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TRADING PATTERNS AT THE TOKYO STOCK EXCHANGE, 1931-1940

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Abstract

This paper relies on daily price indices for stocks and bonds to analyze the functioning of the Tokyo Stock Exchange (TSE) in the period 1931-1940. Although the TSE was a large and liquid market, its pricing mechanisms significantly deviated from weak-form efficiency. In this context, *zaibatsu* insiders were able to make abnormal returns via informed trading, while other uninformed investors could rely on technical rules to make abnormal profits. The TSE was a risky financial environment in which investors adjusted their portfolios significantly in the aftermath of major events. Potential herding behaviours, price manipulation and reciprocal positive causality (contagion) were observed across markets. These deficiencies may partially explain Japan's shift to bank-centered finance after WWII.

Keywords: emerging stock markets, technical trading, herding, event analysis.

JEL code: G14, N25,

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Highlights:

- We analyze the informational efficiency of Tokyo Stock Exchange (TSE) using daily indices
- Pricing mechanisms significantly deviated from weak-form efficiency
- Using technical trading yielded abnormal profits
- TSE was a risky casino-like financial environment characterized by herding
- These deficiencies may partially explain Japan's shift to bank-centered finance after WWII

Trading patterns at the Tokyo Stock Exchange, 1931-1940

1. Introduction

Although Japan was still a lower income industrializing country in the 1930s, by the international standards of the interwar, the Tokyo Stock Exchange (TSE) had become a large and active market. However, it remains unclear to what extent it was an efficient one. In this paper, we examine the microstructures of the Japanese financial market from 1931 to1940. This period corresponds to steady industrialization, rapid increase of military expenditures, an increasing role of the Japanese army in setting the political agenda, in particular the invasion of Manchuria in 1931, and the decision to launch a full scale war against China in 1937. The motivation for our investigation of the functioning of capital markets in pre-WWII Japan is to contribute to the debate on the respective roles of banks and capital markets in pre-WWII Japan, and on the cause for the shift to a bank-based financial structure after 1945 (Hamao et al. 2005, Ishii 2007, Okazaki 2007, Teranishi 2007). In addition, the information generated could contribute to a better understanding of current financial and political dynamics in the developing world.

We use daily price indices for the three available market segments: 'industrials', 'utilities', and 'bonds'. This high frequency dataset was compiled from Japanese yearbooks from the *Toyo Keizai* ('The Oriental Economist') published in the 1930s and early 1940s. Our results suggest that while the Tokyo Stock Exchange was relatively large and liquid compared to other markets at that time, its pricing mechanisms significantly deviated from weak-form efficiency, in a context of persistent volatility, sudden increases in uncertainty surrounding major economic events, and significant cross-market spillovers. This overall context of low efficiency made it possible for *zaibatsu* insiders to make consistently abnormal returns via informed trading, while other investors could gain from adopting technical trading rules. The apparent lack of informational efficiency may be one factor explaining Japan's shift to bank-based finance post WWII. Our results also suggest that appropriate institutional development is a prerequisite for stock markets to efficiently contribute to the allocation of savings in emerging economies.

Over recent years, an increasing body of empirical research has focused on the historical exploration of past capital market dynamics in an event analysis approach; for instance, Frey and Kucher (2000) studied domestic and foreign Austrian, Belgian, French, German, and Swiss bonds in Zurich Stock Exchange. In a more focused study, Oosterlinck (2003) analyzed the impact of military developments and political events on French bond market dynamics between 1942 and 1944, using a daily database. His results suggested that the investors' perception of Vichy France was primarily affected by De Gaulle's struggle to gain legitimacy within the Allied forces, rather than by military developments.[1] More recently, some attempts have been made to analyze the informational dynamics of capital markets prior to the 1950s. Waldenström (2010) looked at the Danish and Swedish bond markets between 1938 and 1948 and discovered that WWII-related default costs explained a significant part of sovereign yield spread across markets. Using data covering the period 1902-1925, Moore (2010) highlighted that firm liquidity levels rather than risk exposure were an important determinant of cross-section returns in the Madrid and Zurich Stock Exchanges.

However, all of these authors focused on Western 'developed' markets of the time. To the best of our knowledge, the analysis of informational dynamics and cross-market linkages in TSE we present in this paper is the first retrospective empirical investigation of a non-Western capital

[1] Other studies have investigated the influence of events on bonds, for instance Brown and Burdekin (2000) on US bonds during the civil war, Brown and Burdekin (2002) on German bonds traded in London during WWII, Walderström and Frey (2008) on Nordic (Denmark, Finland, Norway, and Sweden) bonds during the same period.

market in the pre-WWII period.[2] It should be noted that 1930s Japan had shared certain characteristics with present-day emerging nations: its economy was characterized by low living standards, uneven wealth distribution, fast capital accumulation, international trade integration, high political risk, and low transparency.

The remainder of this paper is organized as follows. Section 2 briefly presents the Tokyo Stock Exchange and the major dynamics affecting the Japanese economy in the 1930s. Section 3 presents the dataset and employs a battery of econometric tests to analyze informational efficiency levels. Section 4 analyzes market uncertainty with a focus on sudden endogenous volatility shifts in return series. Section 5 investigates short-run spillovers among the three segments of the Tokyo Stock Exchange. Finally, section 6 brings together our conclusions.

2. *The TSE in interwar Japan: an emerging market in a newly industrialized country*

By the international standard of the interwar, the TSE was a large and active market. The market value of stocks listed in all Japanese stock exchanges (of which TSE was by far the largest) was large relative to the GDP, around 1 or above in the 1930s, and the value traded was twice the GDP. These two indicators were actually higher in Japan than in the US, and a similar pattern can be observed regarding market turnover (ratio of value traded relative to the market value of stocks listed). Such market depth and liquidity is astonishing considering the large income gap that existed between the two countries (Hamao et al. 2005).

[2] Ho and Li (2010) looked at breaks in the series of monthly prices for 11 Chinese bonds during the interwar period but they did not analyze informational efficiency. If could be noted however that their results suggest that military events related to the successive episodes of the Sino-Japanese conflict had a stronger long term effect than events related to the civil war, although short term effects were similar. In a related field, Grossman and Imai (2009) performed an event analysis for turning points in the value of the yen in the 1920s.

TSE was, however, an emerging market in the interwar.[3] Japan already had a long history of sophisticated financial techniques[4], but the development of market capitalization was initially limited by the reluctance of the most prominent family businesses, the *zaibatsu* firms, to adopt the Western style joint-stock company organization and to have a significant part of the shares traded publicly.[5] Non-*zaibatsu* firms gradually entered the market in the late 19th century by issuing equities in different fields of activities, in particular banks, railroads, and spinning companies. However, borrowing remained the dominant source of capital for the non-finance sector until WWII. The rise in market capitalization became possible around the turn of the century with the introduction of institutional innovations. The establishment of securities companies[6] created conditions which facilitated the issuance of equities and short-term investment. The rise in market capitalization was also spurred by the adoption of the new commercial code of 1899 stipulating that equities should be marketable (Miyamoto 1984, 56), and by the opening the financial market to foreign investors.[7]

The expansion of Japan's manufacturing activities and international trade accelerated during WWI as a result of the drastic decline of European export to Asia that which was a consequence of

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[3] TSE was initially established, in 1878, at the initiative of Shibuzawa Eichi, a prominent non-*zaibatsu* entrepreneur of the Meiji era, as a joint stock company dealing mainly with public bonds issued for compensating the samurai for the loss of their stipends as a result of early Meiji institutional changes (Masaki 1973, 10).

[4] Formally organized rice futures markets existed in Osaka from the mid 18th century (Hamori et al. 2001).

[5] Zaibatsu firms dominated certain sectors, in particular mining, shipbuilding, shipping, and international trading, and were also extremely active in banking and insurance companies, collecting a sizable share of private savings, and making capital available to companies of the same group (Mitsubishi, Mitsui, Sumitomo, Yasuda…). On zaibastu finance, see for instance Asajima (1984) and Sugiyama (1985),

[6] The first one, in 1897, was *Koike Shoten* (*Koike Securities*), the forerunner of Yamaichi securities (Noda 1978, 93).

[7] In 1906, Hokkaido Mining and Kansai Railways issued the first private bonds denominated in British pounds; these bonds were partly subscribed in by British investors such as the *Chartered Bank of Japan, Australia, and China* (Noda 1978, 100).

the conflict and the rising cost of freight for transoceanic shipping. These new conditions created opportunities for new ventures financed through the issuance of equities, resulting in a rapid expansion of market capitalization (Figure 1). The uneven income distribution contributed to high levels of saving and capital accumulation, in a trend culminating during WWII (Moriguchi and Saez 2008). The development of equity markets continued after WWI. In 1921, for the first time, a *Zaibatsu* firm (Mitsubishi Mining) offered common stocks to the general public of subscribers; the number of shareholders rose dramatically from 28 to 7955. *Mitsubishi Gomei* (partnership company) still controlled 60% of paid up capital, but the figure was down from 97.5% in 1920 (Masaki 1978, 43).[8] Other *zaibatsu* groups gradually followed this example during the 1920s and early 1930s.

