Global versus Local Asset Pricing:
Evidence from Arbitrage of the MSCI 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 worldwide 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 managers may for example liquidate proportionally 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 (as 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 up-weighted stocks. In analogy to the intuition of the Capital Asset Pricing Model (CAPM), a lower risk contribution to the total tradeable asset supply risk implies a lower stock “beta” and earns a lower stock specific return. A multi-asset supply shock like an index revision represents a simultaneous shock to all stock betas. More interesting still, such a shock generally modifies the global stock beta differently than the local stock beta. Hence, we can interpret a global equity index change like MSCI index redefinition as a natural experiment on global versus local asset pricing. An important contribution of our paper is to show that MSCI stocks are priced globally and not locally: global and not local premium changes explain the cross section of price changes around the announcement event.

The equilibrium framework in Greenwood (2005) has obvious shortcomings as a theory of limited arbitrage. 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 important hedging benefits of the optimal arbitrage strategy itself and their price impact are implicitly discarded. Allowing arbitrageurs to acquire net speculative positions reveals that their optimal strategy consists
not only in anticipating risk premium changes, but in simultaneously reducing their marginal arbitrage risk through a cross-sectional hedge position as long as the information asymmetry persists.

The theoretical contribution of this paper 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. I show that the marginal portfolio risk contribution of the arbitrage position co-determines cross-sectional announcement returns along with the premium change. Such stock-specific arbitrage risk can be approximated by the product of the squared return covariance matrix (\(\Sigma\Sigma\)) and the vector of weight changes from old to new weights \(w^n - w^o\). Intuitively, an arbitrage position in pursuit of high expected returns with portfolio weights proportional to premium change \(\Sigma(w^n - w^o)\) generates an absolute arbitrage risk \((w^n - w^o)'\Sigma\Sigma(w^n - w^o)\) and a marginal arbitrage risk \(\Sigma\Sigma(w^n - w^o)\). Optimization in the mean-variance space requires arbitrageurs to choose a portfolio which optimizes the trade-off between expected arbitrage returns and arbitrage risk. The optimal arbitrage strategy downweights stocks with a positive marginal arbitrage risk contribution and up-weights stocks with a negative arbitrage risk contribution. The marginal arbitrage risk thus becomes a pricing factor along with the premium change itself. Our generalized model nests the Greenwood framework as a special case where liquidity suppliers disappear. In the latter case price adjustment occurs without any speculative position taking or arbitrage risk.

Empirically, we show that the existence of uninformed liquidity providers is crucial for explaining the cross-sectional return pattern around the announcement of asset supply shocks. In accordance with the model predictions, we find the following:

- Pre-announcement returns are determined (positively) by the equilibrium risk premium decrease of each stock, and (negatively) by stock-specific arbitrage risk contribution of the speculative positions held against the liquidity providers. In the run-up to the announcement, speculators acquire stocks with high expected price increases (those with risk premium decreases), but simultaneously hedge their speculative risk by shorting stocks which have a high marginal arbitrage risk.

- Post-announcement returns show a positive cross-sectional relationship to marginal arbitrage risk. The temporary (pre-announcement) price change from the hedging positions is reversed as the liquidity suppliers become informed about the supply shock.

I highlight that the nested Greenwood model is strongly rejected by the data in favor of
our general framework. Asymmetric information appears therefore important for explaining cross-sectional asset return patterns around ‘partially anticipated’ supply shocks.

The empirical analysis 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. I can therefore easily separate a pre- and post-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 any pre- or post-announcement effects. Third, the international dimension of the index change allows us to infer the degree of market integration with respect to asset pricing. Previous empirical work on the degree of international equity market integration has used capital market liberalization as the identifying event to measure risk premium changes (Chari and Henry (2004)). In a similar spirit, we test whether the local or international components of risk premium changes and arbitrage risk determine returns over a more sharply defined event window. Moreover, the index change in our paper is certainly more exogenous than a liberalization policy which may also correlate with changing company cash flows. The evidence shows that the weight change of foreign stocks had the same quantitative asset pricing effect on a given domestic stock as the weight change of any domestic stock. The index weight increase 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. In other words, changes in the global and not local betas explain the return behavior around the announcement of the index change. I infer from our evidence that 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. Initially, these event studies all focus on individual price movements with overwhelming evidence that index inclusions increase share prices and exclusions decrease them. Greenwood (2005) represents the first paper to feature a portfolio approach to index

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1 See for example (Garry and Goetzmann (1986), Harris and Gurel (1986), Shleifer (1986), Dillon and Johnson
revisions and to test the corresponding quantitative cross-sectional asset pricing implications. The portfolio approach allows him to link return effects to fundamental cross-sectional changes in stock price risk premium as opposed to (temporary) liquidity effects considered in the previous literature. It therefore marks an important qualitative advance in the literature. Our paper generalizes this portfolio approach by introducing marginal arbitrage risk as an additional cross-sectional pricing factor under supply shocks.

A broader literature on ‘liquidity effects’ 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 liquidity effects without strong asset pricing foundations.

The paper proceeds as follows: Section 2 outlines a new model of multi-asset arbitrage. I highlight the cross-sectional stock return implications for the pre-announcement, and post-announcement periods in propositions 1 and 2, respectively. The stock price reaction for the implementation dates is summarized in proposition 3. Proposition 4 characterizes the pre- and post-announcement return under the polar cases of complete international market integration and segmentation. Section 3 describes the MSCI index redefinition and discusses summary statistics about the index weight changes, the risk premium changes and the arbitrage risk for individual stocks. I 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 pre- and post-announcement effect, the implementation effect and the degree of global versus local asset price determination. Section 5 concludes.

2 Theory and Hypotheses

2.1 Model Assumptions

This section develops a simple limits-to-arbitrage model which allows us to analyze the return effects of demand shocks in a multi-asset market setting. I 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

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

where $\varepsilon_t$ denotes serially uncorrelated mean zero innovation learned by all market participants at time $t$. The covariance of innovations $\varepsilon$ is given by the matrix $\Sigma$. 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 not 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. These 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. I 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 $\rho$, and access to a riskless asset of zero return. Their optimal demand vector follows as

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

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

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

where $\tilde{\mathcal{E}}_t$ 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. I note that the Greenwood framework is nested in our specification. It is recovered for a parameter $\lambda = 1$ when only arbitrageurs constitute the market.\(^2\)

An apparently restrictive assumption consists in imposing an identical parameter $\gamma$ for the liquidity supply elasticity upon all stocks. It is straightforward to relax this assumption. I can simply replace the scalar $\gamma$ by a matrix

$$\Gamma = \begin{bmatrix} \gamma_1 & 0 & \cdots & 0 \\ 0 & \gamma_2 \\ \vdots & \ddots \\ 0 & \cdots & \gamma_n \end{bmatrix},$$

where stock specific liquidity supply elasticities feature as the diagonal elements. None of the model insights will depend on this modification. Moreover, some of the price effects will not depend on the parameter $\gamma$ at all and we therefore prefer the simpler parameterization.

The very existence of arbitrage opportunities also depends on information asymmetries between different market participants. I incorporate this feature by assuming that the arbitrageurs learn about the index weight change in period $t = 1$, but that liquidity suppliers learn about it

\(^2\)Formally, Greenwood builds on the asset pricing framework in Hong and Stein (1999) and Barberis and Shleifer (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.
only in period \( t = 2 \). This allows arbitrageurs to exploit their information advantage in period \( t = 1 \) with interesting testable cross-sectional asset pricing effects. A second new assumption is that arbitrageurs and (one period later) liquidity suppliers estimate the magnitude of the supply shock only with an error. In particular, we assume that the expected supply shock \( \tilde{E}_1(u) = \tilde{E}_2(u) = \bar{E}_2(u) = \hat{u} = ku \) of both arbitrageurs and liquidity suppliers deviates from true shock \( u \) by a scalar factor \( k > 0 \). By assumption, the estimation error \( u - \hat{u} = (1 - k)u \) affects all stocks in the same direction and in equal proportion, which means that it concerns only the overall magnitude of the shock. The true magnitude of the supply shock is learnt only upon implementation of the index change at time \( t = 3 \). For the case that \( k \neq 1 \), we thus obtain an additional price effect when the implementation of the index change occurs. Assumption 3 summarizes the information structure:

**Assumption 3: Information Structure for the 4 Trading Events**

At time \( t = 0 \), arbitrageurs and liquidity suppliers know that the expected liquidation value of all assets is one and assume a constant supply vector \( S \).

At time \( t = 1 \), only the arbitrageurs learn about the exogenous supply shock \( u = w^a - w^o \) prior to the announcement of the index change. The arbitrageurs over- or underestimate its magnitude by a factor \( k \) so that they hold beliefs \( \hat{u} = \tilde{E}_1(u) = ku \) where \( k \approx 1 \).

At time \( t = 2 \), the liquidity suppliers also learn about supply shock and then share the beliefs of the arbitrageurs, hence \( \bar{E}_2(u) = \hat{u} \).

At time \( t = 3 \), the exogenous supply shock occurs. At that moment arbitrageurs and liquidity suppliers learn the true magnitude of the supply shock so that \( \tilde{E}_3(u) = \tilde{E}_3(u) = u \).

