A Generalized Portfolio Approach to Limited Risk Arbitrage: Evidence from the MSCI Global Index Change

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JEL classification: G11, G14, G15.

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Abstract

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1 Introduction

This paper explores the security price dynamics for an event in which a large number of stocks experience changes in the investor demand. In financial markets, demand shocks often affect more than one security and the size and direction of the demand change may differ across securities. Fund manages may for example liquidate proportional to their holdings when faced with large fund outflows. Simultaneous demand shocks may also result from the build-up or liquidation of hedging positions. Finally, they occur (like in this study) when equity indices are redefined with new stocks included and other stocks deleted from the index.

Exogenous multi-asset demand shocks like index revisions are of particular interest. Simultaneous index weight changes of a large number of stocks have testable cross-sectional asset pricing implications. A recent study by Greenwood (2005) on the revision of the Nikkei 225 index shows that event returns are cross-sectionally determined by the change in the risk premium of each stock. The intuition is straightforward. Stocks for which the weight change is positive experience an effective asset supply contraction after accounting for the increased demand from index tracking investors. A lower residual supply for up-weighted stocks will decrease the risk contribution to total market risk of all stocks which have a strong positive covariance with the upweighted stocks. In analogy to the intuition of the Capital Asset Pricing Model (CAPM), a lower risk contribution to the total tradeable asset supply risk earns a lower stock specific returns and results ceteris paribus in a higher stock price. Announcement returns for the index modification are therefore positively proportional to the risk premium changes. Moreover, the premium changes can be easily characterized as the product of the return covariance matrix and the vector of weight changes.

But as a theory of limited arbitrage, the equilibrium framework in Greenwood (2005) has obvious shortcomings. Most importantly, all investors are assumed to have identical information and represent 'arbitrageurs'. But homogeneity among (non-index tracking) investors implies that the equilibrium price adjustment to the supply shock occurs without any speculative position taking as the net asset supply to the arbitrageurs is fixed. This means that any asset pricing effect from the risk of the arbitrage position itself is implicitly discarded. Positional arbitrage risk is excluded as a limiting factor for intertemporal risk arbitrage. Our theoretical contribution is to develop a new asymmetric information framework of limited multi-asset arbitrage in which the arbitrageurs can acquire net positions against uninformed liquidity suppliers. We show that the marginal portfolio risk contribution of the arbitrage position determines cross-sectional announcement returns. Such stock-specific arbitrage risk can be approximate by the product of the *squared* return covariance matrix and the vector of weight changes.

Our generalized model nests the Greenwood framework as a special case where liquidity suppliers disappear. In this case price adjustment occurs without any speculative position taking or arbitrage risk. The empirical contribution of our paper is to show that the existence of uninformed liquidity providers is crucial for explaining the event return pattern of asset supply shocks. As predicted by theory, cross-sectional announcement returns are determined (positively) by the equilibrium premium change of each stock, and (negatively) by stock-specific arbitrage risk contribution of the speculative positions held against the liquidity providers. Overall, we find strong empirical evidence in support of our generalized model of limited arbitrage. Failure to properly account for the arbitrage risk of the speculative position implies a rejection of the model and therefore a rejection of the basic Greenwood framework or CAPM model of multi-asset arbitrage.

The empirical part focuses on the revision of the global MSCI index announced in December 2000 and implemented in two steps in November 2001 and May 2002. This choice has a number of advantages over the events used in previous studies. First, the weight revision concerned a total of 2566 stocks in 50 countries. It therefore presents an index change of unprecedented scope, which provides great cross-sectional power to discriminate between different theories of imperfect arbitrage and their asset pricing implications. Second, the announcement of the MSCI index revision and its implementation are separated by at least 12 months. We can therefore easily separate the announcement event from the implementation event. In the Nikkei 225 revision considered by Greenwood, announcement and implementation are separated only by one week and the empirical analysis does not attempt to isolate the announcement effect. Third, the international dimension of the index change allows us to infer the degree of market integration with respect to asset pricing. We develop a test which identifies whether the local or global components of risk premium changes and arbitrage risk determine the event returns. The evidence shows that the reweightening of any foreign stocks had the same qualitative asset pricing effect on a given domestic stock as the reweightening of any domestic stock. The index upweightening of a Japanese stock for example alters the IBM stock price in the same magnitude as the identical index weight increase of a U.S. company if both stocks feature the same covariance with the IBM stock return. The international equity market functions today as an integrated market in which stocks are priced globally rather than a segmented market in which premium changes are determined locally.

The finance literature includes a number of studies on the stock price impact of index inclusions and exclusions. These event studies initially all focus on individual price movements with overwhelming evidence that index inclusions increase share prices and exclusions decrease them.[1] Greenwood (2005) represents the first paper to feature a portfolio approach to index revisions and to test the corresponding quantitative cross-sectional asset pricing implications. Our paper generalizes this portfolio approach by introducing positional arbitrage risk as the limiting factor to intertemporal arbitrage and characterizing the additional asset price effect of such arbitrage risk.

A broader literature assesses whether demand and supply shocks correlate with individual stock price returns. Time series studies on block purchases and sales of stocks, as well as the trades of institutional investors, have consistently uncovered evidence of temporary price pressure on individual securities conditional upon unusual demand or supply (Lakonishok, Shleifer and Vishny (1991,1992), Chan and Lakonishok (1993, 1995)). In the international finance literature, Froot, O'Connell and Seasholes (1998) have shown that local stock prices are sensitive to international investor flows, and that transitory inflows have a positive future impact on returns. Focusing on mutual funds, Warther (1995) and Zheng (1999) have documented that investor supply and demand effects may aggregate to the level of the stock market itself. Goetzmann and Massa (2002) show that, at daily frequency, inflows into S&P500 index funds have a direct impact on the stocks that are part of the index. Unlike our work, this literature is generally concerned with the mere existence of asset price effects rather than their quantitative cross-sectional structure.

The paper proceeds as follows: Section 2 outlines a new model of multi-asset arbitrage. We highlight the cross-sectional implications for the announcement and the implementation event in propositions 1 and 2, respectively. Proposition 3 characterizes the model implications under the polar cases of complete international market integration and segmentation. Section 3 describes

[1] See for example (Garry and Goetzmann (1986), Harris and Gurel (1986), Shleifer (1986), Dillon and Johnson (1991), Beniesh and Whaley (1996), Lynch and Mendenhall (1997)). Kaul et al. (2000) examine index reweighting for stocks in the Toronto Stock Exchange 300 index and find that upweighted stocks experience a persistent positive price effect. See also Denis et al. (2003) and Hedge and McDermott (2003).

the MSCI index redefinition and discusses summary statistics about the index weight changes, the risk premium changes and the arbitrage risk for individual stocks. We also characterize the total portfolio risk of the optimal arbitrage strategy relative to a passive holding strategy in the old MSCI index. Section 4 provides the evidence on the announcement effect, the implementation effect and the degree of global versus local asset price determination. We also analyze the ex-post profitability of the various arbitrage strategies. Section 5 concludes.

2 Theory and Hypotheses

2.1 Model Assumptions

This section develops a simple limit-to-arbitrage model which allows us to analyze the return effects of demand shocks in a multi-asset market setting. We consider a 4 period model with N financial assets. The market characteristics are summarized in Assumption 1:

Assumption 1: Market Structure, Asset Supply and Liquidation Value
The financial market with N risky assets allows trading at 4 different times $t = 0, 1, 2, 3$. In period $t = 4$ all assets are liquidated at liquidation prices given by

$$p_3 = \mathbf{1} + \sum_{t=1}^{4} \varepsilon_t.$$

where ε_t denotes serially uncorrelated mean zero innovation learned by all market participants at time t. The covariance of innovations ε is given by the matrix Σ. The asset supply in periods $t = 0, 1, 2$ is given by S. In period $t = 3$, a supply shock reduces the asset supply to $S - u$, where $u = w^n - w^o$ represents the exogenous demand change from old index weights w^o to new index weights w^n. The ex ante $(t = 0)$ expected liquidation price is normalized to the unit vector $\mathbf{1}$.

The stochastic liquidation value generates asset investment risk. The index revision is modeled like in Greenwood (2005) as an exogenous change in the asset supply. Stocks with increased weight face a higher demand by index tracking funds so that their net asset supply $S - u$ is reduced. The supply shock u from the index investors is completely price inelastic. Index investors therefore do no qualify as counterparty to intertemporal arbitrage trades. The behavior of the index investors is fully captured by the one-time supply shock.

A new feature of our framework is the introduction of liquidity supplying agents. Those are the potential counterparty to the arbitrageurs seeking a net arbitrage position. The arbitrage opportunity is further imbedded in the assumption that liquidity suppliers learn about the exogenous liquidity shock only with a delay of one period. We argue that the existence of less informed liquidity suppliers is crucial for explaining the cross-sectional price patterns of event returns. Assumption 2 characterizes the investment behavior of these two types of market participants:

Assumption 2: Arbitrageurs and Linear Liquidity Supply

A unit interval of market participants can be grouped into a set $[0, \lambda]$ of risk arbitrageurs and a set of liquidity suppliers $[\lambda, 1]$. Arbitrageurs have a CARA utility and a risk aversion parameter ρ, and access to a riskless asset of zero return. Their optimal demand vector follows as

$$x^A = (\rho\Sigma)^{-1}\widetilde{\mathcal{E}}_t(p_{t+1} - p_t),$$

where p_t denotes the price vector in period t and $\widetilde{\mathcal{E}}_t$ their expectation for the consecutive price appreciation. Liquidity suppliers provide in each stock a linear asset supply which depends on the asset supply elasticity γ and is given by the vector

$$x^S = \gamma\overline{\mathcal{E}}_t(p_{t+1} - p_t),$$

where $\overline{\mathcal{E}}_t$ characterizes the expectations of the liquidity suppliers.

The arbitrageurs are optimizing agents who maximize the CARA utility over their one period investment horizon. The liquidity suppliers by contrast represent an ad hoc addition to the model. A literal interpretation consists of interpreting liquidity suppliers as underdiversified investors with suboptimal demands featuring only one individual stock. Alternatively, we could interpret the downward sloping demand curve as the aggregate demand of heterogeneous agents with different reservation values coming from different asset valuations. We note that the Greenwood framework is nested in our specification. It is recovered for a parameter $\lambda = 1$ when only arbitrageurs constitute the market.[2]

The very existence of arbitrage opportunities depends also on information asymmetries between different market participants. We incorporate this feature by assuming that the liquidity suppliers learn about the supply shock with a delay, that is only in period $t = 2$. A second new assumption is that arbitrageurs and in $t = 2$ also the liquidity suppliers estimate the magnitude

[2] Formally, Greenwood builds on the asset pricing framework in Hong and Stein (1999) and Barberis and Schleifer (2003) and assumes a time varying dividend process. We dispense with the dividend process and just assume a stochastic liquidation value. No important insight is lost under this simplification.

of the supply shock as $\widetilde{\mathcal{E}}_2(u) = \overline{\mathcal{E}}_2(u) = \widehat{u} = ku$, where $k > 0$ is a scalar. If the true magnitude of the supply shock is learnt only upon implementation of the index change, then we obtain an additional implementation effect when the index change occurs. Assumption 3 summarizes the information structure:

Assumption 3: Information Structure

Arbitrageurs learn about the supply shock at time $t = 1$. They estimate the magnitude of the supply shock to be $\widehat{u} = \widetilde{\mathcal{E}}_1(u) = ku$ where $k > 1$ corresponds to an overestimation and $0 < k < 1$ to its underestimation. Liquidity suppliers learn about the estimated supply shock $\widehat{u}$ only with a delay at time $t = 2$. At time $t = 3$ the supply shock occurs and the true magnitude of the supply shock u becomes known to the arbitrageurs and liquidity suppliers alike.

For the special case that $k = 1$, both arbitrageurs and liquidity providers correctly anticipate the magnitude of the supply shock. No specific cross-sectional return pattern can then be predicted for the implementation event. But in practice, it may be difficult to predict the exact magnitude of a supply shock. For example, in the case of the MSCI index redefinition, the exact global capitalization of all MSCI index funds was unknown.[3]

2.2 Model Solution and Hypothesis

It is straightforward to solve the model backwards period by period. The CARA utility assumption for the arbitrageurs and the linear liquidity supply result in a linear asset demand for all stocks. Market clearing then implies

$$\begin{aligned} S \quad &= \lambda(\rho\Sigma)^{-1}\widetilde{\mathcal{E}}_t(p_{t+1} - p_t) + (1-\lambda)\gamma\overline{\mathcal{E}}_t(p_{t+1} - p_t) \quad \text{for} \quad t = 0, 1, 2 \\ S - u \quad &= \lambda(\rho\Sigma)^{-1}\widetilde{\mathcal{E}}_t(p_{t+1} - p_t) + (1-\lambda)\gamma\overline{\mathcal{E}}_t(p_{t+1} - p_t) \quad \text{for} \quad t = 3. \end{aligned}$$

The index change by $u = w^n - w^o$ is represented as a negative asset supply shock at time $t = 3$. Upweighted stocks are held to a larger extent by index funds and this reduced the residual supply in these stocks. Given a liquidation value of $p_4 = 1 + \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \varepsilon_4$, we can directly determine the price at time $t = 3$ as $p_3 = 1 + \varepsilon_1 + \varepsilon_2 + \varepsilon_3 - r_4$, where the period 3 risk premium follows as $r_4 = \left[I + (1-\lambda)\gamma\frac{\rho}{\lambda}\Sigma\right]^{-1}\frac{\rho}{\lambda}\Sigma(S - u)$. Without the supply shock, the equity premium is given by $r = \left[I + (1-\lambda)\gamma\frac{\rho}{\lambda}\Sigma\right]^{-1}\frac{\rho}{\lambda}\Sigma S$. The difference $r - r_4 = \left[I + (1-\lambda)\gamma\frac{\rho}{\lambda}\Sigma\right]^{-1}\frac{\rho}{\lambda}\Sigma u$ captures asset price effect induced by the supply shock.

[3] Even MSCI itself seems to dispose of very vague estimates of this capitalization.

Unlike the liquidity suppliers, arbitrageurs anticipate this price change at time $t = 1$ and exploit their information advantage at their expense. They accumulate net speculative positions under the belief that $\widetilde{\mathcal{E}}_1(u) = \widehat{u}$, whereas $\overline{\mathcal{E}}_1(u) = 0$. At time $t = 2$, both the arbitrageurs and the liquidity suppliers anticipate the supply shock with $\widetilde{\mathcal{E}}_2(u) = \overline{\mathcal{E}}_2(u) = \widehat{u}$. Finally, the exact magnitude of the shock becomes known at time $t = 3$, when $\widetilde{\mathcal{E}}_3(u) = \overline{\mathcal{E}}_3(u) = u$.

