The Effect of World War One on Stock Market Integration

JOB MARKET PAPER

Lyndon Moore*

Abstract

The pre-1914 globalized world of free capital flows and integrated markets disintegrated during World War One. Monthly data on over 7300 individual securities from 12 stock exchanges over a period of 26 years quantifies the extent to which stock market disintegration occurred as a result of the war and the restrictive government legislation introduced. I use the international arbitrage pricing theory (IAPT) to measure integration. While Allied and Neutral countries' stock exchanges reintegrated in the early 1920s after wartime capital controls were relaxed, the exchanges of Berlin and Vienna segmented from world capital markets after the war.

Introduction

Economists agree that the years leading up to World War One were characterized by increasing degrees of economic integration. Commodity and factors prices converged, international migration increased, and international trade expanded.[1] Financial markets integrated as interest rates converged, covered interest rate parity held more closely, savings and investment correlations fell, and government bond spreads fell.[2] Cross-listed stocks exhibited smaller price differentials, and national stock markets moved together more closely.[3]

The prevailing view is that market integration was greatly reduced after the war. Much of the discussion of the post-1914 drop in integration is of a qualitative nature and can not precisely time the drop in international integration: "By 1919, the old international economy was nothing but a distant memory" (Silverman (1982)); "the process (of globalization) unraveled in the face of two world wars and the Great Depression" (Bordo (2002)); and "from 1914 to 1945, this global economy was destroyed. Two world wars and a Great Depression accompanied a rise in nationalism and increasingly non-cooperative policymaking" (Obstfeld and Taylor

*Many people have contributed to this project over a period of four years. My advisors have helped me to implement the model and explain the concepts. My family, the Economic History Association, and Northwestern University have provided invaluable financial assistance. Economists, historians, and friends around the world have suggested data sources and assisted me to obtain the data used in this paper. Fellow graduate students have assisted with programming advice, and last but not least, my thanks go to the many Northwestern undergraduates who have carefully entered the data into spreadsheets. A complete list of thanks appears in Appendix A.

[1] Findlay and O'Rourke (2003) and O'Rourke and Williamson (1994) discuss price convergence; Chiswick and Hatton (2003) and Williamson (2004) discuss migration; whereas Baldwin and Martin (1999), Bordo, Eichengreen, and Irwin (1999), and Estevadeordal, Frantz, and Taylor (2002) examine trade flows.

[2] See Volosovych (2005), Obstfeld and Taylor (2003), and Rousseau and Sylla (2003) about interest rate convergence; Obstfeld and Taylor and Calomiris and Hubbard (1996) on interest parity; Flandreau and Rivière (1999) and Taylor (1996) for savings-investment correlations; and Bordo and Rockoff (1996), Ferguson (2001), and Obstfeld and Taylor on bond spreads.

[3] See Garbade and Silver (1978) and Neal (1985) for evidence on cross-listed stocks. Obstfeld and Taylor (2003) and Goetzmann, Li, and Rouwenhorst (2001) examine market correlations.

(2003)). Rajan and Zingales (2003) suggest that financial development and openness were not immediate victims of the war, beginning to fall only during the 1930s or 1940s. Researchers hesitate to precisely date the end of the integrated era, and do not provide clear reasons as to why the world economy did not rapidly reintegrate once the fighting stopped.

The use of a diverse group of indicators, some of which are of poor quality make inference difficult. Some limitations of the currently used data are that the information on foreign capital stocks is only measured every 10 years, real and nominal interest differentials are somewhat noisy, and the correlation of stock returns across countries (measured in U.S. dollars) is at least consistent with an equally well integrated financial system pre- and post-1914 (see Obstfeld and Taylor).[4] Data on savings-investment correlations also suggest that financial integration did not break down immediately following the war, but rather in the mid 1920s (Taylor (1996)).

I use disaggregated stock market data at monthly frequency to time market integration and segmentation more precisely. In addition, disaggregated data allow the researcher to control for the shocks that hit bond and equity markets. I use an international arbitrage pricing theory (IAPT) model to test if worldwide common risk factors can explain the cross-sectional returns on securities in all national markets. The IAPT estimates the price of risk across markets, and allows us to condition on economic shocks that may (differentially) impact national markets. If worldwide common factors can not adequately explain worldwide security returns then stock markets are segmented.

I collect data from the principal stock exchanges in 12 countries, Amsterdam, Berlin, Johannesburg, London, Madrid, Montreal/Toronto, New York, Paris, Sydney, Tokyo/Osaka, Vienna, and Zurich, from January 1900 through December 1925. I record the prices of stocks and government bonds every 28 days (every fourth Friday), the dividend history of all securities, the issued capital of all securities, and adjust the data for capital operations (takeovers, stock splits, new issues, etc.). The data set contains over 810,000 price observations and over 110,000 dividend observations. My main findings are that: (1) stock markets were closely integrated in the pre-1914 era; (2) stock market integration fell during the war and the years immediately following the war; (3) Allied and Neutral countries' stock markets reintegrated once the restrictive wartime regulations were removed in the early 1920s. The markets of Berlin and Vienna segmented from other markets, possibly due to disputes over reparations payments and hyperinflation in those countries in the early 1920s. Section I discusses the contemporary literature on financial market integration. Section II presents the historical background of securities trading before and after World War One. Section III develops the IAPT model, introduces the data used to estimate the model, and presents summary statistics of the national markets. Section IV discusses the empirical results of market integration, while Section V concludes and suggests areas for future research.

I. Measurement of Financial Integration

Economists' measures of market integration can be classified into two groups: measures based on prices and measures based on quantities. Price measures of integration compare the prices of identical or similar goods, factors of production, or securities in two or more markets. The closer the prices are in different markets and the more closely those prices move together, the more integrated markets are. The drawback

[4] Obstfeld and Taylor suggest that this may be due to correlated shocks hitting world equity markets at the same time. The IAPT framework that I use allows me to condition on securities' sensitivities to economic shocks. Differential returns on securities that can not be accounted for by their sensitivities to shocks are evidence of a lack of integration.

with price tests is that if the two markets have similar endowments, preferences, and technology, then the prices of goods, factors of production, and assets may be close, even in the presence of substantial barriers to trade, migration, and arbitrage. Quantity tests compare the flows of goods, factors of production between two or more markets. The presence of "large" flows (where "large" has to be defined as large relative to something else) is taken as *prima facie* evidence of integration. Quantity tests also suffer from conceptual problems, succinctly summarized by Taylor (1996): "a small autarkic country with capital scarcity no different from the 'world' market will exhibit no incipient flows upon opening itself to capital flows. Conversely, countries with substantial barriers to capital mobility may nonetheless experience capital flows of some sort provided international rate-of-return differentials are sufficiently large."[5]

The finance literature tends to prefer the use of security prices and returns to calculate the price of risk in each market and then use the price of risk to test for market integration. This approach has been used by Flood and Rose (2003), Chabot (2000), Bekaert and Harvey (1995), Engel (1993), and Harvey (1991) amongst others. If markets are integrated then the price of risk in each market should be equal. If the price of risk were to be different in one market than another, then agents could take advantage of this to achieve the same expected return at a lower risk. Therefore differences in the price of risk across markets signal a barrier, whether that be due to transaction costs, capital flow restrictions, or something else.

The use of supplementary data to returns has been undertaken infrequently. Bekaert, Harvey, and Lumsdaine (1998) use data on returns, liquidity, financial flows, and economic indicators to date the integration of emerging markets into the world capital market. Breaks in the time series of the measured variables indicate entry to (exit from) the world capital market. The use of multiple financial indicators increases the precision at which entry (exit) dates can be estimated. In addition, the authors find that the use of equity returns is the *least* useful in estimating the dates of integration. This is potentially a weakness, and possibly a strength, of using data solely on equity returns. If we can find little evidence of market segmentation after 1914 it is possible that this finding is due to the weakness of only using returns data. However, if we can find evidence of segmentation only using equity returns then we have some confidence that other data would tend to confirm our findings.

Tests of nineteenth and early twentieth century integration by Garbade and Silver (1978) focus on the two largest markets of London and New York, and compare a relatively small set of securities. Neal (1985) compares a small number of cross-listed securities on the Amsterdam, London, New York, and Paris exchanges in times of crisis from the eighteenth to the early twentieth centuries. His findings are that these markets were integrated in times of crisis and claims that: "integration could obviously have taken place through trading first in one of the commonly listed securities and then in any of the locally traded securities," although he lacks the data to test his conjecture. Goetzmann, Li, and Rouwenhorst (2001) test the correlation of world stock market returns (measured in U.S. dollars) over the period 1850-2000. They find a high correlation in the period leading up to 1914 followed by a sharp drop. This can be loosely interpreted as evidence of a movement away from an integrated market as a result of the war, although the correlation of stock returns approaches pre-war levels as early as the mid 1920s. Although evidence of correlation is interesting it has some drawbacks. First, even though markets may have had substantial barriers between them returns could co-move due to correlated economic shocks. For example, even if there were strong barriers to trade between

[5] Taylor states that quantity tests retain some use over price tests. He claims that price tests suffer from the "need to focus on *identical* assets." While the price of identical assets, such as cross-listed securities, can be easily compared, dissimilar assets can also be compared as long as their differences are carefully controlled for. A method for doing so is developed in Section III.

European stock markets in 1914 the common shock of the start of the war induced large negative returns in all markets. Second, if markets are not well integrated the price of risk may differ between markets and this will not show up. A major limitation of the work of Goetzmann, Li, and Rouwenhorst is the data coverage, as they openly state. Many markets are missing, including important ones such as Amsterdam before 1919. In addition they do not have data on individual securities, only market indices, and they do not possess data on dividends for all markets. Chabot (2000) has avoided the problems associated with partial data by collecting a sample of 2,171 security returns over the period 1866 to 1885 for the London, New York, and regional U.S. markets. He includes dividends payments and capital operations such as stock splits, and new issues to accurately measure the return to investors. He finds that the New York and London stock exchanges were well integrated during this period, although the regional U.S. exchanges were not well integrated with New York and London.

II. Securities Trading in the early 20th Century

The London Stock Exchange was the most important market at the turn of the 20th century, although it faced competition from New York, Paris, and Berlin. The London market had an extremely broad listing of British and foreign securities, with the Paris market being the next most international bourse, followed by Berlin and New York. By 1900 all the major stock exchanges in the world were connected to each other by telegraph, allowing transmission of financial data within minutes from one market to another. Much of the telegraph traffic was devoted to financial communications, with nine wires connecting the London and Paris exchanges by 1908 (Michie (1987, p. 42)). A substantial number of telegraph messages were also transmitted between London and Berlin, Frankfurt, Amsterdam, Brussels, and Vienna. Telephone communications between London and Paris were possible from 1891 with lines later extended to Brussels (1903) and other foreign financial centres. A radio-telephone system connecting London and New York was not established until 1927 (Michie (1999, p. 181)). Stockbrokers were the principal agents in London who maintained branches and contacts in foreign markets to facilitate an international trade in stocks and bonds. To execute foreign transactions required: "long-established and trusted contacts" (Michie (1987, p. 65)), in addition to a means of communication. Arbitrage business, the buying and the (near) simultaneous selling of the same security in a different market, was well established in the early twentieth century particularly between London and New York. Table 1 (Table 3.2 in Michie (1987)) shows the number of firms with arbitrage connections in London and other markets, and vice versa.

Stock exchanges around Europe closed at the end of July 1914, including the neutral markets of Amsterdam and Zurich, although the Madrid Bolsa and Tokyo remained open throughout the war. The Paris official exchange reopened in early August for cash transactions, but closed again on September 2 (*L'Économiste Français* (September 19, 1914)). Off-exchange transactions were allowed and increased rapidly in importance (see Silber (2005) for details on the "New Street" market during the period the NYSE was closed). The exchanges of New York and Paris re-opened in December 1914, London, Amsterdam, Toronto, Johannesburg, and Sydney in January 1915, Vienna in April 1915, Zurich in May 1916, and Berlin in December 1917.[6] Numerous restrictions were placed on the types of transactions that could be entered into during the war on the London exchange, minimum prices were imposed, and arbitrage was banned (see Schwabe (1915)).

[6] The New York exchange was re-opened on November 28, 1914 for restricted trading in bonds (see Lewis (1938)). The Vienna exchange published a price list from April 1915 onwards. The price quotes in Vienna only changed four times throughout the course of the war, suggesting the price quotes were of a purely nominal nature.

Minimum prices were also imposed on Canadian exchanges and in New York (see Armstrong (1997)). The London exchange required all members and clerks who were formerly citizens of "enemy" countries to re-exhibit proof of naturalization, and also required proof that they had denationalized in their country of origin. At the start of the war almost 80% of all foreign-born members and clerks of the London exchange were of German or Austrian birth. Michie (1999, p. 149) claims that the restrictions on trading on the London exchange were so strict during the first months of the war that "All non-U.K. investors were virtually prohibited from selling all or part of their holdings in London, even though that was the principal or sole market for the securities that they owned." In 1915 the rules were still so strict that "Other than in cases like ... Americans and Australians buying securities in London, especially from British investors, ... the Treasury was most unwilling to accept any variation of the restriction" (Michie (1999, p. 150)). U.K. dealings in Allied securities, such as new French and Russian loans, were blocked by Treasury.

Table 1 - Arbitrage connections in 1909

	Firms in London with connections in	Firms in other centre with London connections
Amsterdam	16	20
Berlin	13	13
Johannesburg	10	14
Madrid	0	0
New York	39	61
Paris	27	27
Sydney	6	12
Tokyo	0	0
Toronto	6	10
Vienna	3	3
Zurich	1	1

Securities trading with individuals resident in enemy countries was forbidden by regulation in the U.K. (Trading with the Enemy Act, September 1914), Canada (War Measures Act, August 1914), Australia (War Precautions Act 1914), and the U.S. when it entered the war (Trading with the Enemy Act, 1917). It became an offence to trade securities with an enemy in the U.K., and attempts were made to restrict trafficking through neutral countries, although it was still possible to sell German-owned foreign securities through the Amsterdam market (Glaser (1998)). Enemy-owned securities were confiscated by Custodians of Enemy Property in the Allied countries. The Custodian maintained ownership and collected coupon and dividend payments. During and after the war the Allied Custodians sold off the enemy owned shares so that by 1919 almost all German and Austro-Hungarian holdings of Allied stocks and bonds had been removed. The U.S. seized German property in North America with a value of $425 million.[7] There were also sizable amounts of German-owned securities invested in the gold fields of South Africa, with estimates that Germans or Austrians owned between 4.5% and 11.5% (£6.3 million (*South African Mining Journal*, January 1, 1921)

[7] See Kent (1989, p. 67). In addition many German-owned securities were sold off in early 1914, in anticipation of war, or during the early war years. Lewis (1938) estimates that Germany owned between $575 and $775 million worth of American securities in 1914. Austrian owned property valued at more than $40 million was seized by the U.S. Custodian.

to £16 million (Rosenthal (1968, p. 226)) of the market value of all securities.[8] France seized the securities of Germans, Austrians and Hungarians by a decree of October 1914 (*L'Économiste Français*, October 24, 1914). The Treaty of Versailles confirmed the Allies' rights to dispose of enemy property, including securities, the proceeds of which were to be charged against reparation demands (Article 298 - Annex 4). The treaty also demanded that the Central Powers immediately stop the liquidation of formerly Allied-owned property. The net result of the war was a major unwinding of the bond and equity positions that the Allied and Central Powers had with each other. Restrictions were also imposed on securities dealings between allied countries. New issues of stocks and bonds were forbidden in London. In addition intra-Allied positions were forcibly unwound by governments "from July 1915 onwards ... the (British) government itself started to requisition American securities held by British investors in a desperate search for dollars" (Michie (1999, p. 157)). Late in 1915 the British government established the American Dollar Securities Committee to take charge of disposing of British-owned U.S. securities on the New York market. Lewis (1938) estimates that the Committee sold slightly more than $1 billion worth of British-owned foreign securities on the New York market between 1916 and 1922. French-owned U.S. securities worth approximately $250 million were also sold off during the war (see Lewis). The reduction of foreign ownership of equities, while perhaps temporarily reducing the international linkages between financial markets, could and indeed was reversed. Cottrell (1994) estimates that British holdings of quoted foreign securities rose to £3.38 billion in 1928, an increase of around £1 billion since 1914.

The U.K. government introduced the Companies (Foreign Interests) Act of 1917 that was intended to exclude enemy persons from control of British companies. Bearer shares were eliminated, and shares could not be held by enemies or enemy corporations without the written consent of the Board of Trade. In addition, foreign (not necessarily enemy) shareholders were restricted to hold less than 40% of the issued capital and less than 25% of the voting power of British companies without the consent of the Board of Trade. Three-quarters of the board of directors, including the chairman, had to be British subjects residing in the U.K. (*South African Mining Journal* (January 25, 1919)). The London exchange continued its persecution of German or Austrian members and clerks even after the war had ended. German and Austrian born members had comprised around 3.5% (excluding British born members of German parentage) of the London exchange before the war. In 1919 a rule was passed that members were not allowed to employ any person of enemy birth, and readmittance of persons of Germanic origin was refused. Passage of these rules contributed to the breakdown of the integrated financial market that had centred on London "much trading in foreign securities being repatriated to national markets, like Montreal and Johannesburg, or seeking refuge in neutral centres like Amsterdam or Zurich" (Michie (1999, p. 160)). Restrictions on arbitrage trade between London and New York were kept until the end of 1920, and even after that members of the London exchange complained that "the difficulties surrounding arbitrage business today are far greater than in the pre-war period" (see Michie (1999, p. 241) and Morgan and Thomas (1962, p. 222)), and only in 1922 were the last vestiges of wartime regulation removed from the London exchange (Michie (1999, p. 193)). Some war-time restrictions on international trading in Canadian security markets were kept until 1920 and in New York until 1922 (see Armstrong (1997) and Meeker (1930)).

[8] The U.S. and South African governments eventually compensated former German share and bondholders. The South African government gave the former German owners government bonds. The U.S. government returned cash plus interest after passage of amendments to the Trading with the Enemy Act (1919 and 1920), the Winslow Bill (1923), and the Settlement of War Claims Act (1928) (see Lewis (1938)). German shareholders in the U.K. simply lost their shareholdings, which were credited against reparations demands.

World War One was the event that shifted the world financial centre from London to New York as the U.S. shifted from a net debtor to a net creditor nation. The war changed the focus of the London market from international securities to domestic debt and equity. Foreign governments and corporations began to issue securities in New York in preference to London. In 1913 50% of the nominal value of securities listed on the London exchange consisted of foreign government debt and foreign railways. By 1920 foreign listings in London comprised only 35% of the market.

While some documentary evidence points to the segmentation of stock markets other documentary evidence suggests a continuation of integrated markets. As early as 1919 there were reports that investors were keeping a close eye on developments in other markets "we are informed by persons closely in touch with America and Holland that there are constant enquiries for English industrial investments ... A representative of a well-known English financial house recently visited Switzerland, and he informs us that at nearly all of about eighty institutions he visited, he was told that their clients were enquiring for English industrial investments ... even in France with the present adverse conditions in exchange, there is a constant demand for good English industrial investments" (Michie (1999, p. 177-78) quoting from the London Stock Exchange: General Purposes, June 30, 1919). The *South African Mining Journal* (August 23, 1919) reported that "the best news of the week is ... that the Imperial Government has relaxed the restrictions on Stock Exchange dealings with this country." Signs of a reintegrating market in the 1920s were the setting up of branches of New York finance houses in London and London stockbrokers extending links with continental Europe and the Far East. Pre-war links between Germany and Allied countries began to resume in the 1920s, with trade often passing through Amsterdam on its way to London or New York. The use of the intermediate Amsterdam market was partly to evade the necessity of handing over German-owned foreign securities for reparations payments (Michie (1999, p. 196)).

The anecdotal evidence is mixed as to whether financial integration broke down as a result of the war. To accurately assess whether the integration of stock exchanges was weakened, and if so how much, we need to turn to quantitative evidence for a more definitive answer.

III. Method

If markets are integrated financial capital should freely move across national borders so that the price of risk is equalized across financial securities. In an integrated global financial market the price that investors receive for bearing an equivalent amount of risk should be the same irrespective of whether a security is traded in London, Berlin, or Sydney. If there are capital controls or some other forces that restrict investors' abilities to allocate their wealth freely across national stock exchanges, then the price of risk may differ across markets. An alternative measure of financial market integration (if we were able to measure and quantify capital controls within a country and then aggregate capital controls across countries) would be the level of capital market controls. The problem with this approach is that it is difficult to quantify the effects of capital controls within and between countries. Whether one should use *de jure* or *de facto* capital controls is also problematic. For example, the U.K. prohibited trading in goods and securities with the Central Powers from September 1914. However, the U.K. government did not strictly enforce those rules when the goods or securities were transferred through neutral countries such as the Netherlands or Denmark, at least in the early stages of the war. In addition to the problem of measuring capital controls there may have been other barriers to integration. Transaction costs between stock exchanges may have changed through time and investors non-monetary preferences may also have been important. It is hard to believe that French and

British investors in the immediate post-war years would have been completely indifferent between investing in London and Paris or in Berlin, even if the price of risk were equal.[9] An indirect test of integration, looking at the price of risk, may be able to discern changes in the level of integration between exchanges that an examination of capital regulations, or capital flows, may not be able to pick up.

I use the International Arbitrage Pricing Theory (IAPT) to measure the price of risk. A strength of this approach is that barriers to integration, either *de jure* or *de facto*, will be reflected by different prices of risk between markets. To measure market integration I calculate IAPT model returns of securities assuming that the stock exchanges in our sample were integrated. Deviations of actual security returns from model returns signify segmented markets. The weakness of this approach is that the results may be sensitive to the choice of asset pricing model. If an alternative model to the IAPT determines asset returns then deviations of actual returns from model returns may not signal market segmentation. As the primary goal is to examine whether markets integrated or segmented after the war what is important is the relative performance of the IAPT pre- and post-war. In reality the IAPT may not be able to perfectly describe security returns during the period 1900 to 1925. However, if the model's ability to explain security returns deteriorates after the war the likely reason is that stock markets began to segment. Conversely, if the model can explain stock returns roughly as well post-war as pre-war then this is evidence that little segmentation took place as a result of World War One.

The Arbitrage Pricing Theory was developed by Ross (1976) and international extensions of it were added by Ross and Walsh (1983) and Solnik (1983). The idea underlying the IAPT is that there are a small number of risks that all securities are exposed to in varying degrees. As all securities are exposed to these common risks they are non-diversifiable. Investors are compensated for holding securities that have a higher exposure to a common risk by earning higher expected returns. In addition to the common risks there are also security-specific risks. Risks that are security-specific can be diversified away by holding a broad portfolio of stocks and bonds, hence exposure to security-specific risk should not command a premium. The intuition is that all securities in a market are exposed to common or economy-wide factors such as interest rates, economic growth, financial panics, and war. The French investor who holds a broad selection of French stocks and bonds is still exposed to the risk that a German army will invade and the prices of all his or her securities will fall at the same time. In addition to the non-diversifiable risk an investor faces there is also security-specific risk. For example a company may have good or bad management, gain or lose a lucrative contract, or suffer a fire. The realizations of these idiosyncratic risks are not common across all securities, hence they can be minimized if the investor holds a diverse portfolio of individual securities.

