

# Strategic Asset Allocation: Determining the Optimal Portfolio with Ten Asset Classes

Niels Bekkers  
Mars  
The Netherlands

Ronald Q. Doeswijk\*  
Robeco  
The Netherlands

Trevin W. Lam  
Rabobank  
The Netherlands

October 2009

## Abstract

This study explores which asset classes add value to a traditional portfolio of stocks, bonds and cash. Next, we determine the optimal weights of all asset classes in the optimal portfolio. This study adds to the literature by distinguishing ten different investment categories simultaneously in a mean-variance analysis as well as a market portfolio approach. We also demonstrate how to combine these two methods. Our results suggest that real estate, commodities and high yield add most value to the traditional asset mix. A study with such a broad coverage of asset classes has not been conducted before, not in the context of determining capital market expectations and performing a mean-variance analysis, neither in assessing the global market portfolio.

JEL classification: G11, G12

Key words: strategic asset allocation, capital market expectations, mean-variance analysis, optimal portfolio, global market portfolio.

This study has benefited from the support and practical comments provided by Jeroen Beimer, Léon Cornelissen, Lex Hoogduin, Menno Meekel, Léon Muller, Laurens Swinkels and Pim van Vliet. Special thanks go to Jeroen Blokland and Rolf Hermans for many extensive and valuable discussions. We thank Peter Hobbs for providing the detailed segmentation of the global real estate market that supplemented his research paper. Last, but not least, we thank Frank de Jong for his constructive comments and useful suggestions during this study.

\* Corresponding author, email: [r.doeswijk@robeco.com](mailto:r.doeswijk@robeco.com), telephone: +31 10 2242855.

# 1 Introduction

Most previous academic studies agree on the importance of strategic asset allocation as a determinant for investment returns. In their frequently cited paper, Brinson, Hood and Beebower (1986) claim that 93.6% of performance variation can be explained by strategic asset allocation decisions. This result implies that strategic asset allocation is far more important than market timing and security selection.

Most asset allocation studies focus on the implications of adding one or two asset classes to a traditional asset mix of stocks, bonds and cash to conclude whether and to what extent an asset class should be included to the strategic portfolio, see for example Erb and Harvey (2006) and Lamm (1998). However, because of omitting asset classes this partial analysis can lead to sub-optimal portfolios. This is surprising, as pension funds and other institutions have been strategically shifting substantial parts of their investment portfolio towards non-traditional assets such as real estate, commodities, hedge funds and private equity.

The goal of this study is to explore which asset classes add value to a traditional asset mix and to determine the optimal weights of all asset classes in the optimal portfolio. This study adds to the literature by distinguishing ten different investment categories simultaneously in a mean-variance analysis as well as a market portfolio approach. We also demonstrate how to combine these two methods. Next to the traditional three asset classes stocks, government bonds and cash we include private equity, real estate, hedge funds, commodities, high yield, credits and inflation linked bonds. A study with such a broad coverage of asset classes has not been conducted before, not in the context of determining capital market expectations and performing a mean-variance analysis, neither in assessing the global market portfolio. The second step in portfolio management, i.e. market timing and security selection are tactical decisions. These are beyond the scope of this study.

In short, this study suggests that adding real estate, commodities and high yield to the traditional asset mix delivers the most efficiency improving value for investors. Next, we show that the proportion of non-traditional asset classes appearing in the market portfolio is relatively small. In the remainder of this study we conduct an empirical and literature analysis to establish long-run capital market expectations for each asset class, which we subsequently use in a mean-variance analysis. Then, we provide an assessment of the global market portfolio. Finally, we show how the mean-variance and market portfolio approaches can be combined to determine optimal portfolios.

## 2 Methodology and data

### Methodology

Markowitz (1952, 1956) pioneered the development of a quantitative method that takes the diversification benefits of portfolio allocation into account. Modern portfolio theory is the result of his work on portfolio optimization. Ideally, in a mean-variance optimization model, the complete investment opportunity set, i.e. all assets, should be considered simultaneously. However, in practice, most investors distinguish between different asset classes within their portfolio-allocation frameworks. This two-stage model is generally applied by institutional investors, resulting in a top-down allocation strategy.