In the special case without the linear liquidity supply ($\lambda = 1$) the risk premium simplifies to $r_4 = \frac{\rho}{\lambda}\Sigma(S-u)$ and $r = \frac{\rho}{\lambda}\Sigma S$. At times $t = 1, 2$, the arbitrageurs estimate r_4 as $\widehat{r}_4 = \frac{\rho}{\lambda}\Sigma(S-\widehat{u})$. At time $t = 0$, the risk premium is believed to be given by the vector r in every consecutive period. The asset prices then follow directly as

$$
\begin{aligned}
p_0 &= 1 - 4r \\
p_1 &= 1 + \varepsilon_1 - \widehat{r}_3 - 2r \\
p_2 &= 1 + \varepsilon_1 + \varepsilon_2 - \widehat{r}_3 - r \\
p_3 &= 1 + \varepsilon_1 + \varepsilon_2 + \varepsilon_3 - r_3 \\
p_4 &= 1 + \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \varepsilon_4.
\end{aligned}
$$

This case represents the Greenwood model augmented with prediction error $u - \widehat{u}$ about the magnitude of the supply shock. The change in the equity premium in period 3 is fully incorporated in the asset price at time $t = 1$. Upon announcement of the index modification, the price vector changes from $p_{1-\delta} = 1 + \varepsilon_1 - 3r$ to $p_1 = 1 + \varepsilon_1 - 2r - \widehat{r}_3$. The announcement effect for the prices therefore follows as $\Delta p_1 = r - \widehat{r}_3 = \rho\Sigma\widehat{u} = \rho k\Sigma(w^n - w^o)$. We note that the price adjustment occurs without any equilibrium arbitrage position since all market participants are symmetrically informed. We show in the empirical part of the paper that this nested hypothesis of price adjustment without speculative position taking is strongly rejected by the data.

The existence of liquidity suppliers in the general case with $\lambda < 1$ allows for net arbitrage positions. The price effect is then not only determined by the change in the equity risk premium, but also by the arbitrage behavior of the informed investors. In particular, the risk of the arbitrage position matters for the price effect at the announcement event. Proposition 1 summarizes the price effect in the general case.

Proposition 1: Announcement Returns

On announcement of the weight change from old weights w^o to new weights w^n, the event return is positively proportional to the (expected) premium change $\Sigma(w^n - w^o)$ and negatively proportional to the (expected) arbitrage risk $\Sigma\Sigma(w^n - w^o)$, where Σ

represents the covariance matrix of asset returns. Formally, we have the following linear approximation

$$\Delta p_1 \approx \alpha \times \Sigma(w^n - w^o) + \beta \times \Sigma\Sigma(w^n - w^o),$$

with $\alpha = \frac{\rho}{\lambda} k > 0$ *and* $\beta = -2(1-\lambda)\gamma \left(\frac{\rho}{\lambda}\right)^2 k < 0$.

Proof: See Appendix.

In the baseline case of the Greenwood model with $\lambda = 1$, the announcement price effect simplifies to the single term $\Sigma(w^n - w^o)$. This price effect represents the change in the stock specific risk contribution to the total market risk under the asset supply change $w^n - w^o$. We refer to this term as the risk premium change. In the general case when $\lambda < 1$, arbitrageurs take positions to exploit the expected return effect $\Sigma(w^n - w^o)$ in their trading against the uninformed liquidity suppliers. An arbitrage position proportional to the risk premium change implies a portfolio risk $(w^n - w^o)'\Sigma\Sigma\Sigma(w^n - w^o)$. The marginal arbitrage risk contribution of each individual stock follows as $\Sigma\Sigma(w^n - w^o)$. The actual arbitrage position x^S and also the proportional equilibrium price effect Δp_1 at announcement are a linear combination of the (expected) premium change and the (expected) arbitrage risk contribution with coefficients $\alpha > 0$ and $\beta < 0$, respectively. Any supply shock involving a large number of reweighted stocks allows us to test these parameter restrictions.

Next, we discuss the role of parameter uncertainty about the exact (scalar) magnitude of the supply shock. We assume that its magnitude is revealed in the implementation event when the market experiences the true supply shock. The previous pricing error due to $k \neq 1$, is reversed with an additional price adjustment proportional to $1 - k$. We characterize the implementation returns in Proposition 2 as follows:

Proposition 2: Implementation Returns

On implementation of the weight change from old weights w^o *to new weights* w^n *the respective return is proportional to unexpected premium change* $(1-k)\Sigma(w^n - w^o)$ *and the unexpected arbitrage risk* $(1-k)\Sigma\Sigma(w^n - w^o)$, *where* $(1-k)(w^n - w^o) = u - \mathcal{E}(u)$ *represents the prediction error for the supply shock. Formally, we have the following linear approximation*

$$\Delta p_3 \approx \alpha \times \Sigma(w^n - w^o) + \beta \times \Sigma\Sigma(w^n - w^o),$$

with $\alpha = \frac{\rho}{\lambda}(1-k)$ *and* $\beta = -(1-\lambda)\gamma \left(\frac{\rho}{\lambda}\right)^2 (1-k)$. Therefore, we predict

$$\begin{array}{lllllll} (i) & \alpha < 0 & \textit{and} & \beta > 0 & \textit{and} & k > 1 \\ (ii) & \alpha = 0 & \textit{and} & \beta = 0 & \textit{and} & k = 1 \\ (iii) & \alpha > 0 & \textit{and} & \beta < 0 & \textit{and} & 0 < k < 1, \end{array}$$

for (i) overestimation or (ii) correct estimation or (iii) underestimation of the demand shock $u = w^n - w^o$, respectively.

Proof: See Appendix.

The testable restriction here is whether the coefficients α and β either have opposing signs for the implementation event or are both equal to zero. As the implementation of the MSCI redefinition was undertaken in two steps, we can apply the test to both events.

An important issue in international finance is the degree of integration of different national stock markets. Are asset prices determined locally of globally (Karolyi and Stulz, 2003)? Frequently, market integration is reviewed indirectly by scrutinizing cross-market ownership. But the prevalent home bias may or may not come with market integration in the asset pricing dimension. Here we examine directly the pricing implications for premium changes and arbitrage risk. Under the hypothesis of national market segmentation, we can think of the N assets as partitioned into M national stock markets. Arbitrage may occur primarily within the national market if the arbitrageurs face trading restrictions with respect to foreign assets. We can therefore distinguish the global covariance matrix Σ^G accounting for the full correlation structure between all stocks from a restricted matrix Σ^L which ignores cross-country correlations between stocks in different countries by setting those to zero. Formally,

$$(\Sigma^L)_{ij} = \begin{cases} (\Sigma^G)_{ij} & \text{if stocks } i \text{ and } j \text{ are listed in the same country} \\ 0 & \text{otherwise,} \end{cases}$$

where Σ^G denotes the full covariance of all stock returns. The corresponding local market equity premium change in stock j follows as $[\Sigma^L(w^n - w^o)]_j$ and arbitrage risk as $[\Sigma^L\Sigma^L(w^n - w^o)]_j$. This implies a straightforward test of international market integration summarized in Proposition 3:

Proposition 3: Integrated versus Segmented Equity Markets

Let Σ^G denote the global covariance matrix of all asset returns and Σ^L the corresponding covariance matrix with zeros for all cross-country elements. Define incremental matrices as $\Sigma^\Delta = \Sigma^G - \Sigma^L$ and $\Sigma\Sigma^\Delta = \Sigma^G\Sigma^G - \Sigma^L\Sigma^L$, respectively. The announcement return is positively proportional to the (expected) local premium change $\Sigma^L(w^n - w^o)$ and its international increment $\Sigma^\Delta(w^n - w^o)$ under market integration. It is negatively proportional to the (expected) local arbitrage risk $\Sigma^L\Sigma^L(w^n - w^o)$ and also its international increment $\Sigma\Sigma^\Delta(w^n - w^o)$ under market integration. Formally, we have the following linear approximation

$$\Delta p_1 \approx \alpha^L \times \Sigma^L(w^n - w^o) + \alpha^\Delta \times \Sigma^\Delta(w^n - w^o) + \beta^L \times \Sigma^L\Sigma^L(w^n - w^o) + \beta^\Delta \times \Sigma\Sigma^\Delta(w^n - w^o)$$

with

$$\begin{array}{ll} (i) & \alpha^L = \alpha^\Delta > 0 \quad and \quad \beta^L = \beta^\Delta < 0 \\ (ii) & \alpha^L > \alpha^\Delta = 0 \quad and \quad \beta^L < \beta^\Delta = 0 \end{array}$$

for (i) complete market integration and (ii) for complete market segmentation.

Proof: Follows from Proposition 1 by decomposition of $\Sigma^G$and $\Sigma^G\Sigma^G$.

The regression specification in Proposition 3 nests both extreme cases of complete market integration and complete market segmentation. We also note that the above specification only explores the average degree of market integration or segmentation. Alternatively, we could further decompose the matrices Σ^Δ and $\Sigma\Sigma^\Delta$ into an incremental contribution of each market with respect to all other markets. This allows in principle for more specific tests of integration of any particular country either with respect to the world equity market or any other country market. The largest sample and therefore the greatest statistical power is obtained by pooling all observations.

3 The MSCI Index Redefinition

3.1 MSCI and its Index Maintenance

Morgan Stanley Capital International Inc. (MSCI) is a leading provider of equity (international and U.S.), fixed income and hedge fund indices. The MSCI equity indices are designed to be used by a wide variety of global institutional market participants. They are available in local currency and U.S. Dollars (US$), and with or without dividends reinvested.[4] MSCI's global equity indices have become the most widely used international equity benchmarks by institutional investors. By the year 2000, close to 2,000 organizations worldwide were using the MSCI international equity benchmarks. Over US$ 3 trillion of investments were benchmarked against these indices worldwide and approximately US$ 300 to 350 billion were directly indexed.[5] The indices with the largest international coverage are the MSCI ACWI (All Country World Index), which includes 50 developed and emerging equity markets, the MSCI World Index (based on 23 developed

[4] Aggregating individual securities by different criteria MSCI creates a broad base of indexes such as Global, Regional and Country Equity Indexes, Sector, Industry Group and Industry Indexes, Value and Growth Indexes, Small Cap Equity Indexes, Hedged and GDP-weighted Indexes, Custom Equity Indexes, Real Time Equity Indexes.

[5] See the investment newsletter 'Spotlight on: Throwing Weights Around', Hewitt Investment Group, December 2000.

countries), the MSCI EM (Emerging Markets) Index (based on 27 emerging equity markets), the MSCI EAFE (Europe, Australasia, Far East) Index (based on 21 developed countries outside of North America), the MSCI Europe (based on 14 EU countries (except Luxemburg), plus Norway and Switzerland).

Over time, MSCI's methodology has evolved in order to ensure that the equity index series continue to properly represent these markets and maintain their benchmark character. The design and implementation of the index construction is based on a broad and fair market representation. In theory, a total market index, representing all listed securities in a given market, would achieve this goal. However, in practice, a total market index including all the stocks would be difficult to use as a benchmark for international investors. Therefore, MSCI builds up the indices from industry group level by restricting itself to securities which are truly replicable in global institutional portfolios of reasonable size. To maintain the goal of broad and fair market representation and reflect the evolution of the underlying markets, the indices must be reviewed regularly, which comprises inclusions and exclusions of index components.[6]

MSCI commits in its published guidelines to the principles of transparency and independence from outside interests. All reviews and changes are announced at least two weeks in advance or as early as possible prior to their implementation. Only in rare cases are events announced during market hours for implementation on the same or following day.[7] We now describe the transition to the new index methodology, which marked an exceptional redefinition of all of MSCI's equity indices.

3.2 Announcement Process and Event Windows

In February 2000, MSCI communicated that it was reviewing its weighting policy and that it was considering a move to index weights defined by the freely floating proportion of the stock value.

[6] The index maintenance can be described by three types of reviews. First, there are annual full country index reviews (at the end of May) in which MSCI re-assesses systematically the various dimensions of the equity universe for all countries. Second, there are quarterly index reviews (at the end of February, August, November), in which other significant market events are accounted for (e.g. large market transactions affecting strategic shareholders, exercise of options, share repurchases, etc.). Third, ongoing event-related changes like mergers and acquisitions, bankruptcies or spin-offs are implemented as they occur.

[7] A more descriptive text announcement is sent out to clients for significant events like additions and deletions of constituents and changes in free float larger than US$ 5 billion or with an impact of more than 1% of the constituent's underlying country index.

Such free-float weights would take account of restrictions like Foreign Ownership Limits (FOLs) in different countries and therefore would better reflect the limited investibility of many stocks. Free-float weights were consecutively adopted by MSCI's competitor Dow Jones on September 18, 2000. On the next day, MSCI published a consultative paper on possible changes and elicited comments from its clients. On December 1, 2000, MSCI announced that it would communicate its decision on the redefinition of the MSCI international equity index on December 10, 2000. Fund managers could by then infer that MSCI's adoption of free floats weights was imminent. The second announcement on December 10, 2000 provided the time table for the implementation of the index change in two steps and the new target for the market representation of 85 percent up from previously 60 percent. The equity indices would adjust 50 percent towards the new index on November 30, 2001 and the remaining adjustment was scheduled for May 31, 2002.

MSCI's decision was broadly in line with the previous consultative paper. Only the target level of 85 percent was somewhat higher (by 5 percent) and the implementation timetable was somewhat longer than most observers had expected.[8] December 10, 2000, therefore marks the confirmation of existing market expectations. Many market participants and potential arbitrageurs appear to have anticipated the adoption of free float weights at least since the first announcement ten days earlier.[9] In the remainder of the paper, we refer to December 1, 2000 as the announcement day of the index revision.

We define an event window of 3 trading days around this date which includes the cumulative daily returns from November 30 to December 4. Since early information leakages are plausible

[8] See again the investment newsletter 'Spotlight on: Throwing Weights Around', Hewitt Investment Group, December 2000.