I use Korajczyk's (1996) IAPT framework to test for market integration. Under the IAPT the return on security i in period t can be expressed as:

$$r_{i,t} = \mu_{i,t} + b_{i,1}\delta_{1,t} + ... + b_{i,K}\delta_{K,t} + \varepsilon_{i,t} \quad for\ i = 1..I \tag{1}$$

where $r_{i,t}$ is the realized return on security i in period t, the ex-ante expected return on security i, $E_{t-1}(r_{i,t})$, is equal to $\mu_{i,t}$, and $b_{i,k}$ is the sensitivity of security i to risk factor k ($k = 1..K$).[10] Systematic

[9]Some indication of this is that as late as 1930 ten ex-members of the London stock exchange of German origin were still refused re-admission. The stated reason was that "the re-election of members of ex-enemy birth 'en bloc' would be extremely unpopular" (Michie (1999) quoting from *London Stock Exchange: General Purposes*, June 23, 1930).

[10]The realized return on security i in period t is equal to $\frac{(p_{i,t+1}+d_{i,t}-p_{i,t})}{p_{i,t}}$ where $p_{i,t}$ is the price of security i in period t and $d_{i,t}$ is the amount of the dividend paid between period t and $t+1$. $d_{i,t}$ is adjusted to account for stock splits, new issues

risk shocks are measured by $\delta_{k,t}$, the realization of risk factor k in period t ($E(\delta_{k,t}) = 0$), whereas $\varepsilon_{i,t}$ is the realization of security i's idiosyncratic risk ($E(\varepsilon_{i,t}) = 0$). If the idiosyncratic risks are uncorrelated across securities, $corr(\varepsilon_{i,t}, \varepsilon_{j,t}) = 0$ for $i \neq j$, and if there are an infinite number of securities available to investors then the following pricing equation must hold as an approximation for most securities:[11]

$$\mu_{i,t} \approx riskfree_t + b_{i,1}\lambda_{1,t} + ... + b_{i,K}\lambda_{K,t}. \tag{2}$$

The risk-free rate of return in period t is denoted $riskfree_t$ and the price of factor k risk ($k = 1..K$) in period t is equal to $\lambda_{k,t}$. Pricing equation (2) has several implications. First, only securities with an exposure ($b_{i,k} \neq 0$) to a common risk factor receive a different expected return to the risk free rate, security-specific risk can be avoided (in the limit it can be avoided completely) by holding a sufficiently large selection of securities. Secondly, the price of factor k risk in period t ($\lambda_{k,t}$) must be equal across most securities or there will be arbitrage possibilities. If the price of risk is not equal across most securities then it is possible to construct a sequence of portfolios whose expected returns approach infinity and whose variance approaches zero as the number of securities approaches infinity.

If (1) is the true model for security returns then it is possible to combine (1) and (2) so that the return on security i can be expressed as:

$$r_{i,t} \approx riskfree_t + b_{i,1}(\lambda_{1,t} + \delta_{1,t}) + ... + b_{i,K}(\lambda_{K,t} + \delta_{K,t}) + \varepsilon_{i,t}. \tag{3}$$

Equation (3) states that the return on security i in period t should be explained by the risk-free rate in period t, the sensitivity of security i to the common risk factor k ($b_{i,k}$), the (mean-zero) realization of the common risk factor k ($\delta_{i,k}$), the price received for bearing one unit of risk factor k ($\lambda_{i,k}$), and the (mean-zero) realization of the idiosyncratic risk.

In the period 1900 to 1925 there is no good proxy for a risk-free asset. Short-term government debt was rare, most government debt was in the form of long-term bonds which held risk in the form of a price appreciation or depreciation. To avoid the problem of a non-existent (or potentially unreliable) risk-free rate, I calculate the rate of return on the 'world' market index (where 'world' is defined as the 12 markets in my data set) in period t:

$$r_{world,t} \approx riskfree_t + b_{world,1}(\lambda_{1,t} + \delta_{1,t}) + ... + b_{world,K}(\lambda_{K,t} + \delta_{K,t}) + \varepsilon_{world,t}. \tag{4}$$

I calculate the 'excess' return on each asset (i.e. the return over and above the return on the 'world' market index) in each time period by subtracting (4) from (3):

$$(r_{i,t} - r_{world,t}) \approx (b_{i,1} - b_{world,1})(\lambda_{1,t} + \delta_{1,t}) + ... + (b_{i,K} - b_{world,K})(\lambda_{K,t} + \delta_{K,t}) + (\varepsilon_{i,t} - \varepsilon_{world,t}). \tag{5}$$

If markets are integrated and the IAPT explains asset returns exactly, then (5) holds as an approximation. Further restrictions can be imposed so that (5) holds as an equality (see Connor (1984) and Constantinides (1989)). For estimation purposes I will assume that either the approximation error is small enough to ignore, or that the further restrictions hold.

of stock to existing shareholders, takeovers, etc.

[11] The assumption that security-specific risk is completely uncorrelated across securities can be weakened, for example by assuming that security-specific risk is sufficiently independent so that the law of large numbers applies (Ross 1976).

A. Calculating the Market Index

A market index that aggregates the information from individual securities into a single measure is useful to answer questions such as "how did market x perform over the period of the study?" or "how sensitive was stock i to overall market conditions?" A market index is also used as a common risk factor to measure market integration. All indices are measured in British pounds, and have a base of January 1902 = 100. The market index grows at the (market capitalization weighted) rate of return of individual securities:

$$
\begin{aligned}
Index_{t+1} &= Index_t * (1 + Market\ Return_t) \\
Market\ Return_t &= \sum_{i=1}^{I} w_{i,t} r_{i,t} \\
w_{i,t} &= \frac{p_{i,t} n_{i,t}}{\sum_{i=1}^{I} p_{i,t} n_{i,t}}, \ r_{i,t} = \frac{p_{i,t+1} - p_{i,t} + d_{i,t}}{p_{i,t}}
\end{aligned}
$$

where

$w_{i,t}$ = weight on security i

$r_{i,t}$ = return on security i in period t

$p_{i,t}$ = price of security i in period t (in £)

$d_{i,t}$ = amount (per share/bond) of any dividend/coupon in period t (in £)

$n_{i,t}$ = number of issued units of security i in period t.

Unfortunately, since we don't observe a price for every security in every period, measurement of the market index is dependent on the assumptions we make about the missing price data. The first method is to assume that prices are missing at random (MAR) which discards the information from securities that do not trade in periods t and $t+1$. The advantage of this method is that we can accurately measure the return of a security from period t to $t+1$, the disadvantage is that we do not use all observed price data. The second method is to assume that missing prices can be filled in by linear interpolation, the third method uses the last observed price to fill in missing prices, whereas the fourth method uses the next (future) price to fill in missing prices. Clearly none of the methods of filling in missing data are the 'truth', however they can be useful in testing how robust the market index is to different assumptions about the missing data process. When there are minimal problems of missing data, for example in London, New York, and in pre-war Berlin and Vienna, differences between the four market indices are trivial. When there are many missing data, such as in Amsterdam and Johannesburg, differences between the four measures can be pronounced.

Figures 1.1 through 1.13 show the evolution of the world market index and the individual market indices (stocks and bonds are combined) under the assumptions that prices are MAR, can be interpolated, the last observed price, and the next price. All indices are calculated in British pounds. Movements in the national exchange rates vis à vis the British pound are found in Figure 1.14. Measurement of long run market performance clearly depends on the assumptions made about the missing price observations, in particular the assumption of MAR appears to impart an upward bias to measurement of long-run performance. Having a closed exchange for several years in the middle of a war means that inference about the true level of the (unobservable) index is very sensitive to the assumptions made about the missing prices. In addition the different assumptions make a sizable difference during periods of hyperinflation (hyperinflation ended in Austria in August 1922, and in Germany in December 1923). In general, month to month measures of returns do not appear highly sensitive to the different assumptions made, with the clear exceptions of Berlin and Vienna.

Figures 2.1 through 2.13 present the world market index, world bond index, world stock index, individual market indices, individual market bond indices, and individual stock indices, measured in British pounds, under the MAR assumption. Figure 2.14 shows all national market indices with stocks and bonds combined, under the assumption that prices are MAR. Stocks outperform bonds in all markets except for Madrid over the full 26 years of data.

B. Data

I collect every listed stock and all national government bonds (domestic or foreign) traded on the stock exchanges of Amsterdam, Berlin, Canada (Montreal and Toronto), Johannesburg, Madrid, New York, Sydney, Vienna, and Zurich, plus a sample of securities from Japan (Osaka and Tokyo), London, and Paris. I only observe Tokyo securities that were included in *Kabukai 20nen* (20 years of the stock market). For Paris I only include those securities that were reported by *L'Économiste Français*, and I have yet to compile dividend data for these securities. The London data comprise only a small subset of the thousands of securities quoted on that exchange. The securities included in my data set are those that *The Economist* chose to list in their publication after 1915, hence may be subject to selection bias. Results for Paris and London are therefore somewhat preliminary. Work is underway to add to the London data set with more comprehensive price quotes from *The Times*.

Table 2 - National Market Summary Statistics

	Listed securities Jan 1914	Market Capitalization Jan 1914 (£ m)	Average Annual Return 1900-25 (%, in £)
Amsterdam	668	663	5.6
Berlin	1191	3,470	-8.0
Canada	190	428	9.0
Japan[1]	46	214	8.9
Johannesburg	130	118	11.2
Madrid	48	174	5.3
Sydney	221	111	6.4
Zurich	161	171	4.0
New York	299	2,202	6.0
Vienna	307	697	-5.2
London[1]	198	2,168	4.0
Paris[1]	170	2,045	n.a.

1 - Partial market data for Japan, London, and Paris

The data set consists of every 4th Friday's prices from January 27, 1900 through December 4, 1925. I have chosen the dates to coincide with the dates of Chabot's (2000) London and New York data sets which he has kindly provided. When the exchange of one market was closed, for example due to a public holiday, the nearest day's prices have been used instead. Deviations from this rule are noted in the descriptions of each exchange's data sources in Appendix B. Taxes on dividends and coupons have, in general, been ignored as they are of small amount and vary depending on the owner of the security. The tax on securities' income in the United Kingdom was less than 5% at the turn of the 20th century, although it rose to 20% by the early 1920s, in South Africa the tax rate was under 5%, in Germany 10%, in the Netherlands and Switzerland 0%, and in the U.S. 0% before 1913 but rising thereafter (see Davies (1927)). Summary statistics of the data are presented in Table 2. All returns are computed in a common currency, the British pound.

C. Estimation of Integration

The IAPT model implies that the realized excess return on security i in period t is given by (5). If markets are segmented then the price of risk in each market could be different, consequently security returns will not be explained by an IAPT model that imposes the same price of risk across all markets. If all markets are integrated then the world price of risk should be equal across national markets.[12] Deviations of realized returns from IAPT model returns (which assumes fully integrated markets) are *prima facie* evidence of market segmentation. To test for this I use the following specification for each security i:

$$(r_{i,t} - r_{world,t}) = \alpha_i + (b_{i,1} - b_{world,1})(\lambda_{1,t} + \delta_{1,t}) + ... + (b_{i,K} - b_{world,K})(\lambda_{K,t} + \delta_{K,t}) + (\varepsilon_{i,t} - \varepsilon_{world,t}) \quad (6)$$

where

$r_{world,t}$ = the return on the world market index in period t
$E(\delta_{k,t}) = 0$ for $k = 1..K$ and $t = 1..T$
$E(\varepsilon_{i,t}) = 0$ for $t = 1..T$
$E\left(\varepsilon_{i,t}^2\right) = \sigma_i^2$ for $t = 1..T$
$E(\lambda_{k,t}\varepsilon_{i,t}) = 0$ for $k = 1..K$ and $t = 1..T$
$E(\delta_{k,t}\varepsilon_{i,t}) = 0$ for $k = 1..K$ and $t = 1..T$.

If markets are integrated the IAPT implies that α_i should be equal to zero for most securities. If the excess returns on security i are higher than is warranted by the security's exposure to the common risk factors (positive α_i) or lower than is warranted by the exposure to the common risk factors (negative α_i), then security i is said to be mispriced. The extent of the mispricing (and hence integration) can be quantified by the size of α_i. Although α_i is unobservable I can estimate it by (6) if I know $(\lambda_{k,t} + \delta_{k,t})$ for all k and t.

D. Factor Mimicking Portfolios

In order to estimate (6) I need to specify the common risk factors, $\delta_{k,t}$, and the price of factor k risk, $\lambda_{k,t}$. Two approaches to this exist. The first approach is to specify the factors in advance, estimate each security's sensitivity to that factor, and then estimate the reward (in the form of a higher return) for holding a security that is sensitive to that risk factor. Common risk factors such as the return on the world market portfolio, the return on a basket of currencies, commodity prices, oil prices, and an indicator of the world business cycle have been suggested (see Harvey (1995 a,b)). The advantage of this approach is that it enables us to identify the economic variables that are important in determining security returns. The disadvantage is that it requires the common risk factors to be specified (possibly incorrectly) in advance. The second approach is

[12] An IAPT test may fail to accurately detect segmentation and integration. First, the IAPT may not be the true model of security returns. Second, markets may be segmented but the price of risk is equal in segmented markets by coincidence. Third, there may be (i) common risk factors in market A that the securities in market B are not exposed to (i.e. zero b), and (ii) the common risk factors in market A may be included in the IAPT model (see Korajczyk (1996)).

to extract common risk factors from the data on individual security returns using the asymptotic principal components technique of Connor and Korajczyk (1986, 1987). The advantage of this approach is that the identity of the factors need not be specified in advance, but can be derived from the covariance matrix of security returns. The disadvantage is that the factors derived from the use of principal components can not be mapped back into economic variables. Given the lack of economic variables that are both contemporaneous to our measured security returns and measured in the same manner across all markets I use the asymptotic principal components technique. As the objective is to measure the integration of markets (not the economic determinants of security returns) the drawback of asymptotic principal components is minimal.

The kth-factor mimicking portfolio is a weighted selection of individual securities that has one unit of exposure to common risk factor k ($b_k = 1$), and zero exposure to all other risk factors ($b_j = 0$ for $j \neq k$). By holding the kth-factor mimicking portfolio an investor will achieve a time series of excess returns, $F_{k,t} = \lambda_{k,t} + \delta_{k,t}$.[13] To estimate the excess returns on the factor mimicking portfolios we use the method of asymptotic principal components with missing data (Connor and Korajczyk (1987)). This method assumes that security returns are given by (1), that expected security returns are given by (2), that security sensitivities to the kth common risk factor, $b_{i,k}$, are constant through time, and that the cross-sectional average asset-specific variance is constant through time. The matrix of all securities' excess returns, $\mathbf{R}^e$, is of dimensions I by T where each element of the matrix is $r_{i,t} - r_{world,t}$. Define $n_{t,\tau}$ as the number of securities with observed returns in periods t and τ. Create the matrix $\widetilde{\mathbf{R}}^e$ which is the same as $\mathbf{R}^e$ except that the missing security returns have been replaced with zeros. The T by T matrix $\widetilde{\Phi}$ is formed whereby the t,τ element, $\widetilde{\Phi}_{t,\tau} = \left(\widetilde{\mathbf{R}}^{e\prime}\widetilde{\mathbf{R}}^e\right)_{t,\tau} / n_{t,\tau}$. The factor estimates, $\widehat{F}_{k,t}$, are the first k eigenvectors, (corresponding to the largest eigenvalues) of $\widetilde{\Phi}$. Connor and Korajczyk (1986) show that the estimates, $\widehat{F}_{k,t}$, converge in probability to $F_{k,t}$. I use four factors in the estimation procedure, the return on the world market index, and three principal component factors extracted from $\widetilde{\Phi}$. Chabot (2000) includes the return on the world market index to ensure this common risk factor is not omitted, and uses four factors extracted through principal components. The return on the world market index, $r_{world,t}$, is included because sensitivity to overall market conditions has long been identified as a determinant of security returns. Connor and Korajczyk (1993) argue that with an approximate factor model from one to six common risk factors are enough to adequately explain security returns.

The extracted factors are highly sensitive to outlying security returns. In particular during the period of post-war hyperinflation in Germany and Austria security returns (measured in £) are highly volatile. The extracted factors (correctly) pick up increased nondiversifiable shocks occurring during this period, but there is a concern that measurement error may also have increased. Data on prices and exchange rates are only observed daily and if the exchange rates are measured at a different time of the day to the security prices (and if this timing difference is not constant from month to month) then security returns (measured in £) in the hyperinflationary period may be measured with poor accuracy. An additional concern is that idiosyncratic shocks may be reflected in the extracted factors. While asymptotically this should not be a problem, in the finite sample of security returns available the extracted factors prove sensitive to outlying returns. This is particularly evident in mining stocks, where the occasional monthly jump from one cent to ten cents (a 1000% return) is enough to materially affect the extracted factors. As a robustness check I extract factors from

[13] The excess return achieved by holding one unit of common risk factor k is the reward for holding one unit of such risk, $\lambda_{k,t}$, plus the shock to security returns that are exposed to one unit of risk factor k in period t, $\delta_{k,t}$.

both the $\widetilde{\Phi}$ matrix, and from the weighted matrix, $\widetilde{\Psi}$, where the t, τ element, $\widetilde{\Psi}_{t,\tau} = \left(\widetilde{\mathbf{R}}^{e\prime}\mathbf{W}\widetilde{\mathbf{R}}^{e}\right)_{t,\tau} / n_{t,\tau}$. The I by I diagonal weighting matrix, $\mathbf{W}$, has the inverse of the estimated variances of security returns as diagonal elements , $\frac{1}{\widehat{\sigma}_1^2}, \frac{1}{\widehat{\sigma}_2^2}, ..., \frac{1}{\widehat{\sigma}_I^2}$. Using weights allows us to give a lower weight to those securities that exhibit noisier returns.

E. Rolling Regressions

We now wish to characterize the evolution of the security pricing errors, α_i. The larger the pricing errors, the further α_i is away from zero, the more likely it is that world stock markets are segmented. One approach would be to divide the data into two subsets, say 1900 through 1914 and 1915 through 1925, and estimate α_i for each security in each subset. The problem with splitting the data in two is that it can not reveal when a break in integration occurs. Therefore, I use the rolling regression technique of Korajczyk (1996). The approach has the following steps:

1. Construct factor mimicking portfolios with the asymptotic principal components procedure using all stock exchanges and the full time series of returns from January 27, 1900 through December 4, 1925.
2. For every security in every market estimate (6) individually using a rolling 20-period sub-sample of the data for all securities. For example the first sub-sample consists of returns from January 27, 1900 through July 12, 1901 the second sub-sample February 24, 1900 through August 9, 1901 and so on. This will yield estimates, $\widehat{\alpha}_{i,Jan1900-Jul1900}$, $\widehat{\alpha}_{i,Feb1900-Aug1900}$, ..., $\widehat{\alpha}_{i,Jun1924-Dec1925}$ for $i = 1..7310$, the total number of securities in the data set.
3. Calculate a summary measure of the mispricing for every market through time.

Since deviations of α_i, positive or negative, signify mispricing of that security (under the maintained hypothesis that markets are integrated), the summary measure of mispricing at a point in time I use is the average squared pricing error of all securities in each national market. Using rolling regressions results in estimates, $\widehat{\alpha}_i$, for each security. The value $\widehat{\alpha}_i{}^2$ is an upwardly biased estimate of α_i^2, therefore we need to adjust it downwards by the size of the bias. The estimator $\widehat{\theta}_i = \widehat{\alpha}_i{}^2 - \widehat{\sigma}^2_{\widehat{\alpha}_i}$, the estimated intercept squared less the estimated variance of the intercept, is an unbiased estimator of α_i^2 (for details see Appendix C). In practice I use estimates of $\widehat{\sigma}^2_{\widehat{\alpha}_i}$ that have the White (1980) correction for heteroskedasticity. The evolution of the average squared pricing error, $\overline{\overline{\theta}}_t$, through time is interpreted as the change in stock market integration. The lower $\overline{\overline{\theta}}_t$ is the more evidence there is that stock markets are integrated.

F. Missing Data

There are instances of missing observations in the data. For the Amsterdam, Berlin, Japan, Madrid, and Paris markets I only observe a price if a trade in that security took place on the day on which I observe the price list. If on the day I observe the price list, there was no trade of a particular security, then that price is missing. The other markets have bid and ask quotes which, although occasionally missing, do not suffer as greatly from instances of missing data. Since the underlying process that determines returns may conceivably be related to the observability of prices there is a potential problem with cases of missing data.

If prices are missing at random (MAR), there will not be a bias in estimating the integration of the various stock markets. Formally, the data are MAR if:

$$f\left(M|Y,\phi\right) = f\left(M|Y_{obs},\phi\right)$$

where Y is the matrix of complete data (both observed and unobserved), Y_{obs} are the observed data, M is a matrix of missing-data indicators ($m_{ij} = 1$ if y_{ij} is missing, $m_{ij} = 0$ if y_{ij} is observed), and ϕ denotes unknown parameters (Little and Rubin (2002)). That is, the data are MAR if the missingness of Y depends only on the components of Y that are observed, not on the components of Y that are missing. Tests for MAR exist, but are highly sensitive to model misspecification (Little (1985)). A stricter test of missingness, Little's (1988) test of missing completely at random (MCAR) does exist. The problem with applying Little's MCAR test is that it checks whether the means of observed variables differ across missing data patterns. A missing data pattern is a $1 * I$ vector of ones and zeros denoting which securities' prices are observed and which are not. Since we have more than 7,300 securities and only 338 time periods *every* missing data pattern is unique, rendering tests of differences of means across patterns ineffective. In addition no securities are observed in every time period, although some are traded in almost every time period.

It is quite likely that the data are not missing at random (NMAR), at least to some degree. For example, during the first months of the war with the exception of Madrid, Tokyo, and Canadian mining stocks, security prices are unobserved. The reason the other exchanges decided to close was that the prices on them would have showed significant falls. Thus, these data are not MAR since the probability that prices are missing (in London, Paris, Berlin etc.) depends on those unobserved prices, even conditioning on the modest falls in Madrid and Tokyo. An equivalent way to think of this is that the observed security returns on Madrid and Tokyo are not representative of the security returns if we were to observe prices for the markets that closed due to the war.