In the first part of our analysis, we view the process of asset allocation as a four-step exercise like Bodie, Kane and Marcus (2005). It consists of choosing the asset classes under consideration, moving forward to establishing capital market expectations, followed by deriving the efficient frontier until finding the optimal asset mix. In the second part of our analysis, we assess the global market portfolio. Finally, we show how the mean-variance and market-neutral portfolio approaches can be combined to determine optimal portfolios.

We take the perspective of an asset-only investor in search of the optimal portfolio. An asset-only investor does not take liabilities into account. The investment horizon is one year and the opportunity set consists of ten asset classes. The investor pursues wealth maximization and no other particular investment goals are considered.

We solve the asset-allocation problem using a mean-variance optimization based on excess returns. The goal is to maximise the Sharpe ratio (risk-adjusted return) of the portfolio, bounded by the restriction that the exposure to any risky asset class is greater than or equal to zero and that the sum of the weights adds up to one. The focus is on the relative allocation to risky assets in the optimal portfolio, in stead of the allocation to cash. The weight of cash is a function of the investor's level of risk aversion.

For the expected risk premia we use geometric returns with intervals of 0.25%. The interval for the standard deviations is 1% and for correlations 0.1. In our opinion, more precise estimates might have an appearance of exactness which we want to prevent. We do not take management fees into consideration, except for private equity and hedge funds as for these asset classes the management fees are rather high relative to the expected risk premia of the asset class. Other asset classes have significantly lower fees compared to their risk premia. They are therefore of minor importance, especially after taking the uncertainty of our estimates into account. We estimate risk premiums by

subtracting geometric returns from each other. Hereby, our estimated geometric returns as well as the risk premiums both are round numbers.

In the mean-variance analysis, we use arithmetic excess returns. Geometric returns are not suitable in a mean-variance framework. The weighted average of geometric returns does not equal the geometric return of a simulated portfolio with the same composition. The observed difference can be explained by the diversification benefits of the portfolio allocation. We derive the arithmetic returns from the geometric returns and the volatility.

## **Data**

We primarily focus on US data in the empirical analysis. The choice for this market is backed by two arguments. First, the US market offers the longest data series for almost all asset classes. This makes a historical comparison more meaningful. For instance, the high yield bond market has long been solely a US capital market phenomenon. Secondly, using US data avoids the geographical mismatch in global data. A global index for the relatively new asset class of inflation linked bonds is biased towards the US, French and UK markets, while a global stock index is decently spread over numerous countries. We use total return indices in US dollars.

Asset classes like real estate and private equity are represented in both listed and non-listed indices, while hedge funds are only covered by non-listed indices. Non-listed real estate and private equity indices are appraisal based, which may cause a smoothing effect in assumed risk of the asset class. This bias arises because the appraisals will not take place frequently. However, interpolating returns causes an underestimation of risk. Also, changes in prices will not be immediately reflected in appraisal values until there is sufficient evidence for an adjustment. Statistical procedures to mitigate these data problems exist, but there is no guarantee that these methods produce accurate measures of true holding-period returns, see Froot (1995). As these smoothing effects can lead to an underestimation of risk, this study avoids non-listed datasets and instead adopts listed indices for real estate and private equity. The quality of return data of listed indices is assumed to be higher as they are based on transaction prices. Ibbotson (2006) supports this approach and states “Although all investors may not yet agree that direct commercial real estate investments and indirect commercial real investments (REITs) provide the same risk-reward exposure to commercial real estate, a growing body of research indicates that investment returns from the two markets are either the same or nearly so.”. For hedge funds we will use a fund of fund index that we unsmooth with Geltner (1991, 1993) techniques. Fung and Hsieh (2000) describe the important role of funds of hedge funds as a proxy for the market portfolio of hedge funds.

Appendix A and B contain our data sources. In appendix A we discuss our capital market expectations and in appendix B we derive the market portfolio from a variety of data sources.

### 3 Empirical results

#### Capital market expectations

We estimate risk premia for all asset classes based on previous reported studies, our own empirical analyses of data series and on the basic idea that risk should be rewarded. Obviously, estimates like these inevitably are subjective as the academic literature only provides limited studies into the statistical characteristics of asset classes. Moreover, there is generally no consensus among academics and we lack long term data for most asset classes. Our results should therefore be treated with care, especially since mean-variance analysis is known for its corner solutions, being highly sensitive in terms of its input parameters.