[9] To confirm that the first announcement was the relevant one, we examined transaction volumes in the Euro/Dollar spot market available for the period 01/08/2000 to 24/01/2001. Euro/Dollar spot market transactions should accompany and aggregate the international equity reallocation into the upweighted U.S. market. The data combines all electronically brokered spot contracts in both the EBS and Reuters D-2000 trading platforms on any given day. The first trading day after the pre-announcement, namely Monday, December 4, is characterized by very large spot trading volume of 17,610 contracts. It exceeds the daily average volume by 4051 contracts or 30 percent. By contrast, trading volume on Monday, December 12, - the first trading day after the second announcement - was below average. The transaction volumes indicates that December 1, 2000 was the relevant news event and we refer to this first date as the announcement date. But information leakages even prior to December 1, 2000 are very plausible, as well. The foreign exchange abnormal spot volume also peaked on November 30, 2000, with a total of 17,962 additional contracts (32.5 percent above average). We thank Paolo Vitale and Francis Breedon for generously providing the transaction data.

for the announcement event, we also look at larger event windows with an earlier starting date. In particular, we examine a 5 and 7 day event window which start on November 28 and 24, respectively, and also extends to December 4, 2000. For the first and second implementation event, we also choose alternatively 5 and 7 day windows. These event windows start cumulative daily return measurement two days before the implementation dates of November 30, 2001, and May 31, 2002, respectively, and extend over the next 5 or 7 trading days.

3.3 Index Weight Changes

The new methodology differs from the previous equity index definition in two aspects. First, stock selection is based on freely floating capital as opposed to market capitalization. Second, the market representation is enhanced in the new index. MSCI defines the free float of a security as the proportion of shares outstanding that is available for purchase by international investors. In practice, limitations on the investment opportunities of international institutions are common due to so-called "strategic holdings" by either public of private investors. Given that disclosure requirements generally do not permit a clear identification of "strategic" investments, MSCI labels shareholdings by classifying investors as strategic and non-strategic. Freely floating shares include those held by households, investment funds, mutual funds and unit trusts, pension funds, insurance companies, social security funds and security brokers. The non-free float shares include those held by governments, companies, banks (excl. trusts), principal officers, board members and employees. Non-free float is also defined in terms of foreign ownership restrictions. Such Foreign Ownership Limits (FOLs) can come from law, government regulations, company by-laws and other authoritative statements. MSCI free float-adjusts the market capitalization of each security using a factor referred to as the Foreign Inclusion Factor (FIF). For securities subject to FOLs, the FIF is equal to the lesser of the FOL (rounded to the closest 1 percent increment) and the free float available to foreign investors (rounded up to the closest 5 percent increment above 15 percent and to the closest 1 percent below a 15 percent free float). Securities with an FIF of less than 15 percent across all share classes are generally not eligible for inclusion in the MSCI indices.[10] The second goal of the equity index modification was an enhanced market representation. In its new indices, MSCI targets a free float-adjusted market

[10]Exceptions to this general rule are made only in significant cases, where exclusion of a large company would compromise the index's ability to fully and fairly represent the characteristics of the underlying market.

representation of 85 percent within each industry and country, compared to the 60 percent share based on market capitalization in the old index. Because of differences in industry structure, the 85 percent threshold may not be uniformly achieved. Moreover, the occasional over- and under-representation of industries may also imply that the aggregate country representation may deviate from the 85 percent target.[11]

Next, we describe the effect of the new index methodology on the index composition. Prior to its revision, the MSCI ACWI included a total of 2077 stocks. The new index methodology led to the inclusion of 489 new stocks and the deletion of 298 stocks. The total number of stocks belonging either to the old or new index is therefore 2566. Table 1 provides a breakdown of these stocks by countries and lists for each country the number of retained sample stocks. The sample excludes 62 stocks from the two crisis countries Argentina and Turkey. Our analysis also requires 2 years of historic price data to compute covariance matrices with all other index stocks. For 31 stock codes we were unable to find any information. Another 182 stocks have an incomplete price history prior to the index change.[12] This reduces our data sample from 2566 to 2291 stocks, of which 396 are included and 265 excluded in the index revision.

Table 1, columns (3) and (4) provide the aggregate country weight defined as the sum of all stock weights before and after the index revision, respectively. The largest contribution to the new MSCI index comes from the U.S. stocks with 55.12 percent followed by the U.K. with 10.33 percent and Japan with 9.38 percent. The most dramatic country weight change concerns the U.S. with a 6.24 percent absolute weight increase followed by the U.K. with a 1.07 percent increase. Both countries also feature the largest number of new stocks added to the index. Of the 396 sample stocks added to the new MSCI index, a total of 113 are U.S. stocks and 29 are U.K. stocks. It is also instructive to express stock weight changes in percentage terms (relative to the midpoint) as

$$\Delta v_j = \frac{w_j^n - w_j^o}{\frac{1}{2}\left(w_j^n + w_j^o\right)},$$

where w_j^o and w_j^n represent the old and new index weight of stock j, respectively. The percentage weight change is bounded above by 2 for newly included stocks and below by -2 for deleted stocks. Table 1, columns (5) and (6) report the mean and the standard deviation of the per-

[11] MSCI's bottom-up approach to index construction may lead to a large company in an industry not being included in the index, while a smaller company from a different industry might be included.

[12] We require in particular 80 weekly return observations for the two-year period between July 1, 1998, and July 1, 2000. Otherwise, the return history is incomplete.

centage weight change Δv_j by country. The largest average stock weight increase is experienced by stocks in New Zealand (44.1 percent), the U.S. (39.0 percent) and the U.K. (36.9 percent). Figure 1 plots the percentage weight change of individual stocks against their initial weight (in logs) both for non-U.S. stocks and U.S. stocks. Due to the overall increase in the number of stocks in the new index, nearly all previously included stocks are downweighted. This explains why the median percentage weight change is negative at -19.0 percent. The comparison between U.S. and non-U.S. stocks also reveals that the average size of U.S. stocks is larger than for non-U.S. stocks. This size difference applies equally to the groups of added, deleted and reweighted stocks.

3.4 Risk Premium Change and Arbitrage Risk

Before we can determine the premium change and the arbitrage risk we need to estimate the covariance matrix Σ of stock returns. To proxy for the (expected) covariance matrix, we simply use the historical covariance based on 2 years of return data prior to the event. The estimation window for the covariance covers the period July 1, 1998 to July 1, 2000. It is sufficiently removed from the first announcement on December 1, 2000 to not be affected by the event itself. The covariance estimation for the stock returns is based on weekly data. Since stock prices are sampled around the world, daily sampling may pose inference problems due to asynchronous return measurement. Weekly return sampling appears more robust to this problem and justifies the use of weekly data.[13] On a more general level, using historical data represents certainly an imperfect measure of the forward look covariance, but it is also the mostly likely technique used by arbitrageurs to determine the optimal arbitrage strategy and the ex ante risk of their portfolio position.

A particularly interesting aspect of the MSCI index revision is its international dimension. Revision of individual country indices occur within an integrated national stock market. All local stocks are then the object of an arbitrage strategy. By contrast, international equity markets are frequently referred to as segmented and therefore priced according to a locally determined risk premium. Arbitrageurs might be restricted to arbitrage strategies comprising stocks located only in their home country. The international index revision serves not only as a test for theories

[13] We verified that estimation of the equity return covariance based on a daily return sampling did not qualitatively alter the results.

of imperfect equity arbitrage, but represents simultaneously a test of the degree of international market integration. In particular, we can distinguish global and local equity arbitrage strategies:

1. Global equity arbitrage: Arbitrageurs take speculative positions in all stocks affected by the index and risk is measured by the global covariance Σ^G of dollar returns. The change in the risk premium on stock j is proportional to $[\Sigma^G(w^n - w^o)]_j$ and the arbitrage risk proxied by $[\Sigma^G\Sigma^G(w^n - w^o)]_j$.

2. Local equity arbitrage: Arbitrageurs speculate only on the weight change in one local market. We can therefore define a restricted covariance matrix Σ^L of equity returns which is obtained from Σ^G by setting to zero all stock covariances cross countries. The change in the risk premium under complete market segmentation is proportional to $[\Sigma^L(w^n - w^o)]_j$ and the arbitrage risk proxied by $[\Sigma^L\Sigma^L(w^n - w^o)]_j$.

Table 2 reports summary statistics of the risk premium changes and the corresponding arbitrage risk for different groups of stocks. Panels A and B describe the global and local risk premium change, respectively, while Panels C and D provide summary statistics on global and local arbitrage risk.[14] A graphical representation of the distribution of the global and local risk premium change is provided in Figure 2 and for the arbitrage risk in Figure 3. Both graphs show systematic differences between non-U.S. and U.S. stocks. The dispersion of the change in the local equity premium is relatively small for non-U.S. stocks with a slightly negative mean of -0.005. The corresponding change in the global premium is also negative at -0.009, but features a much higher standard deviation of 0.036 compared to 0.009 for the local premium. Non-U.S. stocks include more down-weighted than up-weighted stocks, which explains the negative mean for the premium change. The larger number of non-zero and typically positive elements in the matrix Σ^G compared to Σ^L also imply a larger dispersion of the stock specific premium change $[\Sigma(w^n - w^o)]_j$ under market integration relative to the case of market segmentation. For U.S. stocks the premium changes behave very differently. The local equity premium change for U.S. stocks shows a highly positive mean of 0.115 and a large standard deviation of 0.074. Two reasons explain this difference to non-U.S. stocks. First, the average percentage weight increase

[14] A comparision between the local and global premium change or arbitrge risk has to take into consideration that the price effect is obtained only after scaling by the aggregate risk aversion $\frac{\rho}{\lambda}$ and $\left(\frac{\rho}{\lambda}\right)^2$, respectively. These coefficients will tend to be considerably smaller under market integration than segmentation.

for U.S. stocks is very high at 39 percent due to a large number of added stocks. The U.S. increased its index representation by 6.24 percent followed by the U.K. with 1.07 percent. We therefore expect the mean premium change to be positive. Second, the U.S. features more stock than any other country. This explains the much larger dispersion of $[\Sigma^L(w^n - w^o)]_j$ compared to non-U.S. stocks. We also note that the global premium change for U.S. stocks is typically slightly smaller than the local premium change. This is illustrated in Figure 2 where most stocks are situated just below the 45 degree line.

The distributional properties of local and global arbitrage risk are closely related to the distribution of the local and global risk premium. The arbitrage risk $[\Sigma\Sigma(w^n - w^o)]_j$ differs from the risk premium only by a quadratic term $\Sigma\Sigma$ replacing the linear term Σ. Figure 3 shows the distribution of local and global arbitrage risk separately for U.S. and non-U.S. stocks. Non-U.S. stocks are characterized by a much higher global than local arbitrage risk dispersion. By contrast, U.S. stocks feature a high correlation between global and local arbitrage risk as illustrated by their distribution along the 45 degree line.

3.5 Portfolio Risk Relative to the MSCI Index

How much overall risk do arbitrageurs take in their pursuit of an optimal arbitrage strategy? The estimation of the covariance matrices allows us not only to access premium changes and arbitrage risk for each individual stock, but also the portfolio risk involved in the entire arbitrage strategy. We assume for simplicity that the initial holdings of an arbitrageur correspond to the stock weights w^o of the old MSCI index. The risk of such a portfolio can be measured as the standard deviation of the portfolio returns, namely

$$Risk^o = (w^{o\prime}\Sigma w^o)^{\frac{1}{2}}.$$

Next, we consider two alternative arbitrage portfolios. We call *linear arbitrage* those portfolio weight changes which are proportional to the index weight change $\Delta\overline{w} = w^n - w^o$. Alternatively, we name *optimizing arbitrage* those weight changes implied by the optimizing behavior of the arbitrageur. Following Section 2, such optimizing arbitrage requires weight changes proxied by $\Delta\widetilde{w} = [\Sigma - \theta\Sigma\Sigma]\,(w^n - w^o)$ with a parameter $\theta = \beta/\alpha = -2(1-\lambda)\gamma\left(\frac{\rho}{\lambda}\right)$. In order to make optimizing arbitrage directly comparable to the linear arbitrage, we define two scaling parameters μ_1 and μ_2 such that $\sum_j(\Delta\widetilde{w} - \mu_1\mathbf{1})_j = \sum_j \Delta\overline{w}_j = 0$ and $\mu_2\sum_j |\Delta\widetilde{w} - \mu_1\mathbf{1}|_j = \sum_j |\Delta\overline{w}|_j$. The rescaled optimal arbitrage portfolio we define as $\mu_2\,(\Delta\widetilde{w} - \mu_1\mathbf{1})$. Like the linear arbitrage portfolio, it features a zero sum of weight change and has the same sum of absolute weight change as the linear arbitrage portfolio. A shift from the original portfolio w^o into one of the two arbitrage portfolios implies portfolio weights given by

$$\begin{aligned}\overline{w}^\kappa &= w^o + \kappa(w^n - w^o) \\ \widetilde{w}^\kappa &= w^o + \kappa\mu_2\left[(\Sigma - \theta\Sigma\Sigma)(w^n - w^o) + \mu_1\mathbf{1}\right],\end{aligned}$$

where the parameter κ denotes the leverage factor. For the linear arbitrage portfolio, the factor $\kappa = 1$ corresponds to the full shift into the new index, while $\kappa > 1$ implies a speculative position beyond the weight change. The weight change of the optimal arbitrage portfolio accounts for the changes in the risk premium and the arbitrage risk contribution of each stock. The latter is scaled by θ. For an initial portfolio position w^o, the percentage risk increase due to linear or optimal arbitrage positions with leverage factor κ follows as

$$\frac{\overline{Risk}^\kappa}{Risk^o} = \left[\frac{\overline{w}^{\kappa\prime}\Sigma\overline{w}^\kappa}{w^{o\prime}\Sigma w^o}\right]^{\frac{1}{2}} \quad \text{or} \quad \frac{\widetilde{Risk}^\kappa}{Risk^o} = \left[\frac{\widetilde{w}^{\kappa\prime}\Sigma\widetilde{w}^\kappa}{w^{o\prime}\Sigma w^o}\right]^{\frac{1}{2}},$$

respectively. Figure 4 plots the change in the risk ratio as a function of the leverage factor κ for the global arbitrage strategy. A linear portfolio weight shift $\overline{w}^\kappa$ into the new index slightly increases the portfolio risk. This is not surprising since the new index increases the weight of U.S. stocks and their relatively higher correlation diminishes the overall international diversification benefits of the new global equity allocation. The risk increases further with a leverage beyond $\kappa = 1$. For a leverage factor of $\kappa = 3$, the risk of the global arbitrage portfolio increases by 13 percent relative to the old MSCI weights. By contrast, the optimizing arbitrage strategy which shifts into weights $\widetilde{w}^\kappa$ achieves a substantial risk reduction even as the leverage increases. Based on parameter estimates for α and β, we calibrate $\theta = 0.001$. We find for example a risk reduction of 33 percent for a leverage factor $\kappa = 3$. This risk reducing effect of the optimal arbitrage strategy compared to a linear arbitrage strategy is due to the term $-\theta\Sigma\Sigma(w^n - w^o)$, which down-weights stocks with very high arbitrage risk contributions. The overall portfolio risk of the leveraged optimal arbitrage portfolio is paradoxically lower than the benchmark portfolio for a wide range of leverage factors κ.

