique aux chocs passés. Afin de prendre en compte ces phénomènes de façon appropriée nous modélisons les relations entre marchés à l'aide de modèles GARCH bivariés asymétriques. Les résultats de nos estimations montrent que le marché américain a la plus forte influence sur le marché helvétique en terme de rentabilité et de volatilité. Les liens avec les autres marchés en termes de rentabilité sont relativement faibles. Les marchés anglais et allemand ont également une forte influence sur le marché suisse en terme de volatilité. Enfin, nous trouvons que l'influence du marché suisse sur les autres marchés est relativement faible.

Zusammenfassung:

In diesem Artikel werden die bestehenden Verbindungen zwischen dem Schweizer Aktienmarkt und den fünf grössten Aktienmärkten weltweit (USA, Japan, Grossbritannien, Deutschland und Frankreich) bezüglich der Rendite und der Volatilität untersucht. Wir stellen fest, dass konditionale Heteroskedastizität in allen Märkten vorkommt und konditionale Volatilität asymmetrisch auf vergangene Schocks reagiert. Zur gebührenden Berücksichtigung dieser Phänomene modellieren wir eine Serie von bivariaten asymmetrischen AR(1)-GARCH(1,1), um die existierenden Verbindungen zwischen dem Schweizer Aktienmarkt und den fünf anderen Aktienmärkten zu messen. Die Resultate weisen darauf hin, dass der amerikanische den Schweizer Aktienmarkt bezüglich Rendite und Volatilität am stärksten beeinflusst. Die Verbindungen zu den anderen Märkten bezüglich der Rendite sind relativ schwach. Der deutsche und der britische Markt beeinflussen den Schweizer Aktienmarkt stark bezüglich der Volatilität. Andererseits stellen wir fest, dass der Schweizer Aktienmarkt einen statistisch signifikanten, aber ökonomisch schwachen Einfluss auf die anderen Aktienmärkte hat.

On the dynamic interdependence of international stock markets: A Swiss perspective

1. Introduction

In an era of increasing globalisation, the transmission of movements in international financial markets is an important issue for economic policy, especially in periods where markets are very agitated. The determination of hedging and diversification strategies by an international investor also depends crucially on the nature and magnitude of the relationships existing between different stock markets. Statements supporting the existence of these links are frequently found in the financial press.¹ These links have also been investigated in many different ways by a growing body of academic research attempting to describe and quantify the way in which financial markets interact.

The literature of the transmission of movements between financial markets can be divided in two groups. The first group contains the early literature which focuses exclusively on the links existing between series of returns of national market indices. A first type of papers concentrates naturally on the comovements existing between different markets and simply examines correlations, in order to determine the potential benefits of diversification. GRUBEL (1968) is the first to consider this issue and computes the potential gains of international diversification from a US point of view. A second type of papers extends this approach and investigates whether the return in one country at time t is useful for predicting the return on another market at time $t+1$. The simplest way to get an idea about this phenomenon is to examine lagged correlation or to perform univariate regressions of a country index return on lagged foreign index returns as in COPELAND and

1. A recent example is *The Wall Street Journal Europe* which wrote on April 5, 2000: "Yesterday's mayhem on Wall Street is sure to reverberate on European markets today " (Heard in Europe, p.13).

COPELAND (1998). A similar approach has been to estimate a dynamic simultaneous equations system as in KOCH and KOCH (1991). In the same spirit EUN and SHIM (1989) estimate a VAR system in order to get for each market an impulse response function to past shocks stemming from other countries. PEIRO *et al.* (1998) also estimate a system of equations but they make an explicit distinction between the ability to influence and the sensitivity of each market. More sophisticated approaches have also been proposed. MALLIARIS and URRUTIA (1992) provide explicit causality test to detect which markets are leading the others. ARSHANAPALLI and DOUKAS (1993) use cointegration tests to document the linkages and dynamic interactions between markets. Despite there is no systematic conclusions regarding the direction and magnitude of existing international links, two findings have been frequently reported: the US market is the most influential market as it leads many other markets and the lead-lag relationships existing between different markets vanishes beyond one day.

The second group of studies is more recent and it analyses simultaneously the dynamic relationship existing between daily stock returns and also between stock return volatilities as it has been widely documented that volatility is not constant over time. The evolution of the conditional volatility through time has been successfully modelled as an ARMA process. This type of models is known under the acronym of GARCH models which stands for Generalised Auto Regressive Conditional Heteroskedasticity models and has been proposed by ENGLE (1982) and BOLLERSLEV (1986). HAMAOKA *et al.* (1990) use a univariate GARCH model to document the volatility spillovers between New York, Tokyo and London stock exchanges. They find that the links between the volatilities of different markets are significant and that an increase in volatility in one market induces an increase in volatility in another market. KAROLYI (1995) conducts the same type of analysis but uses multivariate

GARCH models to document the dynamic interactions existing between conditional means and variances of the index returns of the US and Canadian markets.

A second generation of GARCH models has been introduced by NELSON (1991). These models explicitly take account of a feature already documented by BLACK (1976), i.e. the asymmetric response of volatility to past shocks. More precisely it has been shown that the conditional volatility is higher after a negative shock than after a positive shock of the same magnitude or in other terms that bad news have more impact on the conditional volatility than good news. The most popular explanation for the existence of this effect is that after a negative shock the debt to equity ratio rises and makes therefore the firm more risky. This is why this effect has been termed the leverage effect. This feature has been modelled within several different GARCH specifications - the most popular being the EGARCH model of NELSON (1991) and the model of GLOSTEN *et al.* (1993). The existence of significant asymmetric volatility spillovers across markets has been documented by BOOTH and KOUTMOS (1995), KOUTMOS (1996), BOOTH *et al.* (1997) for different markets in the framework of multivariate EGARCH models with constant correlations.