In this study we proceed with the risk premia and standard deviations as shown in Table 1. Appendix A contains the reasoning for these estimates and for the correlation matrix.

[INSERT TABLE 1]

#### Mean-variance analysis

Table 2 shows the optimal portfolio based on the mean-variance analysis and its descriptive statistics for a traditional portfolio with stocks and bonds as well as a portfolio with all assets. On top of the traditional asset classes of stocks and bonds, this analysis suggests that it is attractive for an investor to add real estate, commodities and high yield. The Sharpe ratio increases from 0.346 to 0.396. The allocation to real estate is quite high. To bring this into perspective, we would suggest that the proposed portfolio weight is overdone. When one, for example, would be willing to perceive utilities as a separate asset class, it is likely that it also would get a significant allocation as this sector also has a low correlation to the general stock market.

Table 2 also illustrates that mean-variance analysis tends towards corner solutions as it neglects credits which has characteristics comparable with bonds. However, with these parameters it prefers bonds in the optimal portfolio.

[INSERT TABLE 2]

Figure 1 shows the benefits of diversification into non-traditional asset classes. In the volatility range of 7% to 20% the diversification benefits vary between 0.40% and 0.93%. This additional return is economically significant. For example, at a volatility of 10% the additional return is 0.56%. The efficient

frontier of a portfolio with stocks, bonds and the three asset classes real estate, commodities and high yield comes close to the efficient frontier of an all asset portfolio. By adding these three asset classes, an investor almost captures the complete diversification benefit.

[INSERT FIGURE 1]

For various reasons not all investors use cash to (un)leverage their investment portfolio. Therefore, it is interesting to observe the composition of efficient portfolios in a world without the risk free rate. Figure 2 shows the asset allocation on the efficient frontier in an all asset portfolio starting from a minimum variance allocation towards a risky portfolio. It maximizes the expected excess return constrained by a given volatility.

[INSERT FIGURE 2]

In the least risky asset allocation, an investor allocates 77.7% of the portfolio towards fixed-income assets. Next to bonds and stocks, real estate and commodities receive a significant allocation in portfolios with a volatility in the range of 7.5%-12.5%. High yield is also present in most of the portfolios in this range. For riskier portfolios, private equity shows up and, in the end, it ousts bonds, real estate, commodities and stocks (in this order). For defensive investors, inflation linked bonds and hedge funds enter the portfolio.

We have tested the sensitivity of the mean-variance analysis to the input parameters. Table 3 shows the impact on the optimal portfolio of an increase and a decrease in the expected volatility of an asset by a fifth, all other things being equal. Note that a change in volatility affects both the arithmetic return and the covariance matrix. Again, this table demonstrates the sensitivity of a mean-variance analysis to the input parameters. An increase in expected volatility leads to a lower allocation to that asset class. High yield even vanishes completely from the optimal portfolio. It is noteworthy that commodities are hardly affected by a higher standard deviation. A decrease in volatility mostly leads to a higher allocation, with the exception of hedge funds and commodities. Commodities, despite their expected zero risk premium, add value due to the strong diversification benefit. In this analysis, they appear to be insensitive to a change in their expected volatility. Credits and bonds are quite similar asset classes and, in a mean-variance context, the optimal portfolio tends to incline towards one or the other.

[INSERT TABLE 3]

In short, the mean-variance analysis suggests that adding real estate, commodities and high yield to the traditional asset mix of stocks and bonds creates most value for investors. Basically, adding these

three asset classes comes close to an all asset portfolio. Private equity is somewhat similar to stocks, but shows up in riskier portfolios, moving along the efficient frontier. This part of the efficient frontier is interesting for investors in search of high returns without leveraging the market portfolio. Hedge funds as a group do not add value. Obviously, when investors attribute alpha to a particular hedge fund, it changes the case for that fund. This also applies to private equity. Credits and bonds are quite similar asset classes and in a mean-variance context the optimal portfolio tends to tilt to one or another. Inflation linked bonds do not show up in our mean-variance analysis. The inflation risk premium and the high correlation with bonds prevent an allocation towards this asset class in that setting. However, for defensive investors who primarily seek protection against inflation this asset class can be very interesting.