For simplicity, we refer to the stock price change at time \( t = 1, 2, 3 \) as pre-announcement effect, post-announcement effect and implementation effect, respectively. For the special case that \( k = 1 \), both arbitrageurs and liquidity providers correctly anticipate the magnitude of the supply shock. I show in the next section that in the latter case 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

\(^3\)Even MSCI itself seems to dispose of very vague estimates of this capitalization.
stocks. Market clearing then implies

\[ S = \lambda (\rho \Sigma)^{-1} \tilde{\epsilon}_t(p_{t+1} - p_t) + (1 - \lambda) \gamma \tilde{\epsilon}_t(p_{t+1} - p_t) \quad \text{for} \quad t = 0, 1, 2 \]

\[ S - u = \lambda (\rho \Sigma)^{-1} \tilde{\epsilon}_t(p_{t+1} - p_t) + (1 - \lambda) \gamma \tilde{\epsilon}_t(p_{t+1} - p_t) \quad \text{for} \quad t = 3. \]

The index change by \( u = w^n - w^o \) is represented as a negative asset supply shock at time \( t = 3 \). Up-weighted stocks are held to a larger extent by index funds and this reduces the residual supply in these stocks. Unlike the liquidity suppliers, arbitrageurs anticipate this price change at time \( t = 1 \) and exploit their information advantage. They accumulate net speculative positions under the belief that \( \tilde{\epsilon}_1(u) = \tilde{u} \), whereas the lack of such information implies \( \tilde{\epsilon}_1(u) = 0 \) for the liquidity suppliers. After the public announcement of the index change at time \( t = 2 \), both the arbitrageurs and the liquidity suppliers anticipate the supply shock with \( \tilde{\epsilon}_2(u) = \tilde{\epsilon}_2(u) = \tilde{u} \).

Finally, the exact magnitude of the shock becomes known at the implementation date of the index change given by time \( t = 3 \), when \( \tilde{\epsilon}_3(u) = \tilde{\epsilon}_3(u) = u \).

In order to acquire an intuition for the different price effects along the time line, we first consider the baseline model with no liquidity supply \( (\lambda = 1) \) and correct expectations about the magnitude of the supply shock \( (k = 1) \). I can define the (adjusted) price \( \overline{p}_j^t \) for stock \( j \) as the equilibrium price \( p_j^t \) adjusted for the sum of successive innovations to the liquidation price, that is

\[ \overline{p}_j^t = p_j^t - \sum_{i=1}^{t} \epsilon_i^j. \]

The terminal value is (by construction) given by \( \overline{p}_4^t = 1 \). In the absence of any supply shock, the period liquidity premium is simply \( r^j = \frac{\rho}{\lambda} [\Sigma S]_j \), which implies an initial stock price 4 period earlier of \( \overline{p}_0^t = 1 - 4r^j \). The supply shock \( u \) changes the premium for the last period to \( r_4^j = \frac{\rho}{\lambda} [\Sigma (S - u)]_j \), while all other expected returns remain unchanged. When arbitrageurs learn about the supply shock at time \( t = 1 \), the stock price changes by

\[ \Delta \overline{p}_1^j = r^j - r_4^j = \frac{\rho}{\lambda} [\Sigma u]_j. \]

The price change \( \Delta \overline{p}_1^j \) for stock \( j \) depends on the entire vector of covariances \( \Sigma \), with all other stocks as well as the entire vector of weight changes \( u \). The vector product can be positive or negative independently of the sign of the element \( u_j \). Both up-weighted or down-weighted stocks may therefore experience either a positive or negative price effect. Hence, the model does not imply any tight link between the weight change \( u_j \) of stock \( j \) and its price change at time \( t = 1 \). I also highlight that the supply shock itself at \( t = 3 \) does not create a price jump for the adjusted price \( \overline{p}_3^j \). This baseline case represents a simplified version of the Greenwood model (2005).
Next, we consider the first model extension where we still assume $\lambda = 1$, but allow for expectational errors ($k \neq 1$) with respect to the magnitude of the supply shock. The expected return premium in the last period is now given by $\hat{r}_4^j = \frac{\rho}{\lambda} \Sigma (S - \bar{u})_j$ and the price change at time $t = 1$ follows as

$$\Delta p_1^j = r^j - \hat{r}_4^j = \frac{\rho}{\lambda} \Sigma \bar{u}_j = \frac{\rho}{\lambda} k \Sigma u_j.$$  

At time $t = 3$, arbitrageurs learn the true $u$ and this triggers an additional price change

$$\Delta p_3^j = -(r^j_4 - \hat{r}_4^j) = \frac{\rho}{\lambda} \Sigma (u - \bar{u})_j = \frac{\rho}{\lambda} (1 - k) \Sigma u_j.$$  

The larger the expectational error $(1 - k)$ about the magnitude of the supply shock, the larger is the price adjustment around the implementation event $t = 3$. Note also that no systematic price change occurs at time $t = 2$, since by assumptions we have only symmetrically informed arbitrageurs and the full price adjustment (apart from the expectational error) has occurred at time $t = 1$.

The second model extension consists of a price elastic liquidity supply with $\lambda < 1$. Now, our model features less informed liquidity suppliers against which the better informed arbitrageurs can acquire speculative positions. Given a liquidation value of $p_4^j = 1$, we can directly determine the price at time $t = 3$ as $p_3^j = 1 - r_4$, where the period 4 risk premium follows as $r_4 = [I + (1 - \lambda)\gamma \frac{\rho}{\lambda} \Sigma]^{-1} \frac{\rho}{\lambda} \Sigma (S - u)$. Without the supply shock, the equity premium is given by $r = [I + (1 - \lambda)\gamma \frac{\rho}{\lambda} \Sigma]^{-1} \frac{\rho}{\lambda} \Sigma S$. I show (in the Appendix) that the pre-announcement price change now generalizes to

$$\Delta p_1^j = \left[ [I + (1 - \lambda)\gamma \frac{\rho}{\lambda} \Sigma]^{-1} (r - \hat{r}_4) \right]_j = \left[ [I + (1 - \lambda)\gamma \frac{\rho}{\lambda} \Sigma]^{-2} \frac{\rho}{\lambda} \Sigma \bar{u} \right]_j$$

$$\approx \frac{\rho}{\lambda} k [\Sigma u_j] - 2(1 - \lambda) \gamma \left( \frac{\rho}{\lambda} \right)^2 k [\Sigma \Sigma u_j],$$

where we used a linear approximation to the inverse function. The price or return effect at $t = 1$ is now not only determined by the change in the equity risk premium $\Sigma u$, but also by the arbitrage risk term $\Sigma \Sigma u$ of the arbitrageurs. Proposition 1 summarizes the return effect in the general case for the vector price changes.

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4 The normalization of the liquidation price vector to 1 implies that any price change translates into an equally large event return. The market capitalizations of all stock influence the level of all risk premia, but index weight changes are the sufficient metric to capture cross-sectionally the risk premium changes.
Proposition 1: Pre-Announcement Returns

Prior to 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 \( \Sigma \) represents the covariance matrix of asset returns. Formally, we have the following linear approximation

\[
\Delta p_1 \approx \alpha_1 \times \Sigma(w^n - w^o) + \beta_1 \times \Sigma\Sigma(w^n - w^o),
\]

with \( \alpha_1 = \frac{\rho}{\lambda} k > 0 \) and \( \beta_1 = -2(1 - \lambda)\gamma \left( \frac{\rho}{\lambda} \right)^2 k < 0 \).

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 \( w^n - w^o \). I refer to this term as the risk premium change since it is proportional to the beta change of a stock given by \( \Delta \text{beta} = -\left( \sigma_m^2 \right)^{-1} \Sigma(w^n - w^o) \), where \( \sigma_m^2 \) represents the market variance. The index revision is therefore a large-scale modification of all stock betas and should change all stock prices proportionally given that stock cash flows remain unchanged. It is also interesting to note that the price effect induced by the beta change does not depend on a correct specification of the overall asset supply \( S \), but only on the change \( w^n - w^o \) of this supply. Our pricing theory is therefore immune to the so-called Roll’s critique according to which \( S \) is very difficult to identify.

In the general case when \( \lambda < 1 \), arbitrageurs take positions to exploit their knowledge about the expected premium change \( \Sigma(w^n - w^o) \) in their trading against the uninformed liquidity suppliers. The information advantage allows them to exceed the CAPM-based fair risk compensation. Optimization in the mean-variance space consists for arbitrageurs in a portfolio choice which linearly combines a ‘return seeking’ position with a risk reducing ‘hedge’ position. The ‘return seeking’ is best achieved by a portfolio proportional to the premium or beta change, namely \( \Sigma(w^n - w^o) \). To understand the hedging position, we calculate the absolute portfolio risk of the return seeking position, which is simply \( (w^n - w^o)^\Sigma\Sigma(w^n - w^o) \).

The marginal arbitrage risk of such a position follows as \( \Sigma\Sigma(w^n - w^o) \). The optimal hedge position is designed to partially reverse these marginal risk contributions. A hedge portfolio \( -\Sigma\Sigma(w^n - w^o) \) reduces weights in stocks with positive marginal arbitrage risk contributions and increases weights in stocks with negative marginal risk contributions. An optimal arbitrage portfolio combines the ‘return seeking’ component and the ‘risk reducing’ hedge component and therefore features two distinct cross-sectional price effects characterized by the linear combination \( \alpha_1 \Sigma(w^n - w^o) + \beta_1 \Sigma\Sigma(w^n - w^o) \) with coefficients \( \alpha_1 > 0 \) and \( \beta_1 < 0 \), respectively. A supply
shock like the MSCI revision allows us to test these parameter restrictions. The corresponding empirical results are presented in section 4.1.

