TOBAM*
CORE INVESTMENTS

DIVERSIFICATION DASHBOARD

March 2019

Diversification Ratios®

TOBAM's Diversification Ratio® (DR) measures to what extent a portfolio is diversified. The DR^2 (square of the diversification ratio) measures the number of independent sources of risk to which a portfolio is exposed. As the table shows, the "broad market" indices do not fully utilise diversification capabilities. In addition to a snapshot of each market's DR^2, the table shows the DR^2 of a well-diversified portfolio, and the fraction of available diversification used by the index.

Universes	DR^2 Benchmark	DR^2 Anti-Benchmark®	% diversification captured by benchmark
MSCI All Countries World	3.77	14.70	25.7%
MSCI World	3.51	12.43	28.2%
MSCI US Equity	2.95	8.71	33.9%
MSCI Emerging Markets	3.92	9.09	43.1%
MSCI Pacific Ex-Japan	3.23	7.21	44.9%
MSCI UK Equity	3.29	5.77	57.0%
MSCI Japan	3.07	6.07	50.6%
MSCI EMU	3.04	7.30	41.6%
BofA Merrill Lynch US Corporate & High Yield	4.01	5.33	75.2%
BofA Merrill Lynch Global High Yield	5.53	7.14	77.4%

Source: TOBAM, figures as of February 28, 2019.

On the 'Asynchrony Trap' in Correlation Estimation

Modern Portfolio Theory states that investors are rewarded only for the undiversifiable risk and so unsurprisingly some investors seek to hold a well-diversified portfolio. Correlation amongst assets is the cornerstone in building a well-diversified portfolio and as such precise estimation of correlations is crucial. The most common and well-known Pearson correlation estimator could lead to some unwanted biases when the input returns are not observed synchronously which is often the case when building portfolios with global assets.

In this month's Dashboard, we highlight the biases of the Pearson estimator and illustrate the empirical properties of an alternative correlation estimator used at TOBAM that is able to handle the case when asset prices are not observed synchronously. This is the first Dashboard dedicated to the Plesiochronous Correlation Estimator used at TOBAM. We call this estimator "Plesiochronous" for its ability to handle observations that are "nearly- synchronous", where "plesio" stands for "near" in ancient Greek.

Introduction

The estimation of correlation (or covariance) matrices is an important step in the construction of quantitative portfolios, especially for strategies that focus on exploiting diversification benefits that rely on imperfect correlations amongst underlying assets. However, this estimation is challenging when assets span multiple time zones and asset prices are observed on a daily basis.

Indeed, the most well-known and widely used Pearson Estimator (the default method in statistical software tools such as Microsoft Excel and MATLAB) assumes that input returns are synchronous. However, in reality, assets from different geographical regions trade in different time zones. Using this

estimator with daily data results in a systematic bias towards zero correlation, and can lead to unwanted biases in portfolio optimization.

A simple remedy is to use lower frequency data. However, reduced frequency introduces new problems. For instance, reduced frequency requires data with longer history. Suppose, that at least 250 observations are needed for the estimate to be meaningful, then using monthly data for example requires a time period of 20 years. Now, financial markets may not be stationary over such long periods of time, and many asset prices are not available over such long periods.

An alternative solution to this problem is to use the Plesiochronous Correlation Estimator with daily observations. In this Dashboard, we provide empirical evidence of this method.

In the first section of this Dashboard, we briefly discuss the problems of estimating correlation between asynchronous time series through concrete examples.

In the second section, we provide empirical evidence of the value added by the Plesiochronous estimator when used for measuring the correlation between two assets. The more complex process of estimating full correlation matrices for use in portfolio optimization and associated theoretical considerations will be discussed in a second Dashboard on this topic.