### **Market portfolio**

Both academics and practitioners agree that the mean-variance analysis is extremely sensitive to small changes and errors in the assumptions. We therefore take another approach to the asset allocation problem, in which we estimate the weights of the asset classes in the market portfolio. The composition of the observed market portfolio embodies the aggregate return, risk and correlation expectations of all market participants and is by definition the optimal portfolio. In practice however, borrowing is restricted for most investors and at the same time borrowing rates usually exceed lending rates. The result is that the market portfolio is possibly no longer the common optimal portfolio for all investors, because some might choose risky portfolios on the efficient frontier beyond the point where no money is allocated to the risk free rate. In addition, an investor's specific situation could also lead to a different portfolio. Despite this limitation, the relative market capitalization of asset classes provides valuable guidance for the asset allocation problem. In this setting, the market-neutral weight for a particular asset class is its market value relative to the world's total market value of all asset classes.

Figure 3 shows the global market portfolio based on a variety of data sources. Appendix B provides details about the market portfolio and its dynamics for the period 2006-2008. The asset classes stocks and investment grade bonds (government bonds and credits) represent more than 85% of the market for these years. At the end of 2008 we estimate this number at 88.8%. This means that the size of the average remaining asset class is less than 2.0%. Based on this analysis, we conclude that the proportion of non-traditional asset classes appearing in the market portfolio is relatively small.

[INSERT FIGURE 3]

## **Combination of market portfolio and mean-variance analysis**

The mean-variance analysis can be combined with the market portfolio. Here, we choose to take the market portfolio as a starting point which we subsequently optimize with turnover and tracking error constraints. We choose to take the market portfolio as a starting point, as it embodies the aggregate return, risk and correlation expectations of all market participants without the disadvantage of delivering the corner solutions of the mean-variance analysis.

Table 4 shows the optimal portfolios with different tracking error constraints and a maximum turnover of 25% (single count) relative to the market portfolio. In other words, in this example we limit ourselves to finding optimized portfolios with portfolio weights that do not differ more than 25% from the market portfolio, calculated as the sum of the absolute difference between the market portfolio and the optimized portfolio for each asset class. Focusing on the 0.25% tracking error constraint, it appears that the analysis recommends especially adding real estate, commodities and high yield, and removing hedge funds and inflation-linked bonds. This is logical, as the results from the mean-variance analysis are applied in this market-portfolio-adjustment process. There is a 12.5% shift in portfolio weights. Obviously, less constraints result in a higher risk premium and a higher Sharpe ratio, until we end up with the theoretically optimal portfolio from the mean-variance analysis. Within this methodology, investors must determine their own individual constraints, while the market portfolio and the portfolio optimized by mean-variance are considered as the boundaries for the asset classes.

[INSERT TABLE 4]

## **4 Summary and conclusions**

Our mean-variance analysis suggests that real estate, commodities and high yield add most value to the traditional asset mix of stocks, bonds and cash. Basically, adding these three asset classes comes close to an all asset portfolio. The portfolio with all assets shows a diversification benefit along the efficient frontier that varies between 0.40% and 0.93% in the volatility range of 7% to 20%. That is an economically significant extra return for free.

Another approach to the asset allocation problem is assessing the weights of the asset classes in the market portfolio. Based on this analysis we conclude that the proportion of non-traditional asset classes appearing in the market portfolio is relatively small.

One can combine the mean-variance analysis with the market portfolio. Within this methodology, investors must determine their own individual constraints, while the market portfolio and the portfolio optimized by mean-variance are considered as the boundaries for the asset classes.

## References

Altman, E.I., 1998, "The Anatomy of the High Yield Bond Market: After Two Decades of Activity-Implications for Europe", research paper.

Amin, G., and H. Kat, 2005, "Welcome to the Dark Side: Hedge Fund Attrition and Survivorship Bias 1994-2001", *Journal of Alternative Investments*, vol. 6, no. 2, 57-73.

Bodie, Z., A. Kane and A. Marcus, 2005, "Investments", McGraw-Hill, sixth edition.

Brinson, G.P., L.R. Hood and G.L. Beebower, 1986, "Determinants of Portfolio Performance", *Financial Analysts Journal*, vol. 42, no. 4, p. 39-44.

Dimson, E., P. Marsh and M. Staunton, 2003, "Global Evidence on the Equity Risk Premium", *Journal of Applied Corporate Finance*, vol.15, no.4, p. 27-38.