Next we discuss the price behavior at time $t = 2$. After the announcement of the index change, liquidity suppliers also learn about the supply shock $\tilde{u}$. Shared beliefs between arbitrageurs and liquidity suppliers then imply a rebalancing of the stock holdings towards the market portfolio. The arbitrageurs sell their long positions in stocks with a risk premium decrease and buy back stocks with high arbitrage risk in which they hold short positions. Since the price adjustment in the premium change has already occurred due to the price pressure of speculative buying, the only remaining price adjustment comes from the liquidation of the risk hedging positions. I formalize this intuition in proposition 2:

**Proposition 2: Post-Announcement Returns**

*When the liquidity suppliers learn about the weight change from old weights $w^o$ to new weights $w^n$, the event return is positively proportional to the (expected) arbitrage risk $\Sigma \Sigma (w^n - w^o)$, where $\Sigma$ represents the covariance matrix of asset returns. Formally, we have the following linear approximation

$$\Delta p_2 \approx \beta_2 \times \Sigma \Sigma (w^n - w^o),$$

with $\beta_2 = -\beta_1 = 2(1 - \lambda)\gamma (\xi^2)k > 0$.

Proof: See Appendix.*

The combination of Propositions 1 and 2 implies a distinct price pattern for the portfolio composed of weights given by the marginal arbitrage risk $\Sigma \Sigma (w^n - w^o)$. I can construct such a portfolio as a self-financing portfolio with zero sum of weights and a sum of weights normalized to one. I refer to this portfolio as the hedge portfolio $\pi^H$ since positions $-\theta \pi^H$ constitute the optimal cross-sectional hedge against the arbitrage risk. The hedge portfolio should feature a V-shape around the announcement date of the index change. Initially, the arbitrageurs short this portfolio. This leads to an initial price decrease in the value of the portfolio. After the announcement, the short positions are liquidated and the buying back of the stocks with weights implies an up-swing in the portfolio value. The corresponding empirical results about the post-announcement return behavior are discussed in section 4.2.

Finally, we discuss price effects at time $t = 3$ in the general case with liquidity suppliers. I assume that the exact magnitude of the supply shock is revealed in the implementation event when the market experiences the true supply shock. The previous pricing error due to incorrect expectations ($k \neq 1$) is reversed with an additional price adjustment proportional to $1 - k$. I characterize the implementation returns in Proposition 3 as follows:
Proposition 3: Implementation Returns

On implementation of the weight change from old weights \( w^o \) to new weights \( w^n \) the return vector 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 \( (1 - k)(w^n - w^o) = u - E(u) \) represents the prediction error for the supply shock. Formally, we have the following linear approximation

\[
\Delta p_3 \approx \alpha_3 \times \Sigma (w^n - w^o) + \beta_3 \times \Sigma \Sigma (w^n - w^o),
\]

with \( \alpha_3 = \frac{\lambda}{\bar{\lambda}} (1 - k) \) and \( \beta_3 = -(1 - \lambda)\gamma (\frac{\lambda}{\bar{\lambda}})^2 (1 - k) \). Therefore, we predict

(i) \( \alpha_3 < 0 \) and \( \beta_3 > 0 \) and \( k > 1 \)
(ii) \( \alpha_3 = 0 \) and \( \beta_3 = 0 \) and \( k = 1 \)
(iii) \( \alpha_3 > 0 \) and \( \beta_3 < 0 \) and \( 0 < k < 1 \),

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 \( \alpha_3 \) and \( \beta_3 \) 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. Section 4.3 reports the corresponding empirical results.

An important issue in international finance is the degree of integration of different national stock markets. Are asset prices determined locally or 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. I can therefore distinguish the global covariance matrix \( \Sigma^G \) accounting for the full correlation structure between all stocks from a restricted matrix \( \Sigma^L \) which ignores cross-country correlations between stocks in different countries by setting those to zero. Formally, we define

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

where \( \Sigma^G \) 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 4:
Proposition 4: Integrated versus Segmented Equity Markets

Let $\Sigma^G$ denote the global covariance matrix of all asset returns and $\Sigma^L$ the corresponding covariance matrix with zeros for all cross-country elements. Define incremental (or international) matrices as $\Sigma^L_{\text{Int}} = \Sigma^G - \Sigma^L$ and $\Sigma^L_{\text{Int}} = \Sigma^G \Sigma^G - \Sigma^L \Sigma^L$, respectively. The pre-announcement return can be decomposed into its local and international components as

$$
\Delta p_1 \approx \alpha^L_1 \Sigma^L (w^n - \omega^o) + \alpha^{\text{Int}}_1 \Sigma^L_{\text{Int}} (w^n - \omega^o) + \beta^L_1 \Sigma^L \Sigma^L (w^n - \omega^o) + \beta^{\text{Int}}_1 \Sigma^L_{\text{Int}} (w^n - \omega^o)
$$

and the post-announcement return as

$$
\Delta p_2 \approx \beta^L_2 \Sigma^L \Sigma^L (w^n - \omega^o) + \beta^{\text{Int}}_2 \Sigma^L_{\text{Int}} (w^n - \omega^o)
$$

with

(i) $\alpha^L_1 = \alpha^{\text{Int}}_1 > 0$ and $\beta^L_1 = \beta^{\text{Int}}_1 < 0$ and $\beta^L_2 = \beta^{\text{Int}}_2 > 0$

(ii) $\alpha^L_1 > \alpha^{\text{Int}}_1 = 0$ and $\beta^L_1 < \beta^{\text{Int}}_1 = 0$ and $\beta^L_2 > \beta^{\text{Int}}_2 = 0$

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

Proof: Follows from Propositions 1 and 2 by decomposition of $\Sigma^G$ and $\Sigma^G \Sigma^G$.

The intuition behind this test of market integration is straightforward. Assume the stock price of ‘Ford’ (stock $j$) is equally strongly correlated with both the stock price of ‘GM’ (stock $g$) and the Italian company ‘Fiat’ (stock $f$) and that both GM and Fiat are up-weighted in the MSCI index by the same amount, hence $u_g = u_f > 0$. Under market integration, the index weight increase of both GM and Fiat should produce the quantitatively same pre-announcement effect on the stock price of Ford as $\Sigma^G_{jg} u_g = \Sigma^G_{jf} u_f$. This equality of the cross-border pricing effects is tested by separating the GM element $\Sigma^G_{jg} u_g$ as part of the local premium change $\Sigma^L_{jg} u$ from the Fiat element $\Sigma^G_{jf} u_f$ as part of the international premium change $\Sigma^L_{jf} u$. The corresponding regression coefficients are equal ($\alpha^L_1 = \alpha^{\text{Int}}_1$) if stocks are priced relative to their risk contribution to the global market risk. However, if the risk contribution of Fiat is not part of the market benchmark for the Ford risk premium, then we expect that its change should be without consequence for the Ford stock price. In the latter case we have $\alpha^{\text{Int}}_1 = 0$. A similar logic applies to the coefficients $\beta^L_1$ and $\beta^{\text{Int}}_1$, but with respect to the arbitrageurs. Assume that U.S. stocks are exclusively arbitraged by U.S. investors, Italian stocks by Italian investors, etc.

In this case the sub-matrix $\Sigma^L \Sigma^L$ is sufficient to characterize all arbitrage risk and we have $\beta^{\text{Int}} = 0$. However, the complementary matrix $\Sigma^L_{\text{Int}}$ should feature the same price impact ($\beta^L_1 = \beta^{\text{Int}}_1 < 0$ and $\beta^L_2 = \beta^{\text{Int}}_2 > 0$) if arbitrageurs adopt a global arbitrage strategy and treat foreign and home stocks in a similar way. In the latter case stock markets are integrated with respect to arbitrage behavior.

I also note that the above specification only explores the average degree of market integration or segmentation. Alternatively, we could further decompose the matrices $\Sigma^\text{Int}$ and $\Sigma^\text{Int}$ 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. The regression results concerning international market integration are reported in Section 4.4.

3 The MSCI Index Redefinition

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$), and with or without dividends reinvested.5 MSCI’s global equity indices have become the most widely used international equity benchmarks by institutional investors. By the year 2000, close to 2,000 organizations worldwide were using the MSCI international equity benchmarks. Over US$ 3 trillion of investments were benchmarked against these indices worldwide and approximately US$ 300 to 350 billion were directly indexed.6 The index with the largest international coverage is the MSCI ACWI (All Country World Index), which includes 50 developed and emerging equity markets. This broad index is the focus of our empirical work. MSCI reviews the index composition at regular intervals in order to maintain a broad and fair market representation.7 But in 2000 MSCI initiated a particular index review of exceptional scope described in the following section.

5 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.


7 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.
3.1 Announcement of the Index Change

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. Such free-float weights 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. The consultation process in the fall of 2000 should have alerted speculators to the likely change in the index methodology. Investors are likely to have acquired arbitrage positions prior to the public announcement of the index revision.

The public announcement occurred in two steps. On December 1, 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 extremely likely. The second announcement on December 10, 2000 provided the timetable 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.

Investment newsletters suggest that the formal announcement of the index change on December 10 was largely anticipated by the market. The first announcement on December 1, provided a strong signal that MSCI had already decided in favor of the free float adoption. After the week-end of December 2 and 3, 2000, the financial market re-opened on December 4. I extend the speculative pre-announcement event window until December 4 and assume that knowledge of the index change was widespread thereafter. Event windows for the pre-announcement return effects cover alternatively 3, 5 or 7 trading days prior to December 4. The post-announcement event windows extend over the same number of trading days and start after December 4.