Our paper is in line with the recent literature as it examines the dynamic interdependence in terms of returns and volatility of the Swiss market with the major stock markets of the world. It will try to answer the following question: To what extent are the movements of the Swiss market affected by past movements in other markets? We focus specifically on the Swiss stock market as there is few evidence about it in the previous literature.² We model the dynamics of volatility as a GARCH process which allows asymmetric effects according to the results of previous studies. However as the hypothesis of constant

correlation between returns used in the previous literature has been shown to be too restrictive we use a more flexible specification, called BEKK.³ This paper investigates the links existing between the Swiss market and stock markets from the United States, Japan, United Kingdom, Germany and France on a daily basis over the period 1988-1998. The rest of the paper is organised as follows: Section 2 provides summary statistics for the various indices and also diagnostic tests to assess the main features of the indices. Section 3 describes the econometric models used to document the links between markets. Section 4 presents our empirical results and section 5 summarises the paper and provides concluding remarks.

2. Data description and preliminary statistics

The dataset used in this study includes the daily closing prices of domestic stock indices, P_{it} . They are retrieved from Datastream International and cover the period running from July 1, 1988 to August 1, 1998 for a total of 2630 observations. The indices under consideration are the following: Swiss Market Index for Switzerland, DAX index for Germany, FTSE 100 index for the United Kingdom, CAC40 for France, Standard & Poors 500 for the United States and Nikkei 500 for Japan. The returns are computed as:

$$r_{it} = \log(P_{it}) - \log(P_{it-1}) \quad (1)$$

These indices are all prices indices as they do not include dividends and they are all value-weighted, except the Japanese index which is price-weighted.

An important problem arising in any study of movements concerning financial markets of

2. OERTMANN (1995) studies the interactions between international stock markets including the Swiss market by estimating a VAR system in the same spirit as EUN and SHIM (1989). He finds that the Swiss market is significantly related to foreign markets in terms of innovations. JOCHUM (1999) studies the links existing between markets in terms of volatility and estimates a series of bivariate symmetric GARCH-M models. He finds that the Swiss market is significantly related to foreign markets.

different continents is that timings of the different markets are not the same, which can be problematic with daily observations. In our case we may have a problem with the Japanese market which trades before the Swiss market opens and the US market which trades after the Swiss market closes. As our study focuses on the intertemporal relations between stock markets, i.e. the relation between lagged returns between two markets, we have to take into account the overlapping problem of the computation period for the returns. This non-synchronous trading problem will be relevant in our study in two cases: Firstly, it exists an overlapping period between the computation periods of the lagged US return ($r_{US,t-1}$) and the contemporaneous Swiss return ($r_{CH,t}$). Second, it exists also an overlapping period between the computation periods of the lagged Swiss return ($r_{CH,t-1}$) and the contemporaneous Japanese return ($r_{JP,t}$). The consequence of this overlapping is that the Granger causality between $r_{CH,t}$ and $r_{US,t-1}$ on one side and between $r_{CH,t-1}$ and $r_{JP,t}$ on the other

3. BEKK stands for the initials of the researchers who initially developed the model: BABA, ENGLE, KRAFT and KRONER (1987).

side may be upward biased.⁴ The reported coefficients contain both a pure Granger causality and also a contemporaneous correlation dimension.

In order to limit the overlapping between computation periods, *open to close* returns can be computed, as in HAMAQ *et al.* (1990) or KOUTMOS and BOOTH (1995). In our view, this methodology solves only partially the non-synchronicity problem because it neglects significant periods of time when the market is closed, but when information may arrive. This approach can not take into account the fact that the closing price on day $t-1$ is most of the time not equal to the opening price on day t . However, it is also well known that the opening price is subject to frequent microstructure problems. Finally, HAMAQ *et al.* (1990) have compared the results obtained with these two widely used methods, *close to close* and *open to close* returns and they find that in a similar type of study to ours that they lead to very close empirical results.

***** Insert Table 1 around here*****

Table 1 shows that the six indices have asymmetric distributions as the skewness coefficient is different from zero and mostly that they have more weight in the left part of the distribution. The kurtosis are all larger than 3 indicating that the tails of the distribution are all fatter than those of the normal distribution. These two parameters are combined to test if the distribution is normal in the BERA-JARQUE (1980) test. The test indicates that the normality assumption can be rejected for all the indices considered. We compute the first order autocorrelation for the indices as well as the LJUNG-BOX (1979) statistics for twelve lags to document the presence of any linear dependence in returns. The results indicate that the Japanese and British stock markets present significant first order autocorrelation. When

4. We use the term "Granger causality" in order to distinguish between statistical causality which is investigated in this paper and real causality. It relates to the notion of causality developed in GRANGER (1969).

lags up to order twelve are considered then the US market also presents some linear dependence in returns.

The *Table* also reports the correlations between the returns of the Swiss market and the returns of the other markets. This is one of the simplest way to measure the links existing between different markets. We have also computed lagged correlations to check if some lagged dependence is also present. The results show that the correlation between contemporaneous returns is the highest which confirms the fact that some pervasive factors affect all markets simultaneously and therefore that stock markets tend to move together internationally. Moreover as these coefficients are positive it means that markets tend to move in the same direction and that they incorporate new information in the same manner. It is also of interest to notice that the markets presenting the highest correlation with Switzerland are Germany and France, which are the most important trade partners of the Swiss economy. The correlation between the Swiss returns and lagged US returns is relatively important (0.337) indicating that the returns of the US market Granger causes the returns on the Swiss market but also reflects the fact that both returns overlap the same period as mentioned before. The relatively high correlation of lagged Swiss returns with the Japanese returns indicates that the Swiss market returns Granger cause the Japanese market returns but may probably also reflect an overlapping problem.

MERTON (1980) argues that one of the simplest way to approximate the instantaneous volatility is to take the squared or absolute value of returns. This is one of the reasons why we also study the correlations of squared returns in the lower portion of *Table 1* in order to detect if there is some non-linear (more precisely quadratic) dependence in returns and more specifically to check if there are some patterns in conditional volatility. The results show that there is a strong linear dependence between second moments as the first order autocorrelations and the LJUNG-BOX Q-statistics at twelve lags are highly significant for all

the six indices. This is usually interpreted as evidence of the presence of ARCH-type effects in conditional volatility. In order to check for that more formally we perform ENGLE's ARCH test (1982) for one lag which is distributed as chi-square with one degree of freedom. Again the resulting statistics are all highly significant which confirms that conditional heteroskedasticity is present in the returns of the six indices and that an ARCH modelling should be used to represent the temporal evolution of the indices.