This aspect allows us to clarify a frequent misunderstanding about the limits of arbitrage. The long-term nature of an arbitrage strategy does not necessarily imply that the arbitrage portfolio is excessively risky. In the case of multi-asset supply shocks like the MSCI index revision, the optimizing arbitrage strategy offers an opportunity to reduce absolute portfolio risk exposure relative to the market risk. This absolute risk reduction increases in the time horizon of the arbitrage strategy. Instead, the limits to arbitrage are determined by a trade-off between the expected premium change in any stock and its marginal risk contribution to the arbitrage position. Both dimensions enter into the optimal arbitrage position and determine the announcement return.

4 Evidence

The portfolio approach to limited arbitrage allowed us to derive a sequence of testable implications. We predict that the event returns in each stock are determined by the change in a stock's risk premium and by its marginal risk contribution to the arbitrage portfolio. Intuitively, the risk premium change $\Sigma(w^n - w^o)$ is given by the product of asset supply change $w^n - w^o$ and the covariance matrix Σ of all stocks. Its jth element represents the marginal contribution of security j to the total market risk change induced by the weight change. An arbitrage position proportional to the expected premium change generates total arbitrage risk given by $(w^n - w^o)'\Sigma\Sigma\Sigma(w^n - w^o)$. The marginal contribution of each stock to this arbitrage risk is characterized by $\Sigma\Sigma(w^n - w^o)$. The optimal arbitrage strategy can be proxied as a linear combination of stock weights determined positively by the expected risk premium change $k\Sigma(w^n - w^o)$ and negatively by the expected arbitrage risk $k\Sigma\Sigma(w^n - w^o)$. The optimal arbitrage strategy in combination with the linear liquidity supply trigger proportional announcement event returns as stated in Proposition 1.

Section 4.1 provides the evidence on the announcement effect. Further revisions of the cross-sectional returns occur when the exact (scalar) magnitude of the supply shock becomes known around the implementation. The evidence concerning the over- or underestimation of the supply shock (Proposition 2) is presented in Section 4.2. The empirical counterpart to Proposition 3 about international market segmentation versus integration is provided in Section 4.3. Section 4.4 documents the ex-post profitability of the optimal arbitrage strategy.

4.1 Announcement Effects and Global Equity Arbitrage

The global scale of the MSCI index rebalancing provides an extremely large sample of stocks which experienced a weight change. We dispose of 2291 stocks with a continuous two year price history needed to calculate the global covariance matrix Σ^G. The statistical inference is based on a cross-sectional analysis in which (log) dollar returns Δp_j in stock j over the entire event window are regressed on a constant c, the risk premium change $\left[\Sigma^G(w^n - w^o)\right]_j$ and the corresponding arbitrage risk $\left[\Sigma^G\Sigma^G(w^n - w^o)\right]_j$ in each stock j. Formally,

$$\Delta p_j = c + \alpha \times \left[\Sigma^G(w^n - w^o)\right]_j + \beta \times \left[\Sigma^G\Sigma^G(w^n - w^o)\right]_j + \mu_j,$$

where we allow for clustering of the error term μ_j on the country level.

Table 3, Panel A features the regression results for the full sample of 2291 stocks. We report regression results for a 3, 5 and 7 day event window with a specification including only the constant and the risk premium change as well as the complete specification. A specification without the arbitrage risk term corresponds to the regressions in Greenwood applied here to the announcement event. This specification is correct for the special case $\lambda = 1$ where all market participants are equally informed arbitrageurs and there is no liquidity supply.

We find that the restrictive specification is rejected by the data. The coefficient α is negative while theory predicts a positive coefficient. The rejection of the Greenwood model is evident for each of the three announcement event windows. But under the full specification with the arbitrage risk term, the sign of the coefficient α becomes positive at a high level of statistical significance. The coefficient estimate of 74.18 for the 5 day event window also implies an economically large return difference of approximately 3.6 percent for two stocks with a relative change in their risk premium by one standard deviation or 0.049. The coefficient β also takes on the predicted negative sign with a value of -0.083 for the 5 day event window. This means that an arbitrage risk increase by one standard deviation (or 61.63) in a particular stock induces smaller speculative positions and therefore a decrease in the announcement return by 5.1 percent. We conclude that arbitrage risk presents a second economically significant determinant of the cross-sectional pattern of the announcement returns.

To check the robustness of these results, we also examine specific subsamples. The most dramatic weight changes are concentrated in the subsample of added and deleted stocks. Panel B reports the respective regression results. Again, we can reject the hypothesis that $\beta = 0$. Like in the entire sample and in line with the theoretical model, the coefficient α for the risk premium change is significantly positive and the coefficient β for the arbitrage risk significantly negative in the full specification. The magnitude of the estimated coefficients for the 5 day window implies a 1.9 ($= 32.61 \times 0.057$) percent return increase for a premium increase by one standard deviation and a 2.8 ($= 0.038 \times 72.61$) percent decrease for an arbitrage risk increase by one standard deviation. Overall, the two price effects of the premium change and the arbitrage risks are again economically large. Figure 5 shows the relationship between the predicted arbitrage position and the actual stock returns for the announcement event separately for added and deleted stocks (left) and reweighted stocks (right). The predicted return difference between stocks with the smallest and largest speculative demand is approximately 15 percent over the 5 day window.

These results lend strong empirical support to our portfolio approach to limited arbitrage. The isolation of the announcement return in the data allows us to reject the Greenwood model as a simple CAPM approach to supply shocks. Less informed liquidity suppliers represent an important aspect of an empirically successful description of the cross-sectional return pattern. This follows from the finding that the marginal risk contribution of the arbitrageurs' stock position relative to the liquidity suppliers enters the regression at high levels of statistical and economic significance. Arbitrage risk is an important determinant of the limits to arbitrage.

4.2 Implementation Effects due to Supply Shock Uncertainty

In order to implement an optimal arbitrage strategy, arbitrageurs not only had to anticipate the weight changes, but also the magnitude of the supply shock as well as the amount of arbitrage capital committed by other arbitrageurs. The magnitude of the supply shock may be uncertain because the value of all index tracking wealth is relatively hard to predict. Moreover, many funds might have had some discretion over the exact timing of the index revision since the old and the new index coexisted for the period between the first and second implementation date. It is therefore very plausible that the arbitrageurs' beliefs $\widehat{u} = ku = \widetilde{\mathcal{E}}(u)$ about the magnitude of the shock differ from the correct beliefs u by some factor k, where $k > 1$ corresponds to an overestimation of the shock and $0 < k < 1$ to its underestimation. The implementation of the index revision on November 30, 2001, and May 31, 2002, naturally provides new information about u and allows for more precise posterior beliefs. Proposition 3 distinguishes the return effect resulting from prior underestimation and overestimation. We expect to find opposite signs for the coefficients α and β in both cases.

The two-step implementation process for the MSCI index revision provides us with two separate observations to examine predication errors. In Table 4, Panels A and B report the evidence for the first implementation date and Panels C and D for the second implementation date. For both the 5 and 7 day event window in Panel A, the coefficient α on the risk premium change has a negative sign and is economically large. The coefficient β for the arbitrage risk as the opposite positive sign as predicted for the case of an overestimation of the supply shock magnitude. The results are very similar for the subsample of added and deleted stocks (Panel B). For the second implementation event we find (in absolute terms) smaller coefficients with a positive parameter estimate for α and negative estimate for β. This result indicates that the second supply shock was underestimated contrary to the first one. Overall, we find no evidence which forces us to reject the model since α and β have opposite signs in each regression. The economically and statistically significant coefficient estimates around the implementation events also suggest parameter uncertainty with respect to the magnitude of the supply shock.

4.3 Global versus Local Asset Pricing

Arbitrage strategies could comprise all MSCI stocks or only a subset of reweighted stocks in the local market. The investor mandate might constrain some fund managers not to invest in the foreign equity market. Similarly, dedicated country funds may be limited to investment in only one foreign country. Only a local equity arbitrage strategy is feasible in these cases. In order to discriminate between the role of local and global arbitrage, we define the incremental risk premium change for a global relative to a local investor as

$$\left[\Sigma^{\Delta}(w^n - w^o)\right]_j = \left[\Sigma^{G}(w^n - w^o)\right]_j - \left[\Sigma^{L}(w^n - w^o)\right]_j$$

and the incremental arbitrage risk as

$$\left[\Sigma\Sigma^{\Delta}(w^n - w^o)\right]_j = \left[\Sigma^{G}\Sigma^{G}(w^n - w^o)\right]_j - \left[\Sigma^{L}\Sigma^{L}(w^n - w^o)\right]_j ,$$

where Σ^G represents the covariance of dollar returns for all 2291 stocks and Σ^L the equivalent covariance matrix with zeros for stocks in different countries. The statistical inference is based on the regression

$$\begin{aligned}\Delta p_j \quad = \quad & c + \alpha^L \times \left[\Sigma^{L}(w^n - w^o)\right]_j + \alpha^{\Delta} \times \left[\Sigma^{\Delta}(w^n - w^o)\right]_j + \\ & + \beta^L \times \left[\Sigma^{L}\Sigma^{L}(w^n - w^o)\right]_j + \beta^{\Delta} \times \left[\Sigma\Sigma^{\Delta}(w^n - w^o)\right]_j + \mu_j,\end{aligned}$$

where Δp_j denotes the (log) dollar return for the announcement event. The coefficient α^L measures the return effect of the local premium change and α^{Δ} the incremental premium change for the global arbitrageur. Similarly, β^L and β^{Δ} capture the arbitrage risk effect on returns for the local arbitrageur and the incremental effect for the global arbitrageur, respectively. Equality of the coefficients α^L and α^Δ as well as β^L and β^Δ implies that the risk premium and the arbitrage risk are determined in a fully integrated market. However, for $\alpha^\Delta = 0$ and $\beta^\Delta = 0$ only local asset pricing is return relevant.

Table 5 reports regression results for the decomposition into the local and global announcement return components. In Panel A the sample consists of all stocks. The incremental effects captured by the coefficients α^Δ and β^Δ are significant for each of the event windows and have the expected sign. The risk premium change and the arbitrage risk therefore have a significant international component. Moreover, we cannot reject the hypothesis that $\alpha^L = \alpha^\Delta$ as well as $\beta^L = \beta^\Delta$. Hence, the hypothesis of full market integration can be maintained, while full segmentation is rejected by the data.

Again, we evaluate the robustness of these results in the smaller subsample of added and deleted stocks. These results are reported in Panel B and are qualitatively similar. The coefficient α^Δ is statistically significant for the 5 day window and the coefficient β^Δ for all three event windows. An alternative subsample is formed by all non-U.S. stocks. U.S. stocks are characterized by a relatively high correlation between local and global risk premium changes and arbitrage risk as documented in Figures 3 and 4. This makes discrimination between the local and global pricing component more difficult. Non-US stocks feature a much lower correlation between local and global explanatory variable. The results for non-U.S. stocks are reported in Panel C. Again, the incremental coefficients α^Δ and β^Δ are of the predicted sign and highly significant. Similar to the full sample, we cannot reject the hypothesis of complete equity market integration. We conclude that arbitrage for the MSCI revision was undertaken on a global scale and that a global portfolio approach to limited arbitrage captures the return pattern best.

4.4 Ex-Post Profitability of Arbitrage Strategies

The optimizing arbitrage portfolio downweights stocks with relatively high arbitrage risk. As shown in Section 3.5, portfolio risk of the arbitrageurs is therefore smaller than the portfolio risk of passive investment in the old MSCI index as long as the leverage κ is not too high. At the same time arbitrageurs enjoy an information advantage over the liquidity suppliers and therefore enjoy higher expected returns. It is interesting to ask if these expectations were validated based on ex-post returns. We calculate cumulative ex-post returns for the linear arbitrage portfolio

$\overline{w}^{\kappa}$ and the optimizing arbitrage portfolio $\widetilde{w}^{\kappa}$ as defined in Section 3.5. We choose the leverage parameter $\kappa = 3$ and again $\theta = \beta/\alpha = 0.001$. The latter value is suggested by the parameter estimates for α and β in Table 3.

Figure 8 plots the cumulative return starting on the announcement day of December 1, 2000 until the second implementation date 18 months later. The vertical lines mark the announcement and two implementation dates, respectively. For comparison, we also plot the return on the old MSCI index corresponding to a leverage factor $\kappa = 0$. All three portfolios have a negative return over the 12 and 18 month periods to the first and second announcement event. The optimizing global arbitrage portfolio $\widetilde{w}^{\kappa}$ outperforms the old MSCI index by 5.07 percent at the first implementation date and by 7.99 percent at the second implementation date. By contrast, the linear global arbitrage portfolio $\overline{w}^{\kappa}$ shows a much more modest index outperforming of 0.54 percent and 1.97 percent, respectively. This is not surprising if premium changes are not well proxied by simple weight changes. We can therefore conclude that the optimal global equity arbitrage was very profitable, particularly if the arbitrage was carried out until the second implementation date.

5 Conclusion

The previous finance literature viewed equity index changes as an interesting exogenous event to explore the limits of equity arbitrage. The current paper extends our understanding of such events by developing a more comprehensive portfolio approach to index changes. We propose a new - but simple - heterogenous agent model of multi-asset arbitrage which adds price linear liquidity provision to the Greenwood model. Incorporating information heterogeneity between arbitrageurs and the liquidity supply side of the market has attractive theoretical implications. Arbitrageurs can actually accumulate speculative positions against the less informed liquidity providers. As a consequence, their trading returns can exceed the CAPM-based fair risk compensation. More important still are the asset pricing implications for the announcement event. Similar to Greenwood, we obtain the CAPM price effect which is positive and proportional to the (expected) premium change $[\Sigma(w^n - w^o)]_j$ at the announcement of the index revision. Secondly, equilibrium returns are influenced negatively by the risk contribution of the arbitrage position. This new arbitrage risk term $[\Sigma\Sigma(w^n - w^o)]_j$ is quadratic in the covariance matrix Σ and reflects the arbitrageurs desire to control the risk of the speculative position.

The redefinition of the MSCI index represents an ideal experiment to test our portfolio model of limited arbitrage. The unprecedented scope of the index revision provides us with a sample of 2291 stocks for which the covariance matrix Σ can be estimated and for which we calculated premium changes and arbitrage risk contributions. We find that announcement returns are indeed determined by premium change and the arbitrage risk contribution. Both coefficients have the correct sign and are highly significant explanatory variables. The finding is robust to variations of the event window size and extends to various subsamples.