This new approach of *zaibatsu* firms to equity markets set a momentum leading to a steady rise in market capitalization and the emergence of the TSE, a sizable and active capital market for equities. The reliance on debt in the private non-financial sector (ratio of borrowing to equities and investments) declined sharply during the interwar period from an average of 1.58 in the period 1916-20 to 1.18, 1.09, 0.93, and 0.85 in 1921-1925, 1926-1930, 1931-1935, and 1936-1940 respectively. For leading companies, the ratio was actually much lower, ranging from 0.21 to 0.33 (Fujino and Teranishi 2000, appendix).

Figure 1 around here

In the meantime, public investment had also expanded, largely funded through the issuance of public bonds (Figures 2 and 3). After the suspension of the gold convertibility of the yen, in

[8] The rise in equity capitalization was further amplified by the development a new generation of Zaibatsu (*shinko zaibatsu*) that lacked capital, as exemplified in1928 by the public sales of stocks of Nissan's holding company (Clark 1979, 78).

1931, a deliberate policy of budgetary expansion resulted in the massive issuance of public bonds (Cha 2003), mostly underwritten by the Bank of Japan, but gradually sold on a secondary market (Tomita 2005). This trend was amplified by the militarization of the economy[9] that resulted in a sustained demand for manufactured goods (aircrafts, explosives, machinery, motor vehicles, shipbuilding). However, it was not until late 1930s that total market capitalization of public bonds became larger than stock market capitalization.

In the context of the militarization of the economy and political instability[10] of the 1930s, the concentration of financial power in the hands of a few individuals, the main shareholders of the *zaibatsu* business groups (plus a number of non-family managers of these firms), resulted in low transparency for the TSE.[11] As Teranishi (2007, 50) points out "while stock markets played a role in corporate governance, … resource allocation functions were only exhibited within a narrow group of wealthy individuals." But, in the meantime, the activity of the major banks controlled by industrial business groups (described as "organ bank" or "main bank" by economic historians) consisted largely in "connected lending" (ibid 61). Kinship-based social networks were therefore determinant in financial resource allocation. The interlocking of shareholders and managers between banks and non-banking companies, which resulted in poor bank performances, has been regarded as a major cause of the financial crisis of 1927 (Okazaki et al. 2005).[12] The development

[9] The rapid rise of military expenditures, both in absolute terms and as a percentage of total public expenditures, was largely the consequence of a decision made within the military circle, without government approval, to invade Manchuria in 1931 and to launch a full-scale war against China in 1937.

[10] In particular, the assassination of political figures and top bureaucrats by young activist army and marine officers, and an attempted military *coup d'état* in February 1936.

[11] During the 1930s, *zaibatsu* groups increased their centralized control of the economy through connections with military oligarchy. Cartels were legally encouraged under the Major Industries Control Law and the Industrial Association Law of 1931.

[12] The Showa financial crisis resulted in the bankruptcy of thirty-seven banks, and the collapse of the Suzuki *zaibatsu*.

of equity markets in the 1930s can therefore be regarded as a response on behalf of non-financial firms to the inability of the banking sector to serve efficiently the needs of industrial firms engaged in massive programs of investment. However, little is known about TSE trading patterns. The rest of this paper therefore explores the market's microstructures by means of a battery of empirical tests.

Figures 2 and 3 around here

3. *Informational efficiency in the Tokyo Stock Exchange*

We rely on a high frequency database for the TSE using daily price composite indices for three segments of the market: 'industrials', 'utilities', and 'bonds' for the period ranging from 1/1/1931 to 31/12/1940. The dataset was taken from yearbooks in Japanese from the *Toyo Keizai* ('Oriental Economist') published in the 1930s and early 1940s. The composite indices provided in this source are reported as calculated using information on 25 to 30 industrial companies, 25 utilities companies, and 4 to 5 types of central government bonds (4 types in 1931-1934, 5 thereafter (the name of the companies and the detail of the bonds is not reported). The market was open from Monday to Saturday (except bank holidays), with a few unexplained closures for industrial shares. After the careful removal of inconsistent data points, we calculated returns on day t as $r_t = ln\left(\frac{p_t}{p_{t-1}}\right)$ where p_t is the closing value of the selected index.

Okazaki and Sawada (2006) argue that "policy-promoted consolidation was likely to be accompanied by large organizational costs".

Table 1 around here

Table 1 displays summary statistics for the obtained returns. The industrial market segment posted the highest absolute mean returns over the study period. However, the bond market tended to outperform the two others in terms of risk-adjusted returns as shown by the Sharpe ratio. The level of volatility, 0.009 and 0.004 and 0.002 for the industrial and utilities indices, respectively, is similar to those observed in small contemporary emerging markets, for instance Morocco (0.008) and Tunisia (0.005) in 2004-2009 (Abdmoulah. 2010). Positive skewness in the industrials and utilities markets suggests that investors tended to overvalue good news and undervalue bad news. Not surprisingly, we observe lower volatility levels in the bond market (0.002), which is also the only one displaying negative skewness. This suggests different behavioral patterns of stock and bond market investors, with higher relative risk-aversion levels for bond investors.

All return series tend to strongly depart from normality, also a commonly observed feature in emerging markets. We also find significant levels of excess kurtosis in all markets, which implies that a high level of the observed variance is due to extreme deviations from the mean as opposed to frequent smaller deviations. Evidence of non-normality echoes current debates on the accuracy of applying standardized asset pricing and risk analysis techniques, e.g.. CAPM and the Black-Scholes Option Pricing Model (Ellis and Sundmacher 2011).

We analyze weak-form informational efficiency levels more formally through a set of non-parametric variance ratio tests for the random walk hypothesis[13]. In particular, Wright's (2000) test based on ranks was shown to have high power against a wide range of models displaying serial

[13] Our analysis focuses on the weak form of efficiency hypothesis, which states that price changes are random and have no links to past prices. Rejecting the weak form of informational efficiency suggests a rejection of the semi-strong form (under which price changes reflect all public information) and the strong form (under which price changes reflect both public and private information) of market efficiency.

correlation and is robust in the case of non-normal time series. We report test statistics for different holding periods[14].

To further document efficiency levels, we complement this analysis with a simulation exercise in which a Japanese investor ignores economic fundamentals and follows a purely technical approach to trading. We assume that the Japanese investor follows a variable moving average (VMA) rule, in which an investor takes a long position if the short-term VMA is above the long-term VMA, and exits the market otherwise. This rule is described in equation 1.

$$I_t = \begin{cases} 1 \quad if \quad \frac{1}{S}\sum_{s=1}^{S} P_{t-s} \geq \frac{1}{L}\sum_{l=1}^{L} P_{t-l} \\ 0 \quad otherwise \end{cases} \tag{1}$$

In (1), S and L stand for short and long-term, respectively. Following Brock et al. (1992), we select 1_50, 1_150, 5_150, 1_200 and 2_200 as VMA rules, where 1, 2 and 5 represent the number of days in the short-term moving average and 50, 150 and 200 the number of days in the long-term moving average. When a 'buy' signal is generated, the investor buys the share and holds it until a sell signal is generated, at which time he exits the market. We assume that the borrowing and lending rates are the same and that the risks during buying and selling periods are the same. The return for this strategy is given by $\mu_{t+1} = I_t\left(\frac{P_{t+1}}{P_t} - 1\right) - I_{t-1}\left(I_t - 1\right)\left(\frac{P_{t+1}}{P_t} - 1\right)$. Such rules are often used in empirical testing of market efficiency as they can sometimes pick up some of the hidden patterns that are not detected by linear models (Chang et al, 2004; Lagoarde-Segot and Lucey, 2008). Following Brock et al (1992), the t-statistic is:

[14] As a robustness check we also ran the Kalman filter test of evolving efficiency from Zalewska-Mitura and Hall (1999). Results are available upon request.

$$BS = \frac{\mu_b - \mu_s}{\sqrt{\sigma_b^2 / n_b + \sigma_s^2 / n_s}} \tag{2}$$

With $\mu_{b,s} = \frac{1}{n_{b,s}} \sum_{t=0}^{n+1} R_{t+1} I_t$, and $\sigma_{b,s}^2 = \frac{1}{n_{b,s}} \sum_{t=0}^{n+1} \left(R_{t+1} - \mu_{b,s}\right)^2 I_t$.

A rule is deemed to be effective if returns following a buy signal are significantly higher than returns for the sell signal and those obtained via a buy and hold strategy.

Results for the static efficiency tests are shown in table 2 and indicate a clear departure from informational efficiency. This can be explained by the specific institutional context. Disclosure requirements were lax as evidenced by the absence of listing criteria other than the number of years since establishment, total face value, total paid-up value, and number of stocks (Hamao et al. 2005). Since neither reporting nor auditing was required, we can assume segmentation in access to information existed between *zaibatsu* and non-*zaibatsu* investors. In addition, table 3 reports results from the technical trading rules. Results show that ex-post returns are significantly higher for buy signals than for the sell signals, and consistently beat the buy-and-hold strategy. These results suggest that it would have been rational for uninformed, non-*zaibatsu* investors (such as wealthy rural landlords) to adopt trading strategies disconnected from economic fundamentals, given the context of low informational disclosure and centralized corporate governance. Such strategies may explain the high level of volatility documented earlier.