Dimson, E., P. Marsh and M. Staunton, 2009, "Global Investment Returns Sourcebook 2009", Credit Suisse.

Doyle, E., J. Hill and I. Jack, 2007, "Growth in Commodity Investment: Risks and Challenges for Commodity Market Participants", study from the FSA Markets Infrastructure Department.

Elton, E.J., M.J., Gruber and D.M.C. Agrawal, 2001, "Explaining the Rate Spread on Corporate Bonds", *Journal of Finance*, vol. 56, no. 1, 247-277.

Erb, C.B., and C.R. Harvey, 2006, "The Tactical and Strategic Value of Commodity Futures", *Financial Analysts Journal*, vol. 62, no. 2, p. 69-97.

Fama, E.F., and K.R. French, 2002, "The Equity Premium", *Journal of Finance*, vol. 57, no. 2, p. 637-660.

Froot, K.A., 1995, "Hedging Portfolios with Real Assets", *Journal of Portfolio Management*, vol. 21, no. 4, p. 60-77.

Fugazza, C., M. Guidolin and G. Nicodano, 2007, "Investing for the Long-Run in European Real Estate", *Journal of Real Estate Finance and Economics*, vol. 34, no. 1, p. 35-80.

Fung, W., and D.A. Hsieh, 2000, "Performance Characteristics of Hedge Funds and Commodity Funds: Natural vs. Spurious Biases", *Journal of Financial and Quantitative Analysis*, vol. 35, no.3, p. 291-308.

Geltner, D.M., 1991, "Smoothing in Appraisal-Based Returns", *Journal of Real Estate Finance and Economics*, vol. 4, no. 3, 327-345.

Geltner, D.M., 1993, "Estimating Market Values from Appraised Values without Assuming an Efficient Market", *Journal of Real Estate Research*, vol. 8, no. 3, 325-345.

Gorton, G., and K.G. Rouwenhorst, 2006, "Facts and Fantasies about Commodity Futures", *Financial Analysts Journal*, vol. 62, no. 2, p. 47-68.

Graham, J.R., and C.R. Harvey, 2008, "The Equity Risk Premium in 2008: Evidence from the Global CFO Outlook Survey", working paper.

Graybill, F.A., 1983, "Matrices with Applications in Statistics", Wadsworth International Group, California.

Grishchenko, O.V., and J. Huang, 2008, "Inflation Risk Premium: Evidence from the TIPS Market", working paper.

Hammond, P.B., 1999, "Using Inflation-Indexed Securities for Retirement Savings and Income: The TIAA-CREF Experience", in J. Brynjolfsson and F.J. Fabozzi, *Handbook of Inflation Indexed Bonds*, New Hope.

Hordijk, A.C., and C. Ahlqvist, 2004, "European Market Dimensions: An Inventory of the Investable Market in 11 European Countries", *The Compendium of Real Estate Papers* 2.

Ibbotson, 2007, "Private Equity and Strategic Asset Allocation", research paper.

Ibbotson, 2006, "Commercial Real Estate: The Role of Global Listed Real Estate Equities in a Strategic Asset Allocation", research paper.

Jong, F. de, and J. Driessen, 2005, "Liquidity Risk Premia in Corporate Bond Markets", working paper.

Kaplan, P.D., and S.L. Lummer, 1998, "GSCI Collateralized Futures as a Hedging and Diversification Tool for Institutional Portfolios: An Update", *Journal of Investing*, vol. 7, no. 4, p. 11-17.

Kaplan, S.N., and A. Schoar, 2005, "Private Equity Performance: Returns, Persistence, and Capital Flows", *Journal of Finance*, vol. 60, no. 4, p. 1791-1823.

Lamm, R.M., 1998, "Asset Allocation Implications of Inflation Protection Securities", *Journal of Portfolio Management*, vol. 24, no. 4, p. 8-13.

Li, L., 2002, "Macroeconomic Factors and the Correlation of Stock and Bond Returns", working paper.

Liang, Y., and N.M. Gordon, 2003, "A Bird's Eye View of Global Real Estate Markets", Prudential Real Estate Investors, research paper.

Lummer, S.L., and L.B. Siegel, 1993, "GSCI Collateralized Futures: A Hedging and Diversification Tool for Institutional Portfolios", *Journal of Investing*, vol. 2, no. 2, 75-82.