We highlight the fact that the quadratic nature of the arbitrage risk term does not imply that its role in determining the cross-section of announcement returns is of second order. Its exclusion from the regression implies that the coefficient of the risk premium turns from being significantly positive to significantly negative. This means that our data rejects the nested Greenwood model at high levels of statistical confidence. We conclude that a portfolio approach to limited arbitrage based only on the CAPM structure cannot account for the evidence. However, incorporating less informed liquidity providers into the asset pricing framework provides a tractable model extension of surprising explanatory power for cross-section of returns.

The implementation of the index revision can give rise to further systematic portfolio effects if the magnitude of the shock is either over- or underestimated. We find evidence for both in the two distinct implementation steps of the MSCI modification. The first implementation date appears to be characterized by an overestimation of the supply shock magnitude, while the second event shows evidence for underestimation.

The international nature of the event may raise concerns about whether the global equity market is truly integrated with respect to asset pricing. We explore this issue be decomposing the premium change and the arbitrage risk contribution into a strictly local market component and the incremental component to the global terms. Such a decomposition reveals that the incremental (international) asset price component is highly significant. We conclude that arbitrage for the MSCI revision was undertaken on a global scale and that a global portfolio approach to limited arbitrage captures the return pattern best. This can be interpreted as evidence that MSCI stocks are today priced globally and not locally.

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Appendix

Proposition 1:

The model is solved backwards starting at the terminal asset value p_4. The risk premium for the last period (after the supply shock $u = w^n - w^o$) follows from market clearing at time $t = 3$ as

$$r_4 = \left[\lambda(\rho\Sigma)^{-1} + (1-\lambda)\gamma I\right]^{-1}(S - u),$$

and the price therefore as

$$p_3 = 1 + \varepsilon_1 + \varepsilon_2 + \varepsilon_3 - r_4.$$

At time $t = 2$, both the arbitrageurs and the liquidity suppliers hold expectations $\widetilde{\mathcal{E}}_2(u) = \overline{\mathcal{E}}_2(u) = \widehat{u}$. The risk premium for period 3 is determined by the asset supply S and therefore given by

$$r = \left[\lambda(\rho\Sigma)^{-1} + (1-\lambda)\gamma I\right]^{-1} S,$$

and the price follows as

$$p_2 = 1 + \varepsilon_1 + \varepsilon_2 - \widehat{r}_4 - r,$$

where $\widehat{r}_4 = \left[\lambda(\rho\Sigma)^{-1} + (1-\lambda)\gamma I\right]^{-1}(S - \widehat{u})$ denotes the expected risk premium in period 4.

At time $t = 1$, only the arbitrageurs anticipate the supply shock. Asset price expectations therefore differ and follow as $\widetilde{\mathcal{E}}_1(p_2) = 1 + \varepsilon_1 - \widehat{r}_4 - r$ for the arbitrageurs and $\overline{\mathcal{E}}_1(p_2) = 1 + \varepsilon_1 - 2r$ for the liquidity suppliers. Market clearing then implies

$$\begin{aligned}
\Sigma S &= \lambda\frac{1}{\rho}\widetilde{\mathcal{E}}_1(p_2 - p_1) + (1-\lambda)\gamma\Sigma\overline{\mathcal{E}}_1(p_2 - p_1) \\
&= \lambda\frac{1}{\rho}I\,(1 + \varepsilon_1 - \widehat{r}_4 - r - p_1) + (1-\lambda)\gamma\Sigma(1 + \varepsilon_1 - 2r - p_1) \\
&= (\lambda\frac{1}{\rho}I + (1-\lambda)\gamma\Sigma)(1 + \varepsilon_1 - p_1) + \lambda\frac{1}{\rho}I\,(-\widehat{r}_4 - r) + (1-\lambda)\gamma\Sigma(-2r)
\end{aligned}$$

or

$$
\begin{aligned}
p_1 &= 1+\varepsilon_1+\left(\frac{\lambda}{\rho}I+(1-\lambda)\gamma\Sigma\right)^{-1}\left[\frac{\lambda}{\rho}I\left(-\widehat{r}_4-r\right)+(1-\lambda)\gamma\Sigma(-2r)-\Sigma S\right] \\
&= 1+\varepsilon_1+\left(\frac{\lambda}{\rho}I+(1-\lambda)\gamma\Sigma\right)^{-1}\left[\frac{\lambda}{\rho}I\left(-2r\right)+(1-\lambda)\gamma\Sigma(-2r)-\Sigma S+\frac{\lambda}{\rho}I\left(r-\widehat{r}_4\right)\right] \\
&= 1+\varepsilon_1-2r+\left(\frac{\lambda}{\rho}I+(1-\lambda)\gamma\Sigma\right)^{-1}\left[-\Sigma S+\frac{\lambda}{\rho}I\left(r-\widehat{r}_4\right)\right] \\
&= 1+\varepsilon_1-2r-\left(\frac{\lambda}{\rho}I+(1-\lambda)\gamma\Sigma\right)^{-1}\Sigma S+\left(\frac{\lambda}{\rho}I+(1-\lambda)\gamma\Sigma\right)^{-1}\left[\frac{\lambda}{\rho}\Sigma^{-1}+(1-\lambda)\gamma I\right]^{-1}\frac{\lambda}{\rho}\widehat{u} \\
&= 1+\varepsilon_1-2r-\left(\frac{\lambda}{\rho}\Sigma^{-1}+(1-\lambda)\gamma I\right)^{-1}S+\left(\frac{\lambda}{\rho}I+(1-\lambda)\gamma\Sigma\right)^{-2}\frac{\lambda}{\rho}\Sigma\widehat{u} \\
&= 1+\varepsilon_1-3r+\left(\frac{\lambda}{\rho}I+(1-\lambda)\gamma\Sigma\right)^{-2}\frac{\lambda}{\rho}\Sigma\widehat{u}.
\end{aligned}
$$

The linearization of the last expression for the case that $(1-\lambda)\gamma \approx 0$ implies

$$
\begin{aligned}
p_1 &\approx 1+\varepsilon_1-3r+\left[\left(\frac{\lambda}{\rho}I\right)^{-2}-2\left(\frac{\lambda}{\rho}I\right)^{-3}(1-\lambda)\gamma\Sigma\right]\frac{\lambda}{\rho}\Sigma\widehat{u} \\
&\approx 1+\varepsilon_1-3r+\frac{\rho}{\lambda}k\Sigma u-2(1-\lambda)\gamma\left(\frac{\rho}{\lambda}\right)^2 k\Sigma\Sigma u,
\end{aligned}
$$

where we used $\widehat{u}=ku$. In the absence of the liquidity supply shock the price follows as $p_1(u=0)=1+\varepsilon_1-3r$. The term

$$
\Delta p_1=\frac{\rho}{\lambda}k\Sigma u-2(1-\lambda)\gamma\left(\frac{\rho}{\lambda}\right)^2 k\Sigma\Sigma u
$$

therefore denotes the price reaction around the announcement event due to the arbitrage opportunity. We can also express the aggregate position of the arbitrageurs as

$$
\begin{aligned}
x^A &= S-(1-\lambda)\gamma\overline{\mathcal{E}}_1(p_2-p_1) \\
&= S-(1-\lambda)\gamma\left[r-\frac{\rho}{\lambda}k\Sigma u+2(1-\lambda)\gamma\left(\frac{\rho}{\lambda}\right)^2 k\Sigma\Sigma u\right] \\
&= S-(1-\lambda)\gamma r+(1-\lambda)\gamma\frac{\rho}{\lambda}k\Sigma u-2(1-\lambda)^2\gamma^2\left(\frac{\rho}{\lambda}\right)^2 k\Sigma\Sigma u
\end{aligned}
$$

compared to $x^A(\lambda=1)=S$ for the case where there is no liquidity supply. The term $k\Sigma u$ represents position taking due to expected premium changes and $k\Sigma\Sigma u$ proxies the expected arbitrage risk. The optimal arbitrage position is given by a liner combination of the expected premium change and the arbitrage risk.

Proposition 2:

Let $\widehat{u} = ku$ be the expected supply shock. From proposition 1, we obtain the following price dynamics:

$$\begin{aligned}
p_0 &= 1 - 4r \\
p_1 &\approx 1 + \varepsilon_1 - 3r + \frac{\rho}{\lambda} k\Sigma u - 2(1-\lambda)\gamma \left(\frac{\rho}{\lambda}\right)^2 k\Sigma\Sigma u \\
p_2 &= 1 + \varepsilon_1 + \varepsilon_2 - r - \widehat{r}_4 \\
p_3 &= 1 + \varepsilon_1 + \varepsilon_2 + \varepsilon_3 - r_4.
\end{aligned}$$

Immediately before the correct magnitude of the supply shock becomes known at time $t = 3$, we have

$$\begin{aligned}
p_{3-\delta} &= 1 + \varepsilon_1 + \varepsilon_2 + \varepsilon_3 - \widehat{r}_4 \\
&= 1 + \varepsilon_1 + \varepsilon_2 + \varepsilon_3 - \left[\lambda(\rho\Sigma)^{-1} + (1-\lambda)(\rho_L \sigma^2 I)^{-1}\right]^{-1} (S - \widehat{u})
\end{aligned}$$

and the implementation effect becomes

$$\begin{aligned}
\Delta p_3 &= -r_4 + \widehat{r}_4 \\
&= \left[\frac{\rho}{\lambda}\Sigma^{-1} + (1-\lambda)\gamma I\right]^{-1} (u - \widehat{u}) \\
&= \left[I + \frac{\rho}{\lambda}\Sigma(1-\lambda)\gamma I\right]^{-1} \left(\frac{\rho}{\lambda}\Sigma\right)(1-k)u.
\end{aligned}$$

A linear approximation gives

$$\begin{aligned}
\Delta p_3 &\approx \left[I - (1-\lambda)\gamma\frac{\rho}{\lambda}\Sigma\right] \left(\frac{\rho}{\lambda}\Sigma\right)(1-k)u \\
&\approx \frac{\rho}{\lambda}(1-k)\Sigma u - (1-\lambda)\gamma \left(\frac{\rho}{\lambda}\right)^2 (1-k)\Sigma\Sigma u.
\end{aligned}$$

Table 1: Summary Statistics on Weight Changes

We report summary statistics by country on the (1) total number of stocks concerned by MSCI index revision, (2) total number of sample stocks with complete historic price data, (3) new and (4) old country weights in percent. For the sample stocks we also provide the (5) mean and (6) standard deviation of the percentage weight change Δv within the country.

Country	(1) MSCI Stocks	(2) Sample Stocks	(3) New Weight	(4) Old Weight	(5) Mean(Δv)	(6) SD(Δv)
Argentina	17	0	0.03	0.07	–	–
Australia	71	66	1.28	1.29	0.395	0.939
Austria	17	16	0.04	0.09	−0.702	1.021
Belgium	18	16	0.28	0.39	−0.308	0.991
Brazil	50	47	0.30	0.49	−0.638	1.041
Canada	89	80	1.93	1.97	0.195	1.025
Chile	30	30	0.07	0.18	−0.777	0.941
China	43	37	0.26	0.35	0.091	1.215
Colombia	9	8	0.00	0.01	−1.184	0.560
Czech Republic	6	6	0.01	0.03	−0.958	0.149
Denmark	27	24	0.28	0.40	0.098	1.211
Egypt	14	11	0.01	0.01	0.033	0.000
Finland	30	27	1.00	0.98	−0.598	1.116
France	63	59	3.77	4.93	−0.279	1.03
Germany	59	51	2.76	3.71	−0.276	1.013
Greece	24	21	0.16	0.16	0.033	0.000
Hong Kong	34	32	0.66	0.93	−0.511	1.137
Hungary	13	13	0.03	0.04	−1.079	0.913
India	76	74	0.12	0.35	−1.037	0.943
Indonesia	32	32	0.02	0.03	−1.171	1.039
Ireland	16	15	0.34	0.30	0.044	0.942
Israel	52	49	0.16	0.24	−0.765	1.407
Italy	47	41	1.38	1.99	−0.436	1.107
Japan	348	333	9.38	10.71	0.035	1.068
Korea	82	69	0.45	0.57	−0.119	1.102
Luxembourg	3	3	0.01	0.05	−1.093	0.478
Malaysia	86	84	0.12	0.29	−0.696	1.186
Mexico	27	25	0.3	0.59	−0.674	0.938
Morocco	12	11	0.01	0.01	0.033	0.000
Netherlands	26	24	2.17	2.42	−0.045	0.665
New Zealand	15	10	0.04	0.05	0.441	1.446
Norway	24	22	0.16	0.20	0.007	0.834
Pakistan	18	18	0.00	0.01	−1.339	0.706
Peru	11	10	0.01	0.02	−0.294	1.344
Philippines	21	20	0.02	0.05	−0.901	1.176
Poland	22	19	0.04	0.06	−0.404	0.945
Portugal	11	10	0.15	0.23	−0.728	0.492
Russia	12	9	0.08	0.14	−0.550	1.178
Singapore	40	34	0.26	0.38	−0.221	1.167
South Africa	48	45	0.47	0.55	−0.378	0.922
Spain	34	31	1.21	1.38	−0.830	0.964
Sri Lanka	8	8	0.00	0.00	−0.753	0.589
Sweden	37	35	0.84	1.00	−0.022	0.647
Switzerland	43	38	2.87	2.93	−0.105	1.143
Taiwan	96	89	0.44	0.69	0.111	1.304
Thailand	39	37	0.04	0.08	−0.926	1.176
Turkey	45	0	0.05	0.12	–	–
United Kingdom	140	133	10.33	9.26	0.369	0.924
United States	443	414	55.12	48.88	0.390	1.108
Venezuela	7	5	0.01	0.02	−0.598	1.470
Country Unknown	31	0	0.5	0.38	–	–
Total	2566	2291	100.00	100.00	–	–

Table 2: Summary Statistics on Risk Contribution to Arbitrage Portfolios

We report summary statistics on stock risk premium changes and on their risk contributions to the arbitrage portfolio for both the global covariance matrix Σ^G and local covariance matrix Σ^L of stock returns. In the local covariance matrix elements are set to zero for stocks in different national markets. The covariance matrices are estimated for 2 years of weekly dollar stock returns for the period of July 1, 1998 to July 1, 2000.