Tables 2 and 3 around here

4. Uncertainty and volatility shifts

In a second strand of analysis, we study the presence of sudden shifts in volatility and relate them to major economic, corporate and political events using the ICSS algorithm of Inclan and Tiao (1994) and Bacmann and Dubois (2001). Over recent years, this technique has become common practice for exploring volatility dynamics in emerging markets. Inclan and Tiao's (1994) Iterative Cumulative Sum of Squares (ICSS) algorithm assumes that a time series of interest has a stationary unconditional variance over an initial time period until a sudden break takes place.[15] However, it has been shown that the ICSS algorithm is biased towards finding too many breakpoints caused by serially correlated volatility (Bacmann and Dubois 2001). Following standard practice (e.g. Fernandez, 2007) we first filter the data by fitting an AR(1) model with a GARCH(1,1) specification for the conditional variance of innovations. We then apply the ICSS algorithm to the standardized residuals obtained from the estimation. As an additional robustness check, we incorporated the detected volatility breaks in a model for market returns[16]:

$$\begin{aligned} r_t &= \alpha + \beta r_{t-1} + \delta h_t + e_t \\ h_t &= \delta + d_1 D_1 + \ldots + d_n D_n + \alpha_1 h_{t-1} + \alpha_2 e_{t-1}^2 \end{aligned} \qquad (1)$$

Equation (1) describes the stock return mean r_t that depends on an autoregressive process as well as a risk premium parameter δ capturing the tradeoff between volatility and returns. Returns volatility is measured by conditional variance *ht*, which has three components: a constant, an autoregressive term (the GARCH term), and the last period's squared residual (the ARCH term).

[15] See appendix 2 for a detailed presentation

[16] As shown in appendix 2, we first specified a simple AR (1) model for each series and implement ARCH-LM test for serial correlation in the residuals. In each market, we found serial dependence in the mean and in the residuals. This suggests that a GARCH(1,1) model coupled with an autoregressive process is an appropriate modeling strategy for Japanese stock returns. The GARCH-in-mean specification is chosen in order to take into account the theoretical relationship between risk and returns. The latter is captured by the parameter δ.

The sum $\alpha_1 + \alpha_2$ captures the degree of volatility persistence. $D_1 \dots D_n$ are the dummy variables: 1 for each point of sudden change of variance onwards and 0 for otherwise.

We estimated GARCH-M (1.1) models for the three markets (Appendix 2, Table A2). Following Wang and Moore (2008), we report three model specifications: one model without any volatility shift, one model including all the identified shocks, and a model including only the significant shocks. Inspection of this table shows that β is significant at the 1% level for the three markets when dummies are not included. This confirms previous results pointing to a lack of informational efficiency. In addition, the risk premium parameter δ is consistently insignificant in all markets except the utilities market, where shocks on the previous period's variance significantly impact daily returns. This suggests that Japanese investors included a risk premium parameter in their utilities portfolio choices, perhaps to compensate for lower informational efficiency levels.

Turning to the variance equation, we find that GARCH-M (1,1) effects (ARCH and GARCH) are significant for all markets. Measures of volatility persistence given by $\alpha_1 + \alpha_2$ are very close to 1 for the standard GARCH-M (1,1) without regime shifts, indicating extreme persistence in volatility. As expected, volatility persistence is lower when we incorporate the regime shifts detected by the ICSS algorithms. However, we find that these shocks account for about 25% of volatility persistence in the Tokyo Stock Exchange; a small figure when compared with results obtained for contemporaneous emerging markets. For instance, using a similar methodology, Wang and Moore (2009) found that volatility persistence was reduced up to 67.3% (for Slovakia) in a panel of five Central European emerging markets.

In addition, GARCH effects remain significant when dummy variables are introduced for the three markets. This is to be contrasted with the seminal study by Aggarwal et al. (1999), which detected that these effects were eliminated in eight countries out of a sample of sixteen emerging markets for the 1985-1995 period. Ljung-Box statistics performed on standardized residuals (Also in Appendix 2, Table A2) reveals that there is still significant autocorrelation in the residual series.

This result is common for thinly traded emerging markets: applying a similar GARCH-M(1,1) filter, Abdmoulah (2010) found significant autocorrelation in the least liquid emerging markets of the Middle East and North Africa (MENA) region (Tunisia and Jordan). Taken together, these results suggest significant volatility persistence in the 1930s Tokyo Stock Exchange. This may be explained by lower liquidity, higher transaction costs, lower efficiency, and greater segmentation, in an overall context of high uncertainty. By 21st century standards, the 1930s Tokyo Stock Exchange could thus be considered a 'frontier market'.

We then consider the robust endogenous volatility shifts hence identified and associate them to significant economic, financial, and political events (Table 4)[17]. In order to reduce arbitrariness in the selection of events, we relied on annual chronologies reported in the *Toyo Keizai* yearbook and retained events occurring either the same day or during the previous two or three working days, excluding therefore Sundays and bank holidays.[18] We selected as a presumably related event the most plausible candidate at the closest date of the break. This means that we omitted information on date of implementation of decision already announced previously, or events with a scope limited to a particular sector in the case of bond series.[19]

Table 4 around here

The main information obtained from this exercise is that the volatility shifts were essentially influenced by political decisions with strong economic implications. Neither the invasion of Manchuria (September 19, 1931) nor the outbreak of the Sino-Japanese war (July 7, 1937) are

[17] Results from the ICSS algorithm analysis and GARCH model appear in appendix 2.

[18] For a few cases (e.g. break of 07/10/33 on bonds series), we went further back in time to identify a plausible date.

[19] E.g., decision by cotton textile producers to establish a fund for the development of textile production in Manchuria.

identified as having an impact on equities or bonds traded in the TSE. The same remark applies to the attempted *coup d'état* of February 26, 1936 which is not associated with a break. These results echo the findings presented in papers looking at events affecting bonds series in WWII Europe but with an even stronger relation to economic policy.[20]

5. *Cross-market spillover*

This section investigates short run linkages between the three segments of TSE (industrial, utilities, and bonds). We adopt a VAR modeling approach to model shock transmissions in the Japanese financial markets via the inspection of generalized impulse response functions and variance decomposition analysis.[21] Stationarity analysis rules out the possibility that the series may be cointegrated given that logged prices are found to be stationary with a drift. In the absence of ex-ante information on the causal structure of shock transmission in the three financial markets, we set the variables of interest at the top of the X_t vector to derive General Impulse Response Functions (GIRF). However, the forecast error variance decompositions of a GIRF do not sum up to unity. Therefore we adopted the practice of Hasbrouck (1995) for variance decompositions by sequentially ordering each market first in the system to obtain the maximum share of its innovation and then order it last in the system to obtain its minimum share. The average of the maximum and minimum shares becomes the final single decomposition share of the innovation.

Examination of the Granger causality results (Table 5) suggests the existence of significant linkages across markets. We find bidirectional causality between the bond and industrial markets as

[20] Purely political events had little influence on the series. The sole exception is the formation of the *Hiranuma* cabinet in January 1939. For a general presentation of the political context and main events of the 1930s, see for instance Sims (2001).

[21] For robustness, we also used a DCC GARCH model. Methodology and results are presented in Appendix 4.

well as between the industrial and utilities markets. We also find unidirectional causality running from the bond to the utilities markets. This indicates that although equity capitalization was larger than that of bond market, the latter was dominant.

Table 5 and Figure 4 around here

Inspection of Generalized Impulse Response Functions shows that contemporaneous shocks occurring in the utilities and industrials markets have a significant impact on the bond market (Figure 4). Shocks to the bond and utilities markets have a significant impact on the industrial market, while shocks to the bond and industrials markets have a significant impact on the utilities markets. All shocks are positive, suggesting herding behavior and a lack of portfolio diversification opportunities. However, these volatility spillovers die out two to four trading days after the initial shock.

Turning to the Variance Decomposition Analysis, we find that the industrial and utilities market are less endogenous than the bond market (Table 6). Shocks to their own past values explain up to 89% of forecast error variance as opposed to 96% in the bond market. Utilities market dynamics explain up to 15% of the industrial market, while the industrial market explains up to 13% of the utilities market, suggesting higher integration in the two stock market indices. By contrast, our results reveal a sharp segmentation between stock and bond markets. The industrial and utilities indices only explain up to 2.28% and 2.26% of the bond market's variance, respectively.

The lack of transparency appears as the most likely explanation for both herding behavior and market segmentation. Two types of investors were operating in the TSE. On the one hand, controlling families of *zaibatsu* firms that had access to insider information, a critical asset in an institutional context characterized by the insufficient reporting by listed companies and absence of external auditing. These investors had access to information on the performances of industrial and utilities companies, but they also had strong incentives to maintain family shareholding at a stable level, at least for the core companies of the *zaibatsu* group.

On the other hand, the mass of minor investors, in particular rural landlords and other wealthy mid-size players that had no access to insider information on equities. Unfortunately, their behavior is not documented by strong evidence. Our conjecture is that these investors had little choice but to adopt a casino-like approach, selecting assets on the basis of the most dependable information available to them, bonds related events, taking bets on spillover effects from bonds to equities.