***** Insert Figure 1 around here*****

Another way to check for the presence of conditional heteroskedasticity is simply to represent graphically the returns of the indices as is done in *Figure 1*. We observe in this *Figure* that volatility is changing over time: periods of high volatility are followed by periods of low volatility. This phenomenon is called volatility clustering and is well captured by GARCH models. The correlation between second moments is a first approximation to represent the linkage of volatilities across countries. These links are higher than those observed for raw returns indicating the likely presence of interactions between volatilities of the different markets.

In order to test for the presence of an asymmetric response of variance to past shocks, ENGLE and NG (1993) propose a formal test that we apply to our sample. In this test, two sources of asymmetric response of variance are considered: the sign effect, that is past shocks of different signs have a different effect on the present volatility, and the size effect, that is past shocks of the same sign but different magnitudes have different effects on present variance. The test involves estimating a symmetric GARCH(1,1) model in a first stage and then using the estimated standardised residuals which are defined as $\hat{v}_t = \hat{\varepsilon}_t / \hat{\sigma}_t$. In order to test whether some asymmetric effects are present in squared standardised residuals, the parameters of following regressions are estimated:

$$\hat{v}_{it}^2 = \phi_{i0} + \phi_{i1}S_{it-1}^- + u_{it} \quad (2)$$

$$\hat{v}_{it}^2 = \phi_{i0} + \phi_{i2}S_{it-1}^-\varepsilon_{it-1} + u_{it} \quad (3)$$

$$\hat{v}_{it}^2 = \phi_{i0} + \phi_{i3}S_{it-1}^+\varepsilon_{it-1} + u_{it} \quad (4)$$

where u_{it} is a normally distributed error term with mean zero and constant variance, S_{it-1}^- is a dummy variable equals to 1 if ε_{it-1} is negative and 0 otherwise, S_{it-1}^+ equals 1 if ε_{it-1} is positive or equal to zero and 0 otherwise. A significant positive ϕ_{i1} in equation (2) suggests the presence of sign bias, meaning that the variance of returns is larger after a negative shock than after a positive shock. If the coefficient ϕ_{i2} is significant in equation (3) it suggests the presence of a negative size bias, indicating that negative shocks of different magnitudes have different effects on standardised residuals. Differential effects of positive shocks are tested in equation (4) where the presence of a positive sign bias is investigated. ENGLE and NG (1993) also suggest to test for the simultaneous presence of all three effects with a Lagrange multiplier test distributed as $\chi^2(3)$. This statistics is obtained by multiplying the number of observations by the R^2 of the regression of the squared standardised residuals on the 3 independent variables used in equations (2)-(4). The estimated parameters and results of the tests for the different indices are presented in *Table 2*. A significant size bias is present for all countries except the U.K. indicating that the standardised squared residuals are larger after a negative shock than after a positive shock. Negative and positive size bias are also significant for some markets. The joint test is significant for all markets except Germany and Great Britain. An asymmetric modelling of the temporal evolution of the conditional volatility seems therefore appropriate for most of the markets in our study.

***** Insert Table 2 around here*****

The preliminary statistics and diagnostic tests presented in this section suggest that the returns of the indices we consider are non-normally distributed and serially correlated. They

also indicate that these indices display dependence in second order moments and more precisely time-varying conditional volatility which could be represented by a GARCH model. According to the results of the ENGLE-NG test an asymmetric modelling of the behaviour of volatility seems appropriate. We also document that the return series as well as second order moments are linked internationally and even more strongly for variances. The omission of this phenomenon would certainly give an incomplete picture of the linkages existing between the different markets. We now turn to the description of the models we use to measure the dependence between the various markets considered in this study.

3. Econometric models

The results obtained in the previous section suggest the presence of asymmetric ARCH effects in the time-series of returns. This section discusses the main features of the specific models used in our study. The reader interested by a more general discussion on ARCH models can find it in BOLLERSLEV *et al.* (1992) or BOLLERSLEV *et al.* (1994).

3.1. Univariate GARCH models

In a first step we estimate univariate models for each market trying to take into account the various features of the data documented in the previous section. We model the mean equation as an autoregressive process of order one as first-order autocorrelation has been observed in the data (as documented in *Table 1*) and also because of the effect of non-synchronous trading on index returns.⁵ The conditional variance equation is then modelled as a classical GARCH model to which we add an asymmetric term representing the leverage effect. We have chosen the specification proposed GLOSTEN *et al.* (GJR, 1993) as ENGLE

and NG (1993) have found that it yields more appropriate results than the EGARCH specification of NELSON (1991), especially for large shocks.⁶ The model is:

$$r_t = a_0 + a_1 r_{t-1} + \varepsilon_t$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \gamma (S_{t-1}^- \varepsilon_{t-1}^2) + \beta_1 \sigma_{t-1}^2 \quad (5)$$

The term $\gamma (S_{t-1}^- \varepsilon_{t-1}^2)$ represents the leverage effect, where S_{t-1}^- equals 1 if ε_{t-1} is negative and 0 otherwise. The error term ε_t is supposed to be conditionally normally distributed with mean 0 and conditional variance σ_t^2 . If the leverage effect is present γ should be significant and positive. It indicates that after a large negative shock (a bad news) the volatility increases more than after a positive shock of the same magnitude (a good news). As the model is non-linear it is estimated with the method of maximum likelihood. As the errors are assumed to be normally distributed, we maximise the following likelihood function:

$$L(\theta) = -\left(\frac{1}{2}\right) \left(T \cdot \ln(2\pi) + \sum_{t=1}^T \left(\ln(\sigma_t^2) + \left(\varepsilon_t^2 / \sigma_t^2 \right) \right) \right) \quad (6)$$

where θ represents the set of parameters to be estimated. The estimates are obtained through the non-linear optimisation algorithm of BERNDT *et al.* (1974). As the standardised residuals resulting of this estimation have frequently shown to be non-normal for financial data, we use the robust standard errors of BOLLERSLEV and WOOLDRIDGE (1992). These authors have shown that the maximisation with respect to a conditional normal distribution even if the real underlying distribution is non-normal yields efficient estimates.

5. We have also estimated models with a larger number of lags but without improving significantly the log-likelihood value or the value of the AKAIKE information criteria rejecting therefore the adequacy of these specifications.