		Obs.	Mean	S.D.	Min	Max
Panel A: Change in Risk Premium under Global Pricing						
All Stocks	$[\Sigma^G(w^n - w^o)]_j$	2,291	0.006	0.049	−0.173	0.249
Added and Deleted Stocks	$[\Sigma^G(w^n - w^o)]_j$	661	0.013	0.057	−0.173	0.280
U.S. Stocks	$[\Sigma^G(w^n - w^o)]_j$	414	0.070	0.047	−0.078	0.249
Non-U.S. Stocks	$[\Sigma^G(w^n - w^o)]_j$	1877	−0.009	0.036	−0.173	0.219
Panel B: Change in Risk Premium under Local Pricing						
All Stocks	$[\Sigma^L(w^n - w^o)]_j$	2,291	0.017	0.056	−0.074	0.345
Added and Deleted Stocks	$[\Sigma^L(w^n - w^o)]_j$	661	0.027	0.072	−0.071	0.345
U.S. Stocks	$[\Sigma^L(w^n - w^o)]_j$	414	0.115	0.074	−0.074	0.345
Non-U.S. Stocks	$[\Sigma^L(w^n - w^o)]_j$	1877	−0.005	0.009	−0.052	0.031
Panel C: Risk Contribution to Global Arbitrage Portfolio						
All Stocks	$[\Sigma^G\Sigma^G(w^n - w^o)]_j$	2,291	25.88	61.63	−179.46	335.31
Added and Deleted Stocks	$[\Sigma^G\Sigma^G(w^n - w^o)]_j$	661	33.36	72.61	−179.46	335.31
U.S. Stocks	$[\Sigma^G\Sigma^G(w^n - w^o)]_j$	414	100.49	66.14	−84.17	335.31
Non-U.S. Stocks	$[\Sigma^G\Sigma^G(w^n - w^o)]_j$	1877	9.42	46.62	−179.46	302.09
Panel D: Risk Contribution to Local Arbitrage Portfolio						
All Stocks	$[\Sigma^L\Sigma^L(w^n - w^o)]_j$	2,291	20.35	57.00	−71.15	391.95
Added and Deleted Stocks	$[\Sigma^L\Sigma^L(w^n - w^o)]_j$	661	30.12	74.09	−71.15	391.95
U.S. Stocks	$[\Sigma^L\Sigma^L(w^n - w^o)]_j$	414	119.30	77.46	−71.15	391.95
Non-U.S. Stocks	$[\Sigma^L\Sigma^L(w^n - w^o)]_j$	1877	−1.47	2.90	−18.69	11.77

Table 3: Announcement Event

We perform cross sectional regressions of the event window equity returns Δp_j (denominated in dollars and expressed in percentage points) on a constant, the change in the risk premium $\left[\Sigma^G(w^n - w^o)\right]_j$ and the arbitrage risk $\left[\Sigma^G\Sigma^G(w^n - w^o)\right]_j$ of each stock j. Formally,

$$\Delta p_j = c + \alpha \times [\Sigma^G(w^n - w^o)]_j + \beta \times [\Sigma^G\Sigma^G(w^n - w^o)]_j + \mu_j.$$

The covariance matrix Σ^G is estimated for 2 years of weekly dollar stock returns for the period of July 1, 1998 to July 1, 2000. We use 3 day or 5 day or 7 day event windows (WS). Panel A reports the coefficients for the entire sample, Panel B for only the added and deleted stocks and Panel C for the subsample of U.S. stocks. Robust and country cluster adjusted t-values are reported in parenthesis. We indicate in bold significance at the 1 percent level.

WS	c	[t]	α	[t]	β	[t]	R^2
Panel A: Announcement Event (All Stocks, N=2291)							
3	0.545	[1.21]	−12.282	[−2.16]			0.011
3	**1.403**	[3.34]	**40.520**	[3.16]	**−0.045**	[−4.19]	0.042
5	−0.602	[−0.94]	−24.098	[−2.62]			0.024
5	0.997	[1.73]	**74.180**	[4.98]	**−0.083**	[−8.76]	0.087
7	1.442	[2.69]	−20.389	[−2.29]			0.016
7	**2.635**	[5.57]	**52.999**	[3.76]	**−0.062**	[−5.52]	0.049
Panel B: Announcement Event (Only Added and Deleted Stocks, N=661)							
3	0.407	[0.83]	−13.014	[−2.46]			0.015
3	1.081	[2.17]	32.615	[2.48]	**−0.037**	[−3.78]	0.037
5	−0.922	[−1.38]	**−34.751**	[−4.12]			0.059
5	1.081	[2.17]	32.615	[2.48]	**−0.038**	[−3.78]	0.037
7	0.855	[1.39]	**−29.942**	[−3.49]			0.042
7	**1.881**	[3.20]	39.57	[2.08]	**−0.058**	[−4.66]	0.070
Panel C: Announcement Event (Only Non-U.S. Stocks, N=1877)							
3	0.442	[0.88]	−14.014	[−1.42]			0.009
3	**1.365**	[2.89]	**40.929**	[2.77]	**−0.048**	[−3.71]	0.047
5	−0.882	[−1.40]	−25.358	[−1.66]			0.016
5	0.705	[1.22]	**69.038**	[3.76]	**−0.082**	[−7.32]	0.083
7	1.208	[2.06]	−25.048	[−1.47]			0.014
7	**2.462**	[4.75]	**49.634**	[2.83]	**−0.065**	[−4.87]	0.051

Table 4: Implementation Events

We perform cross sectional regressions of the event window equity returns Δp_j (denominated in dollars and expressed in percentage points) on a constant, the risk premium change $[\Sigma^G(w^n - w^o)]_j$ and the arbitrage risk $[\Sigma^G\Sigma^G(w^n - w^o)]_j$ of each stock j. Formally,

$$\Delta p_j = c + \alpha \times [\Sigma^G(w^n - w^o)]_j + \beta \times [\Sigma^G\Sigma^G(w^n - w^o)]_j + \mu_j.$$

The covariance matrix Σ^G is estimated for 2 years of weekly dollar stock returns for the period of July 1, 1998 to July 1, 2000. Regression results for the 5 and 7 day event windows (WS) of the first implementation event is reported in Panel A for the entire sample, in Panel B for only the added and deleted stocks. Panels C and D provide corresponding results for the second implementation event. Robust and country cluster adjusted t-values are reported in parenthesis. We indicate in bold significance at the 1 percent level.

WS	c	[t]	α	[t]	β	[t]	R^2
Panel A: First Implementation Event (All Stocks, N=2291)							
5	**2.469**	[3.36]	21.379	[2.11]			0.026
5	1.423	[1.76]	**−42.915**	[−2.85]	**0.055**	[4.28]	0.061
7	2.933	[2.48]	12.201	[0.80]			0.005
7	1.700	[1.30]	**−63.606**	[−4.49]	**0.064**	[3.85]	0.036
Panel B: First Implementation Event (Only Added and Deleted Stocks, N=661)							
5	1.873	[2.07]	27.658	[2.56]			0.048
5	0.864	[0.98]	−40.682	[−1.76]	**0.057**	[3.25]	0.084
7	2.406	[1.71]	20.133	[1.38]			0.017
7	1.206	[0.88]	−61.134	[−2.53]	**0.068**	[3.97]	0.051
Panel C: Second Implementation Event (All Stocks, N=2291)							
5	**−1.225**	[−5.26]	**−11.584**	[−3.66]			0.0147
5	−0.662	[−2.14]	22.988	[1.98]	**−0.029**	[−2.84]	0.0349
7	**−2.276**	[−7.26]	**−22.746**	[−3.92]			0.032
7	**−1.298**	[−3.08]	37.395	[2.63]	**−0.051**	[−3.79]	0.067
Panel D: Second Implementation Event (Only Added and Deleted Stocks, N=661)							
5	−0.736	[−2.60]	**−17.094**	[−3.69]			0.044
5	−0.337	[−0.73]	9.919	[0.56]	−0.022	[−1.67]	0.057
7	**−1.871**	[−4.45]	**−30.342**	[3.57]			0.065
7	−1.190	[−2.13]	15.759	[0.75]	−0.038	[−2.60]	0.083

Table 5: Local versus Global Asset Pricing

We perform cross sectional regressions of the event window equity returns Δp_j (denominated in dollars and expressed in percentage points) on a constant, the change in the risk premium $[\Sigma^L(w^n - w^o)]_j$ of a local arbitrage portfolio, difference between the global and local risk premium change $[\Sigma^\Delta(w^n - w^o)]_j$, the arbitrage risks for the local arbitrage portfolio $[\Sigma^L\Sigma^L(w^n - w^o)]_j$ and the incremental arbitrage risk to the global arbitrage risk $[\Sigma\Sigma^\Delta(w^n - w^o)]_j$. Formally,

$$\Delta p_j = c + \alpha^L \times [\Sigma^L(w^n - w^o)]_j + \alpha^\Delta \times [\Sigma^\Delta(w^n - w^o)]_j + \beta^L \times [\Sigma^L\Sigma^L(w^n - w^o)]_j + \beta^\Delta \times [\Sigma\Sigma^\Delta(w^n - w^o)]_j + \mu_j.$$

The covariance matrix Σ^G is estimated for 2 years of weekly dollar stock returns for the period of July 1, 1998 to July 1, 2000. We obtain Σ^L by setting to zero all stock covariances across countries to capture only within country arbitrage and define $\Sigma^\Delta = \Sigma^G - \Sigma^L$ and $\Sigma\Sigma^\Delta = \Sigma^G\Sigma^G - \Sigma^L\Sigma^L$. We use 3 day or 5 day or 7 day event windows. Panels A reports the coefficients for all stocks, Panel B only for added and deleted stock and Panel C only for U.S. stocks. Robust and country cluster adjusted t-values are reported in parenthesis. We indicate in bold significance at the 1 percent level.

WS	c	[t]	α^L	[t]	α^Δ	[t]	β^L	[t]	β^Δ	[t]	R^2
Panel A: Announcement Event (All Stocks, N=2291)											
3	1.354	[3.24]	33.680	[0.77]	39.169	[2.56]	−0.037	[−0.85]	**−0.047**	[−3.43]	0.043
5	0.921	[1.65]	52.967	[1.35]	**74.912**	[4.31]	−0.061	[−1.64]	**−0.087**	[−7.60]	0.088
7	**2.505**	[5.25]	16.959	[0.34]	**54.127**	[3.20]	−0.024	[−0.49]	**−0.068**	[−5.09]	0.052
Panel B: Announcement Event (Only Added and Deleted Stocks, N=661)											
3	1.073	[2.32]	89.966	[2.23]	23.836	[1.68]	−0.094	[−2.47]	**−0.037**	[−2.85]	0.047
5	0.541	[0.89]	138.915	[2.51]	52.752	[2.56]	**−0.157**	[−3.16]	**−0.076**	[−5.58]	0.124
7	**1.857**	[3.25]	53.423	[1.17]	36.45	[1.86]	−0.071	[−1.72]	**−0.061**	[−4.03]	0.071
Panel C: Announcement Event (Non-U.S. Stocks, N=1877)											
3	**1.362**	[3.10]	**121.216**	[2.75]	33.701	[1.93]	−0.265	[−1.38]	**−0.042**	[−2.93]	0.053
5	0.695	[1.23]	108.681	[1.84]	**65.479**	[3.06]	−0.195	[−0.61]	**−0.079**	[−6.27]	0.084
7	**2.512**	[4.39]	97.632	[2.03]	45.253	[2.24]	−0.162	[−0.61]	**−0.062**	[−4.04]	0.052

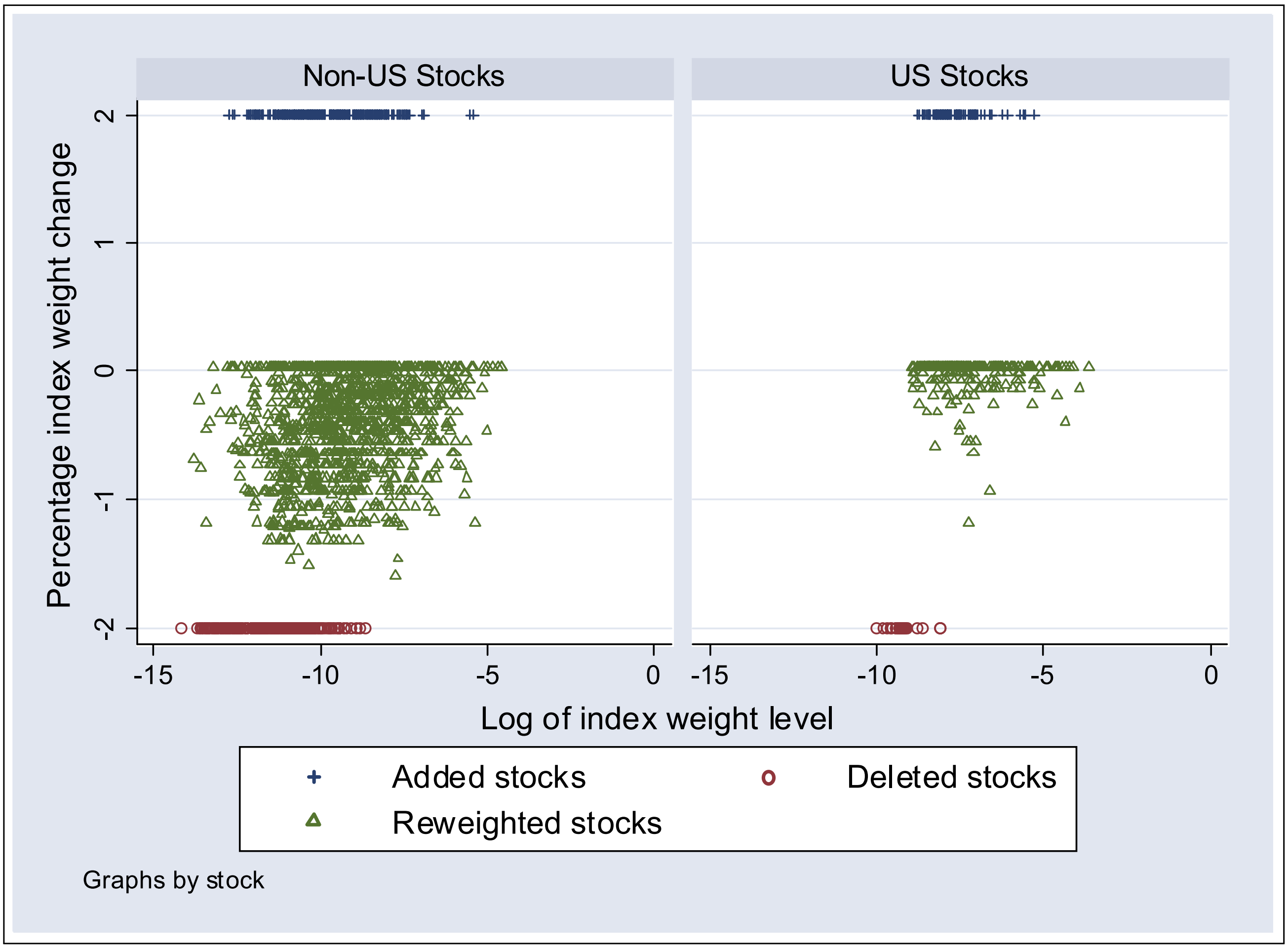

Figure 1: The percentage weight change for U.S. and non-U.S. stocks is plotted as a function of the log of the level of the old weight in the index (or the new weight in case of stock additions)