6. Conclusion

The objective of this paper was to shed light on the functioning pre-WWII Japanese capital markets by conducting an empirical investigation of market microstructure. We first analyzed informational dynamics using variance ratio tests and technical trading analysis and significantly rejected the weak-form efficiency hypothesis. We then used the ICSS algorithm of Inclan and Tiao (1994) and Bacmann and Dubois (2001) and then detected a number of regime shifts in volatility surrounding major economic, corporate, and political events. Results from a GARCH-M (1,1) model confirmed the presence of relatively low informational efficiency levels and significant volatility persistence, especially surrounding major economic events. Overall, these results suggest the presence of permanent behavioral biases in the Tokyo Stock Exchange. Finally, we modeled cross-market linkages via the inspection of generalized impulse response functions and variance decomposition analysis derived from a SVAR model. These results indicated significant short-run spillovers across markets, suggesting that sudden rises in uncertainty created 'financial contagion' across the various segments of TSE. Overall, this analysis suggests that the TSE was similar to an emerging market, in the sense that a lack of informational efficiency caused investors to significantly adjust their portfolios in the aftermath of major events, with potential herding, price manipulation and reciprocal positive causality (contagion) across markets.

Turning back to the debate on the cause of the shift to bank-centered finance after 1945, two complementary interpretations could be considered in the light of our findings. Since both banks and capital markets were apparently quite inefficient in interwar Japan, the shift could be due to a change in relative (in)efficiency. A first possible explanation of the dominant role of banks in postwar Japan is that the policy of "dissolution of the *zaibatsu*" implemented by the US occupation authorities in 1945 resulted in effect in a loss of power (and wealth) for the controlling families that played a key role in the both banks and capital markets in the interwar. The interlocking of management and shareholding of large firms did not disappear but the kinship-based social networks that determined the flow of "connected lending" in the interwar became irrelevant. However, the same remark applies to the flow of insider information on equity markets. A second explanation for the postwar shift to bank centered finance, which is complementary rather than contradictory, could be that, under strict supervision by the Ministry of Finance and the Bank of Japan in the post-WWII period, banks became able to provide financial services in a more efficient way.

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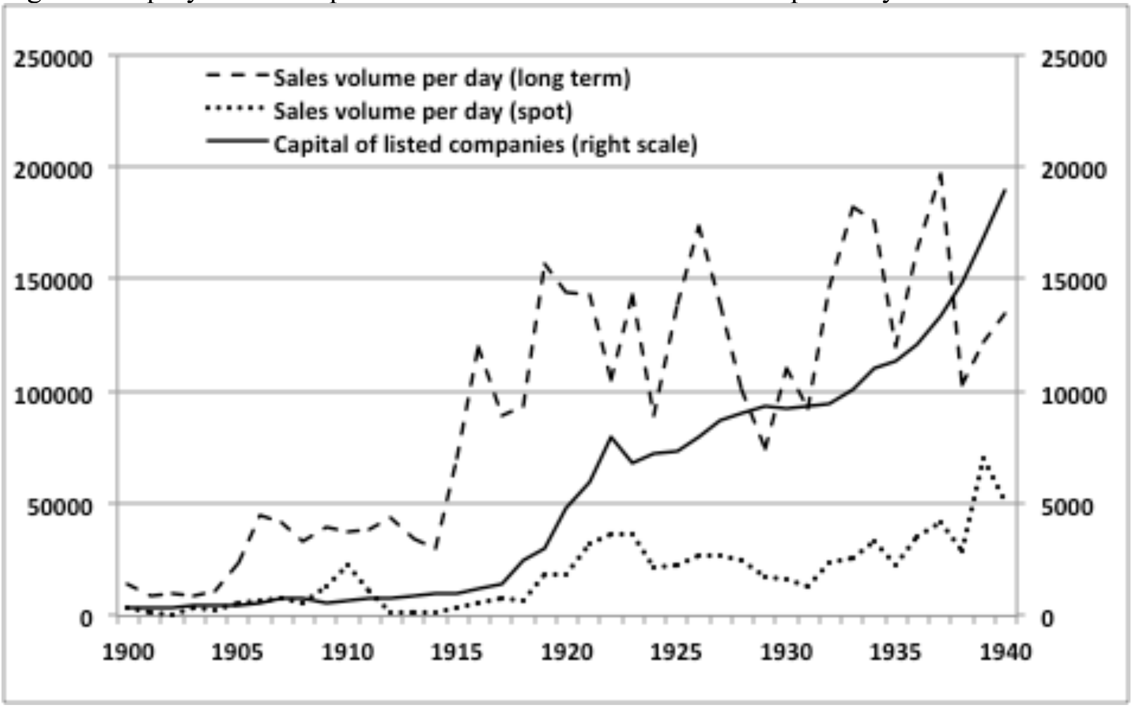
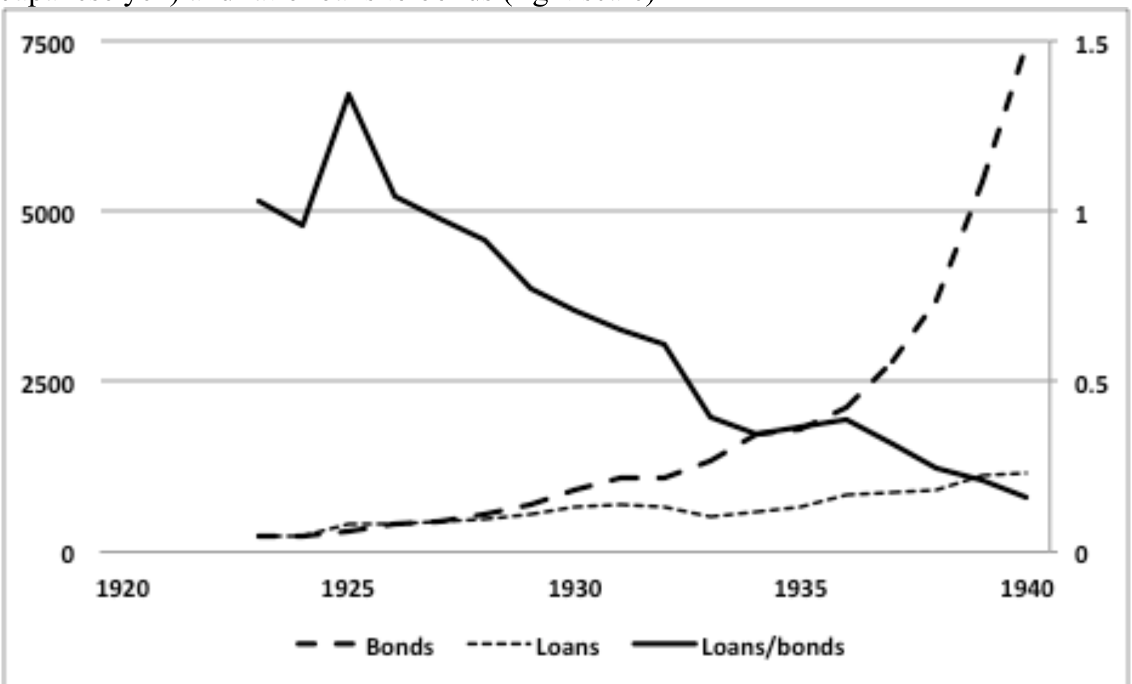
FIGURES

Figure 1. Equity market capitalization and turnover in current Japanese yen



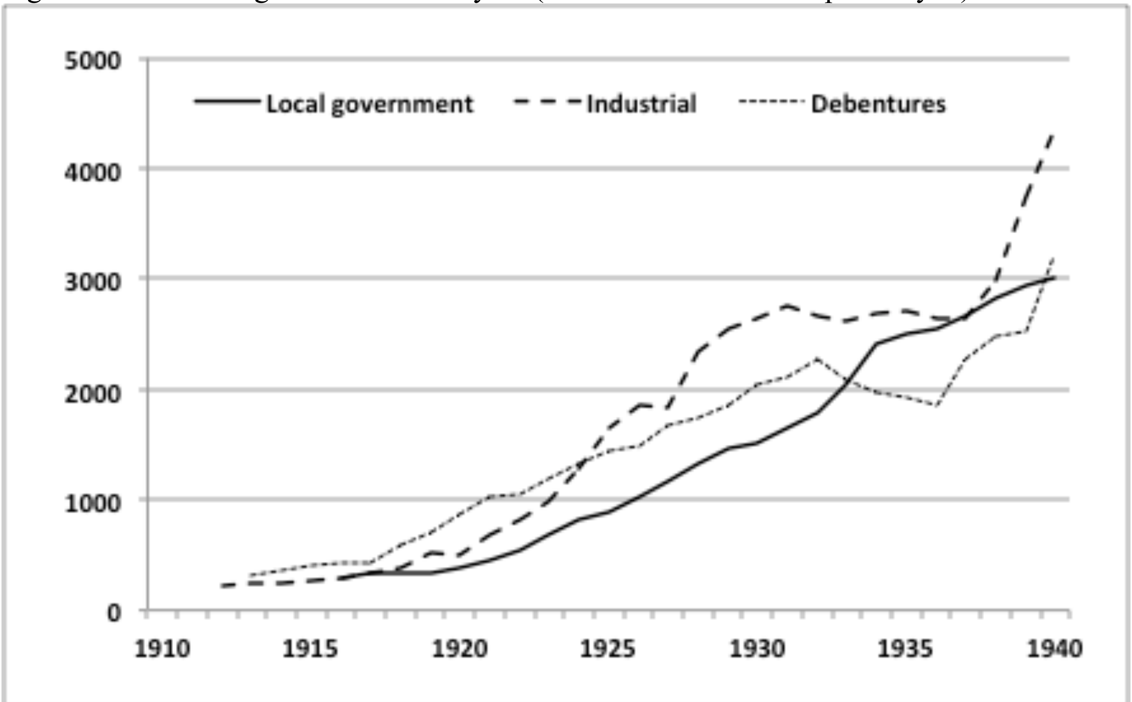
Source: Tokyo Stock Exchange (reported in *Historical Statistics of Japan*, file 11-25A)