Markowitz, H.M., 1952, "Portfolio Selection", *Journal of Finance*, vol. 7, no. 1, p. 77-91.

Markowitz, H.M., 1956, "The Optimization of a Quadratic Function Subject to Linear Constraints", *Naval Research Logistics Quarterly*, vol. 3, no. 1-2, 111-133.

Masters, M.W., 2008, Testimony Before the US Senate.

McKinsey Global Institute, 2007, "The New Power Brokers: How Oil, Asia, Hedge Funds, and Private Equity are Shaping Global Capital Markets", research paper.

McKinsey Global Institute, 2008, "Mapping the Global Capital Markets - Fourth Annual Report", research paper.

Norman, E.J., G.S. Sirmans and J.D. Benjamin, 1995, "The Historical Environment of Real Estate Returns", *The Journal of Real Estate Portfolio Management*, vol. 1, no. 1, p. 1-25.

Ong, S.E., and M. Ranasinghe, 2000, "Portfolio Variance and Correlation Matrices", *Journal of Real Estate Portfolio*, vol. 6, no. 1, p. 1-6.

Phalippou L., 2007, "Investing in Private Equity Funds: A Survey", working paper.

Phalippou, L., and O. Gottschalg, 2007, "The Performance of Private Equity Funds", Review of Financial Studies, forthcoming.

Posthuma, N., and P.J. van der Sluis, 2003, "A Reality Check on Hedge Fund Returns", working paper.

Hobbs, P., and H. Chin, 2007, "The Future Size of the Global Real Estate Market", RREEF research paper.

Swensen, D.F., 2000, "Pioneering Portfolio Management", Free Press, New York.

Welch, I., 2008, "The Consensus Estimate for the Equity Premium by Academic Financial Economists in December 2007", working paper.

Wilshire, 2008, "Report on State Retirement Systems: Funding Levels and Asset Allocation", research paper.

## Appendix A: Capital market expectations

Risk premia for stocks and bonds are well documented and long term data series extending over 100 years are available. We will therefore start with the risk premia for stocks and bonds. Then, we derive the risk premia of other asset classes by comparing historical performance data and consulting the literature. In order to estimate volatilities and correlations, we rely more on our own historical data, due to a lack of broad coverage in the literature. Below, we discuss returns and standard deviations for each asset class. Afterwards, we estimate correlations among all asset classes.

### Stocks

Extensive research on the equity-risk premium has been conducted in recent years. Fama and French (2002) use a dividend discount model to estimate an arithmetic risk premium of 3.54% over the period 1872-2000 for US stocks, while the realized risk premium for this period is 5.57%. In the period 1951-2000, the observed difference is even larger. They conclude that the high 1951-2000 returns are the result of low expected future performance. However, the US was one of the most successful stock markets in the twentieth century, so a global perspective is important to correct this bias. Dimson, Marsh and Staunton (2009) use historical equity risk premia for seventeen countries over the period 1900-2008. They conclude that their equity risk premia are lower than frequently cited in the literature, due to a longer timeframe and a global perspective. Table A.1 provides an overview of historical risk premia and volatilities.

TABLE A.1  
OVERVIEW OF HISTORICAL RISK AND RETURN CHARACTERISTICS FOR STOCKS

SOURCE	COUNTRY	RISK PREMIUM ON CASH	ST. DEV. ANN. RETURNS	ST. DEV. OF MONTHLY RETURNS	DATA
MSCI US	US	3.1%	18.4%	15.4%	1970-2008
MSCI WORLD	WORLD	3.0%	18.8%	14.8%	1970-2008
FAMA AND FRENCH (2002)*	US	3.9%	18.5%	N.A.	1872-2000
	US	2.5%	19.6%	N.A.	1872-1950
	US	6.0%	16.7%	N.A.	1951-2000
DIMSON, MARSH AND STAUNTON (2009)	US	5.2%	20.2%	N.A.	1900-2008
	UK	4.2%	21.8%	N.A.	1900-2008
	WORLD	4.4%	17.3%	N.A.	1900-2008
ST. DEV. OF MSCI WORLD IN EURO'S			22.0%	16.0%	1970-2008