6. Empirically the EGARCH model appears to be too sensitive to large shocks.

3.2. Multivariate GARCH models

As we are interested in the interrelationship between different markets a multivariate GARCH framework is necessary. The extension to the multivariate setup is almost straightforward as we assume that variance-covariance matrix follows a GARCH process. However this task is complicated by the proliferation of parameters. Let us illustrate this with a simple example with two equations. Here we focus on the description of the temporal evolution of variance-covariance matrix H_t . The multivariate GARCH process for a two-dimension problem can be written as:

$$\begin{pmatrix} \sigma_{1t}^2 \\ \sigma_{12t} \\ \sigma_{2t}^2 \end{pmatrix} = C + A \cdot \begin{pmatrix} \varepsilon_{1t-1}^2 \\ \varepsilon_{1t-1}\varepsilon_{2t-1} \\ \varepsilon_{2t-1}^2 \end{pmatrix} + B \cdot \begin{pmatrix} \sigma_{1t-1}^2 \\ \sigma_{12t-1} \\ \sigma_{2t-1}^2 \end{pmatrix}$$

$$\text{where } A = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}, B = \begin{pmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{pmatrix}, C = \begin{pmatrix} c_{11} \\ c_{12} \\ c_{22} \end{pmatrix} \quad (7)$$

In the simple case of two equations, we observe that the estimation of the variance system requires 21 parameters. This number jumps to 78 in the case of 3 equations, 210 in the case of 4 equations and 465 in the case of 5 equations. This general model becomes quickly very difficult to estimate as the number of parameters increases dramatically. In order to remedy to this problem different simplifications of this specification have been proposed. BOLLERSLEV *et al.* (1988) have proposed to make the A and B matrices diagonal, but this specification typically removes the potential interactions in the variances of two markets. BOLLERSLEV (1990) has proposed a model with constant correlations between markets. However LONGIN and SOLNIK (1995) have shown that this assumption is violated in international stock markets. A third simplification is known under the BEKK acronym. This specification is discussed in details in ENGLE and KRONER (1995) and assumes that the variance process can be described as follows:

$$H_t = C_0^* C_0^* + A' \varepsilon_{t-1} \varepsilon_{t-1}' A + B' H_{t-1} B \quad (8)$$

where A , B and C_0^* are matrices of dimension (2×2) , ε_t is the (2×1) vector of errors. The advantage of this specification is that it reduces significantly the number of parameters to be estimated without imposing strong constraints on the shape of the interaction between markets. In this specification, the variance system has 11 parameters for 2 equations, 24 for 3 equations, 42 for 4 equations, 65 for 5 equations. One more advantage of this specification is that a leverage term can also be easily introduced in a similar fashion to the model proposed by GLOSTEN *et al.* (1993) for the univariate case. Because of these advantages we use this type of specification to document the interactions existing between the Swiss market and the major world markets. We estimate a series of bivariate models with an asymmetric BEKK specification of the variance. More precisely the model we estimate is the following:

$$r_t = K + Lr_{t-1} + \varepsilon_t$$

$$H_t = C_0' C_0 + A' \varepsilon_{t-1} \varepsilon_{t-1}' A + B e H_{t-1} + N' \chi_{t-1}^- \chi_{t-1}^- ' N \quad (9)$$

$$\text{where } r_t = \begin{pmatrix} r_{1t} \\ r_{2t} \end{pmatrix}, K = \begin{pmatrix} k_1 \\ k_2 \end{pmatrix}, L = \begin{pmatrix} l_{11} & l_{12} \\ l_{21} & l_{22} \end{pmatrix}, \varepsilon_t = \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix}$$

$$C_0 = \begin{pmatrix} c_{11} & c_{12} \\ 0 & c_{22} \end{pmatrix}, A = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}, B = \begin{pmatrix} b_{11} & b_{12} \\ b_{12} & b_{22} \end{pmatrix}, N = \begin{pmatrix} n_{11} & n_{12} \\ n_{21} & n_{22} \end{pmatrix}$$

Again the mean equation is modelled as a vector autoregression of order one because of the autocorrelation found in index return and also because of the influence of one market on another never lasts more than one day as it has been found in the previous literature. As in the univariate case we assume that the residuals follow a conditional multivariate normal distribution with mean 0 and variance-covariance matrix H_t . There are some differences with the original BEKK specification in equation (8) which are proposed by KRONER and

NG (1998) in order to allow for asymmetry in volatility. The two differences are the autoregressive term $B \varepsilon H_{t-1}$, where ε is the Hadamard product (element by element multiplication) and the asymmetry term $N' \chi_{t-1}^- \chi_{t-1}^- N$ where $\chi_t = \min(0, \varepsilon_t)$. By using the Hadamard product for the volatility term we constrain the volatility transmission mechanism. In this setup the only possible way for a market to influence another market volatility is through shocks. If we do not impose this constraint the precise effect of a market on another market volatility would be difficult to interpret.

As in the univariate case, the model is estimated with the method of maximum likelihood. In the multivariate case, the likelihood function to maximise is the following:

$$L(\theta) = -T \ln 2\pi - \frac{1}{2} \left(\sum_{t=1}^T \ln |H_t| + \sum_{t=1}^T \varepsilon_t' H_t^{-1} \varepsilon_t \right) \quad (10)$$

This function is also maximised with the BERNDT *et al.* (1974) algorithm. The results of BOLLERSLEV and WOOLDRIDGE (1992) also apply for the multivariate case and we therefore compute robust standard errors according to their correction for the different parameters we estimate.

4. Empirical results

4.1. Results for univariate models

In a first step we estimate the univariate GJR models described in equation (5). *Table 3* gives the results of the maximum likelihood estimations. The test of significance are computed with the robust standard errors of BOLLERSLEV and WOOLDRIDGE (1992). The LJUNG-BOX Q-statistics are computed on standardised residuals and squared standardised residuals to check if there is any linear and non-linear dependence in standardised residuals. We also provide the results of the ENGLE-NG (1993) tests on standardised residuals in order

to check if the asymmetric response of variance to past shocks documented in *Table 2* has been properly captured by the GJR model.