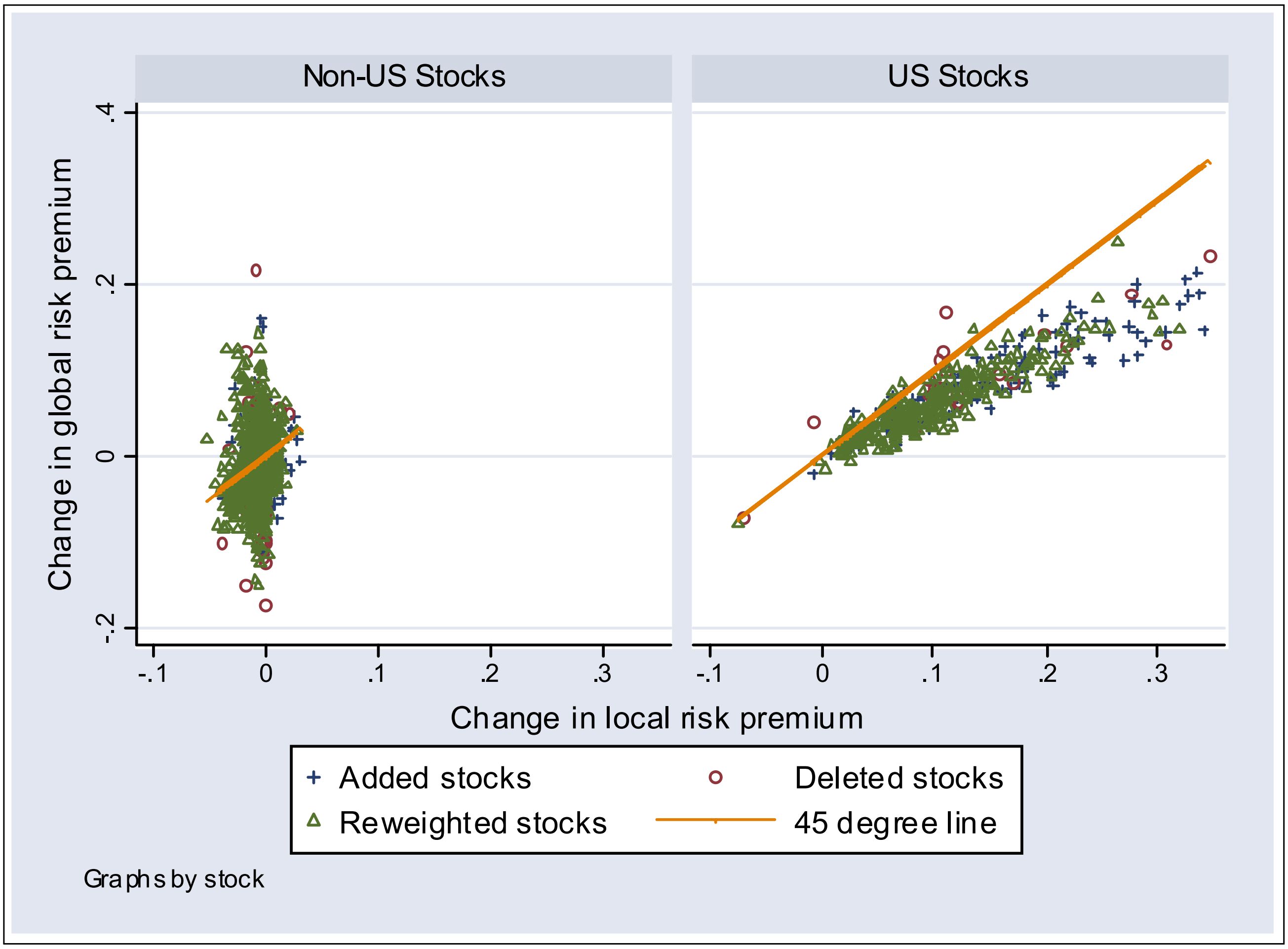

Figure 2: Plotted are the risk premium changes $[\Sigma^L(w^n - w^o)]_j$ of individual stocks j under local asset pricing (market segmentation) against the risk premium changes $[\Sigma^G(w^n - w^o)]_j$ of the same stock under global asset pricing (market integration).

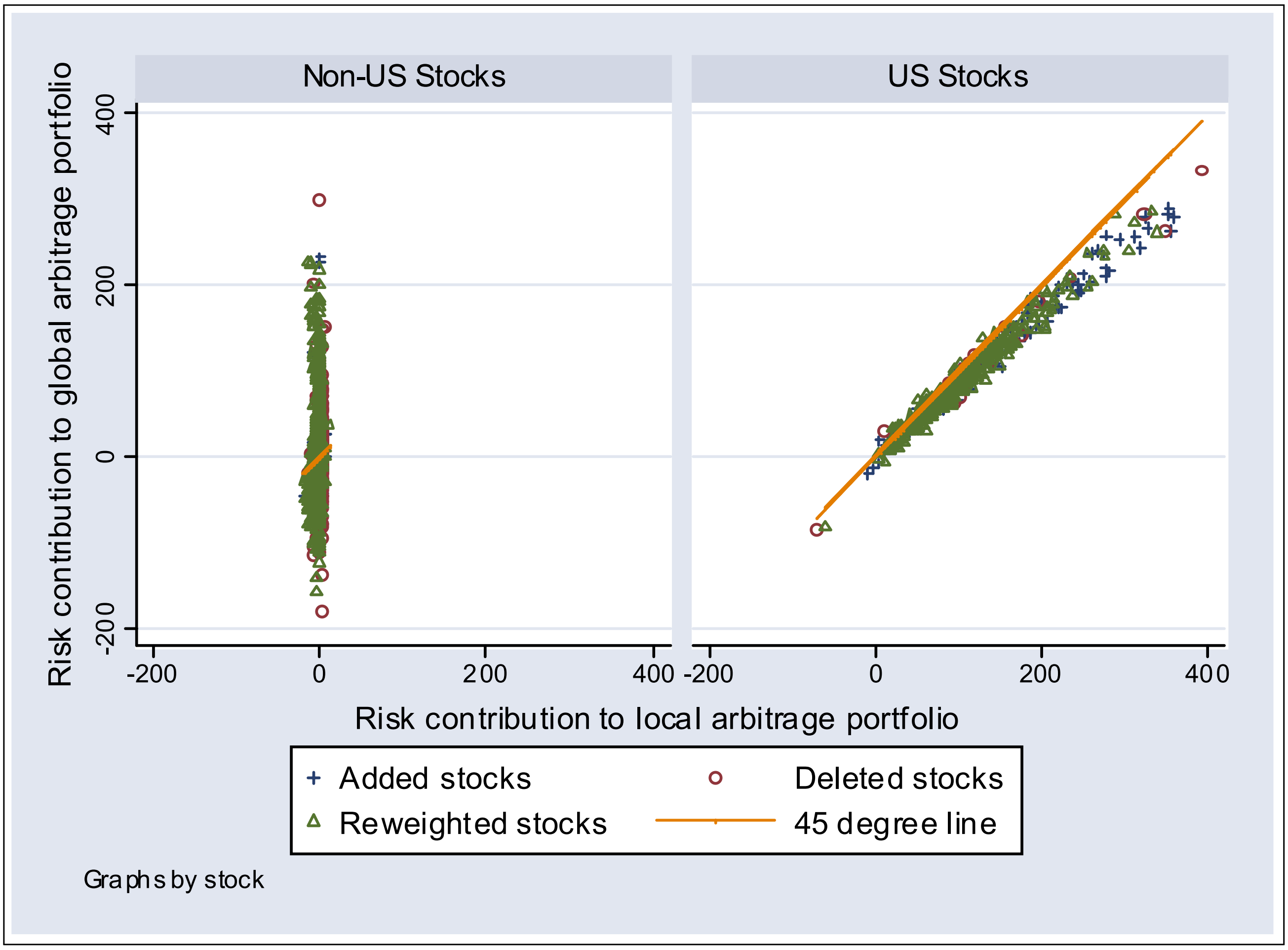

Figure 3: Plotted are the arbitrage risk contributions $[\Sigma^L\Sigma^L(w^n - w^o)]_j$ of individual stocks j to local arbitrage portfolios composed only of local stock (x-axis) against the arbitrage risk contributions $[\Sigma^G\Sigma^G(w^n - w^o)]_j$ of the same stock to a global arbitrage portfolio of all stocks (y-axis).

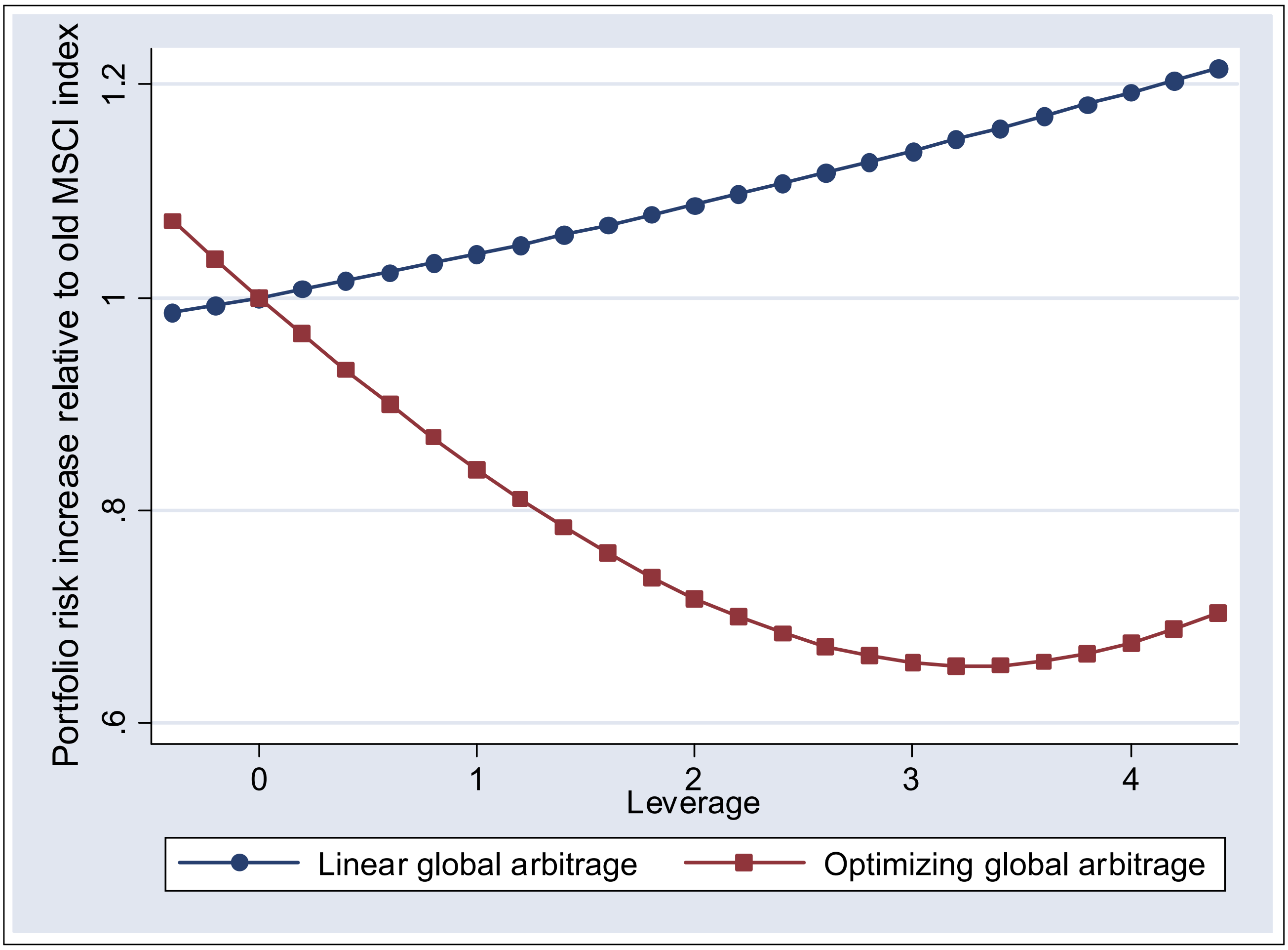

Figure 4: Plotted is the total risk of an arbitrage portfolio under leverage factor κ relative to the total portfolio risk of the old MSCI index for both a linear shift into the new index (Linear global arbitrage) and alternatively an optimizing strategy with parameter $\theta = 0.001$.