Figure 2. Bonds and loans in the assets of Ministry of Finance's trust fund (in million of current Japanese yen) and ratio loans to bonds (right scale)



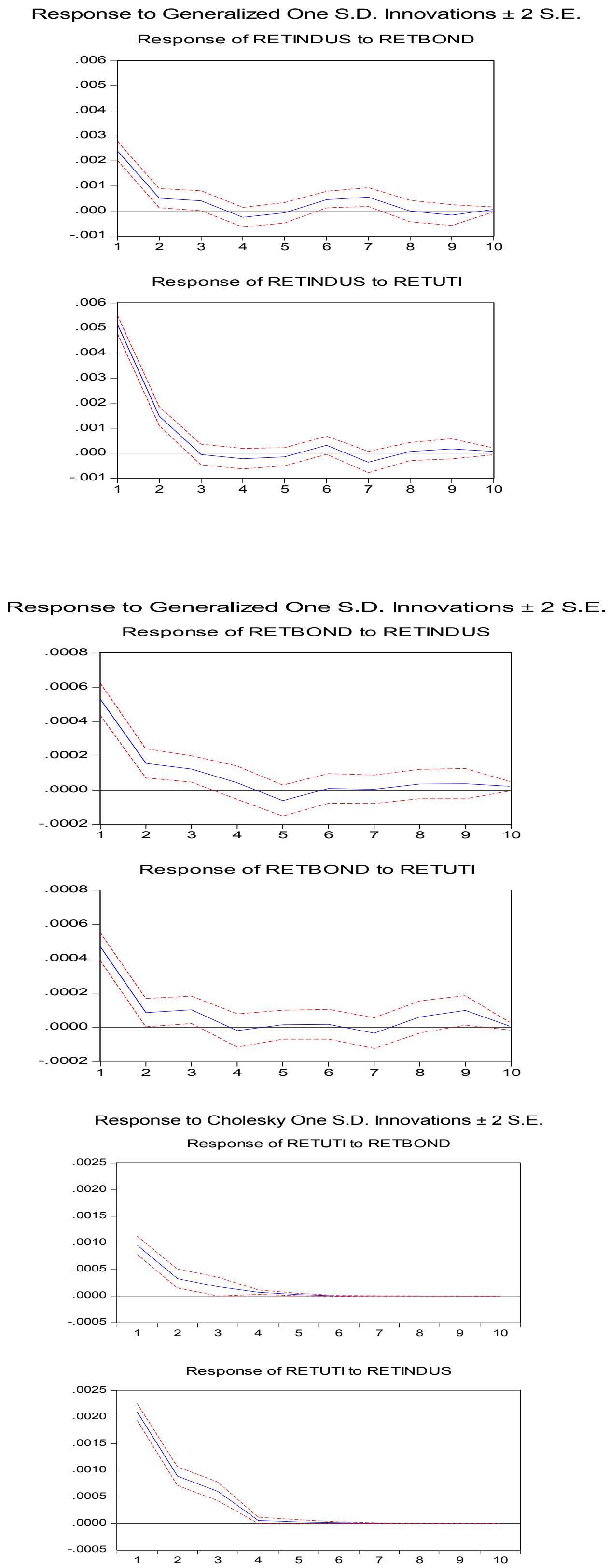
Source: Ministry of Finance (reported in *Historical Statistics of Japan*, file 11-26).

Figure 3. Outstanding bonds at end of year (in million of current Japanese yen)



Source: Data of Bond Underwriters Association (reported in *Historical Statistics of Japan,* file 11-13).

Figure 4: Generalized Impulse Response Functions



TABLES

Table 1. Descriptive statistics of TSE daily series

	Industrials	Utilities	Bonds
Mean	0.000312	7.63E-05	7.28E-05
Median	0	0	0
Maximum	0.115069	0.063716	0.017382
Minimum	-0.059547	-0.034729	-0.019689
Std. Dev.	0.00925	0.004299	0.001936
Skewness	1.516052	0.905465	-0.459048
Kurtosis	28.71567	34.91172	22.72522
Jarque-Bera	60064.65	101354.9	38651.55
Probability	0	0	0
Sharpe ratio	0.03372973	0.01774831	0.0376033
Sum	0.670076	0.181557	0.17324
Sum Sq. Dev.	0.183888	0.043994	0.008914
Observations	2150	2381	2379

Table 2. Non-parametric variance ratio analysis

	Industrials		Utilities		Bonds	
Block length	R1	R2	R1	R2	R1	R2
k=2	6.686**	6.220**	10.651**	10.849**	4.683**	3.705**
k=5	4.341**	4.186**	15.061**	14.895**	4.924**	4.334**
k=10	3.910**	3.534**	15.979**	15.435**	4.084**	3.794**
Bootstrapped critical values	k=2		k=5		k=10	
	R1	R2	R1	R2	R1	R2
0.5%	-2.615	-2.509	-2.734	-2.615	-2.358	-2.471
5%	-1.580	-1.656	-1.610	-1.640	-1.702	-1.691
95%	1.662	1.742	1.634	1.642	1.544	1.884
99.5%	2.856	2.731	2.747	2.792	2.608	2.648

Table 3 Variable moving average (VMA) technical trading analysis

Panel A Industrials	N(buy)	N(sell)	Buy	Sell	Buy-Sell	Buy-Buy and hold
VMA(1,50)	501	501	0.0018	-0.0007	0.0025	0.0015
					2.9192**	2.7260**
VMA(1,150)	477	477	0.0019	-0.0006	0.0026	0.0017
					2.9737**	2.9462**
VMA(5,150)	204	203	0.0019	0.0012	0.0007	0.0016
					0.3181	1.2206
VMA(1,200)	461	461	0.0020	-0.0007	0.0027	0.0017
					3.0101**	3.0260**
VMA(2,200)	328	327	0.0017	0.0003	0.0014	0.0014
					1.1289	1.7258
Panel B Utilities	N(buy)	N(sell)	Buy	Sell	Buy-Sell	Buy-Buy and hold
VMA(1,50)	463	464	0.0012	-0.0009	0.0022	0.0012
					4.7658**	3.5632**
VMA(1,150)	437	438	0.0014	-0.0010	0.0024	0.0014
					5.0972**	4.0289**
VMA(5,150)	166	167	0.0039	-0.0026	0.0065	0.0038
					4.4658**	3.7189**
VMA(1,200)	428	429	0.0016	-0.0008	0.0024	0.0016
					5.1459**	4.5476**
VMA(1,200)	283	283	0.0034	-0.0022	0.0056	0.0033
					7.1135**	5.7149**
Panel C Bonds	N(buy)	N(sell)	Buy	Sell	Buy-Sell	Buy-Buy and hold
VMA(1,50)	457	456	0.00039	-0.00006	0.0004	0.0003
					2.1752*	2.2659*
VMA(1,150)	441	440	0.00039	-0.00004	0.0004	0.0003
					2.1551*	2.2507*
VMA(5,150)	184	183	0.00108	-0.00024	0.0013	0.0010
					2.5772*	2.6589**
VMA(1,200)	421	420	0.00055	-0.00003	0.0006	0.0005
					2.9689**	3.4835**
VMA(2,200)	291	290	0.00082	-0.00008	0.0009	0.0007
					3.0996**	3.5946**

Note: For each market, we report the results for the various VMA rules. The first two columns gives the number of buy and sell signal generated. The third and fourth column gives the average returns associated to buy and sell signal. The fifth and sixth columns give the average difference in buy-sell and buy-buy and hold returns as and the associated test statistic. (*) and (**) indicate significance at the 5% and 1% level, respectively.