1. Issues in Correlation Estimation with Asynchronous Returns

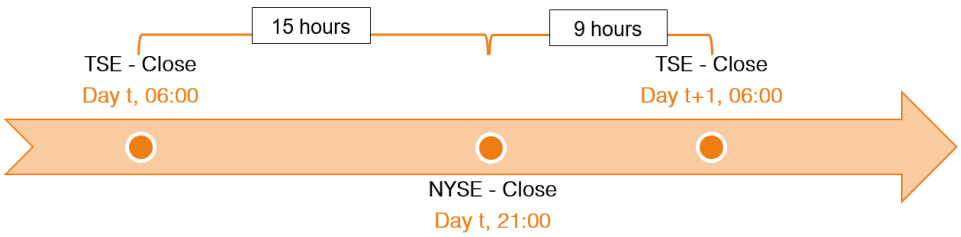
Pearson correlation is designed to measure the level of co-movement of synchronous timeseries of returns. In practice, investors routinely estimate correlations of international stocks trading in different time zones. In such cases, returns are not synchronous and using a Pearson estimator leads to the systematic underestimation of asset correlations, biasing negative or positive estimates towards zero. The magnitude of this bias is particularly noticeable for daily returns.

For instance, the Pearson correlation between the daily returns of 'Apple' computed with close prices and open prices respectively, is a mere 0.35 over the period December, 2013 to December, 2018. However, the expected correlation is +1 since both timeseries use prices of the same asset, although at different times. As such, relying on a Pearson estimator in the presence of asynchronous prices could potentially lead one to erroneously conclude that two stocks have a relatively low correlation when their true correlation is relatively high.

Another problem of asynchronous returns is that large asynchrony in returns could potentially result in significant non-contemporaneous correlations. For instance, the trading hours of Japan and USA do not overlap and represent a good example to illustrate this phenomenon. Figure 1 shows the closing times of the Tokyo Stock Exchange (TSE) and the New York Stock Exchange (NYSE). USA and Japan are so far apart that the NYSE closing bell is nearer to the next day closing bell of TSE than that of the same day. As such, one may observe that:

"The US market is more correlated to tomorrow's Japanese market than today's"

Figure 1: Open and Close Times of The Tokyo Stock Exchange and The New York Stock Exchange

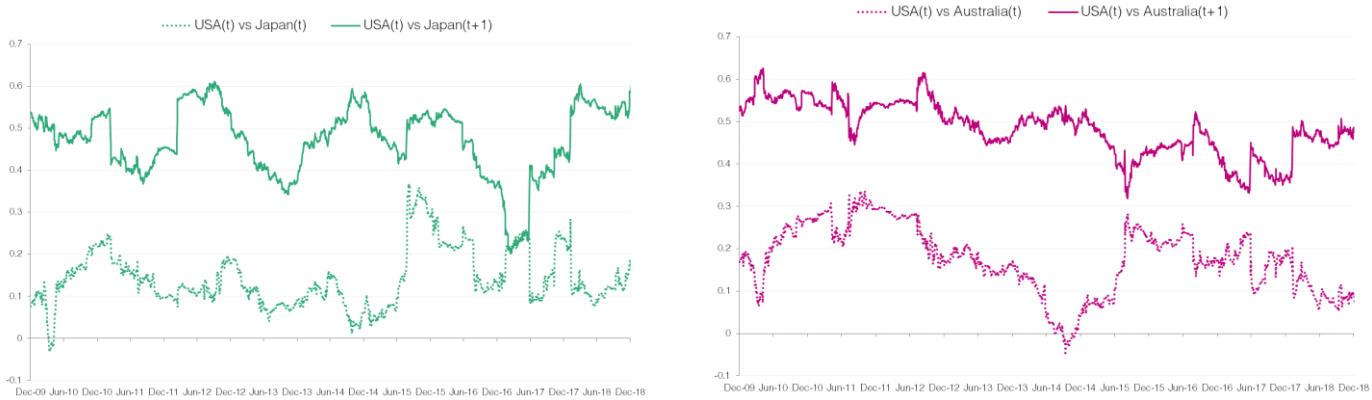


All times are in GMT. TSE – The Tokyo Stock Exchange; NYSE – The New York Stock Exchange

Figure 2 confirms this effect by comparing the contemporaneous correlation and one-day lagged correlation between the market indices of USA and that of Japan and Australia. We can clearly see that the one-day lagged correlation is higher than the contemporaneous correlation.