***** Insert Table 3 around here*****

The coefficient of the mean equation a_1 indicates that there is significant first order autocorrelation in returns. It is interesting to notice that once the conditional heteroskedasticity has been properly taken into account, this coefficient becomes significant for all the markets. We observe that the Swiss stock market presents the largest asymmetric response to past shocks as is witnessed by the large and significant γ coefficient. It is followed by the Japanese, German and French market. The UK and US markets also present a significant asymmetric response but of much smaller magnitude. These results do not correspond exactly to those found when testing the asymmetry in squared standardised residuals from a GARCH(1,1) model. This may be due to the fact that in some cases the ENGLE-NG (1993) tests are conservative (lower nominal size and power). The β_1 coefficient indicates the magnitude of the persistence in variance. The Swiss market has the smaller persistence (0.645) compared to the other markets which are all much closer to one.

The values obtained for the various Q-statistics indicate that all the linear and quadratic dependence in residuals has been captured by this type of model. Most of the asymmetric reaction of variance has been properly captured for the Swiss, German and British markets as shown by the values of the ENGLE-NG test. Some asymmetry remains however in the US, French and Japanese markets. Taken together, these results indicate that the AR(1)-GJR model captures the major part of the features documented in section 2 and that a multivariate extension of this model seems appropriate for modelling the dynamic interactions between the Swiss stock market and the major world markets.

4.2. Results for bivariate models

Before estimating the system described in equation (9) we have to check whether the two stock index time series are cointegrated in order to be certain that a VAR model is appropriate. If the series appear to be cointegrated an error correction term should be included in the mean equations. We first test for stationarity of the logarithm of stock indices and of the returns using an augmented DICKEY-FULLER (1979, 1981) test with trend and four lags. *Table 4* indicates the logarithms of stocks indices can be considered as I(1) because the logarithms of indices are non-stationary but the returns (the first difference of the logs) are stationary. This raises the question of the eventual cointegration between different stock indices. In order to test for this possibility we use the ENGLE-GRANGER (1987) cointegration test (EGC in *Table 4*). With a standard DICKEY-FULLER test on the residuals of the regression of the logarithm of one stock index on another we cannot reject the null hypothesis of no cointegration for all the pairs of markets we consider. We also use an augmented test (Augmented EGC in *Table 4*) developed by PANTULA, GONZALES-FARIA and FULLER (1994) which determines the optimal number of lags for the augmented DICKEY-FULLER test. In this case we also cannot reject the null of no cointegration for all the pairs. We conclude from all the results in *Table 4* that there is no need to include an error correction term in the VAR system described by equations (11) and (12).

***** Insert Table 4 around here*****

We therefore estimate a series of bivariate models as described in equation (9) in order to measure the links existing between the Swiss stock market and the major world markets. In order to have a more precise picture of the role of each parameter in the system, we develop the mean and variance equations of the system described in (9):

$$r_{1t} = k_1 + l_{11}r_{1t-1} + l_{12}r_{2t-1} + \varepsilon_{1t} \quad (11)$$

$$r_{2t} = k_2 + l_{21}r_{1t-1} + l_{22}r_{2t-1} + \varepsilon_{2t} \quad (12)$$

$$\begin{aligned} \sigma_{1t}^2 = & c_{11}^2 + a_{11}^2 \varepsilon_{1t-1}^2 + 2a_{11}a_{21} \varepsilon_{1t-1} \varepsilon_{2t-1} + a_{21}^2 \varepsilon_{2t-1}^2 + b_{11} \sigma_{1t-1}^2 + \\ & n_{11}^2 \chi_{1t-1}^2 + 2n_{11}n_{21} \chi_{1t-1} \chi_{2t-1} + n_{21}^2 \chi_{2t-1}^2 \end{aligned} \quad (13)$$

$$\begin{aligned} \sigma_{12t} = & c_{11}c_{12} + a_{11}a_{22} \varepsilon_{1t-1}^2 + (a_{21}a_{12} + a_{11}a_{22}) \varepsilon_{1t-1} \varepsilon_{2t-1} + a_{21}a_{22} \varepsilon_{2t-1}^2 + b_{12} \sigma_{12t-1} + \\ & n_{11}n_{22} \chi_{1t-1}^2 + (n_{21}n_{12} + n_{11}n_{22}) \chi_{1t-1} \chi_{2t-1} + n_{21}n_{22} \chi_{2t-1}^2 \end{aligned} \quad (14)$$

$$\begin{aligned} \sigma_{2t}^2 = & c_{12}^2 + c_{22}^2 + a_{12}^2 \varepsilon_{1t-1}^2 + 2a_{12}a_{22} \varepsilon_{1t-1} \varepsilon_{2t-1} + a_{22}^2 \varepsilon_{2t-1}^2 + b_{22} \sigma_{2t-1}^2 + \\ & n_{12}^2 \chi_{1t-1}^2 + 2n_{12}n_{22} \chi_{1t-1} \chi_{2t-1} + n_{22}^2 \chi_{2t-1}^2 \end{aligned} \quad (15)$$

The convention in these estimations is that subscript 1 concerns the Swiss market and subscript 2 the foreign market. The terms l_{12} and l_{21} measure the interactions between past and present market returns. Regarding the volatility spillovers the coefficients a_{21} and n_{21} are relevant for measuring the effect of the foreign market volatility on the Swiss stock market volatility. The volatility spillover from the Swiss market to the foreign market are captured by the coefficients a_{12} and n_{12} . *Table 5* provides the results of the maximum likelihood estimation. The test of significance of the parameters are computed with the robust standard errors of BOLLERSLEV and WOOLDRIDGE (1992). The LJUNG-BOX Q-statistics are computed on standardised residuals and squared standardised residuals of every market to check if there is any linear and non-linear dependence in residuals.

The markets which has the strongest Granger causality on the Swiss market return is the US market with a highly significant coefficient of 0.378. This effect should be attenuated given the fact that this coefficient also captures a small fraction of contemporaneous comovements between the two markets as mentioned in section 2. The other markets are all

significantly linked to the Swiss market but with a much lower intensity. The l_{21} coefficient is relevant for measuring the Granger causality of the Swiss market on the foreign markets. It is of interest to notice that all the foreign markets are also significantly Granger caused by the returns of the Swiss market.