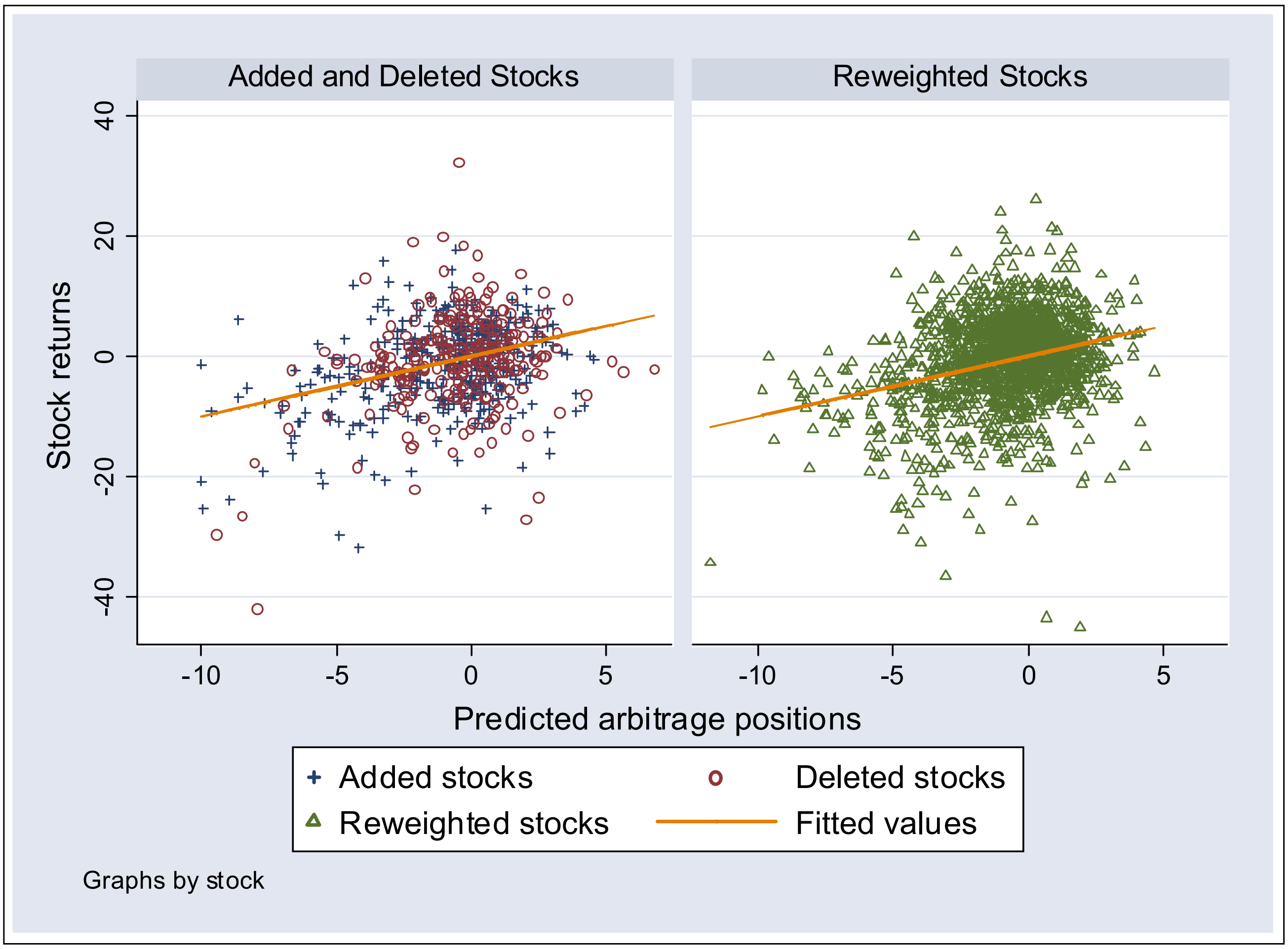

Figure 5: Annoucement event: Plotted are the stock returns for a 5 day window around the announcement event against the predicted arbitrage positions in each stock.

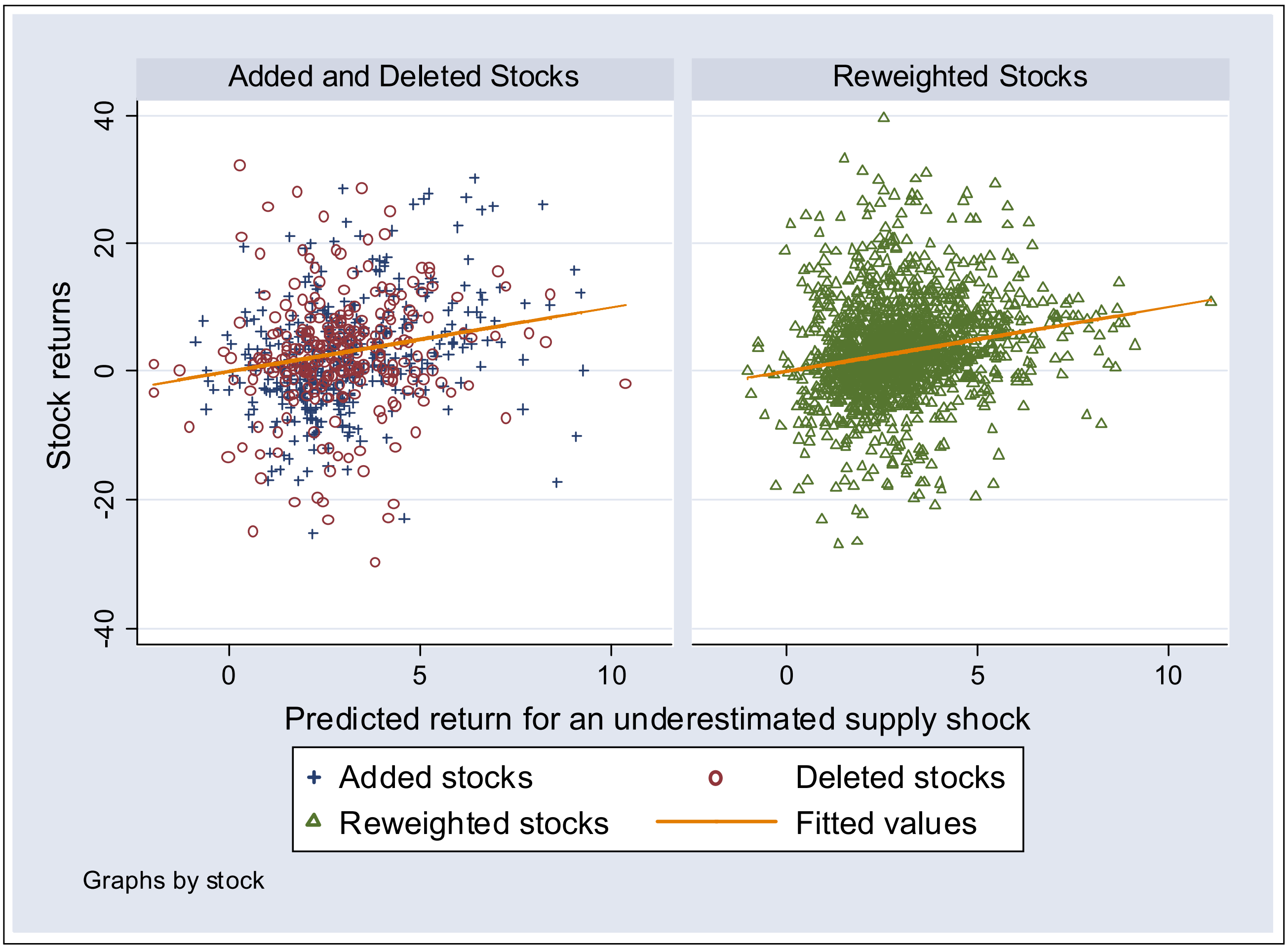

Figure 6: First implementation event: Plotted are the stock returns for a 7 day window around the first implementation event against the predicted returns for an underestimated magnitude of the supply shock.

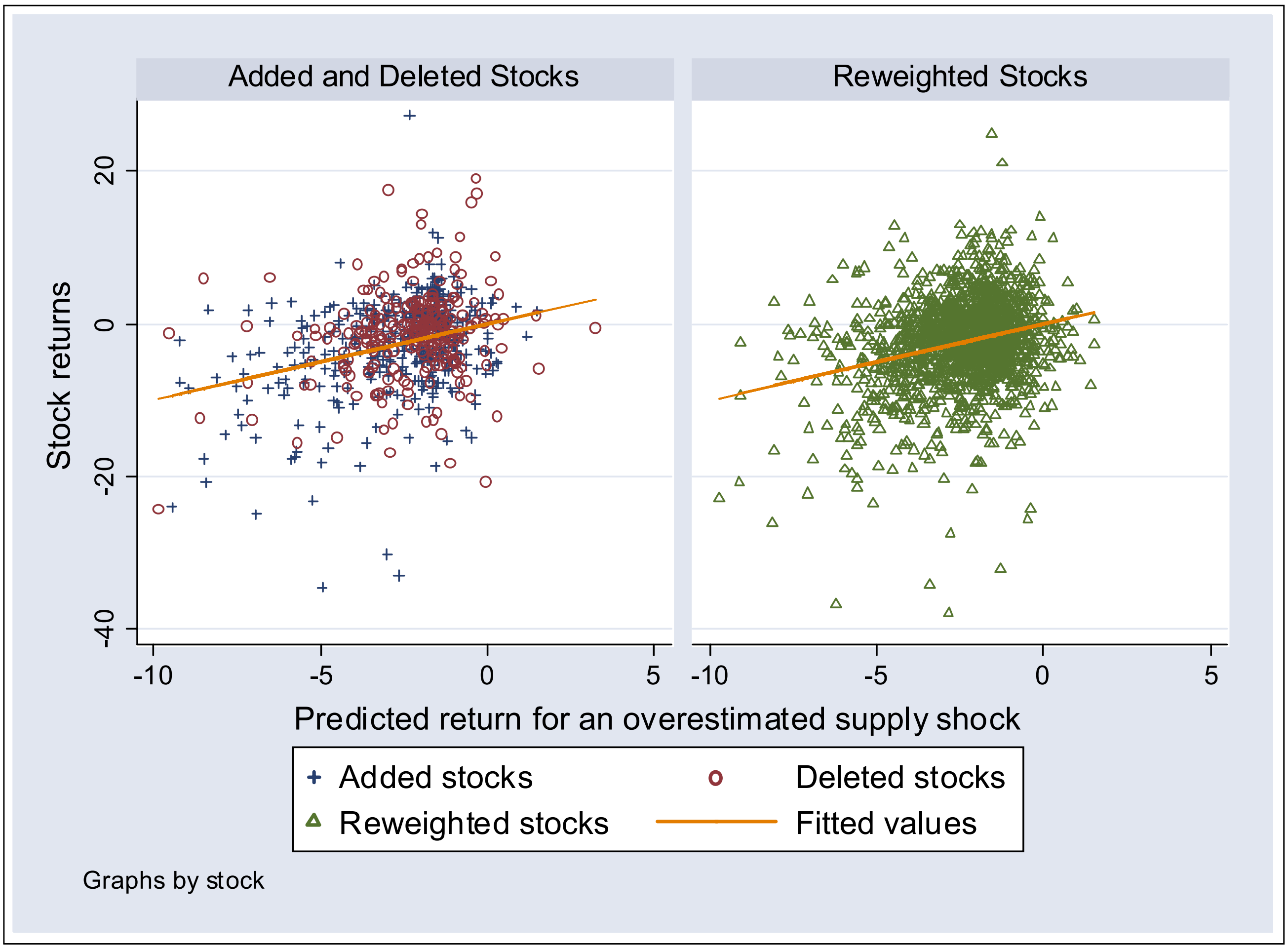

Figure 7: Second implementation event: Plotted are the stock returns for a 7 day window around the second implementation event against the predicted returns for an overestimated magnitude of the supply shock.

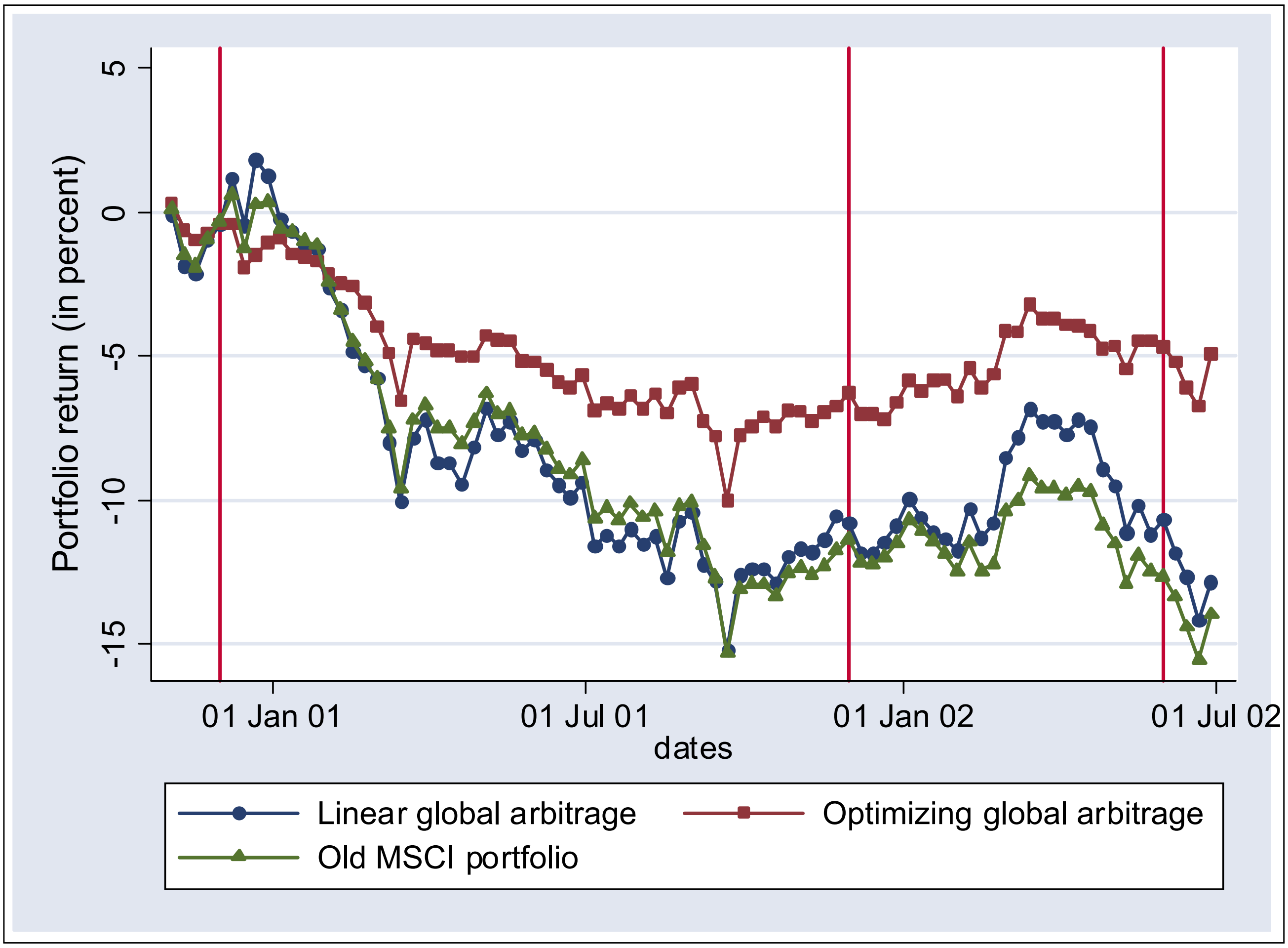

Figure 8: Plotted are the cumulative dollar returns from the announcement day for the linear arbitrage portfolio and the optimizing arbitrage portfolio (for a leverage parameter $\kappa = 3$) relative to old MSCI index. The vertical lines mark the announcement day and the two implementation days.