Based on the above illustration, Japanese and US stocks might appear more appealing in terms of their diversification potential if one were to rely on contemporaneous correlation because US and Japanese stocks tend to have low contemporaneous correlations. It is worth noting that ignoring the time differences when estimating correlations could have a significant impact on the portfolio construction techniques that rely on correlation/covariance matrices. For example, Minimum Volatility and Most Diversified portfolios would erroneously place a higher weight than warranted on US and Japanese stocks compared to that of Europe when constructed on a universe of international stocks simply because US and Japanese stocks would have lower correlations compared to European stocks due to the larger time difference between US and Japan.

Figure 2: Rolling correlation and one day lagged correlation of USA vs Japan and Australia



Source: TOBAM and Bloomberg. Period of Analysis: 31-Dec-2008 to 28-Dec-2018 (10 Years). Daily Gross Total Returns in local currency of MSCI USA, MSCI Japan and MSCI Australia are used in this analysis. One year rolling Pearson correlations are plotted. USA(t) vs Japan(t) represent the contemporaneous correlation between USA and Japan computed using returns observed at day t. USA(t) vs Japan(t+1) represent the one-day lagged correlation between USA and Japan computed using returns observed at day t in USA and day t+1 in Japan.

One way to tackle the problem of asynchrony is to reduce the sampling frequency of returns i.e., to use weekly returns as opposed to daily returns. However, it is well known that a reduced number of observations in the time series could also adversely impact the precision of the estimates. Moreover, weekly returns are not quite perfectly synchronous either. The Pearson correlations estimated using weekly returns are still biased but to a much smaller extent compared to the daily correlations. Another solution could be to use intra-day data to compute correlations, so that the returns are nearly synchronous. However, world equities do not yet trade 24/7, and overnight trading for most stocks do not offer enough liquidity yet.

In the next section, we provide empirical evidence that using the Plesiochronous estimator circumvents the problems described above using daily (asynchronous) returns, and leave to a second Dashboard the use of the Plesiochronous estimator in a portfolio construction process, and related theoretical aspects.

2. Empirical Evidence of the Value-added of the Plesiochronous Estimator

In this section, we provide empirical evidence that the Plesiochronous estimator yields substantial improvements over the regular Pearson estimator using observed historical stock return data and not

simulated returns for both the estimators. Note that we labelled this estimator Plesiochronous for its ability to handle observations that are "nearly- synchronous", where "plesio" stands for "near" in ancient Greek.

2.1 Correlation between Open-to-open Returns and Close-to-close Returns

In order to illustrate the ability of the Plesiochronous Estimator to correct for non-synchronicity, we estimate the correlation between returns of the same stock, observed at different times. More precisely, we estimate the correlation between close-to-close daily returns (hereinafter, Returns (Close)) and open-to-open daily returns (hereinafter, Returns (Open)) of the same stock. This example is very intuitive as we expect the true correlation to be +1 and so it allows us to compare the two correlation estimators – the Plesiochronous estimator and Pearson against a known true value.

Figure 3: Returns (Open) vs Returns (Close)