It is interesting to examine the returns of selected portfolios around December 4, 2000. I define in particular four ‘self-financing’ portfolios with a zero sum of weights and a sum of

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9 We also checked that all results are robust to extending the pre-announcement period only up to December 1, 2000. The results are qualitatively very similar.
absolute weights normed to 1:

- The linear portfolio has portfolio weights $\varpi^{Lin}$ proportional to the weight change $w^n - w^o$.
- The premium portfolio has portfolio weights $\varpi^{Pm}$ proportional to the premium change $\Sigma (w^n - w^o)$.
- The hedge portfolio has portfolio weights $\varpi^{Hed}$ proportional to the arbitrage risk $\Sigma \Sigma (w^n - w^o)$.
- The optimal portfolio has portfolio weights $\varpi^{Opt}$ proportional to $\Sigma (w^n - w^o) - \theta \Sigma \Sigma (w^n - w^o)$ with $\theta = 0.001$.

Figure 1 graphs these four portfolios for the 6 week period from November 13 to December 22, 2000. The week-end of December 1 to December 4 is not characterized by any exceptional returns for either of the four portfolios. It seems therefore correct to extend the pre-announcement period until December 4. Only on December 5, do we register a strong price reaction for the linear portfolio, the premium portfolio, and particularly the hedge portfolio. Most noticeable in Figure 1 is the value decline of the hedge portfolio by more than 5 percent from November 6 to December 4, 2000. Short-selling of the portfolio $\varpi^{Hed}$ by arbitrageurs throughout November 2000 can in principle explain this relative price decline. Our theory also predicts that the price decline of the hedge portfolio should be reversed once the liquidity suppliers learn about the index change. After December 4, we find indeed a temporary price increase for the hedge portfolio in accordance with proposition 2. Figure 2 therefore provides support for our event window choice.

I have to be careful when interpreting the pre-announcement return of the premium and hedge portfolio. Proposition 1 predicts a positive pre-announcement return for the premium portfolio and a negative pre-announcement returns for the hedge portfolio conditional on controlling for the other portfolio. Only a multi-variable regression analysis can reveal if the pre-announcement return behavior corresponds to proposition 1. But short of a formal regression analysis, we can still examine the return behavior of the optimal portfolio. Returns of the optimal portfolio combine the premium and hedge portfolio and inference is not tainted by a lack of conditioning. The optimal portfolio shows indeed the price run-up predicted in proposition 1. The optimal portfolio increases in value by 6 percent from November 6 to December 4, 2000.

\footnote{The multi-variable regression analysis in section 4.1. shows that a plausible hedge parameter value is given by $\theta = \beta/\alpha = 0.001$. The latter value is suggested by the parameter estimates for $\alpha$ and $\beta$ in Table 3.}
2000. Price pressure from the arbitrageurs’ position build-up in the optimal portfolio provides an explanation for the steady price increase.

Figures 2 and 3 document the performance of the same 4 portfolios around the first and second implementation day, respectively. There is no evidence for any strong price reaction on either of the two implementation dates. But for the first implementation event, we notice a 2 percent value decrease for the optimal portfolio after December 1, 2001. This depreciation could result from an over-estimation of the magnitude of the supply shock \( k > 1 \). The second implementation event is marked by the opposite appreciation of the optimal portfolio. The latter observation could correspond to an underestimation of the magnitude of the supply shock \( w^n - w^o \). But only a regression analysis can reveal if the parameter restrictions in proposition 3 are fulfilled and if we have joint significance of the two price effect.

### 3.2 Overview of the Index Weight Changes

MSCI’s new index 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 or 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. The second goal of the equity index modification was an enhanced market representation. In its new indices, MSCI targets a free float-adjusted 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.\(^\text{11}\)

\(^{11}\)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.
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 country and lists the number of retained sample stocks for each country. 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. 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

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

where $w_j^o$ and $w_j^a$ 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 percentage weight change $\Delta v_j$ 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 4 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, many previously included stocks are down-weighted. 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-

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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.
U.S. stocks. This size difference applies equally to the groups of added, deleted and re-weighted stocks.

### 3.3 Risk Premium Changes and Marginal Arbitrage Risk

In order to determine the premium change and the marginal arbitrage risk we need to estimate the covariance matrix $\Sigma$ 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. I can interpret the global index change as a natural experiment on local versus global asset pricing. The degree of market integration versus segmentation can be measured in two dimensions. First, we explore whether the cross-sectional price changes around the announcement event correspond to premium changes induced by either local or global beta changes. The international nature of the weight changes assures that local and global beta changes are generally different. If local beta changes alone explain the price behavior, we infer market segmentation. If the incremental premium changes between the global and the local premium have additional and equal explanatory power, we conclude that global asset pricing and therefore market integration represents the correct benchmark. Second, a similar argument applies to marginal arbitrage risk. If arbitrage strategies are confined to exploiting local premium changes for local stocks, only the risk contribution of local stocks matters. By contrast, global arbitrage strategies optimize over the marginal risk contribution of all local and all international stocks. The marginal risk contribution of local stocks to the portfolio should equal that of the international stocks and both factors should reveal an equal price impact. I can summarize the two polar cases of market

---

\(^{13}\)We verified that estimation of the equity return covariance based on a daily return sampling did not qualitatively alter the results.
integration and segmentation as follows:

1. Global asset pricing and global equity arbitrage: Arbitrageurs take speculative positions in all stocks affected by the index and risk is measured by the global covariance $\Sigma^G$ 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 asset pricing and local equity arbitrage: Arbitrageurs speculate only on the weight change in one local market. I can therefore define a restricted covariance matrix $\Sigma^L$ of equity returns which is obtained from $\Sigma^G$ by setting to zero all cross-country covariances. 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. To better interpret these statistics, we can relate the premium change to the corresponding beta change using

$$\Delta \beta_j = -\frac{[\Sigma(w^n - w^o)]_j}{\sigma^2_m}.$$ 

The weekly market volatility of the global index is estimated as $\sigma^2_m = w^o \Sigma w^o = 0.936$. A global premium change for a stock therefore corresponds to a beta change of similar magnitude. I also highlight the large cross-sectional dispersion of beta changes. The standard deviation for the global premium change in Table 2 is given by 0.049, which implies 0.052 for the standard deviation of global beta changes. The MSCI index revision generated a substantial beta change for a large cross-section of stocks.

A graphical representation of the distribution of the global and local risk premium change is provided in Figure 5. It reveals systematic differences between non-U.S. and U.S. stocks. First, we consider non-U.S. stocks. The dispersion of their local equity premium change is relatively small with a negative mean of $-0.005$. The corresponding average change in the global premium is also negative at $-0.009$, but features a much higher standard deviation of 0.036 compared to only 0.009 for the local premium. I note that non-U.S. stocks include more down-weighted than up-weighted stocks, which explains the negative mean for both local and global premium changes. Compared to the global covariance matrix $\Sigma^G$, the local covariance matrix $\Sigma^L$ features by construction many zero elements, which tends to generate less dispersion in the local relative
to the global premium change. The dispersion of local premium changes is particularly small for stocks from countries with a minor representation in the MSCI index. Most interesting is the low correlation between local and global premium changes for non-U.S. stocks. The correlation of local and global premium changes correspond to the correlation of the local and global beta changes and can be calculated as

\[ \text{Corr}_{j \notin \text{US}} \left[ \Delta \beta^L_j, \Delta \beta^G_j \right] = \text{Corr}_{j \notin \text{US}} \left[ \Sigma^L_j (w^n - w^o), \Sigma^G_j (w^n - w^o) \right] = 0.149. \]

This low correlation allows for sufficient discriminatory power between local and global asset pricing effects. Weight changes by other international stocks exercise an important influence on the global beta change for most non-U.S. stocks and therefore differentiate global beta from local beta changes. This aspect underlines that the degree of market integration is very important for the price effect of a global supply shock like the MSCI index revision. Market integration generally implies a completely different price effect for non-US. stocks compared to market segmentation.

For U.S. stocks the premium changes behave very differently. The local equity premium change for U.S. stocks shows a positive mean of 0.115 and a large standard deviation of 0.074. I also note that the local premium change here is typically only slightly smaller than global premium change as illustrated in Figure 5. Most U.S. stocks are situated just below the 45 degree line. The large number of U.S. stocks in the MSCI index explain why for U.S. stocks the corresponding rows in the global and local covariance matrices differ less than for stocks from other countries because fewer cross-country covariances are set to zero. As a consequence, local and global premium and beta changes are highly correlated for U.S. stocks; that is

\[ \text{Corr}_{j \in \text{US}} \left[ \Delta \beta^L_j, \Delta \beta^G_j \right] = \text{Corr}_{j \in \text{US}} \left[ \Sigma^L_j (w^n - w^o), \Sigma^G_j (w^n - w^o) \right] = 0.911. \]

This high correlation makes the U.S. stocks less suited for inference about global versus local asset pricing. Intuitively, most of the change in the beta for U.S. stocks is induced by the index weight changes of other U.S. stocks with strong effects on both the local and global betas.

Figure 6 plots the marginal arbitrage risk contribution of each stock under global arbitrage against the marginal risk contribution under local arbitrage. Local arbitrage risk accounts only for the risk of positions in pursuit of local beta changes, whereas global arbitrage risk is related to positions exploiting global beta changes. The distribution of local and global marginal arbitrage risk are closely related to the distribution of the local and global risk premium changes. The marginal arbitrage risk \( [\Sigma_j (w^n - w^o)] \) differs from the risk premium change only by a quadratic
term $\Sigma \Sigma$ replacing the linear term $\Sigma$. Again, we find that non-U.S. stocks are very different from U.S. stocks. Local and global marginal arbitrage risk have a low correlation of only 0.172 across non-U.S. stocks. However, for U.S. stocks, this correlation is approximately 0.987 and indicates strong colinearity. Meaningful inference about global versus local arbitrage risk is therefore restricted to the sample of non-U.S. stocks.