***** Insert Table 5 around here*****

The estimated a_{21} coefficients representing the effect of a past foreign shock on the Swiss volatility are all significant and are the most pronounced for the German, British and US market, indicating that a news in these markets generates significantly higher volatility on the Swiss market. On the other hand, the coefficient a_{12} indicates the effects of a news on the Swiss market to the foreign volatility the next day. It is of interest to notice that the Swiss market has a significant effect on all the markets but with a reduced magnitude. The n coefficients measure the links between volatility and negative surprises. n_{21} represents the effect of a bad news on a foreign market to the present volatility of the Swiss market. Again, the volatility of the Swiss market appears to be sensitive to all the markets considered in our study with the largest magnitude being by far that of the US coefficient. On the other hand, n_{12} measures the effect of a bad news from the Swiss market to foreign markets. Here we observe that a bad news on the Swiss market appears to have some effect only on the volatilities of the French and US market but with a small magnitude indicating that the effect of an innovation from the Swiss market on foreign volatility is fairly symmetric. The Q-statistics for the standardised residuals and squared standardised residuals indicate that there is no more linear or quadratic dependence in standardised residuals and that the bivariate GARCH models provide a reasonable representation of the return process.

We also performed the test of the null hypothesis that $a_{12} = a_{21} = n_{12} = n_{21} = 0$, or in other words that there is no link between news and the volatilities of the different markets. We

use a likelihood ratio test which is distributed as a $\chi^2(4)$. The results, provided in the last row of *Table 5*, indicate that the null hypothesis is rejected at high levels of significance which confirms the presence of links between volatilities and innovations of different markets.

In order to evaluate more precisely the impact of a past shock (ε_{it-1}) on a market to the present volatility of another market, we isolate this effect assuming that all other variables are constant. For shocks to the Swiss stock market, we compute:

$$\Delta\sigma_{1t}^2 = a_{21}^2 \cdot (\Delta\varepsilon_{2t-1})^2 \text{ if } \varepsilon_{2t-1} > 0, \Delta\sigma_{1t}^2 = (a_{21}^2 + n_{21}^2) (\Delta\varepsilon_{2t-1})^2 \text{ if } \varepsilon_{2t-1} < 0 \quad (16)$$

To determine the impact on a shock of the Swiss market to the foreign market we have to compute:

$$\Delta\sigma_{2t}^2 = a_{12}^2 \cdot (\Delta\varepsilon_{1t-1})^2 \text{ if } \varepsilon_{1t-1} > 0, \Delta\sigma_{2t}^2 = (a_{12}^2 + n_{12}^2) (\Delta\varepsilon_{1t-1})^2 \text{ if } \varepsilon_{1t-1} < 0 \quad (17)$$

These effects are now estimated with the coefficients obtained in *Table 5*. *Table 6* presents the effects of a 5% shock in a foreign market ($\varepsilon_{2t-1} = \pm 0.05$) on the Swiss volatility, in terms of standard deviations, and also the effects of a 5% shock from the Swiss market ($\varepsilon_{1t-1} = \pm 0.05$) to the foreign market .

***** Insert Table 6 around here*****

***** Insert Figure 2 around here*****

We observe from *Table 6* that the shocks from the foreign markets have usually a larger effect on the volatility of the Swiss market than the inverse except for the French stock market which experiences a larger volatility after a shock happening in the Swiss market. The Swiss volatility is mostly influenced by news originating from the German, British and US stock market. We also notice that the leverage effect is the strongest for the US where the impact on Swiss volatility almost doubles, which means that a bad news from the US market induces a lot of uncertainty in the Swiss market. The news on Japanese and French

markets also have some asymmetric effect on the Swiss market volatility. On the other hand news on the German and British stock markets have almost no asymmetric effect on the Swiss volatility. We also notice that the magnitude of the effects of a news from the Swiss stock market on foreign volatility is marginal.

Another way to present the effect of news from a market on the volatility of another market is possible in the framework of the so-called "news impact curve" proposed by ENGLE and NG (1993). These curves link the present volatility of a market with past shocks on another market. The international news impact curves are drawn in *Figure 2* and represent the impact of a lagged foreign shock on the Swiss stock market volatility (conditional variance).

5. Concluding remarks

This paper documents the links in terms of returns and volatilities existing between the Swiss stock market and the five largest stock markets in the world. Preliminary tests on the data indicate that all the six indices under consideration present conditional heteroskedasticity as well as asymmetric responses of conditional volatility to past shocks. As these features are present in the data we estimate a series of bivariate GARCH models which explicitly model the leverage effect in order to quantify the links existing between the various markets. Our conclusions from the analysis of the six stock markets reinforce the view that the returns on Swiss equities is influenced by events in foreign markets, but most significantly by the US market, which confirms results obtained in other studies. Regarding volatility, Germany and UK play also an important role. An original contribution of this paper is to document that the volatility transmission mechanism is asymmetric, i.e. bad news (negative innovations) in a given market increase volatility in the other markets more than good news (positive innovations). This is again particularly true for the US market where a

bad news one day makes the Swiss market very volatile the next day. Another findings of this paper is to show that the links between returns are statistically significant but relatively weak (except with the US market), indicating that such links cannot be exploited to implement profitable trading strategies. We also find that there is little evidence to suggest reverse Granger causality between the Swiss market and foreign markets or in other terms the influence of the Swiss market on foreign markets is weak.

In general these results confirm the fact the Swiss economy is broadly open and is therefore strongly influenced by events abroad and that, as it is a small economy, its impact on other markets is relatively negligible. The reported results also imply that the markets under consideration are to some extent integrated in the sense that non-local information have a significant impact on domestic markets.