\* STANDARD DEVIATION OF THE RISK PREMIUM INSTEAD OF THE STANDARD DEVIATION OF THE NOMINAL RETURN. WE DERIVE GEOMETRIC DATA BY USING THE EQUATION  $R_G = R_A - 0.5 \cdot \text{VARIANCE}$

Both Fama and French (2002) and Dimson, Marsh and Staunton (2003, 2009) find that the historical equity premium was significantly higher in the second half of the twentieth century than it was in the first half. Dimson, Marsh and Staunton (2009) expect a lower equity premium in the range of 3.0%-

3.5% going forward. In this study we use an equity risk premium of 4.75%. This is slightly above the average of countries in a long timeframe and corresponds well with consensus estimates among finance professors as documented by Welch (2008) and among CFOs as reported by Graham & Harvey (2008).

The other estimate we need is stock market volatility. Dimson, Marsh and Staunton (2009) find a standard deviation of 17.3% for global equity during the 109 year period 1900-2008. Over the period 1970-2008 the global MSCI index<sup>1</sup> had a volatility of 18.8% and 22.0% expressed in dollars and euros respectively. We average these last two figures and estimate the volatility of stocks at 20%.

### Government bonds

Dimson Marsh and Staunton (2009) also evaluate the risk premium of bonds over cash. Their data point to a lower risk premium than the Barclays Government Indices which have been available since 1973, see Table A.2. The last decades have been extremely good for government bonds. We use a geometric risk premium of 0.75% for government bonds over cash, in line with the long term historical average from Dimson, Marsh and Staunton (2009).

TABLE A.2  
OVERVIEW OF HISTORICAL RISK AND RETURN CHARACTERISTICS FOR GOVERNMENT BONDS

SOURCE	COUNTRY	RISK PREMIUM ON CASH	ST. DEV. ANN.	ST. DEV. OF MONTHLY RETURNS	DATA
BARCLAYS TREASURIES	US	2.2%	6.5%	5.4%	1973-2008
	US	3.6%	6.3%	5.0%	1984-2008
	US	3.0%	5.5%	4.8%	1999-2008
DIMSON, MARSH AND STAUNTON (2009)	US	1.2%	8.3%	N.A.	1900-2008
	UK	0.4%	11.9%	N.A.	1900-2008
	WORLD	0.8%	8.6%	N.A.	1900-2008

The volatility of bonds has been significantly lower in recent decades compared to longer timeframes as Table A.2 shows. Over the last twenty-five, and the last ten years, it has come down to 6.3% and 5.5% respectively. We think a volatility of 7% is the best proxy for government bonds. This accounts for the inflation targeting monetary policy introduced by major central banks in the early 1980's, while it is in line with the observed volatility in the last decades.

<sup>1</sup> We use the MSCI World Index till 1988, afterwards the MSCI All Countries Index.

## Private equity

For private equity one could expect a risk premium relative to stocks due to low liquidity. Willshire (2008) estimates the risk premium for private equity over stocks at 3% using a combination of each US retirement system's actual asset allocation and its own assumptions, see Table A.3.

TABLE A.3  
OVERVIEW OF HISTORICAL RISK AND RETURN CHARACTERISTICS FOR PRIVATE EQUITY

SOURCE	RISK PREMIUM ON CASH	RISK PREMIUM ON STOCKS	ST. DEV. ANN. RETURNS	ST. DEV. OF MONTHLY RETURNS	DATA
STOCKS: MSCI US	-2.5%		21.9%	16.0%	1998-2008
PRIVATE EQUITY LPX AMERICA	-3.8%	-1.3%	45.6%	28.9%	1998-2008
STOCKS: MSCI EUROPE	1.5%		24.7%	16.6%	1994-2008
PRIVATE EQUITY LPX EUROPE	1.0%	-0.5%	35.0%	19.7%	1994-2008
WILSHIRE (2008)		3.0%	26.0%	N.A.	PROSPECTIVE
PHALIPPOU AND GOTTSCHALG (2007)		-3.0%	N.A.	N.A.	1980-2003
KAPLAN AND SCHOAR (2005)		0.0%	N.A.	N.A.	1980-1997

Kaplan and Schoar (2005) find average returns equal to that of the S&P 500, but they did not correct for sample biases. Using 1328 mature private equity funds Phalippou and Gottschalg (2007) conclude that performance estimates found in previous research overstate actual returns. They find an underperformance of 3% compared to the S&P 500 (net of fees). In a literature overview Phalippou (2007) finds support to Swensen's (2000) claims that private equity generates poor returns and that the low risk observed is the result of a statistical artefact.