### 3.4 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 assess premium changes and marginal arbitrage risk for each individual stock, but also the portfolio risk involved in the entire arbitrage strategy. I 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

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

Next, we consider two alternative portfolios. The first combines the old index weights with the ‘self-financing’ linear portfolio $\omega^{Lin}$ composed of weights proportional to the index weight change $w^n - w^o$. Alternatively, we can combine the MSCI weights with the optimal portfolio $\omega^{Opt}$ which has weights proportional to $\Sigma(w^n - w^o) - \theta \Sigma \Sigma(w^n - w^o)$. A shift from the original portfolio $w^o$ into one of the two arbitrage portfolios implies new portfolio weights given by

$$w^{\kappa Lin} = w^o + \kappa \omega^{Lin} \quad \text{or} \quad w^{\kappa Opt} = w^o + \kappa \omega^{Opt},$$

where the parameter $\kappa$ 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 $\theta = \beta/\alpha$. For an initial portfolio position $w^o$, the percentage risk increase due to linear or optimal arbitrage positions with leverage factor $\kappa$ follows as

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

respectively. Figure 7 plots the change in the risk ratio as a function of the leverage factor $\kappa$ for the global arbitrage strategy. A linear portfolio weight shift $w^{\kappa Lin}$ 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 $w^{\kappa Opt}$ achieves a substantial risk reduction even as the leverage increases. Based on parameter estimates for $\alpha$ and $\beta$, we calibrate $\theta = 0.001$. I 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 (up-weights) stocks with a positive (negative) marginal arbitrage risk contributions. The overall portfolio risk of the leveraged optimal arbitrage portfolio is lower than the benchmark portfolio for a wide range of leverage factors $\kappa$.

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. Moreover, a price elastic liquidity supply implies that expected arbitrage returns are reduced if many arbitrageurs pursue the same arbitrage strategy. However, it will not reduce the risk reduction benefits of the hedge portfolio. A high Sharpe ratio for the arbitrage strategy may therefore come not so much from a high expected excess return, but rather from the reduction of portfolio risk. Focusing only on the (expected or ex-post) excess returns of an arbitrage portfolio may therefore represent a misleading metric for its success.

4 Evidence

The portfolio approach to limited arbitrage allowed us to derive a sequence of testable implications. I 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 $\Sigma$ of all stocks. Its $j$-th element represents the change in the marginal contribution of security $j$ to the total market risk induced by the weight change of all stocks.

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 ar-
bitrage 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 marginal arbitrage risk $k \Sigma \Sigma (w^n - w^o)$. The optimal arbitrage strategy in combination with the linear liquidity supply trigger proportional pre-announcement event returns as stated in Proposition 1.

Section 4.1 provides the evidence on the pre-announcement effect. Further revisions of the cross-sectional returns occur when the liquidity suppliers learn about the supply shock. These post-announcement return patterns are examined in section 4.2. Upon the implementation of the index change, all market participants experience the true magnitude of the supply shock. Given an under- or overestimation of the shock size, this can give rise to further cross-sectional return pattern documented in section 4.3. The empirical counterpart to Proposition 4 about international market segmentation versus integration is provided in Section 4.4.

4.1 Pre-Announcement Effect

The global scale of the MSCI index rebalancing provides an extremely large sample of stocks which experienced a weight change. I dispose of 2291 stocks with a continuous two year price history needed to calculate the global covariance matrix $\Sigma^G$. The statistical inference is based on a cross-sectional analysis in which dollar returns $\Delta p_j$ (defined as log price differences $\ln P^j_t - \ln P^j_{t-1}$) in stock $j$ over the entire event window are regressed on a constant $c$, the stock’s risk premium change $[\Sigma^G (w^n - w^o)]_j$ and its corresponding marginal arbitrage risk $[\Sigma^G \Sigma^G (w^n - w^o)]_j$. Formally, $\Delta p^*_j = c + \alpha_1 \times [\Sigma^G (w^n - w^o)]_j + \beta_1 \times [\Sigma^G \Sigma^G (w^n - w^o)]_j + \mu_j$, where we allow for clustering of the error term $\mu_j$ on the country level.

I define three alternative pre-announcement windows of 3, 5 and 7 trading days all extending until December 4. This allows us to check the robustness of the results with respect to different event window sizes. Table 3, Panel A features the regression results for the full sample of 2291 stocks. I report regression results with a specification including only the constant and the risk premium change as well as the complete specification. A specification without the marginal arbitrage risk term corresponds to the nested Greenwood model. This specification is correct for the special case $\lambda = 1$ where all market participants are equally informed arbitrageurs and there is no liquidity supply.

I find that the restrictive specification is rejected by the data. The coefficient $\alpha_1$ 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 $\alpha_1$ 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 $\beta_1$ 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 5 day pre-announcement return by 5.1 percent. The adjusted R-squared of the full specification is at 0.087 highest for the 5 day event window and more than 3 times higher than under the baseline specification. I conclude that arbitrage risk presents a second economically significant determinant of the cross-sectional pattern of the pre-announcement returns.

To check the robustness of these results, we also examine the sample of added and deleted stocks (Panel B) and the sample non-U.S. stocks (Panel C). Both samples feature qualitatively similar results. In each case and for every window size we reject the hypothesis that $\beta_1 = 0$. As in the entire sample and in line with the theoretical model, the coefficient $\alpha$ for the risk premium change is significantly positive and the coefficient $\beta$ for the arbitrage risk significantly negative in the full specification. The coefficient estimates are slightly smaller in Panel B. 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 a marginal arbitrage risk increase by one standard deviation. Overall, pre-announcement returns provide strong empirical support for our generalized arbitrage model. The estimated effects are also economically significant. The implied return difference between stocks with the smallest and largest speculative demand reaches approximately 15 percent over the 5 day window.

4.2 Post-Announcement Effect

Proposition 2 asserts that the return effect of the hedge position risk is reversed once the liquidity suppliers learn about the index revision. Arbitrageurs then liquidate their arbitrage positions. I define again three different post-announcement windows of 3, 5 and 7 trading days each starting after December 4, 2000. Our preferred cross-sectional specification follows from Proposition 2 as
\[ \Delta p_j^i = c + \beta_2 \times \left[ \Sigma^G \Sigma^G (w^n - w^o) \right]_j + \mu_j, \]

where we now expect \( \beta_2 > 0 \). Table 4, Panel A, reports regression results for the base specification and an augmented specification which includes the premium change \( \Sigma^G (w^n - w^o) \) as an additional control variable. The coefficient \( \beta_2 \) is highly significant at the 1 percent level in all specifications, all samples and for all three event windows. The adjusted R-squared for the base specification reaches 0.138 for the 5 day event window. It is at 0.175 even higher for the sample of added and deleted stocks reported in Panel B. The premium effect captured by the coefficient \( \alpha_2 \) is significant on a 1 percent level for the full sample, but not for the sample of added and deleted stocks or the sample of non-U.S. stocks. I note that the absence of uninformed liquidity suppliers again implies that \( \beta_2 = 0 \), which is strongly rejected by the data.

The post-announcement return pattern provides additional support for our generalized model of risk arbitrage. Combined with the results from the pre-announcement returns we have strong evidence that marginal arbitrage risk is priced. These results lead us to two conclusions. First, the speculative dynamics around supply shocks are best captured in a model which features uninformed liquidity suppliers. The baseline CAPM framework which ignores information asymmetries cannot account for the price pattern. Second, the price significance of the hedging demand around the announcement event confirms the view that hedging of the arbitrage risk was an important element of the speculative strategy of the arbitrageurs.

### 4.3 Implementation Effects due to Supply Shock Uncertainty

While the weight change of individual stocks might have been quite predictable, the same cannot be said about the exact magnitude of the supply shock. 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 \( \hat{u} = k u = \hat{E}(u) \) 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. I expect to find opposite signs
for the coefficients $\alpha_3$ and $\beta_3$ in both cases.

For the 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. 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 $\alpha_3$ on the risk premium change has a negative sign and is economically large. The coefficient $\beta_3$ for the arbitrage risk has the opposite positive sign as predicted for the case of an overestimation of the supply shock magnitude. The results are very similar for the sample 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 $\alpha_3$ and negative estimate for $\beta_3$. 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 $\alpha_3$ and $\beta_3$ 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.