Figures 3.1 through 3.13 illustrate the extent of missing price data in the data set. The figures present the market value of 'tradable' securities for which we observe a price on a particular date divided by the market value of traded and non-traded securities. A security is defined as tradable if it has traded at least once, and will trade at least once more between January 1900 and December 1925.[14] We observe a price for a security if we observe either the transaction price, the bid price, or the ask price. Figure 3.1 shows that before World War One we observe the prices of around 90% of the world market value on a particular day. Once the war began most exchanges shut for an extended period of time, and it was only by the mid 1920s that the extent of missing data fell to the level prevailing before the war. Figures 3.2 through 3.13 detail the differences in missing price observations between exchanges and through time. Amsterdam was a large market, albeit with a large number of illiquid stocks. In Berlin there are few missing data before the war, but after the war cases of missing data become more prevalent, in particular around the time of the armistice in late 1918 and during the hyperinflation of 1922-1923. The volatile Canadian series reflects the sporadic appearance of the mining price list in *The Financial Post*. Missing mining observations are being entered from the recently discovered source of *The Globe and Mail*. We only observe the Tokyo price data every month. As we record the price data for the other exchanges on every 4th Friday, in a year there is one fewer set of price observations for Japan than for the other markets. The gaps in the Japan series reflects that approximately every 13th observation is missing. In addition the Tokyo exchange closed during the Tokyo earthquake of 1923. Missing data are a major issue for the Johannesburg and Madrid markets with many data missing and the extent of missing data changing from month to month. The Sydney market closed for around 3 weeks at Christmas time and for around a week at Easter. In addition, during 1917 and 1918 availability of mining prices in the *Daily Telegraph* was erratic. There are few missing data in New York

[14] Ideally, the denominator would be the market value of *listed* securities on a particular day since a security may appear in the price list before we observe its price for the first time and remain in the price list after we observe its last price.

with the exception of the closing of the exchange during the first months of the war. Most pre-war price observations in Vienna are of bid and ask quotes of which very few are missing. After the war it became less common to see bid and ask quotes. Instead transaction prices take the place of bid and ask quotes which are less frequently observed on a particular day.

Potentially, a more pervasive problem is that securities may not trade because the security is doing badly. If investors stop trading the securities of companies that are in financial difficulties, then the probability the security's price is unobserved may be related to the unobserved price of that security, even after conditioning on all other observed securities' prices. The clearest indication that this problem may exist can be seen from looking at the Johannesburg market. If we construct a market index using only those securities that trade in adjacent periods it appears that an investor could achieve an annual return of 11.2% over 24 years (see Table 2). If instead we construct a market index that assumes an unobserved price is equal to the last observed price the annual return is only 2.1% over 25 years. Investors that could have constructed a portfolio using only those securities that would trade again next period would have done well, investors that constructed a portfolio using all listed securities (including those that did not trade in the next period) did badly. Constructing a market index assuming that investors could foresee which securities would trade in the future is similar to assuming that investors would not buy securities that would tend to perform badly, since the securities that do not trade are those that are doing badly.

Statistical Tests of Missing Returns

Although we do not observe every 28-day excess return over a period of missing price data we can compute the average excess return over periods of missing data. If the price data are MCAR then for each security the sample average of the excess returns for which we have adjacent price data should be 'close' to the sample average of the excess returns (on a 28-day basis) measured over a duration in which there are one or more consecutive missing prices. We can then use a t test to ascertain whether the population means of the adjacent and non-adjacent excess returns are statistically different. It is of course true that there may be a statistical difference in the mean excess returns of adjacent and non-adjacent price data without the difference being economically important. Given the large differences in market indices over long horizons (see Figures 1.1 through 1.13) it appears that (absent other sources of bias) the mean differences are economically important.

The t test for a difference of means requires that we calculate the following statistic for each security:

$$t_{stat,i} = \frac{\overline{r}_{adj,i} - \overline{r}_{non-adj,i}}{\sqrt{\frac{s^2_{adj,i}}{n_{adj,i}} + \frac{s^2_{non-adj,i}}{n_{non-adj,i}}}}$$

where

$\overline{r}_{adj,i}$ = sample average of 28-day excess returns when we observe a price in period t and $t+1$

$\overline{r}_{non-adj,i}$ = sample average of excess returns (on a 28-day basis) when we observe a price in period t and $t+j+1$, $j > 0$[15]

$s^2_{adj,i}$ = sample variance of adjacent excess returns

$s^2_{non-adj,i}$ = sample variance of non-adjacent excess returns

$n_{adj,i}$ = number of adjacent excess returns observed

[15] For example if we observe a price of 10, then nothing until a price of 11 in 84 days and no dividends were paid, we treat this as one observation of a non-adjacent return of 3.2% (on a 28-day basis).

$n_{non-adj,i}$ = number of non-adjacent excess returns observed.

If adjacent and non-adjacent excess returns are drawn from populations with the same mean then t_{stat} should be distributed approximately normally, for large n_{adj} and $n_{non-adj}$. We calculate t stats for every security for which it is possible and compare the t stats for all securities within a national market. Under the null and alternative hypotheses $H_o : \mu_{adj} = \mu_{non-adj}$ and $H_a : \mu_{adj} > \mu_{non-adj}$ approximately 5% of all t statistics should take values above 1.65. If substantially more than 5% of all t-stats take values above 1.65 in each national market, it is highly suggestive that those securities that do not trade, are not trading during periods when they experience lower excess returns than when they are trading. Table 3 presents data on the number of t-tests performed in each market, and the number and proportion of t-tests for which we can reject the null hypothesis at the 95% confidence level.

Table 3 - Tests of Difference in Mean Security Excess Returns

(95% confidence level)

Market	# t-tests reject H_0	# t-tests	proportion rejected
Amsterdam	251	1058	0.24
Berlin	247	1521	0.16
Canada	44	326	0.13
Japan	26	86	0.30
Johannesburg	49	243	0.20
London	9	114	0.08
Madrid	10	81	0.12
New York	49	575	0.09
Paris	66	423	0.16
Sydney	65	467	0.14
Vienna	92	425	0.22
Zurich	28	225	0.12
World	848	5007	0.17

The data suggest that missing data are a cause for concern, especially for the Amsterdam, Japan, Johannesburg, and Vienna markets. The economic effect of the missing data problem depend on how large the differences in means are, and how many data are missing. To provide some idea of the economic impact of the missing data problem we calculate the average difference between adjacent and non-adjacent excess returns for each security, and weight the difference by the proportion of periods for which prices are not observed. We then take an unweighted average of these weighted differences across all securities in a national market. Formally, we measure the economic 'impact' as: $impact = \frac{1}{I}\sum_{i=1}^{I} \frac{\#months\ missing}{338} * (\overline{r}_{adj} - \overline{r}_{non-adj})$, where we have 338 time periods and I securities in a particular market. Table 4 presents the impact for all markets. Since the larger market capitalization securities tend to have less of a problem with missing data, if we were to use a market capitalization weight across securities the summary figure for each market would fall sizably. The economic impact is particularly large for markets containing a large number of illiquid securities such as Amsterdam, Johannesburg, and Vienna after the war. This partly explains the upwards bias of market indices constructed assuming MAR. The larger more liquid markets of Berlin, Japan, London, and New York are little affected by instances of missing data. Above all it should be remembered that the major effect of missing data is the introduction of a slight upward bias which compounds over time. Period to period the four measures of the market index, except in periods of market closure, present a very similar picture of the overall movement of security prices.

Table 4 - "Impact" of differential mean excess returns

($\overline{r}_{adj} - \overline{r}_{non-adj}$, % per annum)

Market	Impact
Amsterdam	12.7
Berlin	2.4
Canada	2.5
Japan	2.0
Johannesburg	5.5
London	-0.6
Madrid	0.0
New York	0.1
Paris	1.1
Sydney	4.3
Vienna	5.1
Zurich	2.5
World	3.1

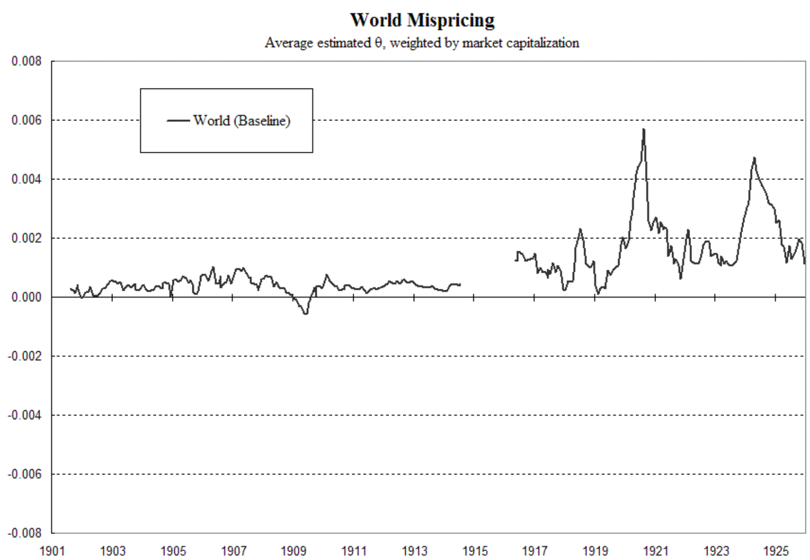
IV. Results

The evolution of $\overline{\widehat{\theta}}_t$ is the measure of stock market integration since $\overline{\widehat{\theta}}_t$ is an unbiased estimator of the average squared pricing error. A rise in $\overline{\widehat{\theta}}_t$ indicates less integrated stock exchanges, a fall in $\overline{\widehat{\theta}}_t$ is interpreted as more integrated stock exchanges. Due to cases of missing data it is not possible to run (6) on every security using every 20-period sub-sample of the data. We estimate $\widehat{\theta}_{i,t}$ for all securities in our data set that have at least 14 returns (calculated from adjacent prices) out of a possible 20 with a four-factor IAPT (the world market index, and three principal component factors from the unweighted matrix $\widetilde{\Phi}$). We then calculate $\widehat{\theta}_t$ by taking the market-capitalization weighted average of $\widehat{\theta}_{i,t}$. This measure of world stock market integration is the baseline model shown in Figure 4.1. World stock market integration does not have an obvious trend until the war, markets are roughly as integrated in early 1914 as they were in the first years of the twentieth century. Due to the closure of most stock markets at the commencement of hostilities, and the use of a 20-period sub-sample of data to calculate $\overline{\overline{\theta}}$, it is only possible to measure integration again in May 1916. A substantial drop in integration is evident, due to wartime regulations and the absence of trading possibilities between warring countries. World stock markets do not return to their pre-war level of integration at any time after the war. As $\overline{\widehat{\theta}}_t$ is an unbiased estimator of the market capitalization weighted average of α_i^2, it has a non-negative expected value. Due to sampling variability realizations of $\overline{\widehat{\theta}}_t$ can, and sometimes do, turn out negative. Negative values of $\overline{\widehat{\theta}}_t$ represent high levels of market integration and/or little precision in estimation of α_i^2.[16]

[16] The formula for the construction of asymptotic confidence intervals for $\overline{\overline{\theta}}$ can be found in Appendix D. The practical implementation of this is in progress.

National market measures of integration are shown in Figures 4.2 through 4.13. The figures show that the pre-war stock markets of Amsterdam, Berlin, London, Paris, New York, Vienna, and Zurich were highly integrated with evidence of a periphery of less-integrated markets such as Canada, Madrid, Sydney, Johannesburg, and Japan. The major effect of the war on stock market integration appears to be a severing of the links between Berlin and Vienna and the world market. The results for London suggests a weakening of integration of the 1920s, although this is possibly due to the small (and non-randomly selected) securities for which I currently have data. The switch from using Osaka prices (observed on the same date as for the other exchanges) to Tokyo prices (monthly averages of high and low prices) in January 1905 is coincident with a large fall in the measured integration of Japan with the world market. It is quite likely that Japan is substantially more integrated with the world than our data suggest, with measured integration lower due to poor quality data for the Tokyo Stock Exchange.

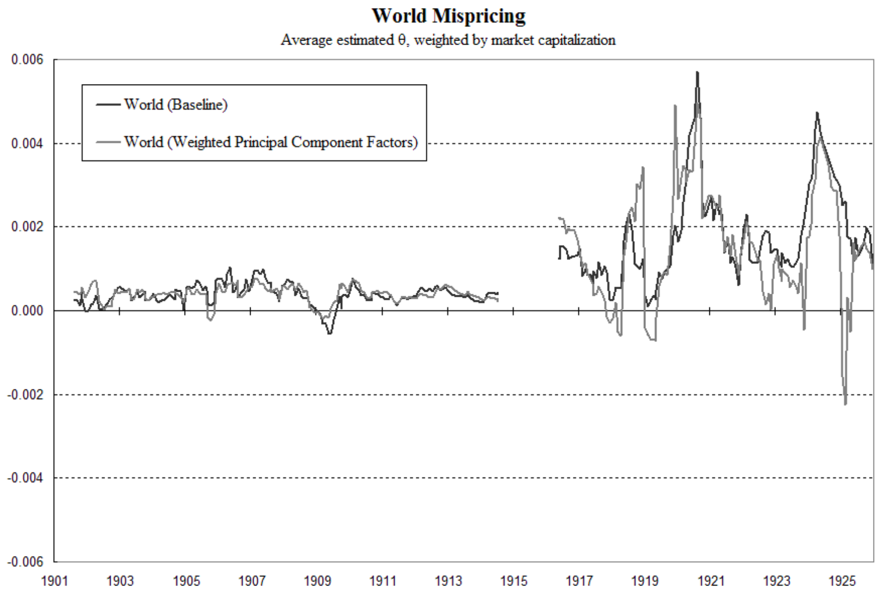
Figure 4.1



Sensitivity to Weighting of Principal Component Factors

The baseline results in Figure 4.1 use three principal component factors from the (unweighted) covariance matrix $\widetilde{\Phi}$ as explanatory variables in the cross-sectional regressions of security returns (6). The sensitivity of the extracted factors to outlying security returns may be driving the finding that markets were less integrated post-war. If the results are sensitive to outlying security returns then extracting factors from the matrix $\widetilde{\Psi}$, which places a lower weight on the returns of securities with a greater variance, and using those factors in (6) should yield qualitatively different results when our mispricing summary measure, $\overline{\widehat{\theta}_t}$, is calculated. Figure 5.1 presents both the baseline mispricing, and mispricing constructed using the weighted covariance matrix $\widetilde{\Psi}$. Qualitatively the results are the same, mispricing is worse after World War One, and quantitatively of a similar magnitude. The finding of lower stock market integration is not sensitive to outlying observations affecting the extracted factors, $\widehat{F}_{k,t}$.

Figure 5.1

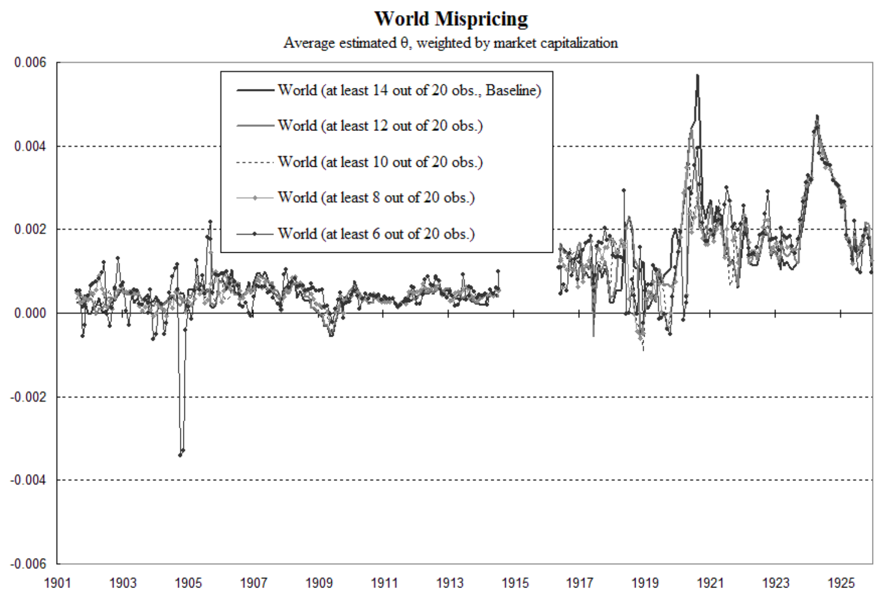


Sensitivity to Missing Data

Given the likely bias in observed security returns discussed in Section III F it is crucial to determine if the missing data issue materially affect the results. If securities for which we usually observe adjacent prices (thus are able to calculate 28-day returns) are systematically different to the securities for which we rarely observe adjacent prices, then basing our results on the more frequently traded securities will introduce a bias to the measurement of market integration.

We test if our results are materially affected by this by adding less frequently traded securities to each sub-sample of data, re-estimating (6) for all securities and then calculating a summary measure of mispricing, $\overline{\widehat{\theta_t}}$. Specifically, we re-calculate $\overline{\widehat{\theta_t}}$ using all securities for which we observe 12 out of 20 returns, then 10 out of 20 returns, 8 out of 20 returns, and 6 out of 20 returns in each sub-sample of data. Figure 5.2 illustrates $\overline{\widehat{\theta_t}}$ for the world market using different thresholds for including a security in the results. The baseline case admits securities for which we observe at least 14 out of 20 returns in a given sub-sample of data. Measurement of market integration does not appear to be greatly affected by the addition of less frequently traded securities. Although missing data is important in determining long-run market performance, measurement of market integration is not greatly affected by including securities that have moderate instances of missing data.

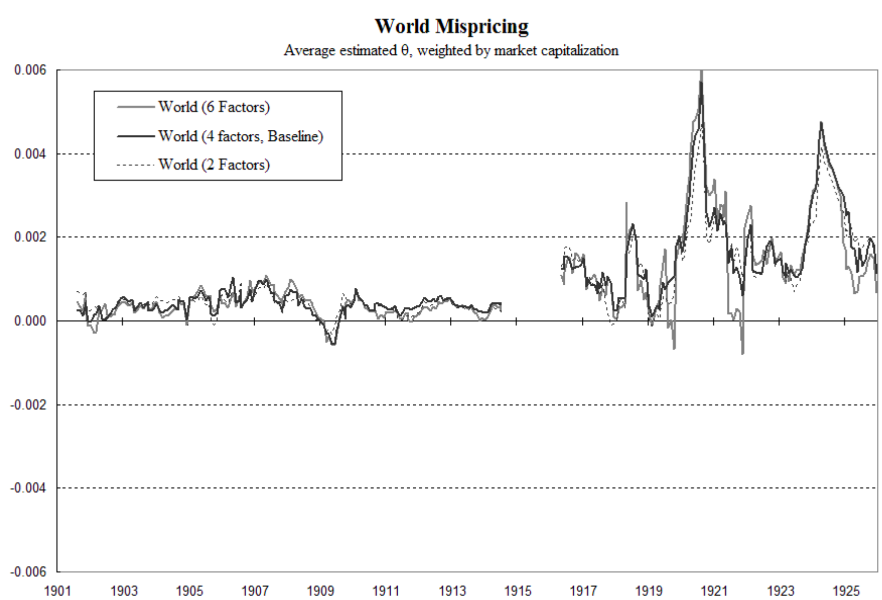
Figure 5.2



Sensitivity to the number of factors

The conclusion in the literature on the number of factors to use in explaining security returns is a qualified one, it depends on the context. Cho, Eun, and Senbet (1986) argue for between one and six factors in an international setting, as do Connor and Korajczyk (1993) for U.S. markets. Chabot (2000) uses five factors to test for market integration using 19th century data.

Figure 5.3

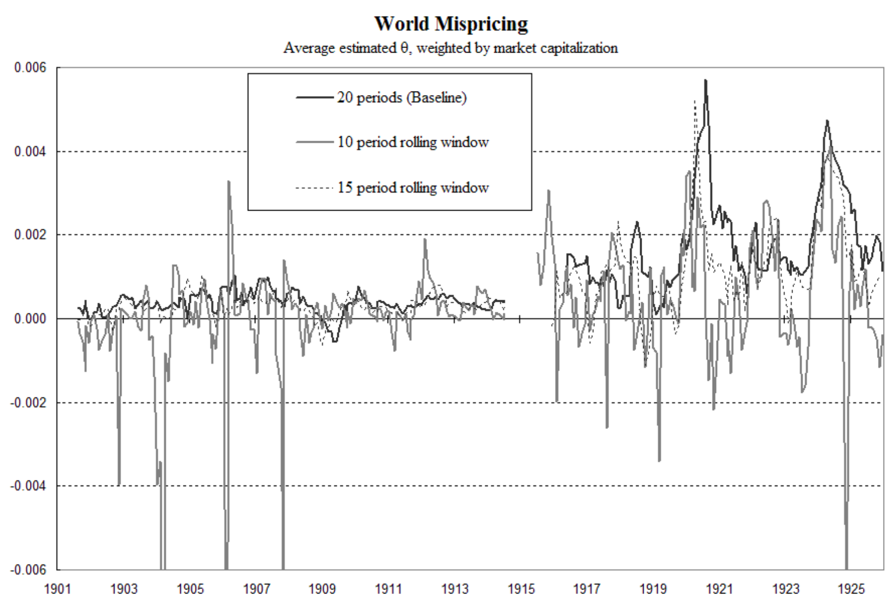


We compare our baseline results using four factors (the return on the world market index plus three principal component factors from $\widetilde{\Phi}$) with results using a two factor model (the return on the world market index and one principal component factor), and a six factor model (the return on the world market index and five principal component factors). Figure 5.3 shows that the results are qualitatively the same and the measurement of integration is of a similar magnitude regardless of whether two, four, or six factors are used.

Sensitivity to the rolling regression window length

The baseline model uses a rolling window of 20 periods, meaning that security returns from one and a half years ago influence the results. Since the window length in the baseline model was chosen somewhat arbitrarily it is useful to investigate if our results are sensitive to that. We re-estimate (6) with a window length of 15 periods (during which we must observe at least 9 returns to include a particular security), and again with a window length of 10 periods (during which we must observe at least 6 returns). Results are shown in Figure 5.4.

Figure 5.4



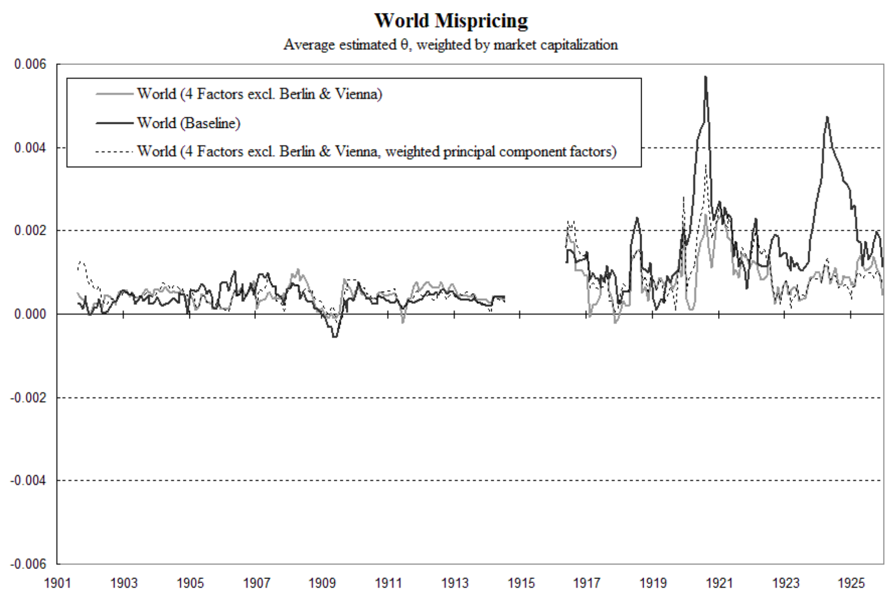
Use of a 15 period window shows broadly similar results to using a 20 period window. The results from a 10 period window are very noisy, but do not contradict results from the 15 and 20 period windows. Measurement of integration appears not to be extremely sensitive to our choice of window length.