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TABLES

Table 1: Descriptive statistics and diagnostic tests

	Switzerland	Germany	UK	France	USA	Japan
Mean	0.0646	0.0533	0.0435	0.0436	0.0539	-0.0147
Std deviation	0.9858	1.1330	0.8039	1.0983	0.7874	1.1394
Skewness	-1.012	-1.002	0.062	-0.186	-0.487	0.210
Kurtosis	15.425	17.244	5.050	6.145	8.981	10.757
Bera-Jarque	17366.9 **	22676.2 **	462.2 **	1099.1 **	4024.1 **	6612.1 **
<i>Correlation of returns</i>						
$\rho(r_t; r_{t-1})$	0.035	-0.020	0.077 **	0.034	0.013	0.124 **
Q(12)	14.93	13.01	28.34 **	19.78	28.27 **	74.33 **
$\rho(r_{CH,t-1}; r_{foreign,t})$		0.040 *	-0.004	-0.021	0.003	0.143 **
$\rho(r_{CH,t}; r_{foreign,t})$		0.670 **	0.533 **	0.622 *	0.268 **	0.264 **
$\rho(r_{CH,t+1}; r_{foreign,t})$		-0.027	0.077 **	0.050 **	0.337 **	-0.088 **
<i>Correlation of squared returns</i>						
$\rho(r_t^2; r_{t-1}^2)$	0.173 **	0.187 **	0.106 **	0.125 **	0.206 **	0.185 **
Q(12)	113.97 **	147.86 **	192.07 **	220.95 **	181.49 **	610.57 **
$\rho(r_{CH,t-1}^2; r_{foreign,t}^2)$		0.154 **	0.049 **	0.090 **	0.043 **	0.090 **
$\rho(r_{CH,t}^2; r_{foreign,t}^2)$		0.837 **	0.324 **	0.636 **	0.254 **	0.233 **
$\rho(r_{CH,t+1}^2; r_{foreign,t}^2)$		0.157 **	0.055 **	0.118 **	0.449 **	0.074 **
ARCH(1) LM test	75.50 **	89.90 **	27.84 **	41.37 **	106.52 **	89.44 **

Note: Mean returns and standard deviations are expressed in percentage. ** indicates that the null hypothesis can be rejected at the 1% level and * at the 5% level. Tests of the null hypothesis that correlations are equal to zero are performed with a BARTLETT test. Q(12) is the LJUNG-BOX statistics for 12 lags and ARCH(1) is the ENGLE ARCH LM test for one lag.

Table 2: Tests for asymmetry in standardised residuals of a GARCH(1,1) model

	Switzerland	Germany	UK	France	USA	Japan
<i>Sign bias</i> (ϕ_{i1})	0.51 **	0.36 *	0.01	0.26 *	0.28 **	0.41 **
<i>Negative size bias</i> (ϕ_{i2})	-0.24	-0.15	0.04	-0.39 **	-0.32 **	-0.20 **
<i>Positive size bias</i> (ϕ_{i3})	-0.34 *	-0.22	-0.02	0.06	-0.26 *	-0.19 **
<i>Joint test (LM)</i>	8.63 *	4.66	0.53	35.03 **	11.09 *	27.58 **

Note: ** indicates that the null hypothesis can be rejected at the 1% level, * at the 5% level. For the sign, negative and positive size bias tests, coefficients are displayed and significance is tested with standard t-test. The joint test is the ENGLE-NG (1993) LM test which is distributed as $\chi^2(3)$.

Table 3: Results for univariate GJR models

	Switzerland	Germany	UK	France	USA	Japan
a_0	0.060 **	0.040 *	0.037 *	0.032	0.046 **	0.002
a_1	0.099 **	0.044 *	0.072 **	0.056 **	0.034	0.118 **
α_0	0.185 **	0.108 *	0.011 **	0.088 **	0.005 **	0.019 **
α_1	0.005	0.048 *	0.024 **	0.016	0.014	0.029 *
γ	0.338 **	0.146 **	0.040 **	0.108 **	0.030 *	0.166 **
β_1	0.645 **	0.798 **	0.938 **	0.856 **	0.962 **	0.877 **
$Q(12)$	14.572	15.821	5.634	14.956	16.386	12.435
$Q^2(12)$	1.072	2.142	9.589	3.744	2.969	7.911
LM	4.185	2.842	1.806	8.005 *	7.989 *	11.234 *

Note: ** indicates that the null hypothesis can be rejected at the 1% level, * at the 5% level. $Q(12)$ is the LJUNG-BOX statistics of standardised residuals for 12 lags, $Q^2(12)$ is the LJUNG-BOX statistics of squared standardised residuals for 12 lags, LM is the ENGLE-NG joint test for asymmetry in variance on standardised residuals

Table 4: Unit root and cointegration tests

	Switzerland	Germany	UK	France	USA	Japan
<i>Augmented Dickey-Fuller unit root tests (H_0: unit root)</i>						
$\log(P_{it})$	-0.839	-0.337	-2.414	-0.938	1.191	-2.170
$\log(P_{it})-\log(P_{it-1})$	-22.941 **	-23.390 **	-22.779 **	-23.645 **	-24.099 **	-23.006 **
<i>Engle and Granger cointegration tests (H_0: no cointegration)</i>						
<i>EGC</i>		-2.04	-3.02	-2.53	-2.11	-0.19
<i>Augmented EGC</i>		-2.06	-3.11	-2.15	-3.07	-0.10

Note: ** indicates that the null hypothesis can be rejected at the 1% level, * at the 5% level.