4.4 Global versus Local Asset Pricing

Arbitrage strategies could comprise all MSCI stocks or only a subset of re-weighted 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 asset pricing, we define the incremental international risk premium change as

$$[\sum^{Int}(w^n - w^o)]_j = [\sum^G(w^n - w^o)]_j - [\sum^L(w^n - w^o)]_j,$$

and the incremental international marginal arbitrage risk as

$$[\Sigma \sum^{Int}(w^n - w^o)]_j = [\Sigma^G \Sigma^G(w^n - w^o)]_j - [\Sigma^L \Sigma^L(w^n - w^o)]_j,$$

where $\Sigma^G$ represents the covariance of dollar returns for all 2291 stocks and $\Sigma^L$ the equivalent covariance matrix with zeros for stocks in different countries. The statistical inference for the
pre-announcement event is based on the regressions

\[
\Delta p_j^1 = c + \alpha_L^1 \times [\Sigma L(w^n - w^o)]_j + \alpha_{Int}^1 \times [\Sigma^{Int}(w^n - w^o)]_j + \\
+ \beta_L^1 \times [\Sigma L \Sigma L(w^n - w^o)]_j + \beta_{Int}^1 \times [\Sigma \Sigma^{Int}(w^n - w^o)]_j + \mu_j;
\]

and for the post-announcement return on

\[
\Delta p_j^2 = c + \beta_L^2 \times [\Sigma L \Sigma L(w^n - w^o)]_j + \beta_{Int}^2 \times [\Sigma \Sigma^{Int}(w^n - w^o)]_j + \mu_j;
\]

where \(\Delta p_j^1\) and \(\Delta p_j^2\) denote the (log) dollar return for the respective event windows of alternatively 3, 5, or 7 trading days. The coefficient \(\alpha_L^1\) measures the return effect of the local premium change and \(\alpha_{Int}^1\) the incremental premium change if stocks are priced globally. Similarly, \(\beta_L\) and \(\beta_{Int}\) capture the marginal arbitrage risk effect on returns for the local arbitrageur and the incremental effect for the global arbitrageur, respectively. Equality of the coefficients \(\alpha_L^1\) and \(\alpha_{Int}^1\) implies global asset pricing and equality of \(\beta_L^1\) and \(\beta_{Int}^1\) (as well as \(\beta_L^2\) and \(\beta_{Int}^2\)) implies global arbitrage. Both suggest an integrated global equity market. However, \(\alpha_{Int}^1 = 0\) suggests local asset pricing and \(\beta_{Int} = 0\) strictly local arbitrage strategies. The latter two cases characterize an internationally segmented market.

Table 6 reports regression results for the decomposition into the local and global pre-announcement return components. In Panel A the sample consists of all stocks. The incremental effects captured by the coefficients \(\alpha_{Int}^1\) and \(\beta_{Int}^1\) are significant for each of the event windows and have the expected sign. The risk premium change and the marginal arbitrage risk therefore have a significant international component. The arbitrage strategies therefore assumed the validity of an international premium change and also engaged in international hedging. Moreover, we cannot reject the hypothesis that \(\alpha_L^1 = \alpha_{Int}^1\) as well as \(\beta_L^1 = \beta_{Int}^1\). 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 sample of added and deleted stocks. These results are reported in Panel B and are qualitatively similar. The coefficient \(\alpha_{Int}^1\) is statistically significant for the 5 day window and the coefficient \(\beta_{Int}^1\) for all three event windows. An alternative sample 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 as well as between local and global marginal arbitrage risk (Figures 5 and 6). 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. On the other hand, their local arbitrage risk variation is small and therefore likely to be statistically insignificant. The results for non-U.S.
stocks are reported in Panel C. Again, the incremental coefficients $\alpha_{1}^{Int}$ and $\beta_{1}^{Int}$ are of the predicted sign and highly significant. Similar to the full sample, we cannot reject the hypothesis of complete equity market integration. I conclude that arbitrage for the MSCI revision was undertaken on a global scale and that global beta changes explain the cross-sectional return pattern best.

Table 7 reports the corresponding regression on local versus global pricing for the post-announcement period. In the full sample, the coefficient $\beta_{2}^{Int}$ is again highly significant with the correct positive sign. Its magnitude is similar to the local arbitrage risk coefficient $\beta_{2}^{L}$ for both the full sample (Panel A) and the sample of added and deleted stocks (Panel B). In the sample of non-U.S. firms (Panel C) only the international coefficient is significant. This is not surprising since local marginal arbitrage risk features hardly any cross-sectional variation among non-U.S. stocks. Overall, post-announcement returns provide additional support in favor of market integration.

5 Conclusion

The previous finance literature viewed equity index changes as an interesting exogenous event to explore the limits of equity arbitrage. This literature has produced evidence for important liquidity effects related to supply shocks. But large-scale multi-asset supply shocks have also a more fundamental interpretation as exogenous changes in stock-specific risk premium. This so-called ‘portfolio approach’ to supply shocks is first explored by Greenwood (2005). The current paper generalizes the portfolio approach to asymmetric information and speculative position taking around the announcement of such supply shocks. I propose a new and simple heterogenous agent model of multi-asset arbitrage which adds liquidity suppliers 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. This brings theory closer to a practitioner’s understanding of arbitrage.

I derive the optimal arbitrage strategy as a trade-off between higher expected returns and lower arbitrage risk. Formally, the optimal portfolio is a combination of a ‘premium seeking portfolio’ and a ‘hedge portfolio’. Both portfolio components have distinct cross-sectional asset pricing implications. First, we obtain a CAPM price effect for each stock $j$ which is proportional
to the (expected) premium change $[\Sigma(w^n - w^o)]_j$. It reflects the changes in the stock’s beta and occurs when arbitrageurs anticipate the index revision. Second, the ability of arbitrageurs to control arbitrage risk via a hedge portfolio generates an additional price effect absent in the Greenwood framework. The optimal arbitrage strategy consists in modifying stock weights according to their marginal arbitrage risk contribution. Intuitively, a premium seeking portfolio $\Sigma(w^n - w^o)$ generates an absolute arbitrage risk $(w^n - w^o)'\Sigma\Sigma\Sigma(w^n - w^o)$ and a marginal arbitrage risk contribution characterized by $\Sigma\Sigma(w^n - w^o)$. Portfolio weights given by $-\Sigma\Sigma(w^n - w^o)$ represent the optimal hedge for the arbitrageur. Their pre-announcement build-up implies a negative return for the portfolio $z^{Hed} = \Sigma\Sigma(w^n - w^o)$ followed by a positive post-announcement return when the hedge is liquidated.

The redefinition of the MSCI index represents an ideal experiment to test our generalized portfolio approach to limited arbitrage. The unprecedented scope of the index revision provides us with a sample of 2291 stocks for which the covariance matrix $\Sigma$ can be estimated and for which we calculated premium changes and marginal arbitrage risk contributions. I find that pre-announcement returns are indeed determined by the premium change and the marginal arbitrage risk contribution. Both coefficients have the correct sign and are highly significant explanatory variables. For the post-announcement period, the marginal arbitrage risk also has a strong positive cross-sectional return effect as predicted by the theory. These findings are robust to variations of the event window size and extend to various subsamples.

The international nature of the MSCI index turns its revision also into a test of global versus local asset pricing. I can decompose the global covariance matrix $\Sigma^G$ consisting of all stocks into (i) a covariance matrix $\Sigma^L$ consisting only of covariances of local stocks domiciled in the same national market and (ii) a complementary matrix $\Sigma^{Int} = \Sigma^G - \Sigma^L$ capturing the effect of international market integration. I find that local premium changes alone cannot account for cross-section of price changes around the announcement event. The international component of the premium changes $\Sigma^{Int}(w^n - w^o)$ is statistically highly significant and of similar magnitude. This allows us to reject the hypothesis of market segmentation: the price changes are best captured by global and not local beta changes. This suggests that asset pricing models should use a global market benchmark instead of working with a national equity market index. A similar conclusion is reached with respect to arbitrage risk. The international component $\Sigma\Sigma^{Int}(w^n - w^o)$ to the marginal arbitrage risk represents a highly significant pricing factor. I conclude that arbitrage strategies for the MSCI revision were implemented on a global scale.
References


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

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

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 \( \tilde{E}_2(u) = E_2(u) = \tilde{u} \). The risk premium for period 3 is determined by the asset supply \( S \) and therefore given by

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

and the price follows as

\[
p_2 = 1 + \varepsilon_1 + \varepsilon_2 - \hat{r}_4 - r,
\]

where \( \hat{r}_4 = \left[ \lambda (\rho \Sigma)^{-1} + (1 - \lambda) \gamma I \right]^{-1} (S - \tilde{u}) \) 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 \( \tilde{E}_1(p_2) = 1 + \varepsilon_1 - \hat{r}_4 - r \) for the arbitrageurs and \( E_1(p_2) = 1 + \varepsilon_1 - 2r \) for the liquidity suppliers. Market clearing then implies

\[
\Sigma S = \frac{1}{\rho} \tilde{E}_1(p_2 - p_1) + (1 - \lambda) \gamma \Sigma E_1(p_2 - p_1)
\]

\[
= \frac{1}{\rho} I (1 + \varepsilon_1 - \hat{r}_4 - r - p_1) + (1 - \lambda) \gamma \Sigma (1 + \varepsilon_1 - 2r - p_1)
\]

\[
= (\frac{1}{\rho} I + (1 - \lambda) \gamma \Sigma)(1 + \varepsilon_1 - p_1) + \frac{1}{\rho} I (-\hat{r}_4 - r) + (1 - \lambda) \gamma \Sigma(-2r)
\]

or

\[
p_1 = 1 + \varepsilon_1 + \left( \frac{1}{\rho} I + (1 - \lambda) \gamma \Sigma \right)^{-1} \left[ \frac{1}{\rho} I (-\hat{r}_4 - r) + (1 - \lambda) \gamma \Sigma(-2r) - \Sigma S \right]
\]

\[
= 1 + \varepsilon_1 - 3r + \left( \frac{1}{\rho} I + (1 - \lambda) \gamma \Sigma \right)^{-2} \frac{\rho \Sigma}{\lambda} \hat{u}
\]

\[
= 1 + \varepsilon_1 - 3r + (I + \theta \Sigma)^{-2} \frac{\rho \Sigma}{\lambda} \hat{u},
\]

where we define \( \theta = (1 - \lambda) \gamma \frac{\rho}{\lambda} \). I note that for \( (1 - \lambda) \gamma \approx 0 \), we can approximate