Sensitivity to the included markets

Visual inspection of Figures 4.3 and 4.11 suggests that the principal stock exchanges of the losers of World War One, Berlin and Vienna, suffered the greatest loss of integration with the world market. To test whether this was indeed the case we proceed as follows. We re-calculate $\widetilde{\Phi}$ and $\widetilde{\Psi}$ excluding all securities from the Berlin and Vienna markets. We extract three principal component factors from both matrices, that together with the return on the world market index (calculated excluding Berlin and Vienna) will be used to price securities in the remaining markets. We re-estimate (6) for the remaining ten markets using rolling regressions and generate the summary measure of integration, $\widehat{\overline{\theta_t}}$, shown in Figure 5.5.

The large fall in integration after the start of the war is greatly reduced once the markets of Berlin and Vienna are excluded. By late 1922 (the year after which most war-time restrictions on securities trading had been removed in Allied countries) stock market integration in the non-Germanic countries was only slightly above the level in the years immediately preceding the war. The fall in stock market integration as a result of the war does not appear to have been evenly felt in national markets, instead the drop in integration is mostly due to Berlin and Vienna segmenting from the other markets. Hyperinflation in both Germany and Austria in the early 1920s may explain part of the measured drop in integration of those countries, not a permanent breaking of links with other countries' stock exchanges. Extending the data until 1930 may be one way to check if the drop in integration is mainly due to hyperinflation.

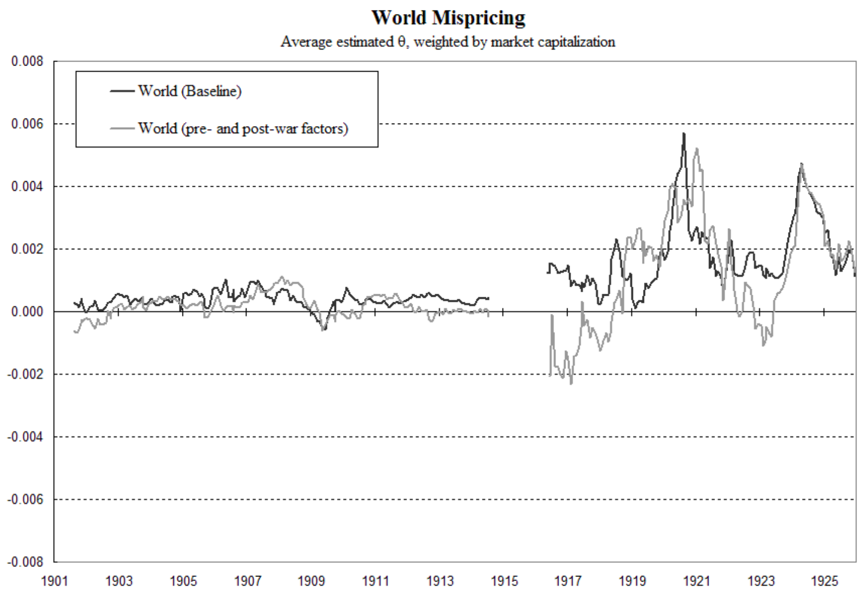
Figure 5.5

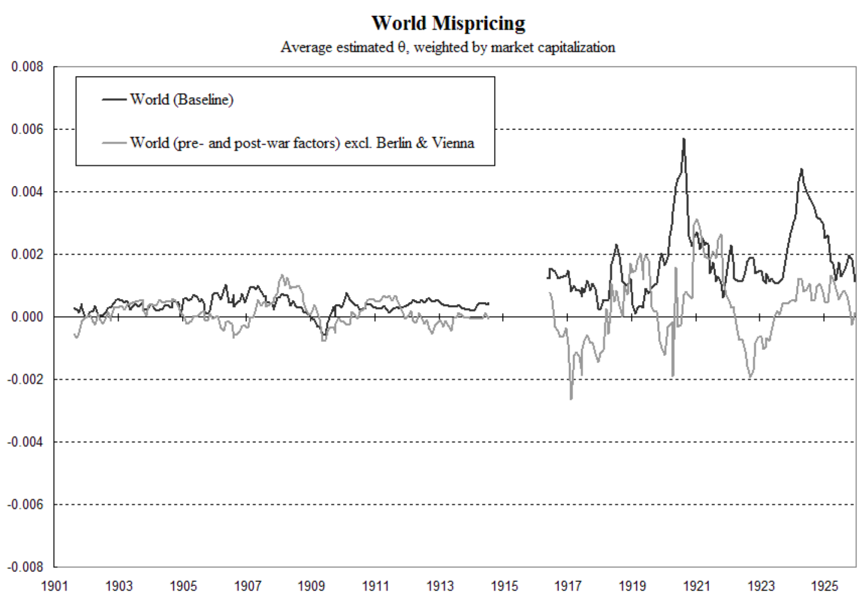


Sensitivity to changing factors

A concern with interpreting the results is that the factors may have changed over time. The economic variables that determined pre-war security returns may not be the same variables that determined post-war security returns. The sources and types of macroeconomic shocks may have changed over time, and using principal components to estimate factors over the entire data set may not be flexible enough to ascertain changes in the factors. An obvious candidate for a post-war factor, largely absent in the pre-1914 world of the gold standard, is a measure of shocks to exchange rates. To determine if changing economic shocks may be influencing our results we allow for different pre- and post-war factors. We use all security returns from January 1900 until July 1914 to estimate factors using principal components and use these factors to explain pre-war security returns. We then use security returns from August 1914 until December 1925 to estimate factors and use these factors to explain post-war security returns. Figure 5.6 shows that allowing for different pre- and post-war factors does not change the main finding, the 12 world stock markets were not as integrated post-war as they were pre-war. However, allowing for changing factors for the 10 Allied and Neutral countries' exchanges, presented in Figure 5.7, illustrates that most of the increase in mispricing is due to Berlin and Vienna segmenting from world capital markets. Our results are not sensitive to the choice of a single set of factors pre- and post-war or allowing the pre- and post-war factors to change.

Figure 5.6 and Figure 5.7





V. Conclusion

I introduce a new data set of securities traded in 12 national markets. Prices of 7310 stocks and government bonds are observed every four weeks over a period of 26 years. Complementary data on dividends and capital operations of these securities enables the calculation of returns. Using the framework of the international arbitrage pricing theory (IAPT), I investigate the extent of stock market integration pre- and post-World War One. Stock markets are found to be substantially less integrated after the start of the war than they were in the last years of the integrated world economy that operated under the gold standard. This conclusion is found to be robust to the inclusion or exclusion of less frequently traded securities, the number of factors used to estimate the IAPT, the weighting of returns used to estimate the IAPT factors, the length of the rolling regression window, and whether the factors are allowed to differ pre- and post-war. However, the drop in integration can be mostly explained by a strong movement towards market segmentation by Germany and Austria. The ongoing arguments between Germany and the victorious powers over the issue of reparations meant that foreign investors in Germany and Austria, and German and Austrian investors in the rest of the world, faced a greater risk than did domestic investors. Until the issue of reparations was settled forfeiture of securities (very liquid assets that are virtually costless to seize) was a real concern to potential foreign stock market investors. The occurrence of hyperinflation in both Germany and Austria during the early 1920s may also have a substantial role to play in explaining the fall in integration. Investigation of this possibility is a fruitful area for future research.

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Appendix A - Thanks

I would like to thank the following people and organizations for their assistance in moving this paper towards completion, it could not have happened without you all.

Ran Abramitzky, Marie Behrend, Eva Beres, Bibliotheek van de Universiteit van Amsterdam, Bibliotheque Nationale de France, George Bittlingmayer, Reinout deBock, Marty Bodenstein, Roland Bodenstein, Bolsa de Madrid, Fabio Braggion, Tobias Bruenner, Federico Bugni, Fabio Caldieraro, Ben Chabot, Ambarish Chandra, Michael Coates, Allan Collard-Wexler, Jesus Crespo-Cuaresma, Mercedes Delgado-Garcia, Ashwini Deshpande, Mauricio Drelichman, Economic History Association, Michalina Fediuszko, Joe Ferrie, Caroline Fohlin, Etienne Gagnon, Sara Gasbarra, Thomas Gehrig, Libertad Gonzalez, Kathleen Hagerty, Meg Halloran, Anne Hanley, Paula Hokama, Kevin Johnson, Joost Jonker, Richard Kim, Geoffrey Kenyota, Christoph Koenig, John Komlos, Bob Korajczyk, David Lee, Elvia Lopez, Terumasa Matsuyuki, Zsolt Macskasi, Pritesh Mehta, Richard Meier, Yuliya Meshcheryakova, Joel Mokyr, Francesca Molinari, Alex Monge, Christine and Warwick Moore, Chiaki Moriguchi, Sayaka Nakamura, Thomas Neukom, Northwestern University (Dissertation Year Fellowship and Graduate Research Grant), Tetsuji Okazaki, Mukul Patil, Rebecca Rajkowski, Tejal Ramnathkar, Alex Roxin, Paulo Santiago, Sandy Shaver, Kate Smigiel, Barrie Shapiro, Staatsarchiv des Kanton Zurich, Staatsbibliothek zu Berlin, State Library of New South Wales, Chris Taber, Ellis Tallman, Esther Tienstra, Gail Triner, Wiener Boerse AG, Nic Vincent, Michelle van Waveren, Erin Wilson, Jeanie Yuh, and Victoria Zahrobsky.

Appendix B - Data Sources

Amsterdam Data for the Amsterdam market come from the *Nieuw Algemeen Effectenblad* available from the library of the University of Amsterdam. This source reports the daily high and low transaction prices for every stock and bond traded in Amsterdam. I have supplemented this with various issues of *Van Oss' Effectenboek*, also available at the University of Amsterdam library, which contains dividends and information on capital operations.

Berlin Pre-1917 data come from *Norddeutsche Allgemeine Zeitung* available at the University of Freiburg (Breisgau) library. This source contains transaction prices for all securities listed on the Berlin exchange. Post-1917 the quality of the coverage in the *Norddeutsche Allgemeine Zeitung* declines dramatically and I switch to using *Amtliches Kursblatt der Berliner Wertpapierbörse*, the official stock exchange record, available at the Staatsbibliothek zu Berlin. The *Kursblatt* contains transaction prices for all securities listed on the Berlin market. Data on dividends and capital operations come from various issues of *Salings Börsen Jahrbuch*, which can be obtained from the Staatsbibliothek zu Berlin and the Kiel Institute for World Economics.

Canada Data for Toronto are available from *The Financial Post* and *Monetary Times*. *The Financial Post* is available on microfilm at the University of Chicago Library, while the *Monetary Times* is available on microfilm from McMaster University Library. The *Monetary Times* is used from 1900 to 1906, while *The Financial Post* is used from 1907 until 1925. The *Monetary Times* is primarily concerned with money and banking, and in 1900 only lists the prices of banks, building societies, and financial intermediaries, although by 1906 it has diversified into reporting the prices of many industrial companies as well as dividends. *The Financial Post* reports all stocks and bonds listed on the Toronto and Montreal exchange, and states that it reports prices for each security from the market in which each security is most actively traded, without giving further details. Hence, some of the data will consist of prices from the Montreal exchange and some from the Toronto exchange, and it is possible that over time the recorded prices of some securities will switch from Toronto prices to Montreal prices and vice versa. *The Financial Post* also reports dividend data, and its pages contain details of securities' capital operations. Missing data from *The Financial Post* and *Monetary Times* have been augmented with price lists from *The Globe and Mail*, available online through the Vancouver Public Library.

Japan I have used data from the Osaka Stock Exchange from 1901 until 1904. These data come from *The Japan Chronicle*, an English language newspaper published in Kobe during this period. Coverage of the Osaka Stock Exchange is irregular in *The Japan Chronicle* after 1904, therefore from January 1905 I switch to using monthly data for Tokyo. My source is *Kabukai 20nen* (20 years of the stock market), available at the University of Tokyo, Economics Department Library. *Kabukai 20nen* contains data on a sample of securities listed on the Tokyo exchange. The price data for Tokyo are averages of the monthly high and low prices for futures contracts. The price data for Osaka are futures contract prices on the same dates as the other exchanges' prices.

Johannesburg Price data come from two Johannesburg daily newspapers, the *Rand Daily Mail* and *The Star*, available on microfilm from Northwestern University Library. These newspapers published a complete list of bid, ask, and transaction prices from the re-opening of the exchange following the Boer War in January

1902 through 1925. Data on dividends and capital operations comes partly from the *Rand Daily Mail* and *The Star* and partly from the *South African Mining Journal*, available from the Center for Research Libraries at the University of Chicago.

London I thank Ben Chabot for providing the data on London from 1900 through 1907. His data were collected from the *Money Market Review*. I add to these data with prices from *The Economist* from 1908 through to July 1914. The scope of the coverage in *The Economist* declines dramatically after 1914, although major securities are still regularly reported. Information on dividends and capital operations comes from various issues of *The Investor's Monthly Manual*, available electronically from the International Center for Finance at Yale, and various issues of *The Stock Exchange Official Intelligence*, and *The Mining manual and mining year book* (1925 issue), available at Northwestern University Library.

Madrid I use the official publication of the Bolsa de Madrid, the *Boletín de Cotización*, available from the library of the Bolsa in Madrid. It contains transaction prices, dividends, and official announcements about capital operations of all listed companies. Additional data is obtained from various issues of *Anuario Financiero y de Sociedades Anónimas.*

New York I thank Ben Chabot for providing data on the New York Stock Exchange (NYSE) and curb companies that traded in New York between 1900 and 1925. His data come from *The Commercial and Financial Chronicle*. In addition I collect data on U.S. and foreign government bonds that traded on the NYSE between 1900 and 1925 from *The New York Times*. Information on coupon payments and the issued capital of each bond comes from various issues of *Moody's: Governments and Municipals*, available at Northwestern University Library.

Paris There were two markets in Paris at the beginning of the 20th century, the *Parquet* or official market, which was heavily regulated, and the unofficial *Coulisse*. I collect data on the official market from *L'Économiste Français*. Work on collecting dividends and coupons is currently underway. The best record of the unofficial market is *Cote de la Bourse et de la Banque*, available on microfilm at the Bibliotheque Nationale de France. This lists most of the securities that traded on the unofficial market, plus information on those securities' dividends. Work on collecting data for the unofficial market is almost complete. The Bibliotheque Nationale is missing several months of microfilm between 1900 and 1925, so I have added to this with data collected from *Cote Desfossés* available at the offices of La Tribune in Paris.

Sydney I use the *Daily Telegraph*, a Sydney daily newspaper as my primary data source for Sydney before 1917, as there was no official stock exchange publication until 1911. The *Daily Telegraph* contains bid and ask quotes for a fairly complete list of securities that traded on the Sydney Stock Exchange. After 1917 the coverage in the *Daily Telegraph* shrinks rapidly, and I switch to using the official publication of the Sydney Stock Exchange, the *Monthly Stock and Share List*, which contains bid and ask quotes, transaction prices, dividends, and capital operation information on all listed securities. The drawback of the *Monthly Stock and Share List* is that it was published only once a month, typically on a Wednesday in the middle of each month. Data for the pre-1917 period are supplemented with data from *T.J. Thompson's Stock and Share Report*, which was published by a prominent Sydney broker. The *Daily Telegraph* is available on microfilm at the State Library of New South Wales (Reference Library), the *Monthly Stock and Share List* and *T.J. Thompson's Stock and Share Report* are available at the State Library of New South Wales (Mitchell Library).

Vienna The official records of the Vienna Stock Exchange are located in the archives of Wiener Börse AG, Vienna. I have used *Amtliches Coursblatt der Wiener Börse* to compile bid and ask quotes, transaction prices, and dividends of all listed stocks and government bonds. Data on the amount of issued stock and capital operations of the securities comes from various issues of *Compass*, available at the Staatsbibliothek zu Berlin.

Zurich To obtain price data I use *Kursblatt der Zürcher Effektenbörse*, the official records of the Zurich stock exchange, available from the Staatsarchiv des Kantons Zurich. The *Kursblatt* contains bid, ask, and transaction prices as well as dividend data. Information on capital operations and company balance sheets comes from *Vade-mecum des bourses de Bâle, Zurich et Genève* and various issues of *Schweizerisches Finanz-Jahrbuch*.

Appendix C - An unbiased estimator of mispricing

The aim is to show that our measure of integration, $\widehat{\theta}_i = \widehat{\alpha_i}^2 - \widehat{\sigma}^2_{\widehat{\alpha}_i}$, is an unbiased estimator of α_i^2.

Using matrix notation write (suppressing the i notation) the vector of coefficients $\boldsymbol{\beta} = \begin{pmatrix} \alpha \\ b_1 \\ . \\ b_k \end{pmatrix}$, the explanatory variables $\mathbf{X} = \begin{pmatrix} 1 & F_{1,1} & . & F_{k,1} \\ 1 & F_{1,2} & . & F_{k,2} \\ . & . & . & . \\ 1 & F_{1,T} & . & F_{k,T} \end{pmatrix}$, and the error terms $\mathbf{U} = \begin{pmatrix} u_1 \\ u_2 \\ . \\ u_T \end{pmatrix}$. Although in practice we use White's (1980) heteroskedasticity adjustment, in case heteroskedasticity is present in the data, the proof outlined here is for the simpler case when the errors are homoskedastic. Although to prove $\widehat{\theta}_i$ is an unbiased estimator we only need to show that $E\left(\widehat{\theta}_i\right) = \alpha_i^2$, it is easier to prove that $\widehat{\boldsymbol{\theta}} = \begin{pmatrix} \widehat{\alpha}^2 - \widehat{\sigma}^2_\alpha \\ \widehat{b}_1^2 - \widehat{\sigma}^2_{b_1} \\ . \\ \widehat{b}_k^2 - \widehat{\sigma}^2_{b_k} \end{pmatrix}$ is an unbiased estimator of $\boldsymbol{\beta}^2$.

The estimator we wish to show is unbiased is $\widehat{\boldsymbol{\theta}} = \boldsymbol{\beta}^2 - \widehat{\sigma}^2_{\widehat{\boldsymbol{\beta}}}$

We first substitute $\widehat{\sigma}^2_{\widehat{\boldsymbol{\beta}}} = s^2_{\widehat{u}} \left(\mathbf{X}'\mathbf{X}\right)^{-1}$ (Stock and Watson (2003) Equation 16.32) giving: $\widehat{\boldsymbol{\theta}} = \widehat{\boldsymbol{\beta}}^2 - s^2_{\widehat{u}} \left(\mathbf{X}'\mathbf{X}\right)^{-1}$

Write $\widehat{\boldsymbol{\beta}} = \boldsymbol{\beta} + \left(\mathbf{X}'\mathbf{X}\right)^{-1} \left(\mathbf{X}'\mathbf{U}\right).$

Therefore, $\widehat{\boldsymbol{\theta}} = \boldsymbol{\beta}^2 + 2\boldsymbol{\beta} \left(\mathbf{X}'\mathbf{X}\right)^{-1} \left(\mathbf{X}'\mathbf{U}\right) + \left(\mathbf{X}'\mathbf{X}\right)^{-1} \left(\mathbf{X}'\mathbf{U}\right) \left(\mathbf{U}'\mathbf{X}\right) \left(\mathbf{X}'\mathbf{X}\right)^{-1} - s^2_{\widehat{u}} \left(\mathbf{X}'\mathbf{X}\right)^{-1}$.

Take expectations: $E\left(\widehat{\boldsymbol{\theta}}\right) = \boldsymbol{\beta}^2 + 2\boldsymbol{\beta} \left(\mathbf{X}'\mathbf{X}\right)^{-1} \left(\mathbf{X}'E(\mathbf{U}/\mathbf{X})\right) +$
$\left(\mathbf{X}'\mathbf{X}\right)^{-1} \mathbf{X}'E(\mathbf{U}'\mathbf{U})\mathbf{X} \left(\mathbf{X}'\mathbf{X}\right)^{-1} - E(s^2_{\widehat{u}}) \left(\mathbf{X}'\mathbf{X}\right)^{-1}$

Simplifying $E\left(\widehat{\boldsymbol{\theta}}\right) = \boldsymbol{\beta}^2 + \sigma^2_u \left(\mathbf{X}'\mathbf{X}\right)^{-1} - \sigma^2_u \left(\mathbf{X}'\mathbf{X}\right)^{-1} = \boldsymbol{\beta}^2$.

Where we make use of $E(\mathbf{U}/\mathbf{X}) = 0$, and $E(s^2_{\widehat{u}}) = \sigma^2_u$ (Stock and Watson (2003) p. 619)

Appendix D - Construction of Confidence Intervals

To derive the asymptotic distribution of the summary mispricing measure, $\overline{\overline{\theta}} = \sum_{i=1}^{N} w_i \widehat{\theta}_i$, I use two stages. First, obtain the asymptotic distribution of $\widehat{\theta}_i$ (i.e. that of an individual security), second apply the delta method to obtain the asymptotic distribution of $\overline{\overline{\theta}}$.

I find the limiting behaviour of $\widehat{\theta}_i$ by obtaining the asymptotic distribution of $\sqrt{T}\left(\widehat{\theta}_i - \alpha_i^2\right) = \sqrt{T}\left(\widehat{\alpha_i}^2 - \widehat{\sigma}^2_{\widehat{\alpha}_i} - \alpha_i^2\right)$.

First, separate the terms by $\sqrt{T}\left(\widehat{\alpha_i}^2 - \widehat{\sigma}^2_{\widehat{\alpha}_i} - \alpha_i^2\right) = \sqrt{T}\left(\widehat{\alpha_i}^2 - \alpha_i^2\right) - \sqrt{T}\left(\widehat{\sigma}^2_{\widehat{\alpha}_i}\right)$.

Second, note that $\widehat{\sigma}^2_{\widehat{\alpha}_i} \longrightarrow \sigma^2_{\widehat{\alpha}_i}$ as $T \longrightarrow \infty$ at rate T (i.e. the estimate of the variance of the intercept term is asymptotically unbiased). To see the convergence speed write $\sigma^2_{\widehat{\alpha}_i} = \frac{1}{T}\frac{E\left(X_i^2\right)\sigma_u^2}{\sigma_X^2}$ (simplified by assuming homoskedastic errors), and noting that the expectation and variances are constants. The OLS estimators are consistent, which means that $\sigma^2_{\widehat{\alpha}_i} \xrightarrow{p} 0$ as $T \longrightarrow \infty$, therefore $\sqrt{T}\left(\widehat{\sigma}^2_{\widehat{\alpha}_i}\right) \xrightarrow{p} 0$ due to $\widehat{\sigma}^2_{\widehat{\alpha}_i}$ converging to zero faster (at rate T) than $\sqrt{T}$ goes to infinity. This implies that $\sqrt{T}\left(\widehat{\alpha_i}^2 - \widehat{\sigma}^2_{\widehat{\alpha}_i} - \alpha_i^2\right) = \sqrt{T}\left(\widehat{\alpha_i}^2 - \alpha_i^2\right) - O_p(1)$.