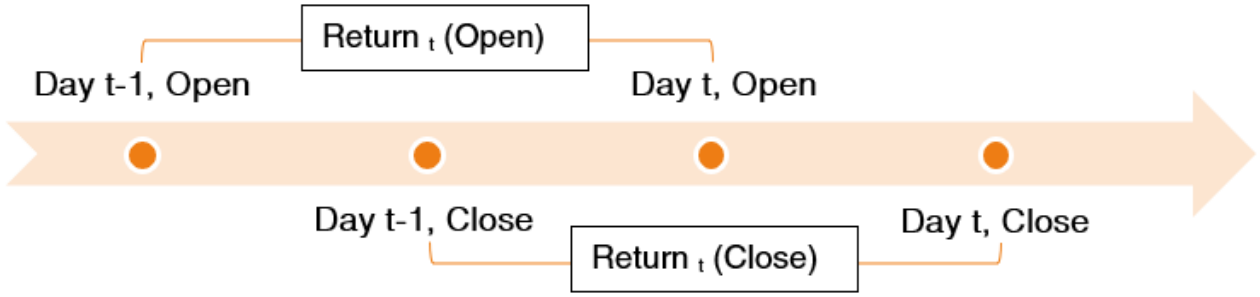
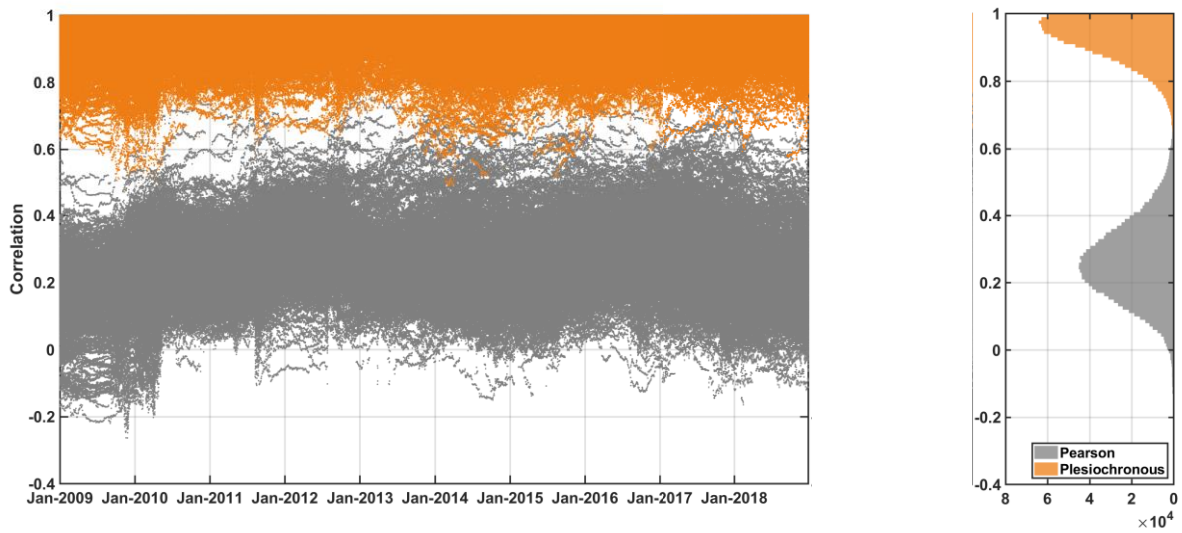


Figure 4 shows the one-year rolling correlation between Returns (Open) and Returns (Close) of all the stocks that were/are part of the MSCI USA universe during the ten-year period December, 2008 to December, 2018. As can be seen from the figure, Pearson correlation is well below +1 on average, whereas the Plesiochronous correlations circumvent the non-synchronicity problem and are near one in most of the cases, as illustrated by the distributions of the correlations on the right-hand side subplot. This illustrates clearly that the Pearson estimator exhibits a downward bias whereas the Plesiochronous Estimator fares better when the returns are asynchronous.

Figure 4: Correlation between Returns (Open) and Returns (Close) of all the Stocks in MSCI USA

PANEL A: Correlations

PANEL B: Distribution of Correlations



Source: TOBAM and Bloomberg. Period of Analysis: 31-Dec-2008 to 28-Dec-2018 (10 Years). All returns are in local currency. Returns (Open) are daily returns calculated from previous open price to current open price. Returns (Close) are daily returns calculated from previous close price to current close price. The right-hand side subplot shows the distributions of the correlations.

2.2 Pearson Estimator and Time Differences

As outlined in the previous sections, trading time differences amongst international stocks induce a bias towards zero in the Pearson correlation estimates when daily (asynchronous) returns are used. In this section, we provide an empirical illustration of this bias by comparing it with a nearly unbiased estimator. When the return frequency is reduced from daily to weekly, the asynchronous trading effect is largely reduced and we know that the Pearson estimator is unbiased when the returns are perfectly synchronous. Therefore, weekly Pearson correlations based on nearly synchronous returns could serve as reasonable proxies for the unbiased estimates of true correlations, thus enabling us to compare these with daily Pearson correlations in order to assess their biases.