Table 4. Identification of events (GARCH model; see appendix 2 for details)

Date of the break	Day of the week	Date of the event	Nature of the main event identified in the *Toyo Keizai* yearbook
			Industrial
25/03/32	Friday	24/03/32	Monetary policy: approval of exchange rate control
24/03/38	Wednesday	18/03/38 a	Industrial policy: adoption of 5-year plan for Manchuria steel industry
19/05/38	Thursday	18/05/38	Trade policy: announcement of an adjustment of trade tariff for important commodities
21/09/38	Thursday	19/09/38	Economic planning: adoption of an allocation system for fertilizers
11/10/38	Tuesday	07/10/38	Economic planning/trade policy: change in the cotton textile export system
07/12/38	Wednesday	06/12/38	Economic planning: issuance of bonds by electric power companies approved
07/01/39	Saturday	05/01/39 b	Politics: formation of the *Hiranuma* cabinet
			Utilities
30/01/31	Friday	28/01/31	Public finance: authorization for the use of the reserve fund for earthquake reconstruction
03/03/32	Monday	02/03/32	Public finance: issuance of the 3rd 4.75% public bonds (10 million yen)
11/06/32	Saturday	11/06/32	Finance: Taiwan Bank and Chosen Bank announce a reduction of their interest rates
08/07/32	Friday	06/07/32	Public finance: issuance of bonds by the Manchuria Railways Co. (50 million yen)
09/12/39	Saturday	07/12/39	Public finance: final 1940 budget including support package to industrial companies
			Bonds
07/10/33	Saturday	03/10/33	Politics: inter-ministerial conference on defense, diplomacy, and public finance
13/08/35	Tuesday	12/08/35	Politics: assassination of *Tetsuzan Nagata*, chief of Mobilization Section, Ministry of War
21/02/36	Friday	17/02/36	Manchuria: Proposal to USSR to establish a joint commission to settle border dispute.
28/03/36	Saturday	28/03/36 c	Politics: announcement of the names of the persons involved in the "February 26 incident"
02/04/36	Thursday	02/04/36	Finance: Bank of Japan suspends sale of 4% interest public bonds (d).
25/04/36	Saturday	24/04/36	Politics: first meeting of the inter-ministerial commission on international relations (e).
02/06/36	Thursday	01/06/36	Public finance: issuance of 3.5% public bonds (413 million yen; maturity on June 1949.
12/08/36	Tuesday	12/08/36	Finance: approval of the fund of the Chamber of Commerce.
06/11/36	Wednesday	02/11/36	Public finance: issuance of y public bonds by Manchuria approved (10 million yen)
14/11/36	Thursday	11/11/36	Military: "*Takase* incident" in Shanghai (f)
17/12/36	Saturday	17/12/36	Politics: decision to abandon accusation against *Bonosuke Hisahara* (February 26 incident)
08/01/37	Thursday	07/01/37	Monetary policy: introduction of capital controls by the Ministry of Finance.
06/08/37	Friday	05/08/37	Monetary policy: introduction of capital controls by the Kwangtung Army (in Manchuria).
16/10/37	Friday	15/10/37	Finance: decision to reduce to less than 10% the dividends served by insurance companies.
24/03/38	Wednesday	18/03/38 a	Industrial policy: adoption of 5-year plan for Manchuria steel industry
16/07/38	Saturday	15/07/38	Public finance: use of part of the reserve funds for import of raw materials.
21/10/38	Friday	20/10/38	Trade policy: reinforcement of export control for textile products.
14/12/38	Wednesday	13/12/38	Issuance of public bonds (400 million yen).
23/12/38	Friday	23/12/38	Finance: announcement of a new banking law.

Notes: (a) Bank holiday on 22 and 23/03/1938; (b) Bank holiday on 5/01/39; (c) "February 26 incident": attempted coup d'état from February 26 to 28; (d) according to information reported in *Toyo Keizai* yearbook, decision made to prevent transactions on the futures market; (e) three ministries involved: War, Navy, and Foreign Affairs. (f) Assassination in Shanghai of *Yasuji Takase*, crew of a Japanese merchant vessel.

Table 5. Granger causality analysis

Dependent variable: RETINDUS			
Excluded	Chi-sq	Df	Prob.
RETBOND	19.306	8	0.013(*)
RETUTI	54.332	8	0.000(**)
All	77.636	16	0.000(**)
Dependent variable: RETBOND			
Excluded	Chi-sq	Df	Prob.
RETINDUS	23.048	8	0.003(**)
RETUTI	13.029	8	0.110
All	52.106	16	0.000(**)
Dependent variable: RETUTI			
Excluded	Chi-sq	Df	Prob.
RETINDUS	126.611	8	0.000(**)
RETBOND	16.022	8	0.042(*)
All	150.122	16	0.000(**)

Table 6. Variance decomposition analysis

Variance Decomposition of RETBOND:				
Period	S.E.	RETBOND	RETUTI	RETINDUS
1	0.002298	96.472	1.961	1.566
2	0.002317	95.854	2.087	2.057
3	0.002322	95.524	2.227	2.248
4	0.002324	95.461	2.257	2.281
5	0.002325	95.458	2.259	2.282
6	0.002325	95.458	2.259	2.282
7	0.002325	95.456	2.260	2.282
8	0.002325	95.456	2.260	2.282
9	0.002325	95.456	2.2601	2.282
10	0.002325	95.456	2.2601	2.282
Variance Decomposition of RETUTI:				
Period	S.E.	RETBOND	RETUTI	RETINDUS
1	0.004585	1.737	89.122	9.139
2	0.004681	1.923	86.019	12.056
3	0.004723	1.949	85.170	12.880
4	0.004739	2.125	84.968	12.906
5	0.00474	2.125	84.947	12.926
6	0.00474	2.125	84.942	12.931
7	0.00474	2.126	84.941	12.931
8	0.00474	2.126	84.941	12.931
9	0.00474	2.126	84.941	12.931
10	0.00474	2.126	84.941	12.931
Variance Decomposition of RETINDUS:				
Period	S.E.	RETBOND	RETUTI	RETINDUS
1	0.010381	2.574	14.002	83.423
2	0.010487	2.651	15.399	81.949
3	0.010497	2.823	15.373	81.803
4	0.010502	2.851	15.405	81.743
5	0.010503	2.852	15.410	81.736
6	0.010503	2.853	15.410	81.735
7	0.010503	2.853	15.411	81.735
8	0.010503	2.853	15.411	81.735
9	0.010503	2.853	15.411	81.735
10	0.010503	2.853	15.411	81.735

Note: This table shows results from a Variance Decomposition Analysis following the method of Habsbrouck (1995).

APPENDICES

Appendix 1: Wright test

Given T observations of first differences of a variable. $\{y_1 \ldots y_T\}$ Wright's R1 and R2 test statistics are defined as:

$$R_1(k) = \left(\frac{\frac{1}{Tk} \sum_{t=k}^{T} \left(r_{1t} + \ldots + r_{1t-K+1} \right)^2}{\frac{1}{T} \sum_{t=1}^{T} r_{1t}^2} - 1 \right) \times \phi(k)^{-\frac{1}{2}} \tag{1}$$

$$R_2(k) = \left(\frac{\frac{1}{Tk} \sum_{t=k}^{T} \left(r_{2t} + \ldots + r_{2t-K+1} \right)^2}{\frac{1}{T} \sum_{t=1}^{T} r_{2t}^2} - 1 \right) \times \phi(k)^{-\frac{1}{2}}$$

$$r_{1t} = \left(r(y(t) - \frac{T+1}{2} \right) \Big/ \sqrt{\frac{(T-1)(T+1)}{12}} \tag{2}$$

$$r_{2t} = \Phi^{-1}\left(r(y_t) \big/ (T+1) \right)$$

In (1) $\phi(k) = \frac{2(2k-1)(k-1)}{3kT}$. r_{yt} is the rank of y_t among observations $y_1 \ldots y_T$. and Φ^{-1} is the inverse of the standard normal cumulative distribution function. Under the martingale difference sequence, r_{yt} are particular permutations of numbers $1, 2, \ldots, T$, each having equal probability of realisation. The exact distribution of $R_1(k)$ and $R_2(k)$ is approximated using a bootstrap method. The process is to calculate $R_1(k)$ for 1000 permutations of $r(x_t)$ and to observe the empirical distribution of the obtained series in order to compute p-values for a two-tailed test.

Appendix 2. The ICSS algorithm and GARCH-in-mean estimations

The test can be defined as follows. Let $\{X\}_{t=1}^{T}$ be a random variable with $E(X_t) = 0$ and $Var(X_t) = \sigma_t^2$. For each point in time k. define $C_k = \sum_{t=1}^{k} X_t^2$and $D_k = \frac{C_k}{C_T} - \frac{k}{T}$. This statistic is F-distributed with T-k and k degrees of freedom. Under the null hypothesis of no volatility break $H_0: var(X_t) = \sigma^2$. The expression $\sqrt{\frac{T}{2}} D_k$converges towards a standard Brownian motion. If this value is greater than a predetermined significance level[22], the point k is considered a volatility breakpoint.

Inclan and Tiao's (1994) suggest adopting a recursive procedure to identify multiple breaks in times series. In the first step. the point in time k^*that maximizes $D_k$is identified and the presence of a volatility break is tested according to the above procedure. If a breakpoint is detected, the sample is then divided in two sections (pre-k^* and a post-k^*). For each sub-sample, steps 1 and 2 are repeated sequentially until the analysis fails to reject H_0. In the third step, additional breakpoints are identified by repeating the sequential analysis over the sample section ranging from the first identified volatility breakpoints to the last identified volatility breakpoint. In the last step, all breakpoints $j = 1. \dots . N_T$ are ranked in ascending order. For each suggested breakpoint j a series of D-statistics are calculated over the period $X[j-1]: X[j+1]$. If $MaxD_k[X(j-1: j+1)]$ is significant, j is considered a structural volatility break; if not, it is dropped out of the vector of identified breakpoints. This last step is repeated sequentially until the number and the localization of volatility breakpoints is stabilized.