\[
(I + \theta \Sigma)(I - \theta \Sigma) = I - \theta^2 \Sigma \Sigma \approx I
\]
and multiplying both sides by \((I + \theta \Sigma)^{-1}\) gives \((I - \theta \Sigma) \approx (I + \theta \Sigma)^{-1}\). It follows that
\[
(I + \theta \Sigma)^{-2} \approx (I - \theta \Sigma)^2 = I - 2\theta \Sigma + \theta^2 \Sigma^2 \approx I - 2\theta \Sigma.
\]
In the absence of the liquidity supply shock the price follows as \(p_1(u = 0) = 1 + \varepsilon_1 - 3r\). The pre-announcement price change is then given by
\[
\Delta p_1 = (I - 2\theta \Sigma)^{-2} \frac{\rho}{\lambda} \Sigma \hat{u} = \frac{\rho}{\lambda} \Sigma \hat{u} - 2\frac{\rho}{\lambda} \theta \Sigma \Sigma \hat{u} = \frac{\rho}{\lambda} k \Sigma (w^n - w^o) - 2(1 - \lambda)k \left(\frac{\rho}{\lambda}\right)^2 \gamma \Sigma \Sigma (w^n - w^o),
\]
where we used \(\hat{u} = ku\). I can also express the aggregate position of the arbitrageurs as
\[
x^A = S - (1 - \lambda)\gamma \mathbf{E} (p_2 - p_1) = S - (1 - \lambda)\gamma \left[ r - \frac{\rho}{\lambda} k \Sigma u + 2(1 - \lambda)\gamma \left(\frac{\rho}{\lambda}\right)^2 k \Sigma \Sigma u \right] = S - (1 - \lambda)\gamma r + (1 - \lambda)\gamma \rho \lambda k \Sigma u - 2(1 - \lambda)\gamma^2 \left(\frac{\rho}{\lambda}\right)^2 k \Sigma \Sigma u
\]
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 linear combination of the expected premium change and the arbitrage risk.

**Proposition 2:**

From proposition 1, we obtain the following price dynamics:
\[
p_0 = 1 - 4r
\]
\[
p_1 \approx 1 + \varepsilon_1 - 3r + \frac{\rho}{\lambda} k \Sigma u - 2(1 - \lambda)\gamma \left(\frac{\rho}{\lambda}\right)^2 k \Sigma \Sigma u
\]
\[
p_2 = 1 + \varepsilon_1 + \varepsilon_2 - r - \hat{r}_4
\]
\[
p_3 = 1 + \varepsilon_1 + \varepsilon_2 + \varepsilon_3 - r_4.
\]
The price at time \(t = 2\) without supply shock is given by \(p_2(u = 0) = 1 + \varepsilon_1 + \varepsilon_2 - 2r\). The arbitrage demand has shifted the stock price vector by \(\Delta p_1\) so that the remaining adjustment is given by
\[
\Delta p_2 = p_2 - p_2(u = 0) - \Delta p_1
\]
\[
\approx -\hat{r}_4 + r - \frac{\rho}{\lambda} \Sigma \hat{u} + 2\frac{\rho}{\lambda} \theta \Sigma \Sigma \hat{u}
\]
\[
= \frac{\rho}{\lambda} \theta \Sigma \Sigma \hat{u}
\]
\[
= (1 - \lambda)\gamma \left(\frac{\rho}{\lambda}\right)^2 k \Sigma \Sigma (w^n - w^o),
\]
where we used the substitution

\[
    r - \hat{r}_4 = \left[ \lambda(\rho \Sigma)^{-1} + (1 - \lambda)\gamma I \right]^{-1} \hat{u} \\
    = \left[ I + (1 - \lambda)\gamma \frac{\rho \Sigma}{\lambda} \right]^{-1} \frac{\rho \Sigma \hat{u}}{\lambda} \\
    \approx \frac{\rho}{\lambda} \Sigma \hat{u} - \frac{\rho}{\lambda} \theta \Sigma \Sigma \hat{u}.
\]

**Proposition 3:**

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

\[
p_{3 - \Delta t} = 1 + \varepsilon_1 + \varepsilon_2 + \varepsilon_3 - \hat{r}_4 \\
    = 1 + \varepsilon_1 + \varepsilon_2 + \varepsilon_3 - \left[ \lambda(\rho \Sigma)^{-1} + (1 - \lambda)(\rho \leq \sigma^2 I)^{-1} \right]^{-1} (S - \hat{u})
\]

and the implementation effect becomes (under linear approximation)

\[
\Delta p_3 = -r_4 + \hat{r}_4 \\
    = \left[ \frac{\lambda}{\rho} \Sigma^{-1} + (1 - \lambda)\gamma I \right]^{-1} (u - \hat{u}) \\
    = \left[ I + (1 - \lambda)\gamma \frac{\rho \Sigma}{\lambda} \right]^{-1} \left( \frac{\rho \Sigma}{\lambda} \right) (1 - k)u \\
    \approx \frac{\rho}{\lambda} (1 - k) \Sigma (w^n - w^o) - (1 - \lambda)\gamma \left( \frac{\rho}{\lambda} \right)^2 (1 - k) \Sigma \Sigma (w^n - w^o).
\]
I 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 $\Delta w$ within the country.

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<th>Old Weight</th>
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<td>–0.926</td>
<td>1.176</td>
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<td>–</td>
<td>–</td>
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<tr>
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<td>133</td>
<td>10.33</td>
<td>9.26</td>
<td>0.369</td>
<td>0.924</td>
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<tr>
<td>United States</td>
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<td>414</td>
<td>55.12</td>
<td>48.88</td>
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<td>1.108</td>
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<td>1.470</td>
</tr>
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<td>0.5</td>
<td>0.38</td>
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<td>–</td>
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</tbody>
</table>

Total | 2566 | 2291 | 100.00 | 100.00 | – | – |
Global premium changes therefore correspond approximately to global stock beta changes. Returns for the period of July 1, 1998 to July 1, 2000. The weekly return variance of the global index is estimated as 0.936. The covariance matrices are estimated for 2 years of weekly dollar stock returns for the period of July 1, 1998 to July 1, 2000. The weekly return variance of the global index is estimated as 0.936. Global premium changes therefore correspond approximately to global stock beta changes.

### Table 2: Summary Statistics on Premium Changes and Marginal Arbitrage Risk

I report summary statistics on stock risk premium changes and on their risk contributions to the arbitrage portfolio for both the global covariance matrix $\Sigma^G$ and local covariance matrix $\Sigma^L$ 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. The weekly return variance of the global index is estimated as 0.936. Global premium changes therefore correspond approximately to global stock beta changes.

<table>
<thead>
<tr>
<th>Panel A: Change in Risk Premium under Global Pricing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obs.</td>
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<tr>
<td>All Stocks</td>
</tr>
<tr>
<td>Added and Deleted Stocks</td>
</tr>
<tr>
<td>U.S. Stocks</td>
</tr>
<tr>
<td>Non-U.S. Stocks</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Panel B: Change in Risk Premium under Local Pricing</th>
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<tbody>
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<td>Obs.</td>
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<tr>
<td>All Stocks</td>
</tr>
<tr>
<td>Added and Deleted Stocks</td>
</tr>
<tr>
<td>U.S. Stocks</td>
</tr>
<tr>
<td>Non-U.S. Stocks</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Panel C: Risk Contribution to Global Arbitrage Portfolio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obs.</td>
</tr>
<tr>
<td>All Stocks</td>
</tr>
<tr>
<td>Added and Deleted Stocks</td>
</tr>
<tr>
<td>U.S. Stocks</td>
</tr>
<tr>
<td>Non-U.S. Stocks</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Panel D: Risk Contribution to Local Arbitrage Portfolio</th>
</tr>
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<tbody>
<tr>
<td>Obs.</td>
</tr>
<tr>
<td>All Stocks</td>
</tr>
<tr>
<td>Added and Deleted Stocks</td>
</tr>
<tr>
<td>U.S. Stocks</td>
</tr>
<tr>
<td>Non-U.S. Stocks</td>
</tr>
</tbody>
</table>
I perform cross sectional regressions of the pre-announcement equity returns $\Delta p^j_t$ (denominated in dollars and expressed in percentage points) on a constant, the change in the risk premium $[\Sigma^G (w^n - w^o)]_j$ and the arbitrage risk $[\Sigma^G \Sigma^G (w^n - w^o)]_j$ of each stock $j$. Formally, 

$$\Delta p^j_t = c + \alpha_1 \times [\Sigma^G (w^n - w^o)]_j + \beta_1 \times [\Sigma^G \Sigma^G (w^n - w^o)]_j + \mu_j,$$

The covariance matrix $\Sigma^G$ is estimated for 2 years of weekly dollar stock returns for the period of July 1, 1998 to July 1, 2000. I use 3 day or 5 day or 7 day event windows (WS) prior to December 4, 2000. 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 clustered adjusted t-values are reported in parenthesis.