Figure 5: Pairwise Pearson correlations (Weekly vs Daily) of all stocks grouped based on their regions of trading

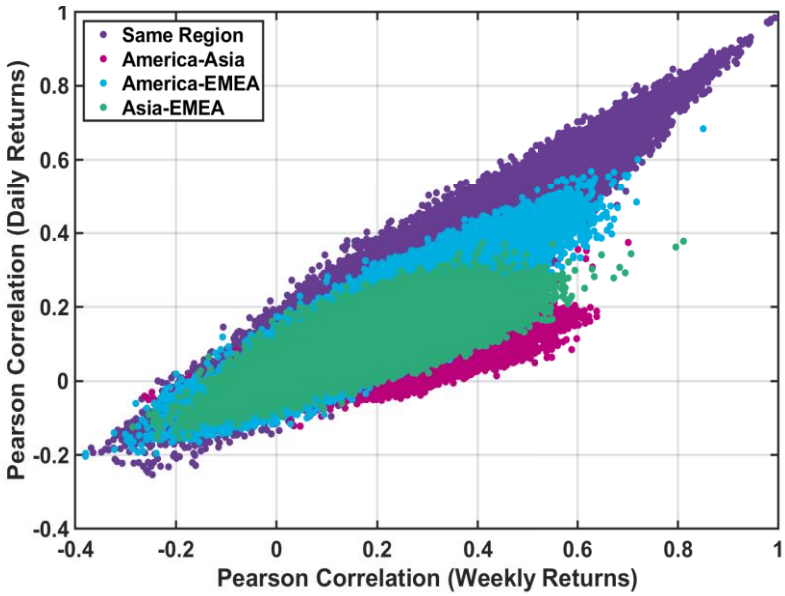


Figure 5 plots the pairwise Pearson correlations of all the stocks in the MSCI World universe over the five-year period December, 2013 to December, 2018 computed using daily returns against those computed using weekly returns. Each correlations pair is coloured according to the regions of its underlying assets. This allows one to observe the impact of time differences on the asset correlation levels. For instance, correlations of all stock pairs from America and Asia are treated as a separate group from correlations of all stock pairs that trade in America and EMEA respectively.

Source: TOBAM and Bloomberg. Period of Analysis: 31-Dec-2013 to 28-Dec-2018 (5 Years). Universe: MSCI World. All returns are in local currency.

As can be seen from the above plot, the daily Pearson correlations are quite different from their weekly counterpart, and clearly don't cluster symmetrically around the diagonal line. In fact, daily Pearson correlations are lower (in absolute value) for stock-pairs of different regions.

In a nutshell: daily Pearson correlation estimates exhibit a clear bias towards zero, compared to the nearly unbiased weekly Pearson estimates.

Indeed, one can notice that the magnitude of this bias increases with the time difference between the regions. For instance, the daily Pearson correlations between American and Asian stocks -with the largest time difference - are also the ones with the largest bias. However, there is no noticeable bias in the daily Pearson correlations of the stocks that trade in the same regions, because the time differences, if any, are small.