[22] The critical value of 1.36 is the 95th percentile of the asymptotic distribution of $\sqrt{\frac{T}{2}} D_k$.

Table A2. Identifying ARCH effects

	Coefficients	P-value	ARCH LM
Bonds			
Bonds(-1)	-.0404419*	0.049	350.961***
Constant	.0000759	0.056	0
Utilities			
Utilities(-1)	.1567876**	0.000	144.587***
Constant	.0000637	0.465	0
Industrials			
Industrials(-1)	.044183*	0.041	203.225***
Constant	.0003021	0.130	0

Table A3. ADF test for stationarity

	Industrial	Utilities	Bonds
Panel 1: Log(price)			
C/T	-1.511	-1.380	-1.714
C/D	-2.229(*)	-1.813(*)	-2.096(*)
Panel 2: Dif(logprice)			
C/T	-36.651(**)	-36.683(**)	-39.756(**)
C/D	-36.600(**)	-36.660(**)	-39.729 (**)

Note: This table presents results for the KPSS test with a constant and a trend (C/T) and with a constant and a drift (C/T) using data on prices and logarithmic returns. 5% and 1% critical values are-3.960 and -3.410 for the test including a constant and a trend; and -2.328 and -1.645 for the test including a constant and a drift (**) and (*) indicate that the null hypothesis of a unit root is rejected at the 1% and 5% levels, respectively.

Table A4. GARCH-in-mean estimations

	Constant	r_{t-1}	h_{t-1}		Constant		h_{t-1}	e^2_{t-1}	$\alpha_1+\alpha_2$	Q(16)	Skewness	Kurtosis
PANEL A:												
without dummies												
INDUSTRIALS	r_t	0	0.058**	0.07	h_t	0.00***	0.785***	0.216***	1.001	4.4812	0.273	19.99
		0.74	0.02	0.14		0	0	0				
UTILITIES	r_t	0.00*	0.159***	0.139**	h_t	0.00***	0.657***	0.245***	0.902	50.562	-1.402	20.28
		0.07	0	0.01		0	0	0				
BONDS	r_t	0	0.072***	0.03	h_t	0.00***	0.292***	0.676***	0.968	50.433	-0.625	30.74
		0.3	0	0.52		0	0	0				
PANEL B:												
with all dummies												
INDUSTRIALS		-0.004	0.022	0.366	h_t	0.00***	0.554***	0.147***	0.701	17.841	0.728	19.190
		0.193	0.629	0.112		0	0	0				
UTILITIES	r_t	-0.002***	0.154***	0.346***	h_t	0.000***	0.581***	0.149***	0.73	54.07	0.052	25.104
		0.01	0	0.006		0	0	0				
BONDS	r_t	0	-0.042	-0.076	h_t	0.000***	0.598***	0.150***	0.748	52.287	-0.012	16.06
		0.26	0.311	0.387		0	0	0				
PANEL C:												
with significant dummies												
INDUSTRIALS	r_t	-0.004***	0.024	0.376***	h_t	0.000***	0.557***	0.151***	0.708	16.266	0.741	19.389
		0.001	0.592	0		0	0	0				
UTILITIES	r_t	-0.002***	0.164***	0.351***	h_t	0.000***	0.590***	0.169***	0.76	55.72	-0.539	21.224
		0.003	0	0.004		0	0	0				
BONDS	r_t	0	-0.042	-0.076	h_t	0.000***	0.598***	0.150***	0.748	52.563	-0.101	16.568
		0.617	0.305	0.687		0	0	0				

Note: ** Significant above 5% level. Q(16) is the Ljung-Box Q-statistic for the 16th order

Table A5. *Volatility breakpoints detected by the ICSS algorithm and GARCH model*

Daily Index	ICSS breaks (Filtered data)	Significant dummies (GARCH model)
Industrial	25/03/32 30/03/32 28/06/32 05/07/32 27/07/34 17/03/38 24/03/38 19/05/38 15/09/38 21/09/38 11/10/38 26/10/38 05/11/38 07/12/38 07/01/39 06/09/39 08/11/39	25/03/32 24/03/38 19/05/38 21/09/38 11/10/38 07/12/38 07/01/39
Utilities	30/01/31 27/01/32 30/01/32 23/02/32 03/03/32 08/04/32 15/04/32 11/06/32 08/07/32 29/08/33 10/04/34 16/10/34 02/11/34 10/03/38 12/04/38 14/04/38 05/11/38 31/01/39 12/04/39 09/12/39	30/01/31 03/03/32 11/06/32 08/07/32 09/12/39
Bonds	07/10/33 13/08/35 21/02/36 28/03/36 02/04/36 25/04/36 02/06/36 12/08/36 06/11/36 14/11/36 17/12/36 08/01/37 30/07/37 06/08/37 16/10/37 29/12/37 24/03/38 26/03/38 16/07/38 21/10/38 14/12/38 23/12/38 20/09/39	07/10/33 13/08/35 21/02/36 28/03/36 02/04/36 25/04/36 02/06/36 12/08/36 06/11/36 14/11/36 17/12/36 08/01/37 06/08/37 16/10/37 24/03/38 16/07/38 21/10/38 14/12/38 23/12/38

Figure A1: Daily returns (industrials)

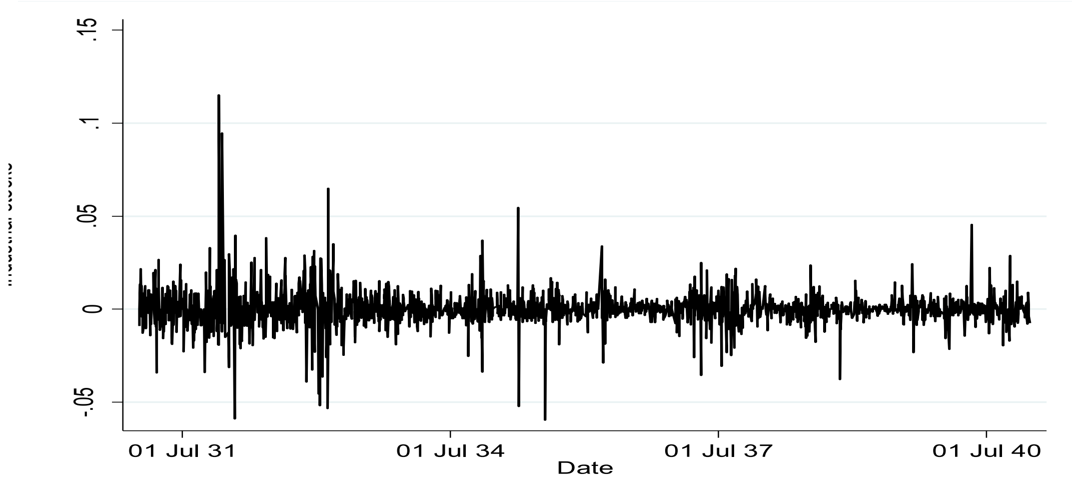


Figure A2: Daily returns (utilities)

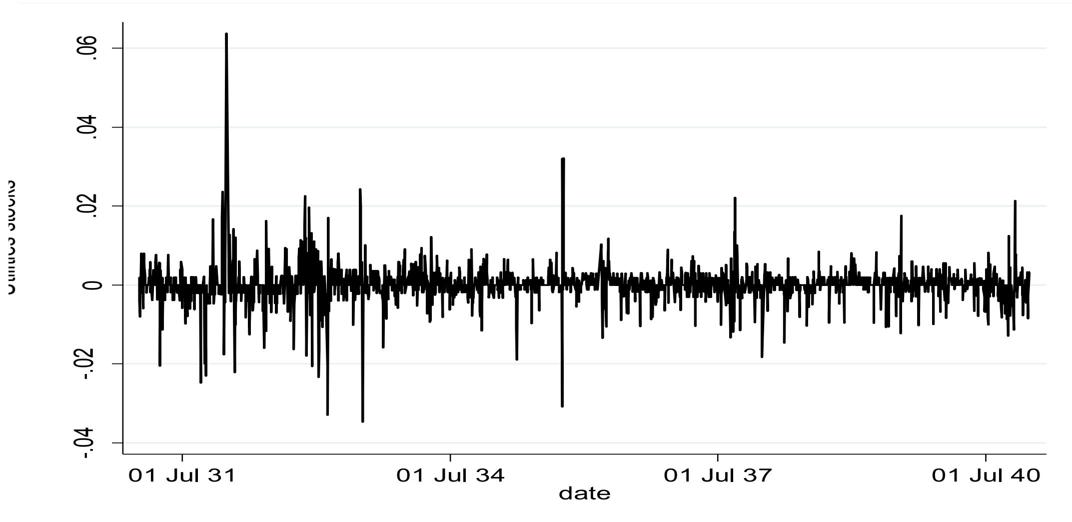
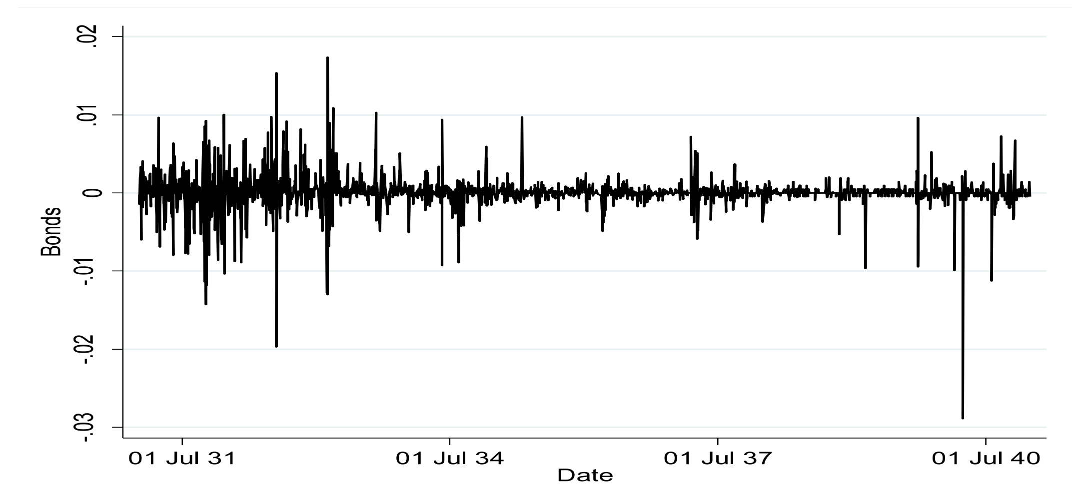