<table>
<thead>
<tr>
<th>WS</th>
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<th>$\alpha_1$</th>
<th>[$t$]</th>
<th>$\beta_1$</th>
<th>[$t$]</th>
<th>$R^2$</th>
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</thead>
<tbody>
<tr>
<td><strong>Panel A: Announcement Event (All Stocks, N=2291)</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>0.016</td>
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<tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
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<td>[-2.46]</td>
<td>-0.037</td>
<td>[-3.78]</td>
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<td></td>
</tr>
<tr>
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<td>[2.83]</td>
<td>-0.065</td>
<td>[-4.87]</td>
<td>0.051</td>
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</table>
I perform cross sectional regressions of the post-announcement equity returns $\Delta p_j^n$ (denominated in dollars and expressed in percentage points) on a constant, the change in the risk premium $\Sigma^G(w^n - w^o)_j$ and the arbitrage risk $\Sigma^G\Sigma^G(w^n - w^o)_j$ of each stock $j$. Formally,

$$\Delta p_j^n = c + \alpha_2 \times [\Sigma^G(w^n - w^o)]_j + \beta_2 \times [\Sigma^G\Sigma^G(w^n - w^o)]_j + \mu_j.$$  

The covariance matrix $\Sigma^G$ is estimated for 2 years of weekly dollar stock returns for the period of July 1, 1998 to July 1, 2000. I use 3 day or 5 day or 7 day event windows (WS) posterior to December 4, 2000. 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 clustered adjusted t-values are reported in parenthesis.

<table>
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<th>$[t]$</th>
<th>$\beta_2$</th>
<th>$[t]$</th>
<th>$R^2$</th>
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<tr>
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<td>[3.30]</td>
<td>0.079</td>
<td>[3.75]</td>
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</table>

39
I perform cross sectional regressions of the event window equity returns $\Delta p_j$ (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,

$$\Delta p_j = c + \alpha_3 \times [\Sigma^G (w^n - w^o)]_j + \beta_3 \times [\Sigma^G \Sigma^G (w^n - w^o)]_j + \mu_j.$$ 

The covariance matrix $\Sigma^G$ 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 clustered adjusted $t$-values are reported in parenthesis.

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<th>$\beta_3$ [t]</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel A: First Implementation Event (All Stocks, N=2291)</td>
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<td></td>
<td></td>
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<tr>
<td>7</td>
<td>2.933 [2.48]</td>
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<td>0.064 [3.85]</td>
<td>0.005</td>
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<tr>
<td>Panel B: First Implementation Event (Only Added and Deleted Stocks, N=661)</td>
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<td></td>
<td></td>
<td></td>
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<tr>
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<td>0.057 [3.25]</td>
<td>0.048</td>
</tr>
<tr>
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<td>20.133 [1.38]</td>
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<td>0.017</td>
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<tr>
<td>Panel C: Second Implementation Event (All Stocks, N=2291)</td>
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</tr>
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<td>−0.029 [−2.84]</td>
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<td></td>
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<tr>
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<td>−17.094 [−3.69]</td>
<td>−0.022 [−1.67]</td>
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</tr>
<tr>
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<td>−30.342 [3.57]</td>
<td>−0.038 [−2.60]</td>
<td>0.065</td>
</tr>
</tbody>
</table>

40
Table 6: Local versus Global Asset Pricing for Pre-Announcement Period

I perform cross sectional regressions of the pre-announcement equity returns $\Delta p^*_t$ (denominated in dollars and expressed in percentage points) on a constant, the change in the risk premium $[\Sigma^G(w^n - w^o)]_j$, the arbitrage risks for the local arbitrage portfolio $[\Sigma^L \Sigma^L (w^n - w^o)]_j$, and the incremental international arbitrage risk to the global arbitrage risk $[\Sigma^G \Sigma^G (w^n - w^o)]_j$. Formally,

$$\Delta p^*_t = c + \alpha^*_t \times [\Sigma^L (w^n - w^o)]_j + \alpha_{1nt} \times [\Sigma^G \Sigma^G (w^n - w^o)]_j + \beta^*_t \times [\Sigma^L \Sigma^L (w^n - w^o)]_j + \beta_{1nt} \times [\Sigma^G \Sigma^G (w^n - w^o)]_j + \mu_j.$$ 

The covariance matrix $\Sigma^G$ is estimated for 2 years of weekly dollar stock returns for the period of July 1, 1998 to July 1, 2000. I obtain $\Sigma^L$ by setting to zero all stock covariances across countries to capture only within country arbitrage and define $\Sigma^G = \Sigma^G - \Sigma^L$ and $\Sigma^G \Sigma^G = \Sigma^G \Sigma^G - \Sigma^L \Sigma^L$. I use 3 day or 5 day or 7 day event windows prior to December 4, 2000. Panel 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 clustered adjusted t-values are reported in parenthesis.

<table>
<thead>
<tr>
<th>WS</th>
<th>$c$</th>
<th>$t$</th>
<th>$\alpha^*_t$</th>
<th>$t$</th>
<th>$\alpha_{1nt}$</th>
<th>$t$</th>
<th>$\beta^*_t$</th>
<th>$t$</th>
<th>$\beta_{1nt}$</th>
<th>$t$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel A: Pre-Announcement Event (All Stocks, $N=2291$)</td>
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<tr>
<td>3</td>
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<td>74.912</td>
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<tr>
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<td>[0.34]</td>
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<td>0.052</td>
</tr>
<tr>
<td>Panel B: Pre-Announcement Event (Only Added and Deleted Stocks, $N=661$)</td>
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<tr>
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<tr>
<td>Panel C: Pre-Announcement Event (Non-U.S. Stocks, $N=1877$)</td>
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<td>-0.062</td>
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Table 7: Local versus Global Asset Pricing for Post-Announcement Period

I perform cross sectional regressions of the post-announcement equity returns $\Delta p_j$ (denominated in dollars and expressed in percentage points) on a constant, 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 $[\Sigma \Sigma \Sigma \Sigma Int (w^n - w^o)]_j$. Formally,

$$\Delta p_j = c + \beta_2^L \times [\Sigma L \Sigma L (w^n - w^o)]_j + \beta_2^{Int} \times [\Sigma \Sigma \Sigma \Sigma Int (w^n - w^o)]_j + \mu_j.$$ 

The covariance matrix $\Sigma G$ is estimated for 2 years of weekly dollar stock returns for the period of July 1, 1998 to July 1, 2000. I obtain $\Sigma L$ by setting to zero all stock covariances across countries to capture only within country arbitrage and define $\Sigma^\Delta = \Sigma G - \Sigma L$ and $\Sigma \Sigma \Sigma^\Delta = \Sigma G \Sigma G - \Sigma L \Sigma L$. I use 3 day or 5 day or 7 day event windows posterior to December 4, 2000. 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 clustered adjusted t-values are reported in parenthesis.

<table>
<thead>
<tr>
<th>WS</th>
<th>$c$</th>
<th>$[t]$</th>
<th>$\beta_2^L$</th>
<th>$[t]$</th>
<th>$\beta_2^{Int}$</th>
<th>$[t]$</th>
<th>$R^2$</th>
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<tbody>
<tr>
<td>Panel A: Post-Announcement Event (All Stocks, N=2291)</td>
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<td>0.073</td>
</tr>
<tr>
<td>Panel B: Post-Announcement Event (Only Added and Deleted Stocks, N=661)</td>
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<td>0.034</td>
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<td>0.075</td>
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<tr>
<td>Panel C: Post-Announcement Event (Non-U.S. Stocks, N=1877)</td>
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<td>[0.264]</td>
<td>0.042</td>
<td>[3.21]</td>
<td>0.069</td>
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</table>
Figure 1: Plotted are the cumulative returns around the announcement date of the index change for four self-financing portfolios with the sum of absolute weights normalized to unity. The ‘linear portfolio’ has weights proportional to the index weight changes $u = w^{n} - w^{o}$, the ‘premium portfolio’ has weights proportional to the risk premium changes $\Sigma u$, the ‘hedge portfolio’ has weights proportional to the marginal arbitrage of risk $\Sigma \Sigma u$ of each stock, and the ‘optimal portfolio’ weights proportional to $\Sigma u - \theta \Sigma \Sigma u$ with $\theta = 0.001$. 
Figure 2: Plotted are the cumulative returns around the first implementation date of the index change for four self-financing portfolios with the sum of absolute weights normalized to unity. The ‘linear portfolio’ has weights proportional to the index weight changes $u = w^n - w^o$, the ‘premium portfolio’ has weights proportional to the risk premium changes $\Sigma u$, the ‘hedge portfolio’ has weights proportional to the marginal arbitrage of risk $\Sigma \Sigma u$ of each stock, and the ‘optimal portfolio’ weights proportional to $\Sigma u - \theta \Sigma \Sigma u$ with $\theta = 0.001$. 
Figure 3: Plotted are the cumulative returns around the second implementation date of the index change for four self-financing portfolios with the sum of absolute weights normalized to unity. The ‘linear portfolio’ has weights proportional to the index weight changes $u = w^u - w^o$, the ‘premium portfolio’ has weights proportional to the risk premium changes $\Sigma u$, the ‘hedge portfolio’ has weights proportional to the marginal arbitrage of risk $\Sigma \Sigma u$ of each stock, and the ‘optimal portfolio’ weights proportional to $\Sigma u - \theta \Sigma \Sigma u$ with $\theta = 0.001$. 
Figure 4: 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 the case of stock additions).
Figure 5: Plotted are the risk premium change $\left[ \Sigma^L (w^n - w^o) \right]_j$ of stock $j$ under local asset pricing (market segmentation) against the risk premium change $\left[ \Sigma^G (w^n - w^o) \right]_j$ of the same stock under global asset pricing (market integration).
Figure 6: 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 7: Plotted is the total risk of an arbitrage portfolio relative to the total portfolio risk of the old MSCI index for two alternative arbitrage strategies: Linear global arbitrage represents a shift (with leverage factor $\kappa$) into the linear portfolio $\mathbf{w}^{Lin}$ and Optimizing global arbitrage represents a shift (under the same leverage) into the optimal portfolio $\mathbf{w}^{Opt}$ with parameter $\theta = 0.001$. 