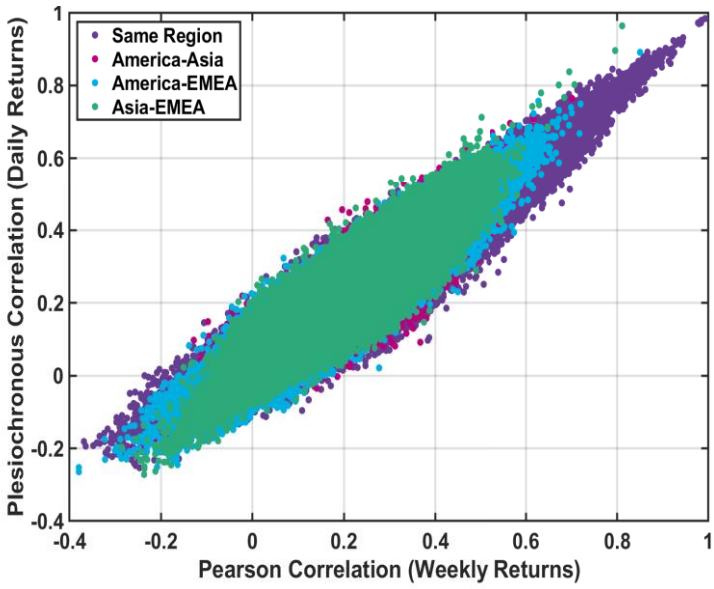
2.3 Plesiochronous Estimator and Time Differences

In Section 2.2 we showed that, due to the non-synchronicity of returns, the Pearson estimator is a biased estimator when daily international stock returns are used. In this section, we repeat the same experiment with the same dataset so as to assess the bias, if any, of the Plesiochronous Estimator.

The weekly Pearson correlation estimates are retained as proxies for unbiased estimates despite the fact that they are not perfectly unbiased.

Figure 6 plots the pairwise Plesiochronous correlations of all the stocks in the MSCI World universe over the five-year period December, 2013 to December, 2018 computed using daily returns against the pairwise Pearson correlations computed using weekly returns. The correlations are once again clustered according to their respective regions in order to assess the impact of the trading time differences. It is evident that the Plesiochronous Estimator estimates do not suffer any significant biases due to asynchronous returns. The correlations of all the different regions are nearly symmetrical around the diagonal line. They are not perfectly symmetrical because the weekly Pearson correlations are still biased at the weekly frequency, but they are of much smaller magnitude compared to that of the daily estimates. This shows that the Plesiochronous Estimator can be a good candidate to be an unbiased estimator whether or not the returns are synchronous. We reserve the theoretical aspects and reasons why the Plesiochronous Estimator is an unbiased estimator to the follow-on Dashboard of this series.

Figure 6: Pairwise correlations (Plesiochronous Correlation vs Pearson Correlation) of all stocks, grouped by their regions of trading



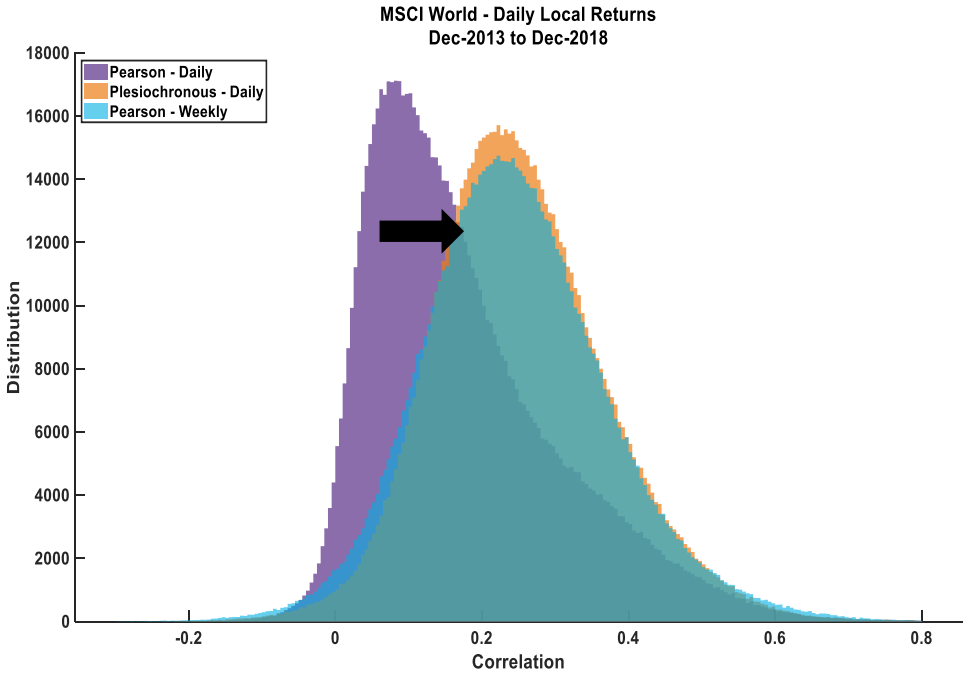
Source: TOBAM and Bloomberg. Period of Analysis: 31-Dec-2013 to 28-Dec-2018 (5 Years). Universe: MSCI World. All returns are in local currency.