Figure A3: Daily returns (bonds)



Appendix 3. The SVAR model

Our approach may be summarized as follows. Consider the moving average form of the reduced structural VAR model:

$$X_t = A^*(L)X_t + u_t \quad ; \quad u_t = \Gamma^{-1}\varepsilon_t \tag{2}$$

Where X_t is a vector of returns. L is the lag operator and A*(L) is a transformed matrix of coefficients such as $A^*(L) = \Gamma^{-1}A(L)$, where Γ is the matrix of contemporaneous parameters and A(L) the initial matrix of VAR parameters. Following standard practice, we orthogonalize structural innovations by setting a diagonal structure on the residuals' variance-covariance matrix. The remaining *n(n-1)/2* identifying constraints are then set following a Cholesky decomposition:

$$\begin{pmatrix} 1 & 0 & 0 \\ \delta_{21} & 1 & 0 \\ \delta_{31} & \delta_{32} & 0 \end{pmatrix} \begin{pmatrix} u_1 \\ u_2 \\ u_3 \end{pmatrix} = \begin{pmatrix} e_1 \\ e_2 \\ e_3 \end{pmatrix} \tag{3}$$

Appendix 4. The DCC GARCH model

We model the pattern of cross-market conditional dynamics based on the DCC GARCH introduced by Engle and Sheppard (2002). This approach can be summarized as follows. Consider the following vector stochastic process:

$$
\begin{aligned}
X_t &= \mu + \varepsilon_t \\
\varepsilon_t &\sim N(0, H_t)
\end{aligned}
\qquad \text{(A1)}
$$

Where *Xt=[X_{1t}. $X_{2t.}$ X_{3t}]* is a vector of financial returns and ε_t the residuals from the filtered time series with zero mean and variance covariance matrix $H_t = \{h_{it}\}$. Letting $D_t = diag\{\sqrt{h_{it}}\}$ and $R_t = \begin{pmatrix} 1 & \rho_{ij,t} & \rho_{ij,t} \\ \rho_{ij,t} & 1 & \rho_{ij,t} \\ \rho_{ij,t} & \rho_{ijt} & 1 \end{pmatrix}$ be the time-varying conditional correlation matrix for ε_t. we have $H_t = D_t R_t D_t$ with each element of *Ht* being equal to $h_{i.t}$ if *i=.j* and $h_{i,t}^{1/2} h_{j,t}^{1/2} \rho_{ij,t}$ otherwise. The elements of D_t are defined as univariate GARCH(1.1) processes such as:

$$
h_{it} = \omega_i + \alpha_i r_{it-1}^2 + \beta_i h_{it-1} \qquad \text{(A2)}
$$

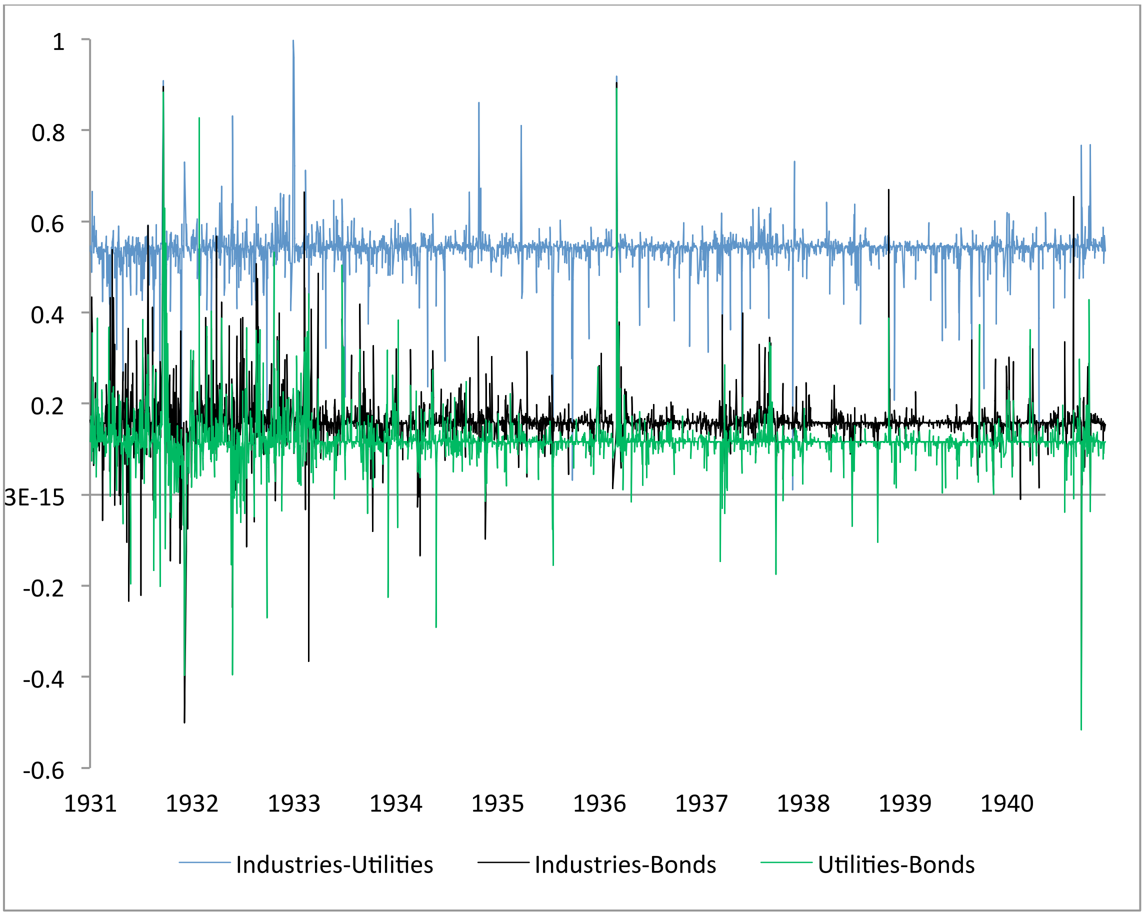
In turn. the dynamic covariance structure also follows a GARCH pattern so that:

$$
\begin{cases}
R_t = (Q_t \otimes I_N)^{-1/2} Q_t (Q_t \otimes I_N)^{-1/2} \\
Q_t = (1 - \alpha - \beta) Q + \alpha z_{t-1} z'_{t-1} + \beta Q_{t-1} \qquad (\alpha + \beta < 1\,;\, \alpha, \beta > 0)
\end{cases}
\qquad \text{(A3)}
$$

Where $\otimes$ denotes the elementwise product of two matrices. Q is a sample covariance matrix of $\varepsilon_{t.}$ and $z_t \sim N(0, R_t)$ are standardized residuals from the univariate GARCH model. Note that the correlation process is driven by two parameters α and β which represent the impact of shocks and lagged conditional correlation on contemporaneous correlations. respectively. Estimation is conducted by decomposing the log likelihood function into a volatility component and a correlation component. Univariate GARCH(1.1) volatility parameters are thus first estimated for each the analyzed series. yielding series of standardized residuals. The latter are used to derive a time-varying correlation matrix via maximum likelihood. Details on the estimation procedure can be found Engle and Sheppard (2002).

Inspection of figure suggests no trend towards integration for the three markets under scrutiny over the study period. However, it appears that the two stock markets display a significantly higher correlation with each other (around 0.6) than with the bond market (around 0.2). It should also be noted that correlations sometimes increase abruptly for particular days. This echoes results from the ICSS analysis and suggests the existence of short run spillovers between markets. However, the bond market appears segmented from the utilities and industrials stock market.

Figure A4. Cross-market conditional correlation coefficient. 1931-1940



Note: this figure plots bivariate time-varying correlation coefficients as estimated from a DCC GARCH model.