Table 5: Results for bivariate GARCH models

	Germany	UK	France	USA	Japan
k_1	0.0548 **	0.0598 **	0.0553 **	0.0472 **	0.0609 **
k_2	0.0448 **	0.0441 **	0.0433 *	0.0455 **	-0.0066
l_{11}	0.1223 **	0.0670 **	0.0593 **	0.0082	0.1128 **
l_{12}	-0.0363	0.0668 **	0.0623 **	0.3777 **	-0.0528 **
l_{21}	0.1036 **	-0.0422 **	-0.0642 *	-0.0262	0.1041 **
l_{22}	-0.0038	0.0978 **	0.0955 **	0.0434 *	0.1003 **
c_{11}	0.3438 **	0.3127 **	0.3680 **	0.3656 **	0.4447 **
c_{12}	0.1151 **	0.0653 **	0.0973 **	0.0735 **	0.0182
c_{22}	0.3614 **	0.0893 **	0.3132 **	0.2285 **	0.1288 **
a_{11}	0.2695 **	0.1500 **	0.1482 **	0.0472 *	0.0956 **
a_{12}	-0.0311 **	-0.0386 **	-0.1134 **	0.0544 **	-0.0859 **
a_{21}	-0.3351 **	-0.2885 **	-0.0406	-0.2510 **	0.0587 *
a_{22}	-0.1531 **	-0.0269	0.1005 **	0.1386 **	0.1878 **
b_{11}	0.6540 **	0.7450 **	0.7092 **	0.6165 **	0.6130 **
b_{12}	0.6994 **	0.8709 **	0.7793 **	0.5310 **	0.6359 **
b_{22}	0.7615 **	0.9536 **	0.8341 **	0.8113 **	0.8659 **
n_{11}	0.4486 **	0.5135 **	0.4628 **	0.4189 **	0.5298 **
n_{12}	0.0374	0.0030	0.1116 **	0.0616 **	0.0038
n_{21}	0.0875 **	-0.0808 *	0.0593 **	0.3143 **	0.0907 **
n_{22}	0.4209 **	0.2103 **	0.2873 **	0.3312 **	0.4331 **
$Q1(12)$	12.18	14.23	15.16	18.46	13.96
$Q2(12)$	16.95	5.29	16.01	14.80	14.41
$Q1^2(12)$	1.77	1.70	1.29	3.10	0.91
$Q2^2(12)$	0.87	20.08 *	5.53	2.69	7.85
LR	25.77 **	27.03 **	12.45 *	164.28 **	12.93 *

Note: ** indicates that the null hypothesis can be rejected at the 1% level, * at the 5% level. $Q(12)$ is the LJUNG-BOX statistics of standardised residuals for 12 lags, $Q^2(12)$ is the LJUNG-BOX statistics of squared standardised residuals for 12 lags, LR is the likelihood ratio test of the hypothesis that there is no variance spillover.

Table 6: Increases in volatility due to a lagged shock

	Germany	UK	France	USA	Japan
<i>Shock from the foreign market to the Swiss market</i>					
+ 5 %	1.676%	1.443%	0.203%	1.255%	0.294%
- 5 %	1.732%	1.498%	0.359%	2.011%	0.540%
<i>Shock from the Swiss market to the foreign market</i>					
+ 5 %	0.156%	0.193%	0.567%	0.272%	0.430%
- 5 %	0.243%	0.194%	0.796%	0.411%	0.430%

Note: This *Table* gives the increase of the standard deviation (in %) due to a shock in a market

FIGURES

Figure 1: Daily returns of world stock indices 1988-1998 (in %)

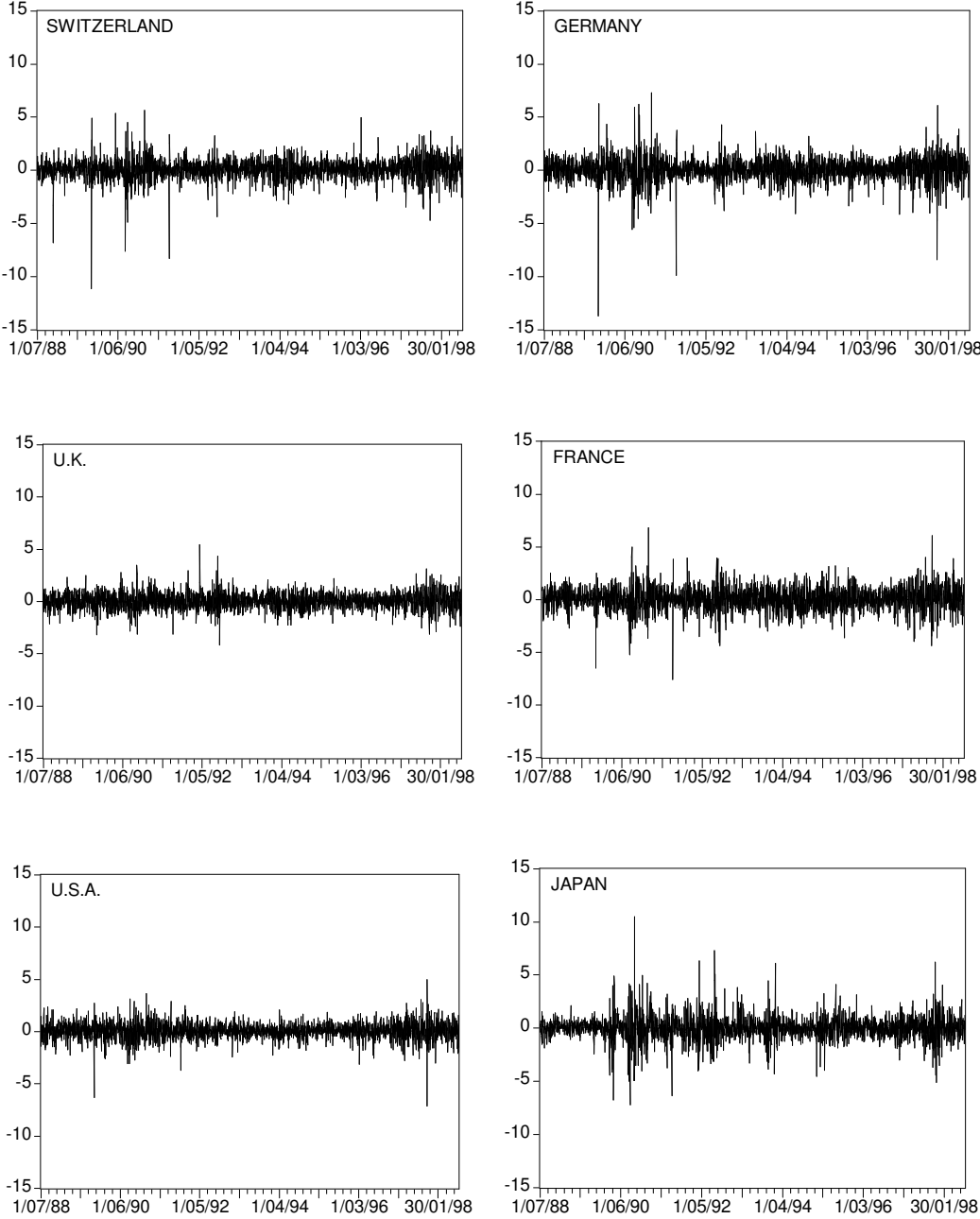


Figure 2: International news impact curves for the Swiss market (in %)