2.4 Distribution of correlations

Figure 7 illustrates the distributions of correlations estimated using the estimators discussed so far – Pearson daily, Pearson weekly and Plesiochronous daily. The correlations are computed over the same five-year period December, 2013 to December, 2018 for all the stocks in the MSCI World universe.

One can notice that the daily Plesiochronous correlations and the weekly Pearson correlations are nearly identical, while the daily Pearson estimates have a significantly lower mean. This illustration reinforces our earlier conclusion that the Pearson estimator is indeed biased towards zero when estimated using daily (asynchronous) returns.

Figure 7: Distributions of pairwise correlations of the three estimators



Source: TOBAM and Bloomberg. Period of Analysis: 31-Dec-2013 to 28-Dec-2018 (5 Years). Universe: MSCI World. All returns are in local currency.

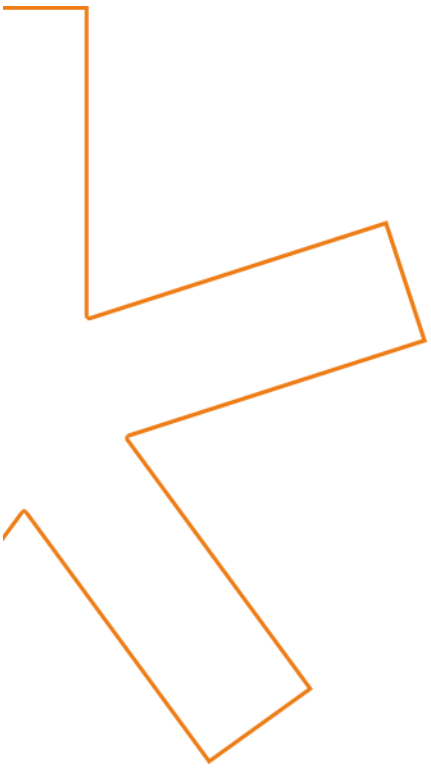
Conclusion

In this Dashboard, we presented the Plesiochronous Correlation Estimator used at TOBAM, which is able to handle the case of asset prices that are not observed synchronously.

The asynchronous trading of international stocks results in underestimating correlations when using the usual Pearson estimator at a daily frequency. Such an effect is mainly the result of not observing prices synchronously. As this is not the result of another economic or fundamental phenomenon, correcting for such biases is important, particularly when using correlation estimates as an input of a portfolio optimization process.

The Plesiochronous Estimator is an unbiased estimator, that effectively corrects for the potential biases in correlations caused by observing asynchronous prices. This estimator enables the effective use of daily data, and as a result significantly shorter estimation windows compared to weekly or monthly data. Finally, compared to the well-known Pearson estimator, it results in reliable correlation estimates, whether the underlying price series are observed synchronously or not.

The more complex process of estimating full correlation matrices for use in portfolio optimization and associated theoretical considerations will be discussed in a second Dashboard on this topic.



For more information

TOBAM is an asset management company offering innovative investment capabilities designed to increase diversification. Its mission is to provide rational and professional solutions to long term investors in the context of efficient markets.

The Maximum Diversification® approach, TOBAM's flagship investment process founded in 2006, is supported by original, patented research and a mathematical definition of diversification and provides clients with diversified core exposure, in both the equity and fixed income markets.

In line with its mission statement and commitment to diversification, TOBAM also launched a separate activity on cryptocurrencies in 2017.

TOBAM currently manages close to US$10 billion (at December 28, 2018). TOBAM's team is composed of 54 professionals.

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