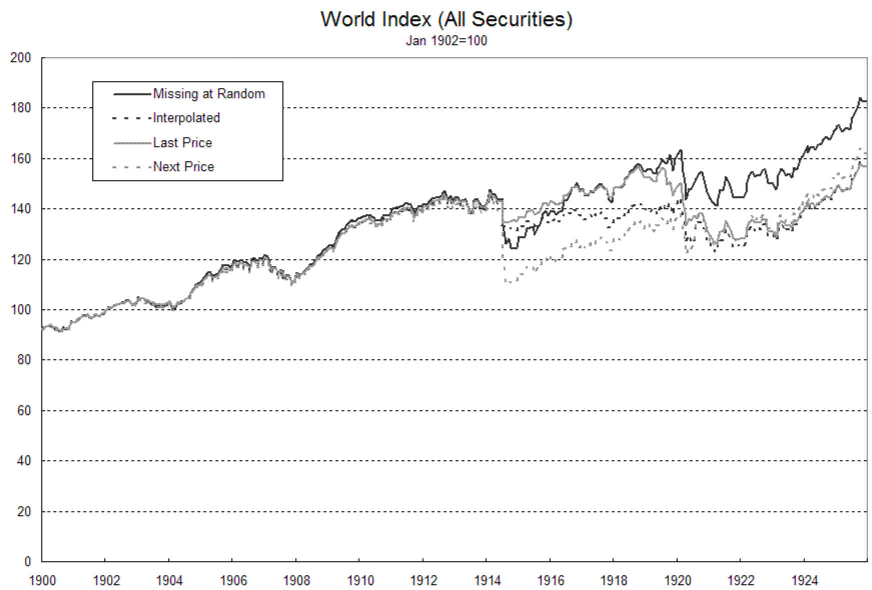
Third, write $\widehat{\alpha_i}^2 = f_1(\widehat{\alpha}_i)$ and $\alpha_i^2 = f_2(\alpha_i)$ and substitute: $\sqrt{T}\left(\widehat{\alpha_i}^2 - \alpha_i^2\right) = \sqrt{T}\left(f_1(\widehat{\alpha}_i) - f_2(\alpha_i)\right)$. By the delta method $\sqrt{T}\left(f_1(\widehat{\alpha}_i) - f_2(\alpha_i)\right) \xrightarrow{d} \sqrt{T}\left(\bigtriangledown f(\alpha)\left(\widehat{\alpha}_i - \alpha_i\right)\right)$. Since $\sqrt{T}\left(\widehat{\alpha}_i - \alpha_i\right) \xrightarrow{d} N\left(0, \sigma^2_{\widehat{\alpha}_i}\right)$ we have that $\sqrt{T}\left(\widehat{\alpha_i}^2 - \alpha_i^2\right) \xrightarrow{d} N\left(0, 2\alpha_i \sigma^2_{\widehat{\alpha}_i}\right)$. In practice we do not know α_i nor $\sigma^2_{\widehat{\alpha}_i}$ therefore replace them with their estimates.

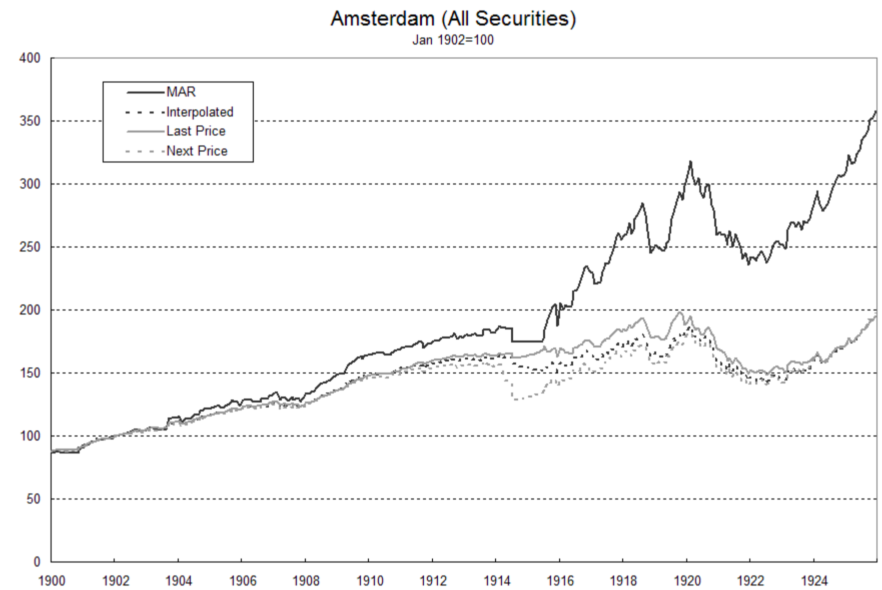
Since we have $\sqrt{T}\left(\widehat{\alpha_i}^2 - \alpha_i^2\right) \xrightarrow{d} N\left(0, 2\alpha_i \sigma^2_{\widehat{\alpha}_i}\right)$ and $\sqrt{T}\left(\widehat{\sigma}^2_{\widehat{\alpha}_i}\right) \xrightarrow{p} \sigma^2_{\widehat{\alpha}_i} = 0$ then by the Slutsky Theorem $\sqrt{T}\left(\widehat{\theta}_i - \alpha_i^2\right) \xrightarrow{d} N\left(0, 2\alpha_i \sigma^2_{\widehat{\alpha}_i}\right)$.

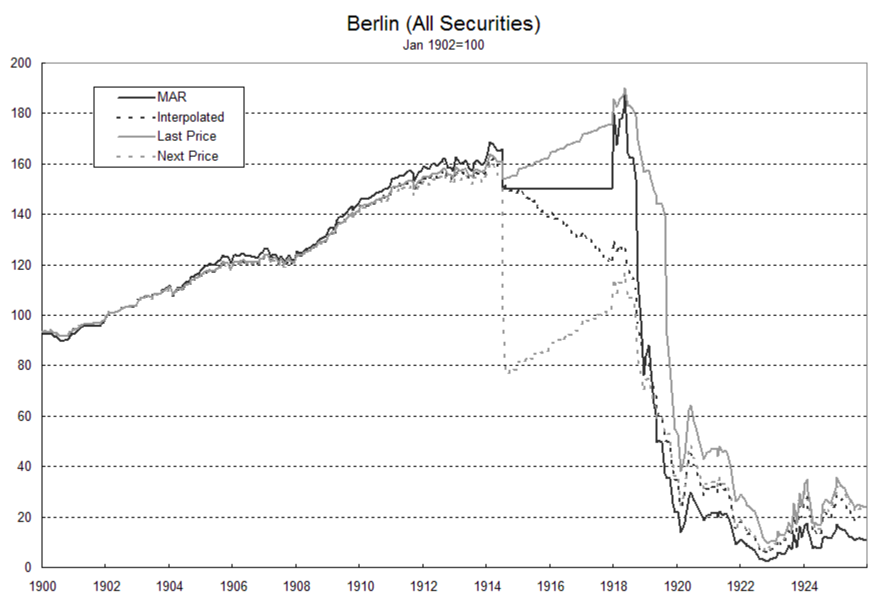
Confidence intervals for α_i^2 at significance level ρ can be calculated noting that since asymptotically $P\left(Z_{\frac{\rho}{2}} \leq \frac{\sqrt{T}\left(\widehat{\theta}_i - \alpha_i^2\right)}{\sqrt{2\widehat{\alpha}_i \widehat{\sigma}^2_{\widehat{\alpha}_i}}} \leq Z_{1-\frac{\rho}{2}}\right) = 1-\rho$ then by re-arranging $P\left(\frac{Z_{\frac{\rho}{2}}\sqrt{2\widehat{\alpha}_i \widehat{\sigma}^2_{\widehat{\alpha}_i}}}{\sqrt{T}} \leq \left(\widehat{\theta}_i - \alpha_i^2\right) \leq \frac{Z_{1-\frac{\rho}{2}}\sqrt{2\widehat{\alpha}_i \widehat{\sigma}^2_{\widehat{\alpha}_i}}}{\sqrt{T}}\right) = 1-\rho$ and finally $P\left(\widehat{\theta}_i - \frac{Z_{\frac{\rho}{2}}\sqrt{2\widehat{\alpha}_i \widehat{\sigma}^2_{\widehat{\alpha}_i}}}{\sqrt{T}} \geq \alpha_i^2 \geq \widehat{\theta}_i - \frac{Z_{1-\frac{\rho}{2}}\sqrt{2\widehat{\alpha}_i \widehat{\sigma}^2_{\widehat{\alpha}_i}}}{\sqrt{T}}\right) = 1-\rho$

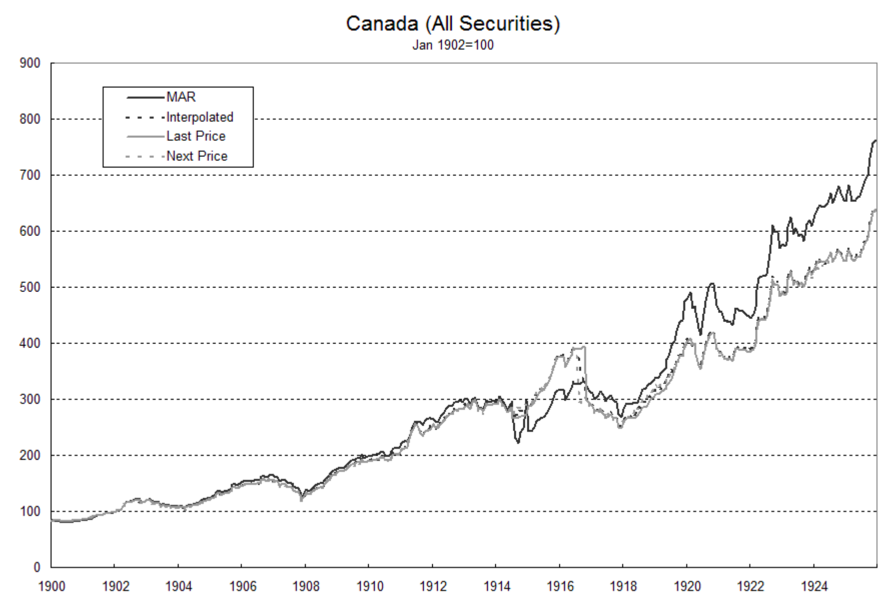
Now we can derive the asymptotic distribution of $\overline{\overline{\theta}} = \sum_{i=1}^{I} w_i \widehat{\theta}_i$ using the delta method, where weights are the share of total market capitalization accounted for by security i. Write $f_1(\widehat{\alpha}_i) = \sum_{i=1}^{N} w_i \widehat{\alpha_i}^2 - \sum_{i=1}^{N} w_i \widehat{\sigma}^2_{\widehat{\alpha}_i}$ and $f_2(\alpha_i) = \sum_{i=1}^{N} w_i \alpha_i^2$. Since we sum measured mispricing over N securities, which are calculated over T time periods, the relevant item to consider is $\sqrt{NT}\left(\sum_{i=1}^{N} w_i\left(\widehat{\alpha_i}^2 - \widehat{\sigma}^2_{\widehat{\alpha}_i} - \alpha_i^2\right)\right)$. Using a similar argument to that used above I argue that $\widehat{\sigma}^2_{\widehat{\alpha}_i}$ is $O_p(1)$ and thus that $\sum_{i=1}^{N} w_i \widehat{\sigma}^2_{\widehat{\alpha}_i}$ is $O_p(1)$. Therefore, $\sqrt{NT}\left(\sum_{i=1}^{N} w_i\left(\widehat{\alpha_i}^2 - \widehat{\sigma}^2_{\widehat{\alpha}_i} - \alpha_i^2\right)\right) = \sqrt{NT}\left(\sum_{i=1}^{N} w_i\left(\widehat{\alpha_i}^2 - \alpha_i^2\right)\right) - O_p(1)$. Applying the delta method obtain $f_1(\widehat{\alpha}_i) \overset{A}{\sim} N\left(f_2(\alpha_i), \frac{\sum_{i,j=1}^{N} 4\alpha_i\alpha_j w_i w_j \sigma^2_{\widehat{\alpha}_i}\sigma^2_{\widehat{\alpha}_j}}{NT}\right)$, where in practice I replace α_i, α_j, $\sigma^2_{\widehat{\alpha}_i}$, and $\sigma^2_{\widehat{\alpha}_j}$ by their estimates. Therefore, our confidence intervals for the summary mispricing measure are $\overline{\overline{\theta}} \pm Z_{\frac{\rho}{2}}\sqrt{\frac{\sum_{i,j=1}^{N} 4\widehat{\alpha_i}\widehat{\alpha_j} w_i w_j \sigma_{\widehat{\widehat{\alpha}_i,\widehat{\alpha}_j}}}{NT}}$.

Figures 1.1 - 1.4

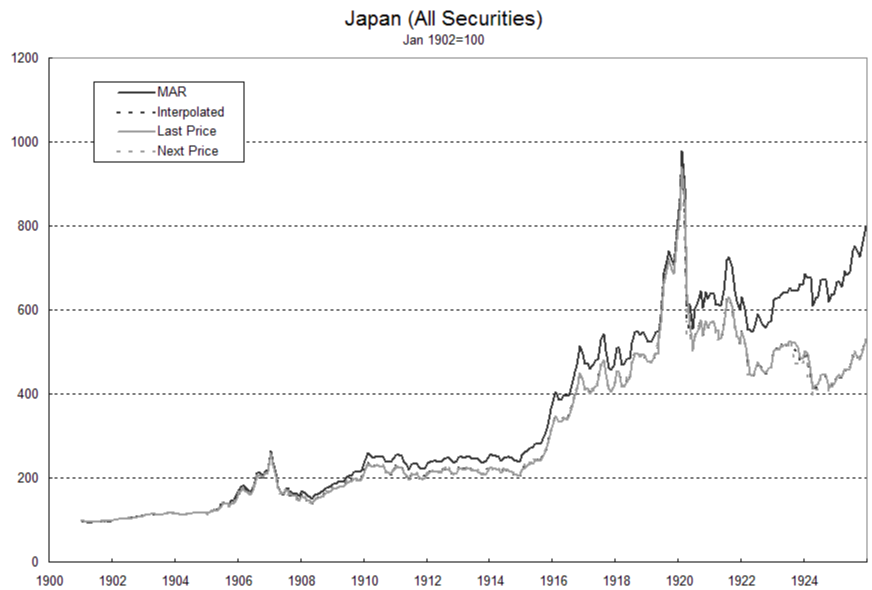


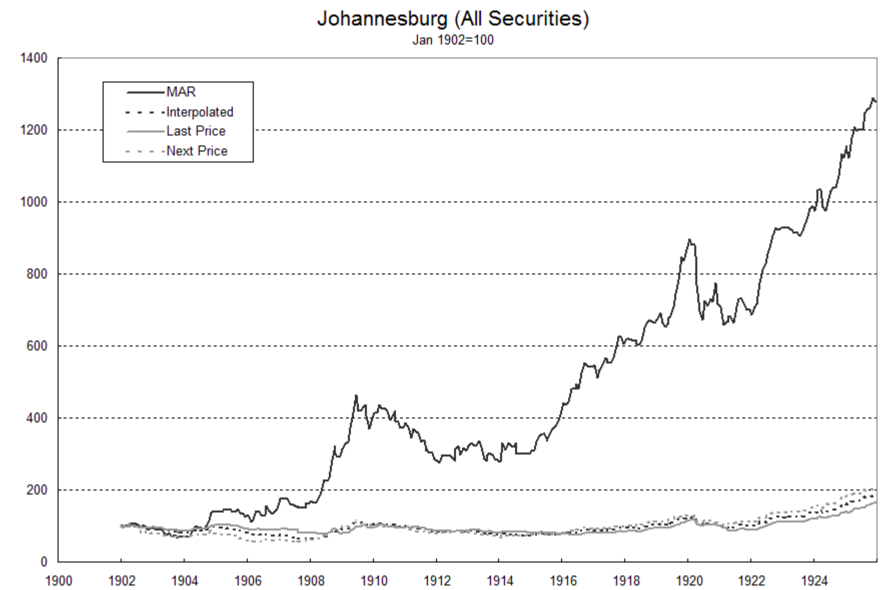


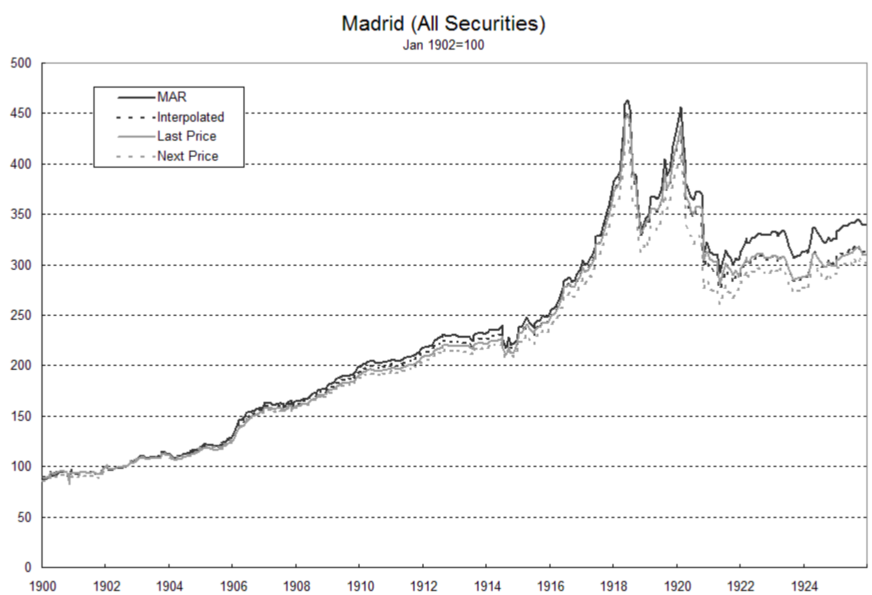


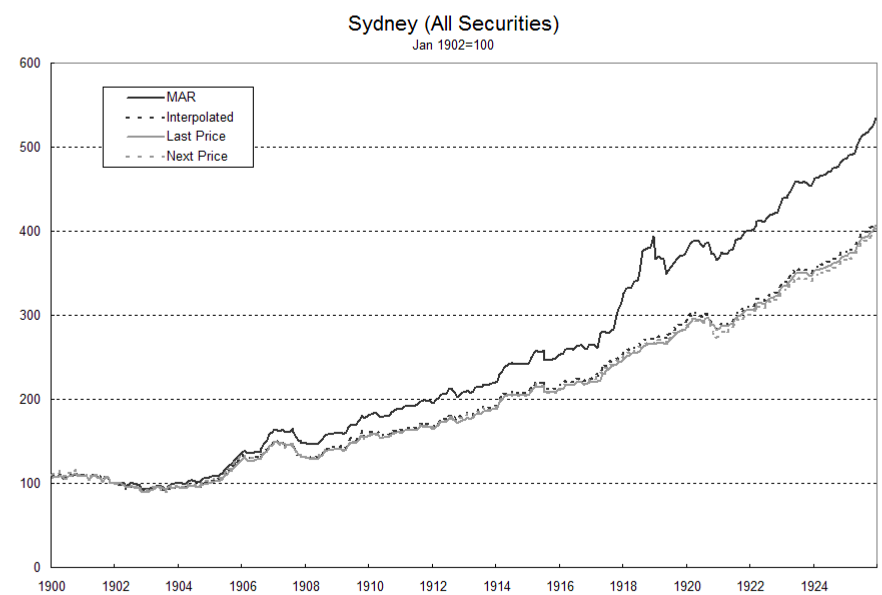


Figures 1.5 - 1.8

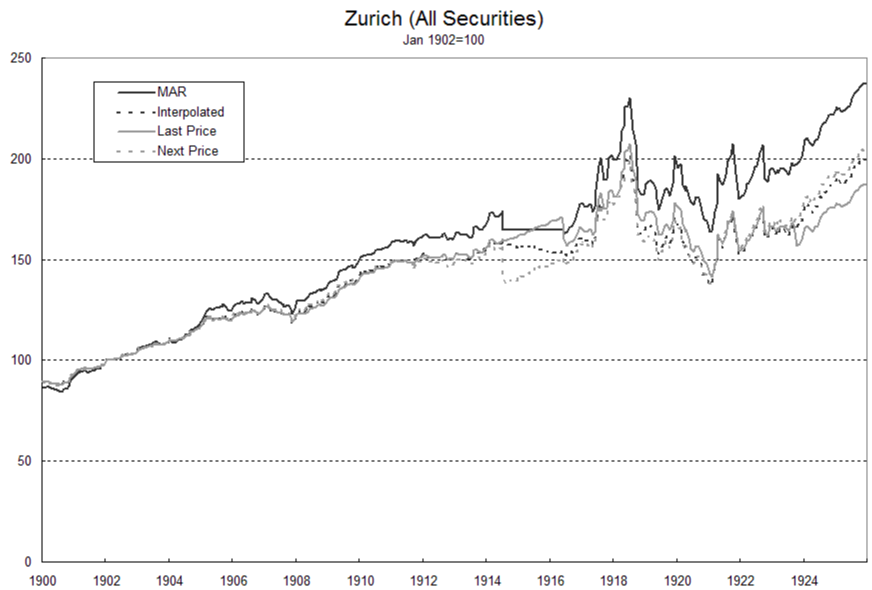


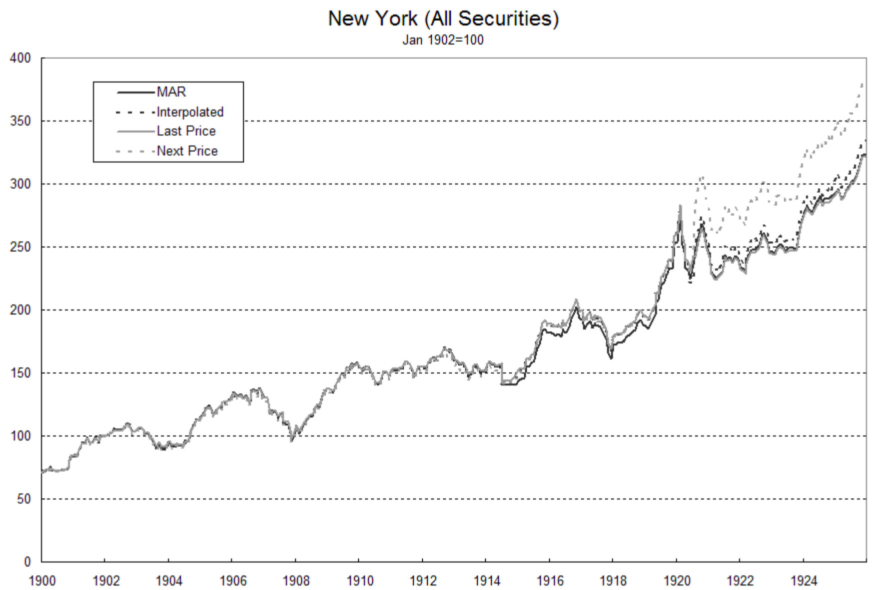


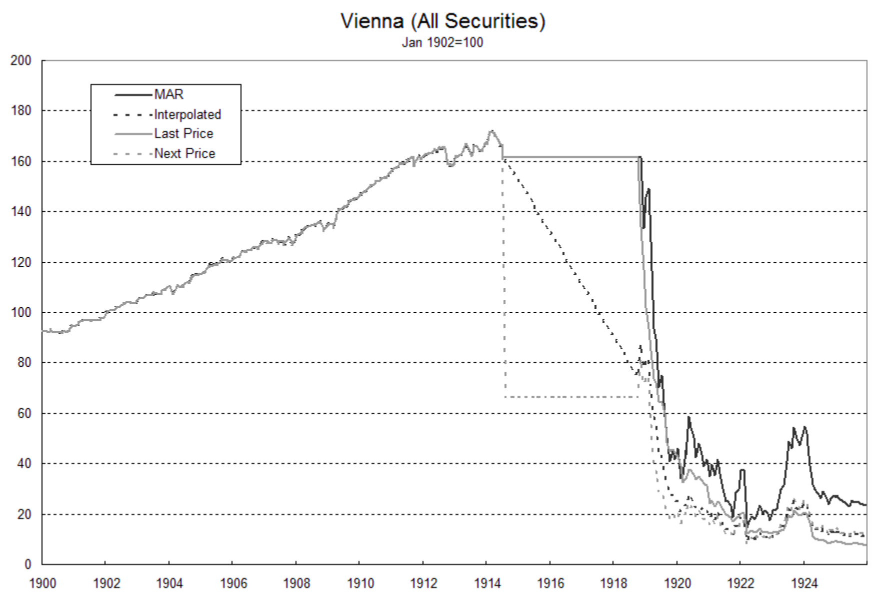


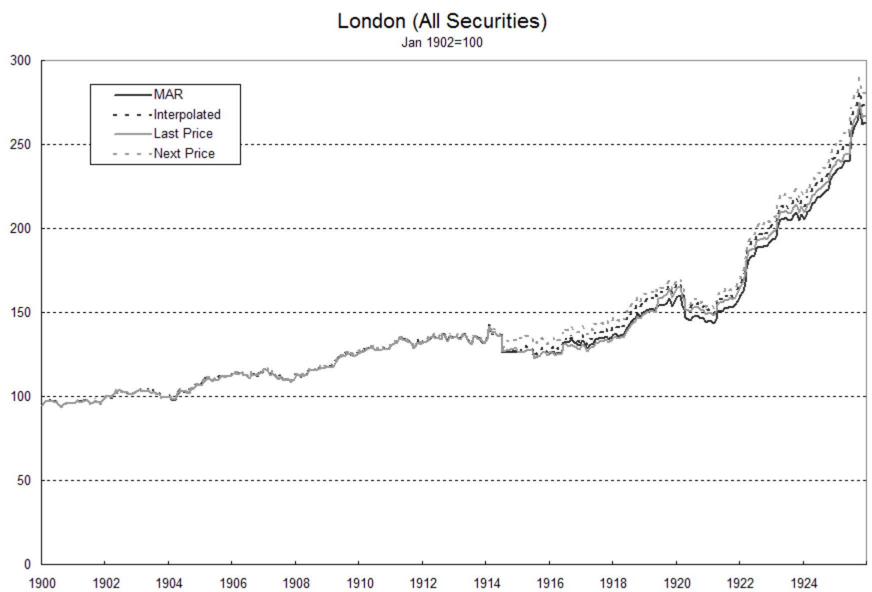


Figures 1.9 - 1.12

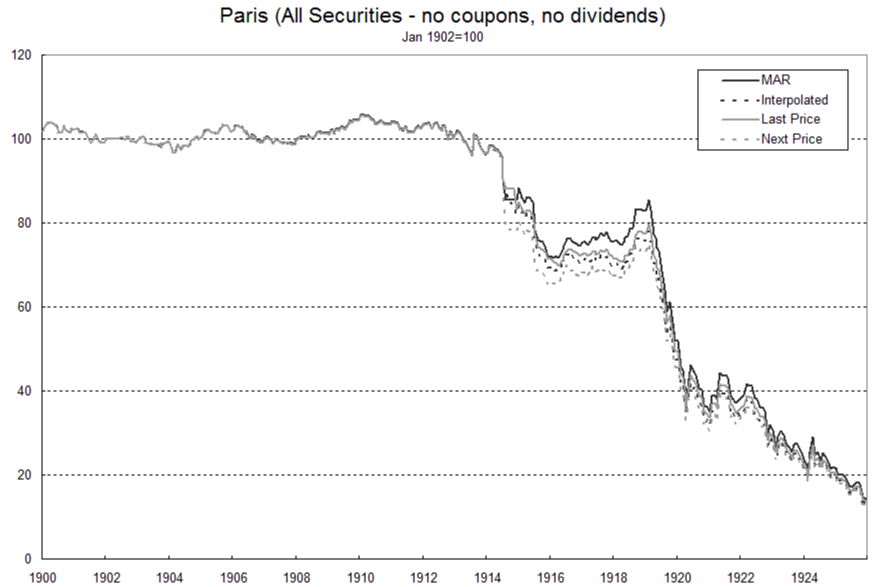


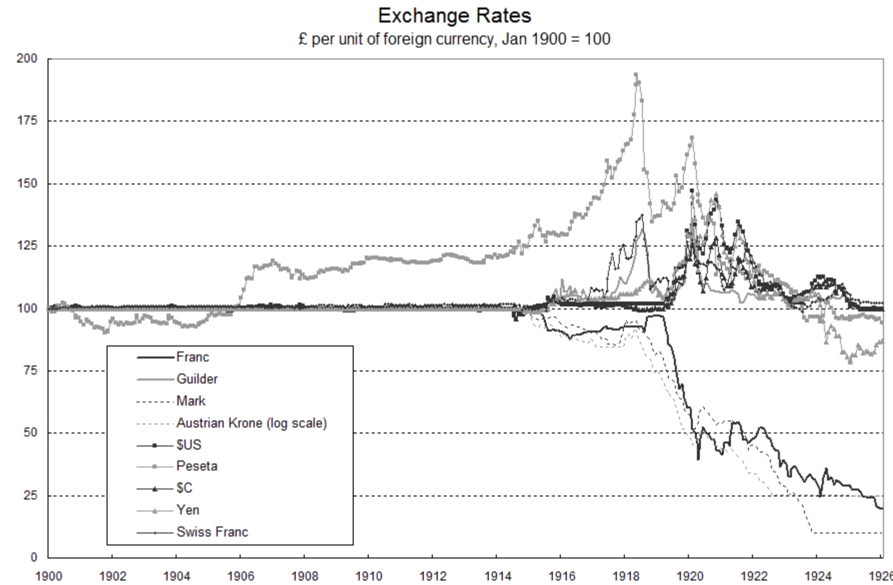




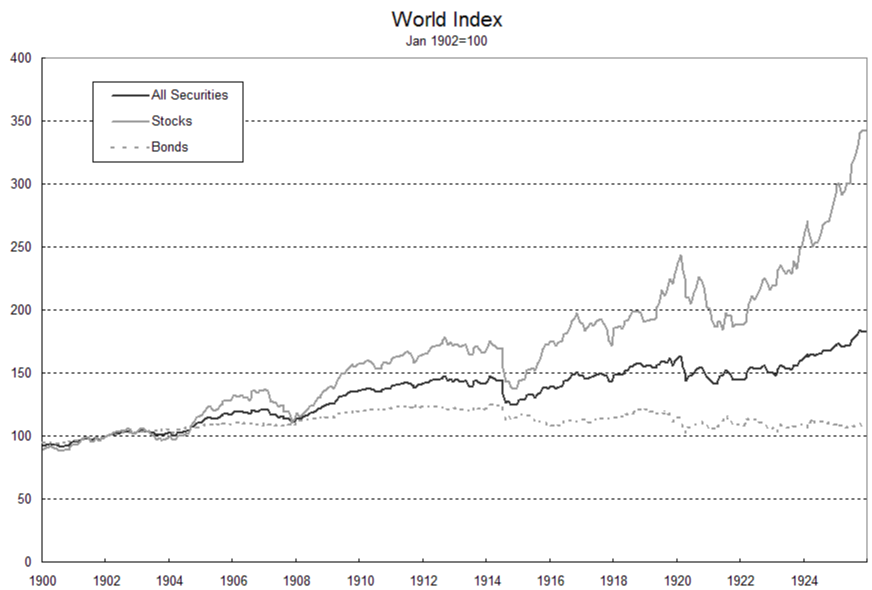


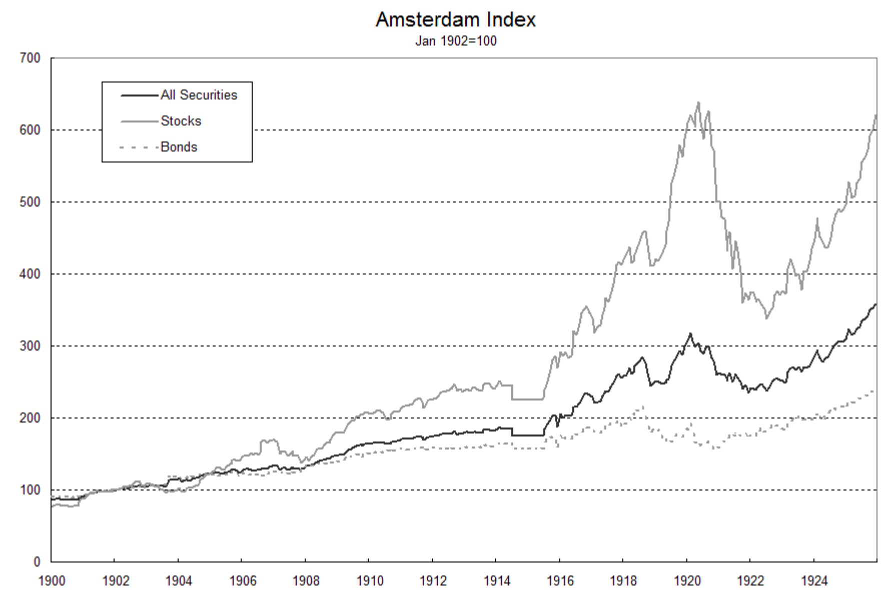
Figures 1.13 - 1.14

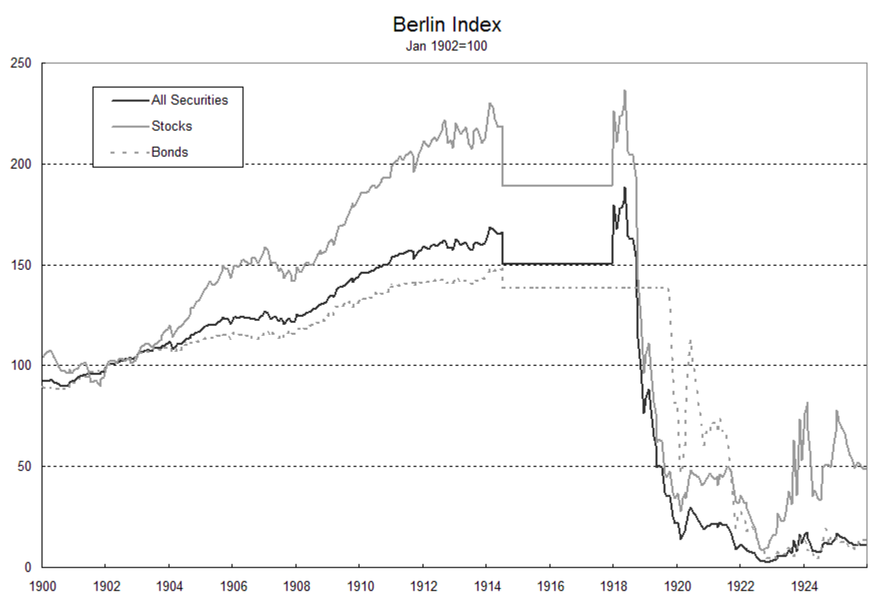


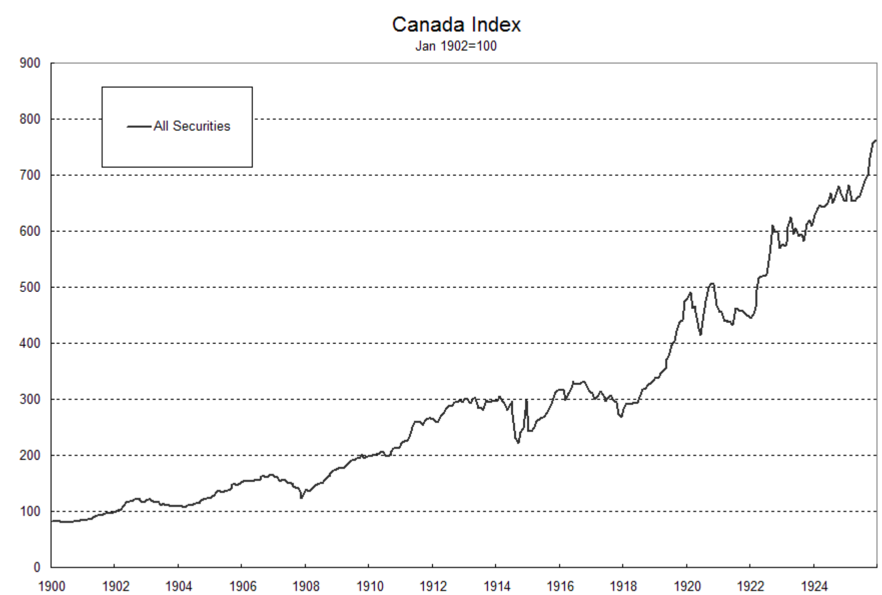


Figures 2.1 - 2.4

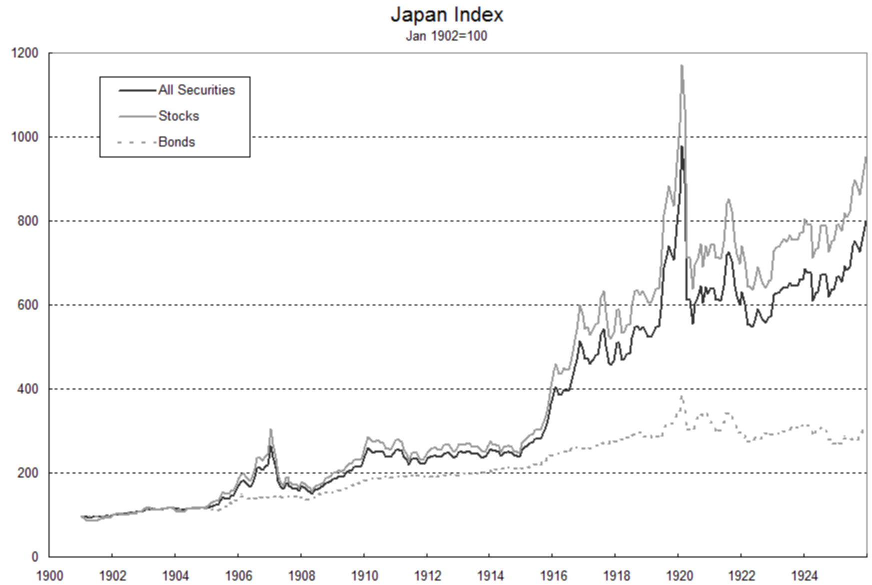


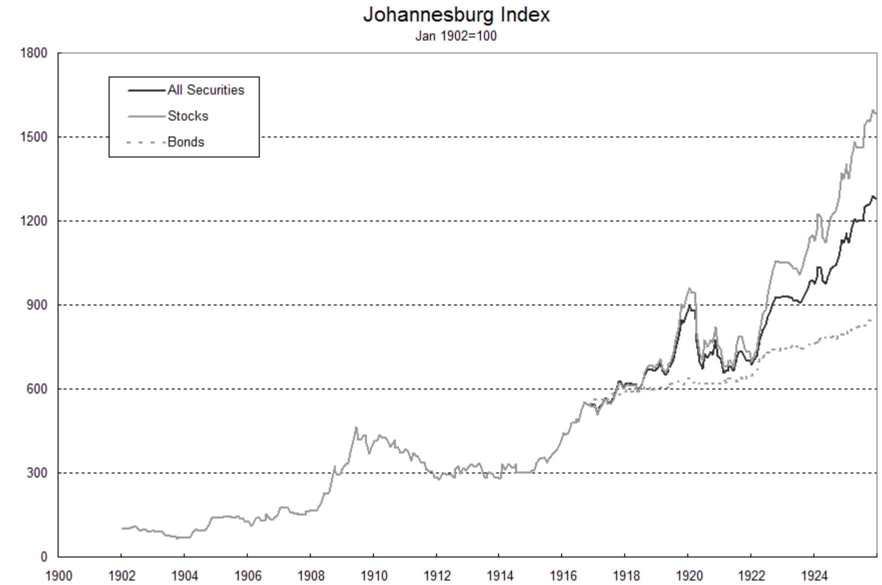


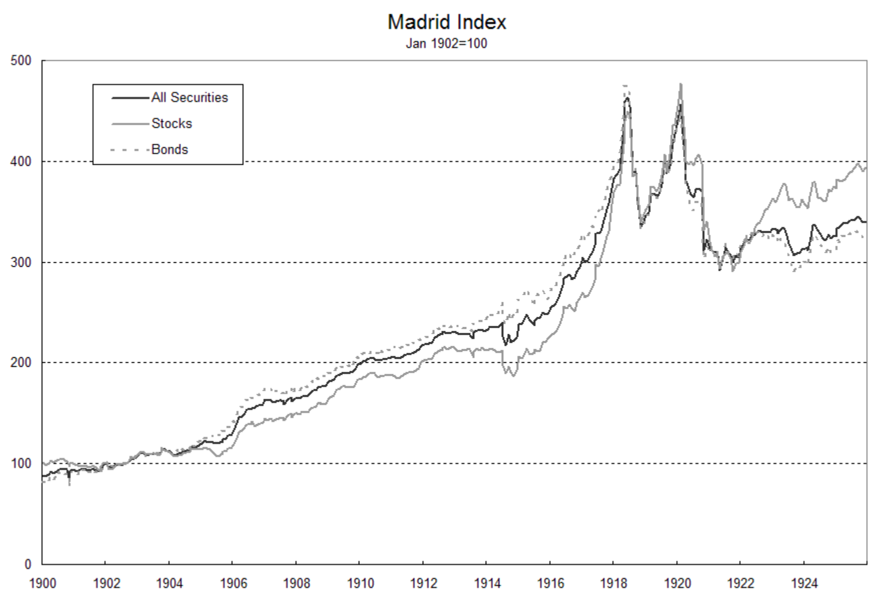


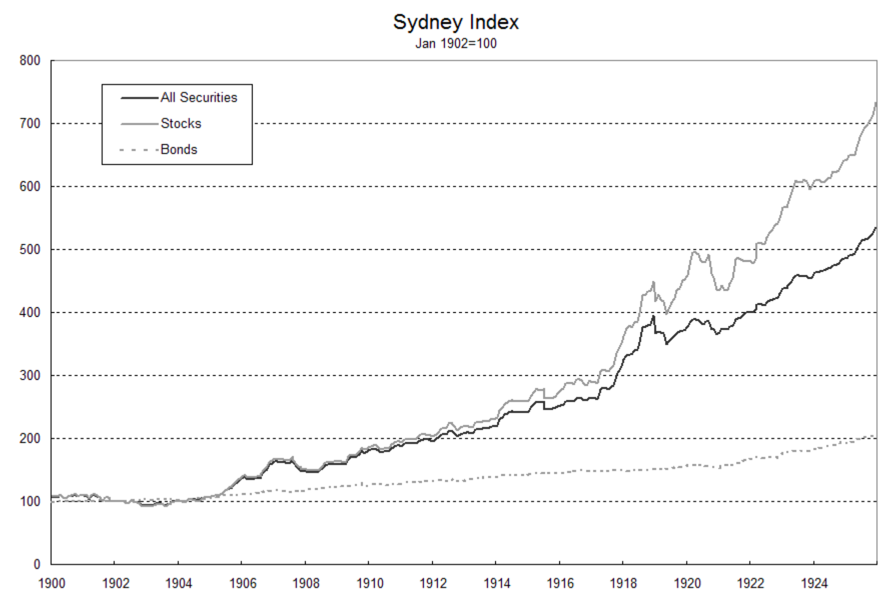


Figures 2.5 - 2.8

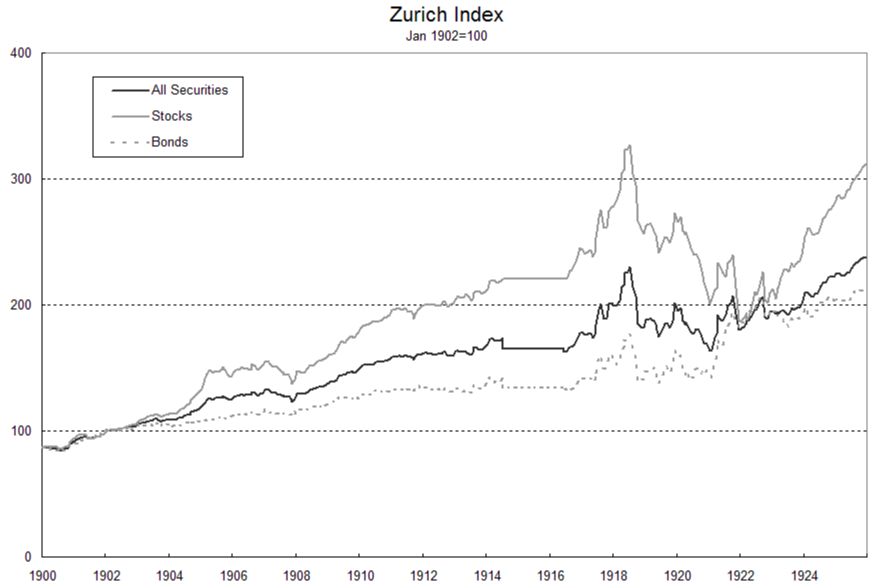


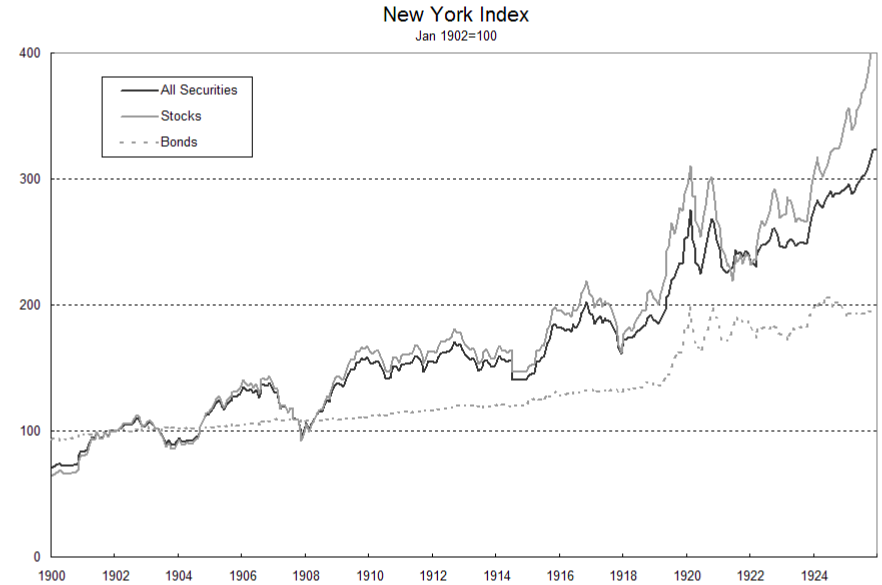


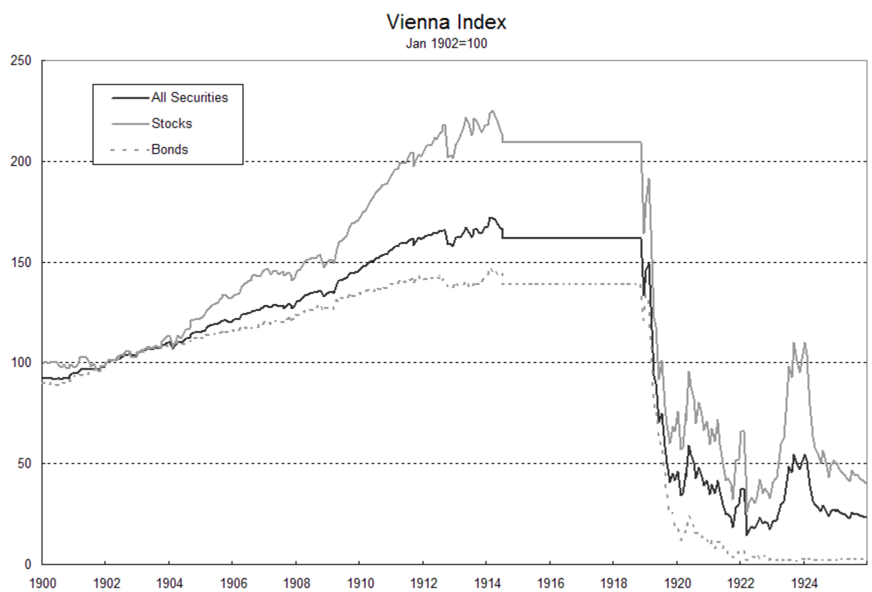


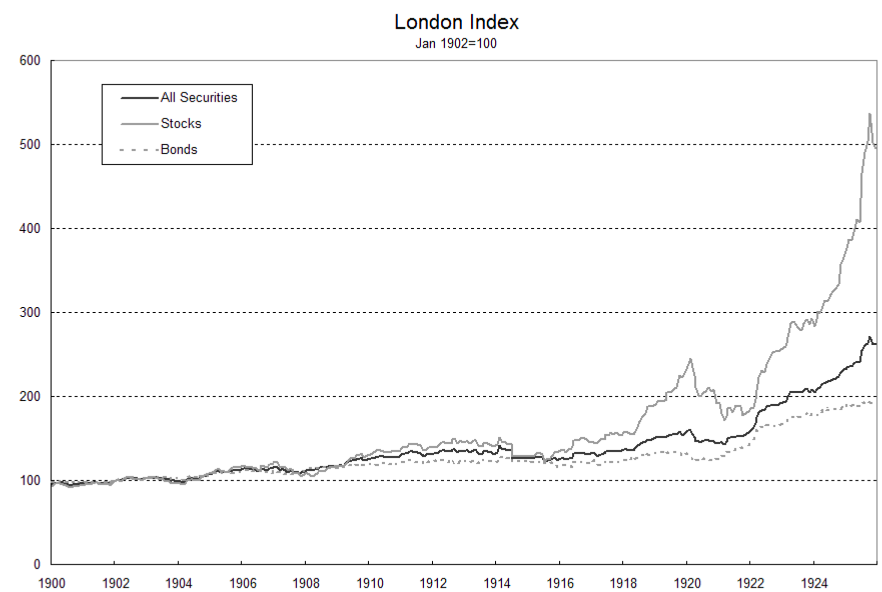


Figures 2.9 - 2.12

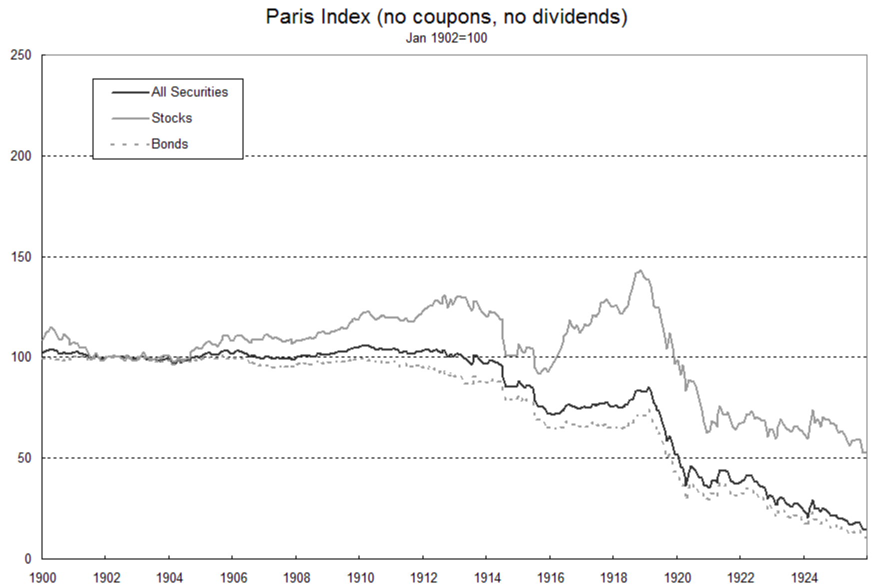


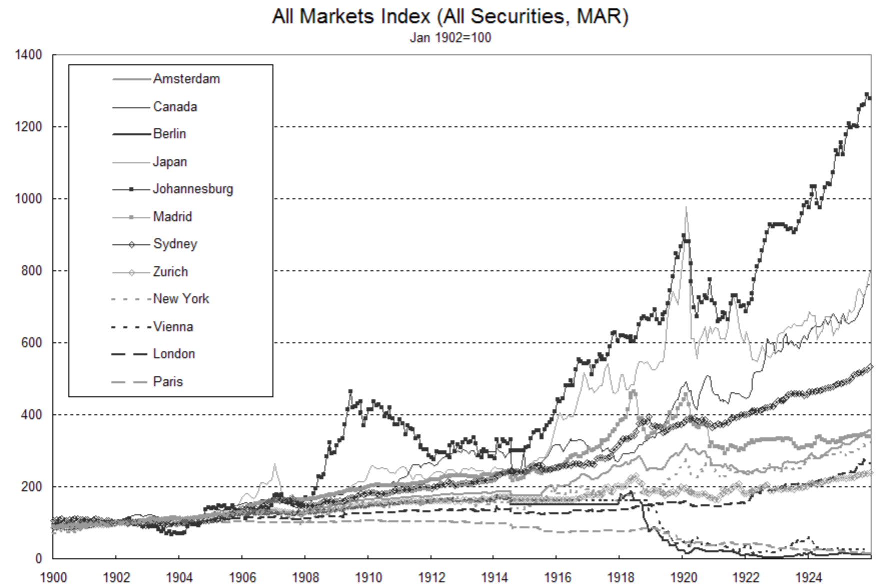






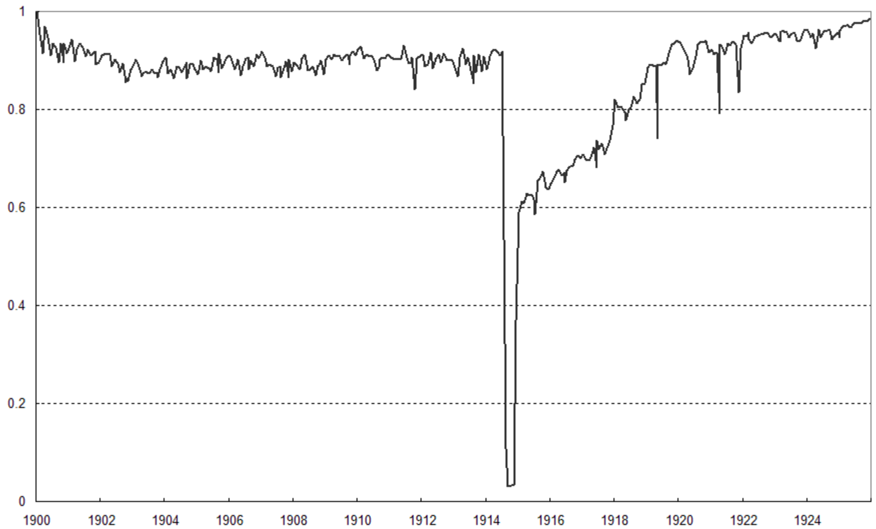
Figures 2.13 - 2.14



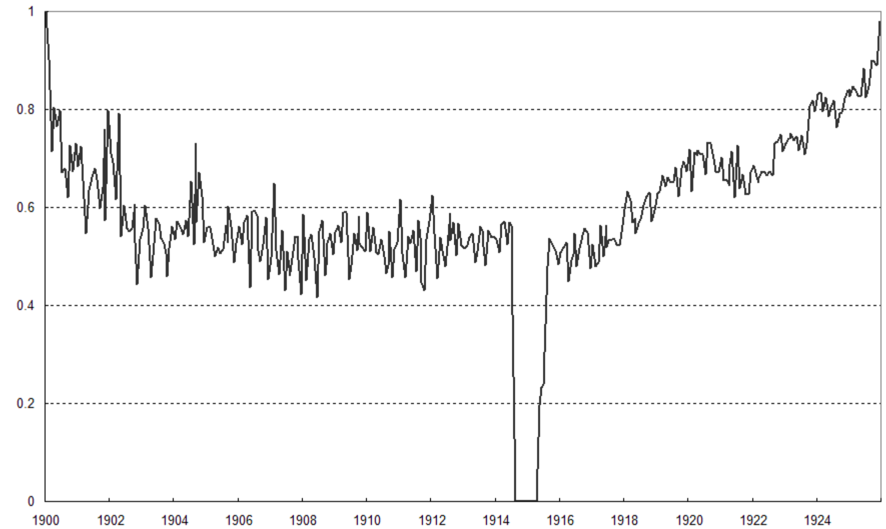


Figures 3.1 - 3.4

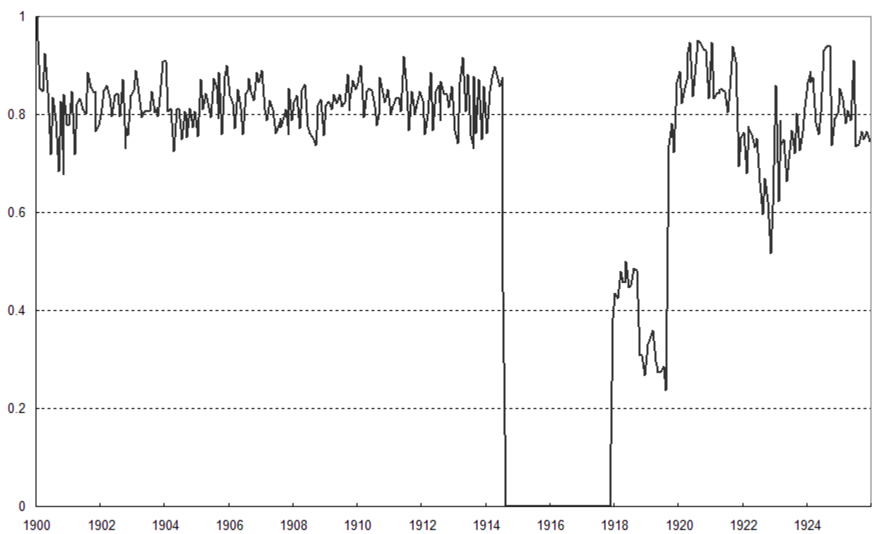
World
Proportion of market capitalization for which we observe a price



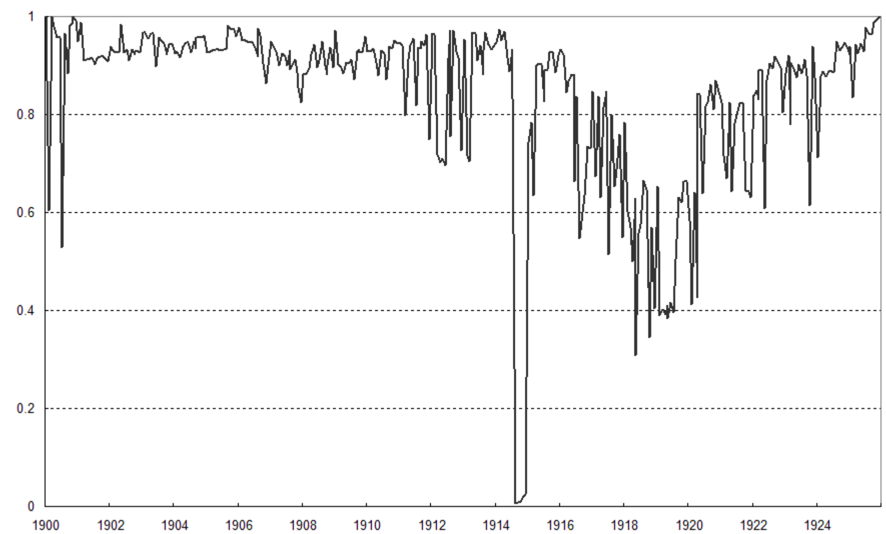
Amsterdam
Proportion of market capitalization for which we observe a price



Berlin
Proportion of market capitalization for which we observe a price



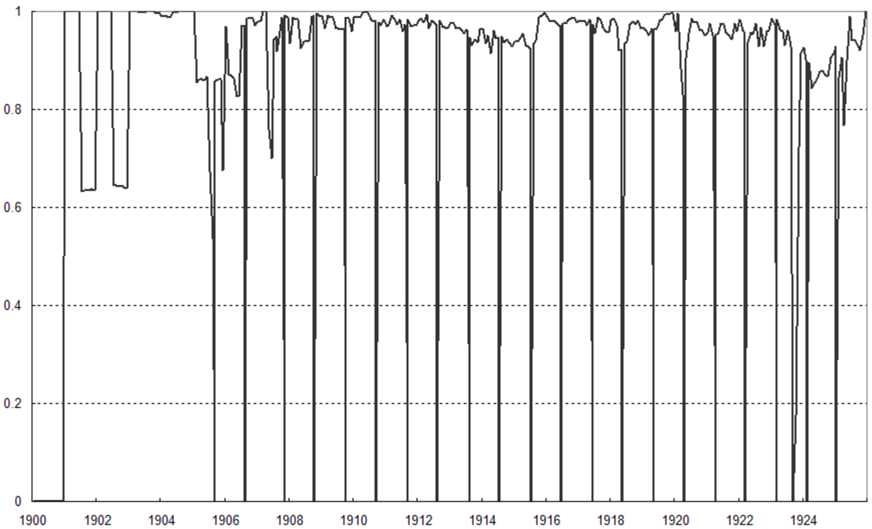
Canada
Proportion of market capitalization for which we observe a price



Figures 3.5 - 3.8

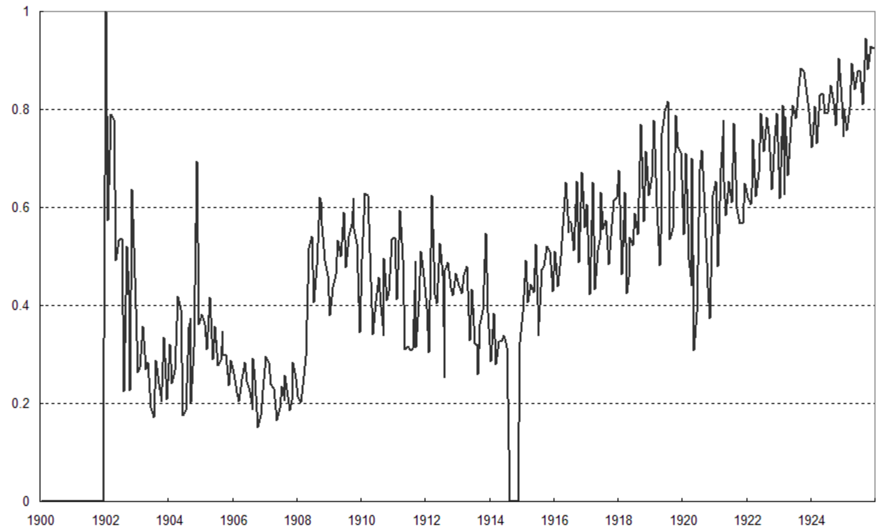
Japan

Proportion of market capitalization for which we observe a price



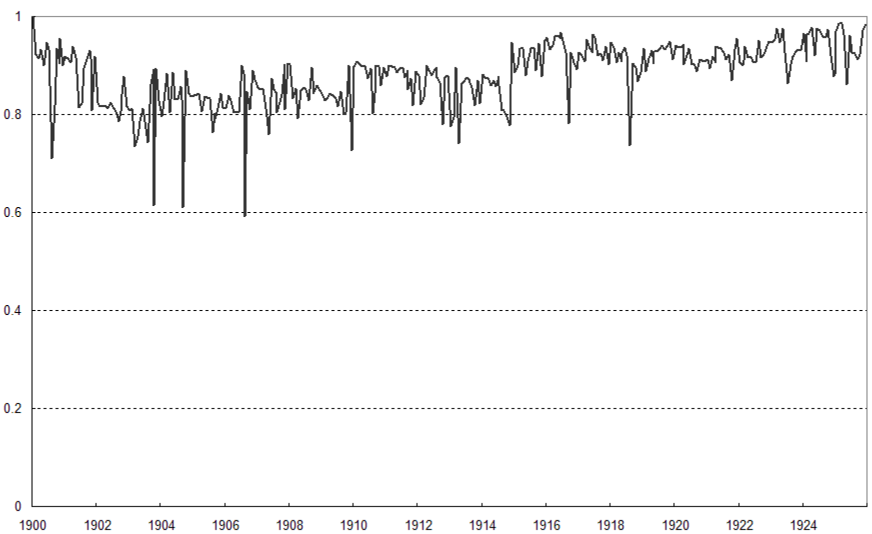
Johannesburg

Proportion of market capitalization for which we observe a price



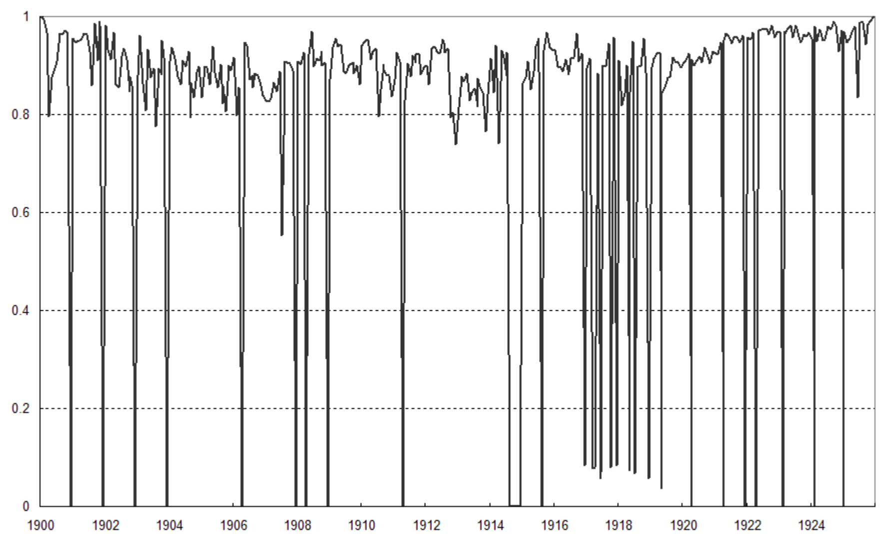
Madrid

Proportion of market capitalization for which we observe a price



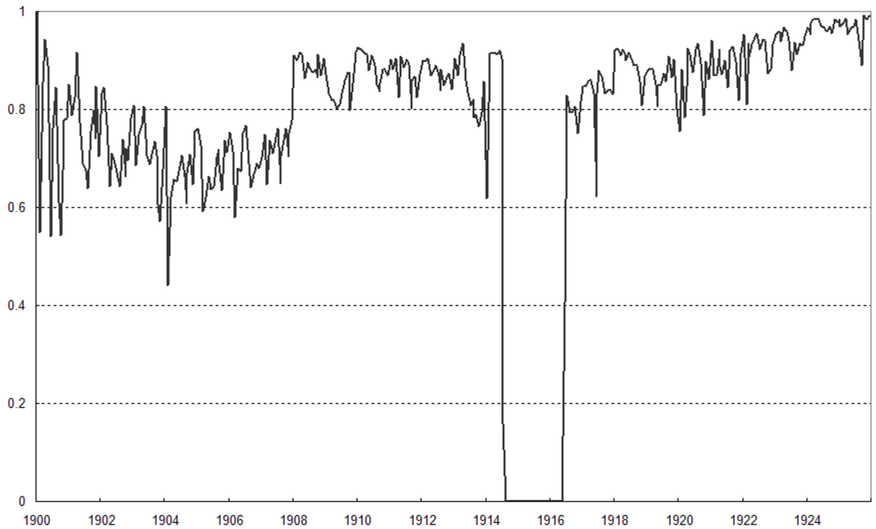
Sydney

Proportion of market capitalization for which we observe a price

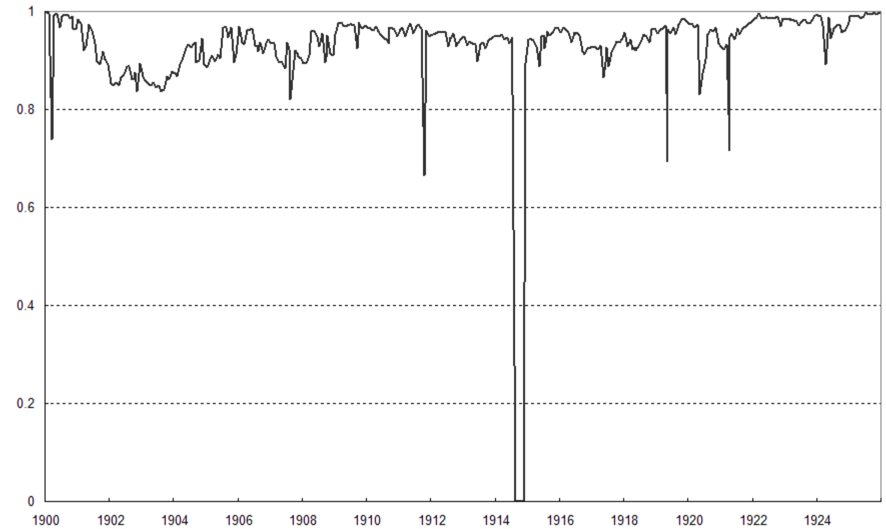


Figures 3.9 - 3.12

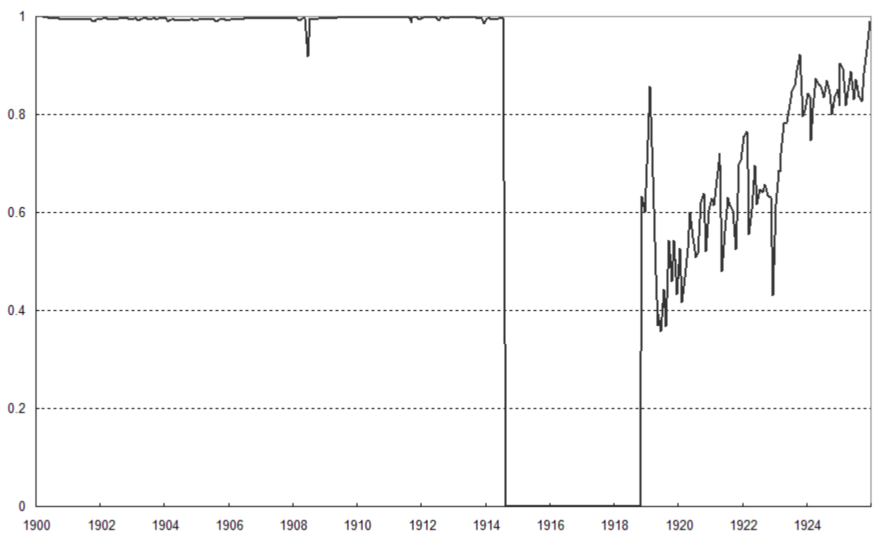
Zurich
Proportion of market capitalization for which we observe a price



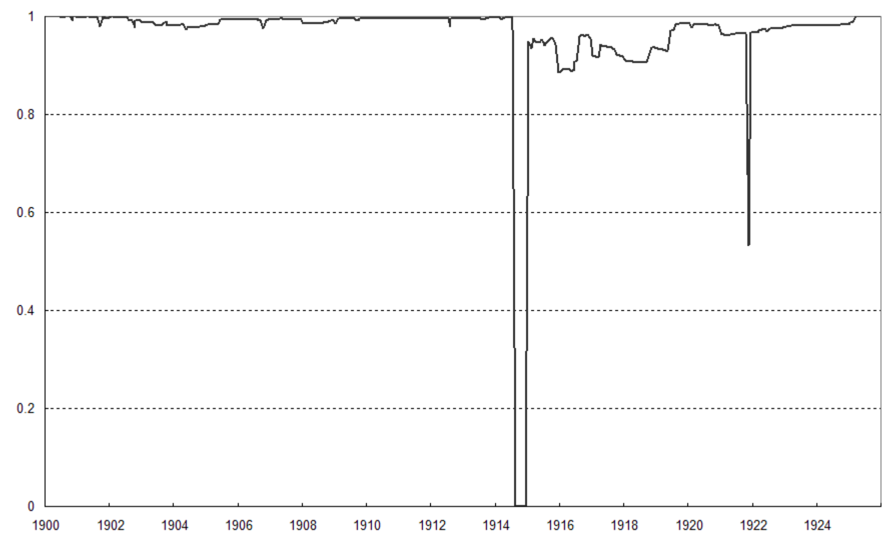
New York
Proportion of market capitalization for which we observe a price



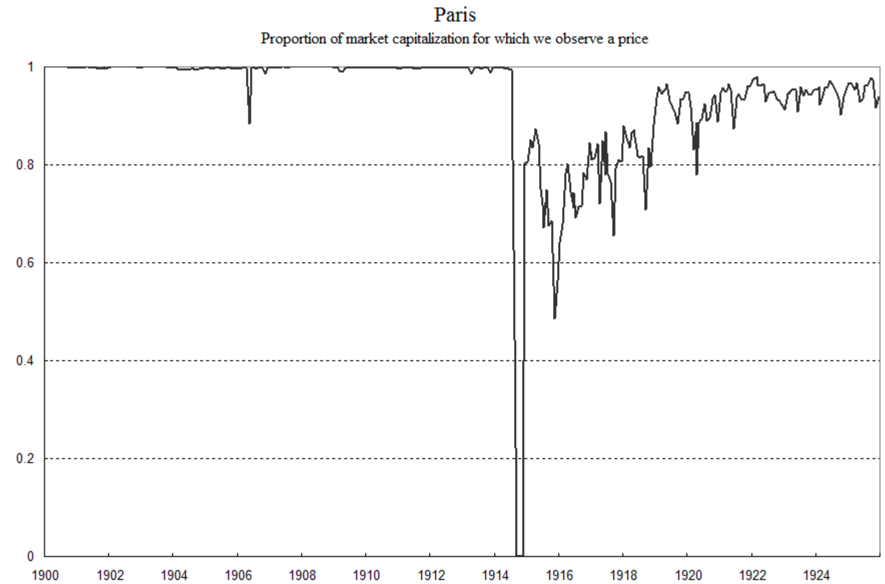
Vienna
Proportion of market capitalization for which we observe a price



London
Proportion of market capitalization for which we observe a price



Figures 3.13

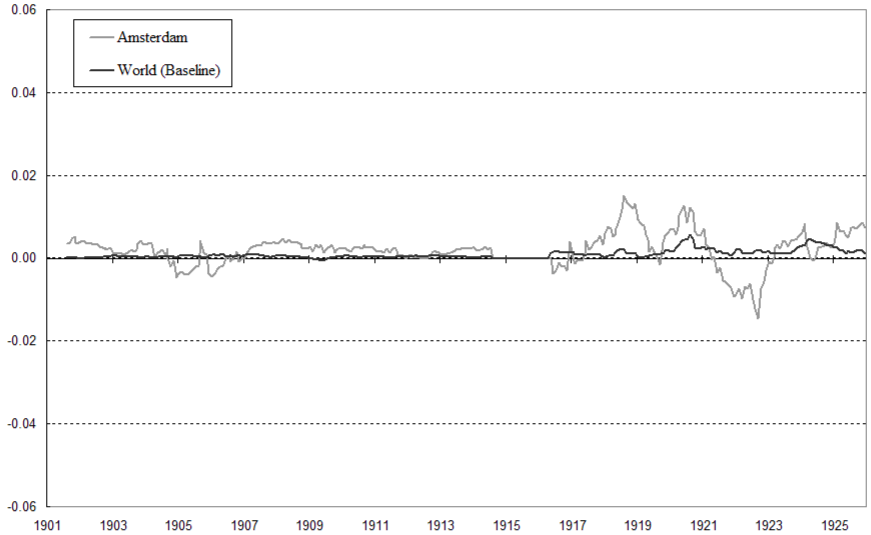


Paris
Proportion of market capitalization for which we observe a price
1
0.8
0.6
0.4
0.2
0
1900
1902
1904
1906
1908
1910
1912
1914
1916
1918
1920
1922
1924

Figures 4.2 - 4.5

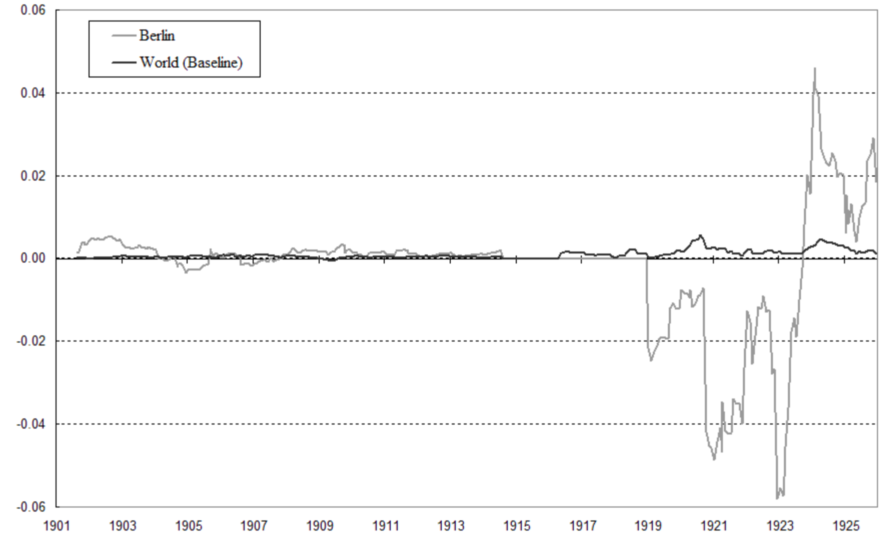
Amsterdam Mispricing

Average estimated θ, weighted by market capitalization



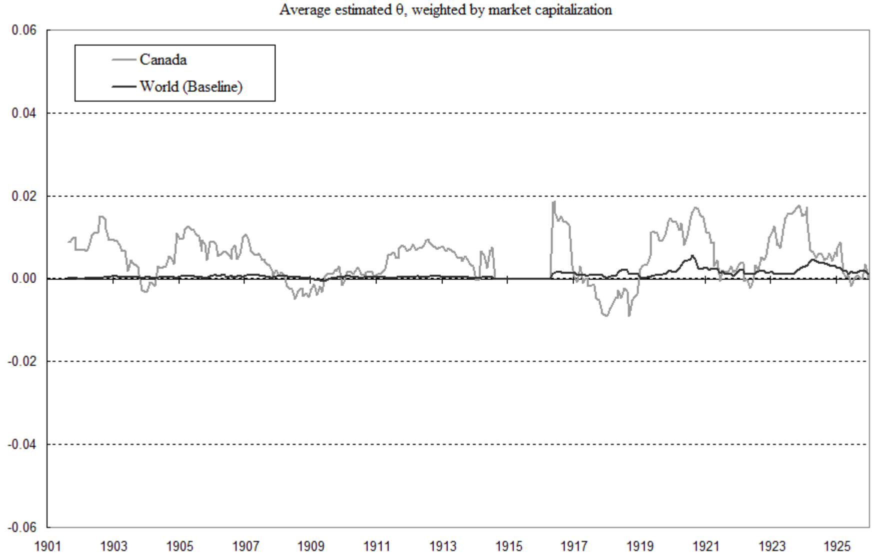
Berlin Mispricing

Average estimated θ, weighted by market capitalization



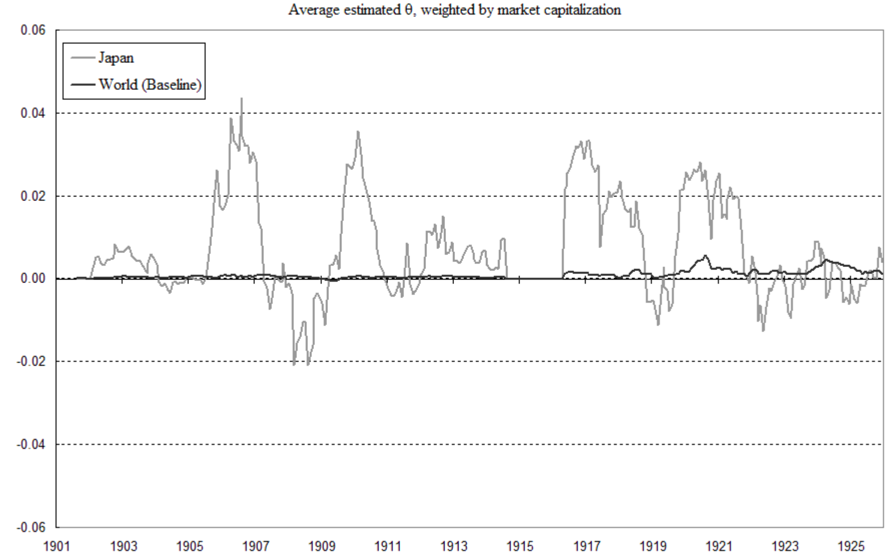
Canada Mispricing

Average estimated θ, weighted by market capitalization

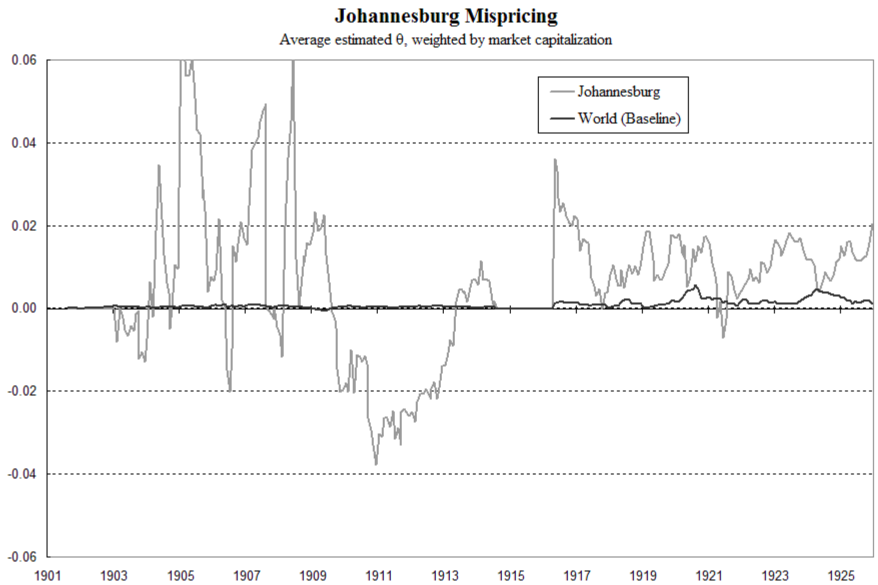


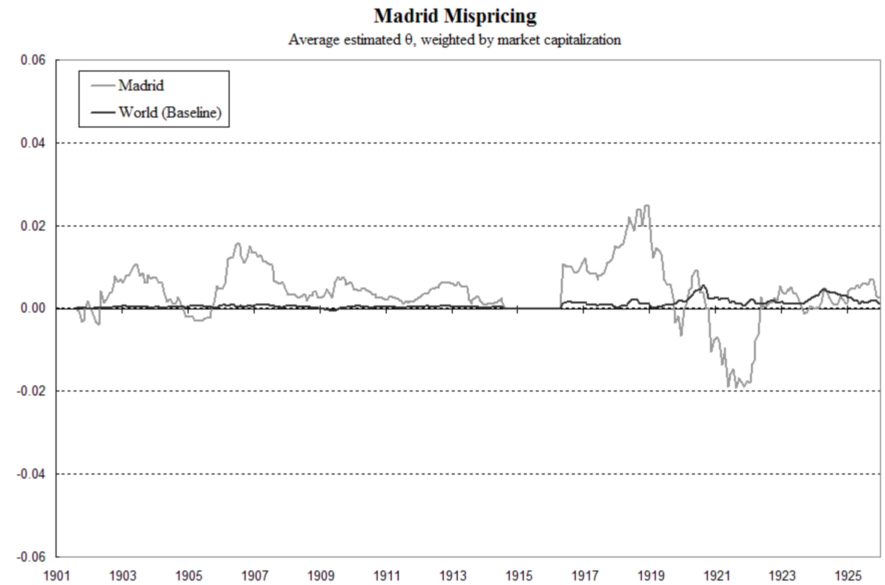
Japan Mispricing

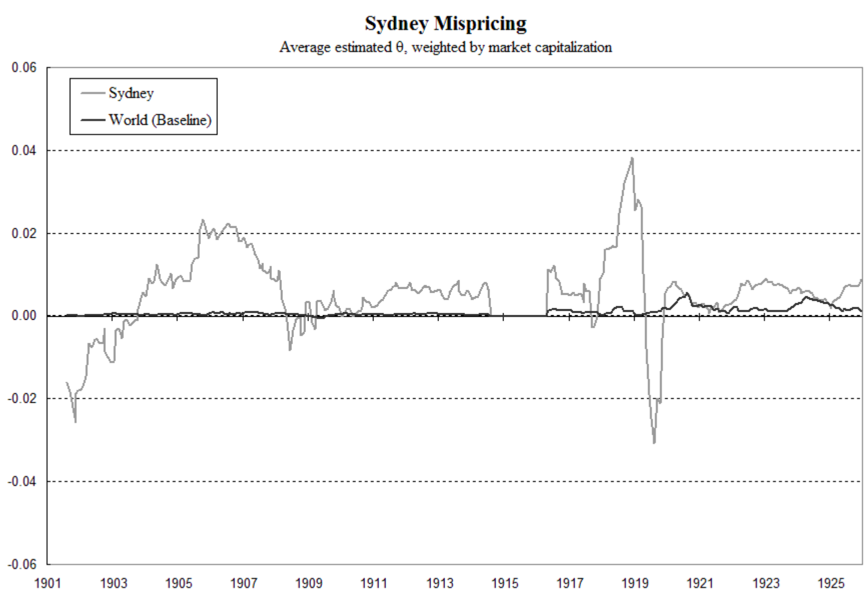
Average estimated θ, weighted by market capitalization

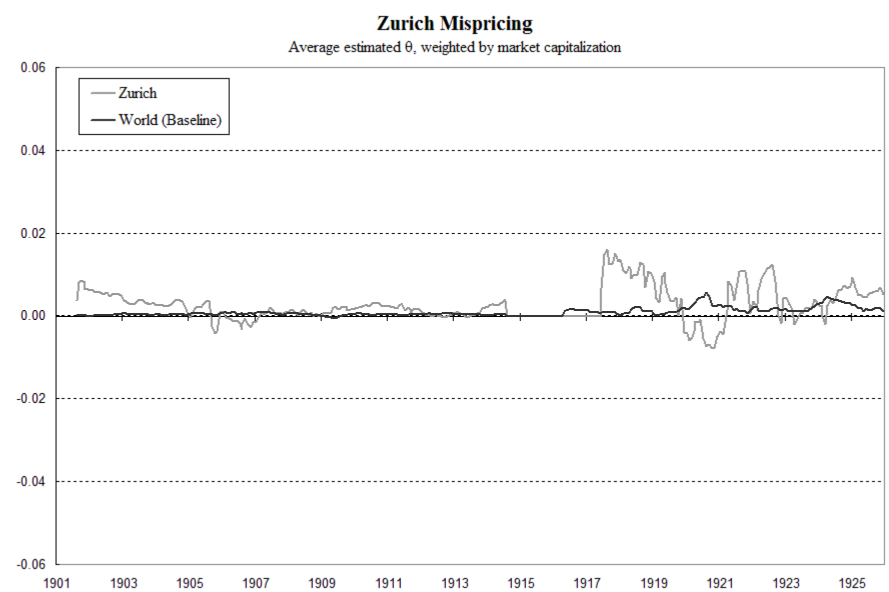


Figures 4.6 - 4.9



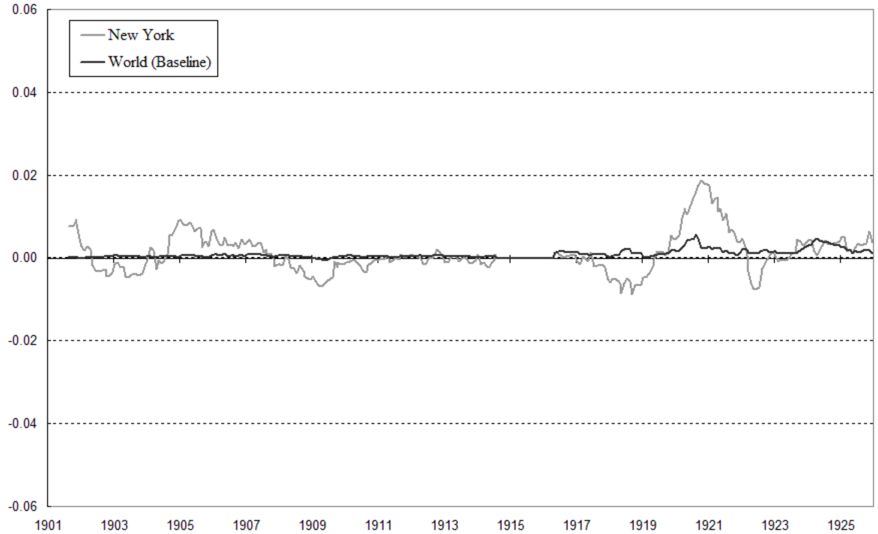




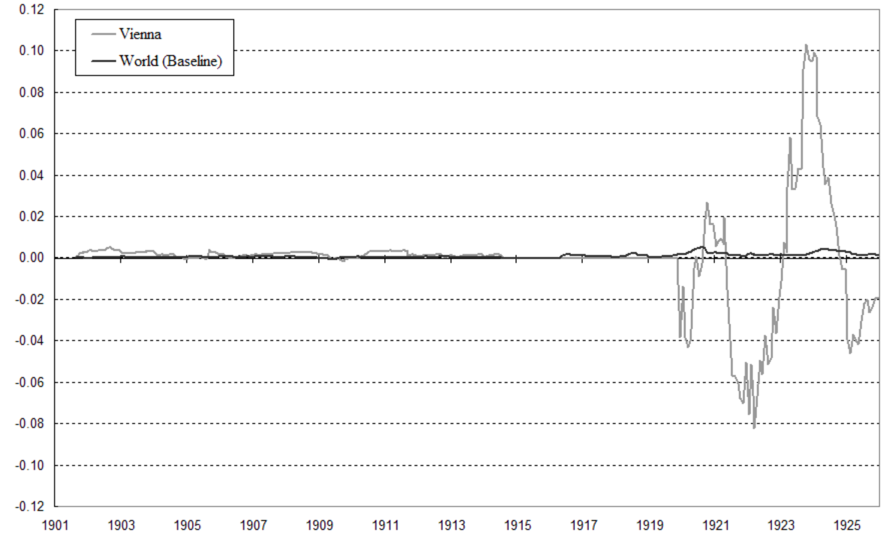


Figures 4.10 - 4.13

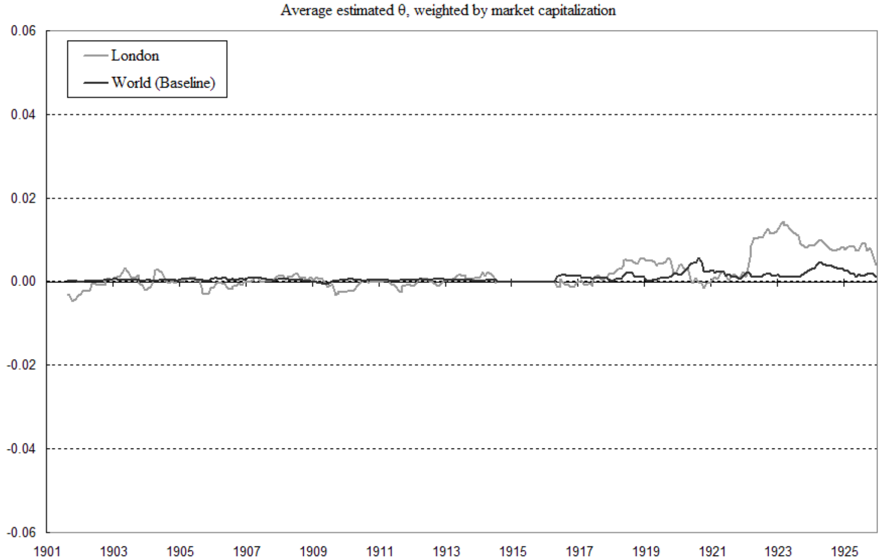
New York Mispricing
Average estimated θ, weighted by market capitalization



Vienna Mispricing
Average estimated θ, weighted by market capitalization



London Mispricing
Average estimated θ, weighted by market capitalization



Paris Mispricing
Average estimated θ, weighted by market capitalization