We use LPX indices which represent listed private equity. Survivorship bias is assumed to be negligible, since the index takes into account that companies are bought or merged, change their business model or are delisted. Our data also show an underperformance, but this concerns a short sample period. Since we do not have enough support from existing literature that private equity returns (net of fees) exceed public equity returns, we assume the risk premia of stocks and private equity to be equal to 4.75%.

Historical returns show private equity had more risk than stocks and other research find a beta for private equity greater than one, see Phalippou (2007). Based on annual standard deviations we should adopt standard deviations for private equity that are almost twice the standard deviations of stocks. However, because our data history is short, we focus on annualized standard deviations of monthly returns. Then, averaged over the US and Europe, the standard deviation is 50% higher for private equity than for stocks. Therefore, we estimate the volatility of private equity at 30%.

## Real estate

Of all alternative asset classes, real estate probably received most attention from academics in the past. A literature review by Norman, Sirmans and Benjamin (1995) tries to summarize all findings. Overall, they find no consensus for risk and return characteristics for real estate. However, more than half of the consulted literature in their paper reported a lower return for real estate compared to stock.

Table A.4 reports an overview of real estate risk and return characteristics. Willshire (2008), and Fugazza, Guidolin and Nicodano (2006) also show lower risk premia for real estate than for stocks. We proceed with a risk premium of 3.75% relative to cash, which is one percent lower than our estimate for stocks. Compared to the long run US history, our estimate seems rather low; but compared to Willshire (2008) on the other hand, it seems high. It is in line with Fugazza e.a. (2006).

TABLE A.4  
OVERVIEW OF HISTORICAL RISK AND RETURN CHARACTERISTICS FOR REAL ESTATE

SOURCE	RISK PREMIUM ON CASH	RISK PREMIUM ON STOCKS	ST. DEV. ANN. RETURNS	ST. DEV. OF MONTHLY RETURNS	DATA
STOCKS: MSCI US	3.0%		18.9%	16.8%	1972-2008
REAL ESTATE: NAREIT US	2.5%	-0.5%	21.9%	15.4%	1972-2008
FUGAZZA E.A. (2006) EUROPEAN STOCKS	5.7%		16.9%		1986-2005
FUGAZZA E.A. (2006) EUROPEAN REAL ESTATE	4.7%	-1.0%	13.2%		1986-2005
WILLSHIRE (2008)		-2.5%	15.0%		PROSPECTIVE

Norman, Sirmans and Benjamin (1995) conclude that most studies found risk adjusted returns for real estate that are comparable to stocks. We take this into account and estimate the volatility of real estate at 16%, whereby ex-ante Sharpe ratios are roughly the same for stocks and real estate, while the ratio of the standard deviations is in line with Fugazza e.a. (2006).

## Hedge funds

The academic literature reports extensive information on biases in hedge fund indices, as shown in Table A.5. However, estimates for the market portfolio of hedge funds are scarce. Funds of hedge funds are often considered to be a good proxy for the market portfolio, since they have fewer biases than typical hedge funds. However, their returns are affected by the double counting of management fees. Fung and Hsieh (2000) estimate the portfolio management costs for a typical hedge fund of fund portfolio to be between 1.3% and 2.9%.

TABLE A.5  
BIASES IN HEDGE FUND INDICES

SOURCE	BIAS	MAGNITUDE	DATA
FUNG AND HSIEH (2000)	BACKFILL	0.70%	1994-1998
	SURVIVORSHIP	1.40%	1994-1998
POSTHUMA AND VD SLUIS (2003)	BACKFILL	2.27%	1996-2002
AMIN AND KAT (2005)	SURVIVORSHIP	0.63%	1994-2001

Table A.6 reports historical risk premia for hedge funds of funds. We use the HFRI fund of funds composite index which is equally weighted and includes over 800 funds. Furthermore, it is broadly diversified across different hedge fund styles. Like McKinsey (2007) suggests, we find a weakening performance of hedge funds over cash. When we average the aggressive and conservative estimate of the risk premium over cash, we find a risk premium of roughly 1.25%. This is the estimate that we use in this study.

Over the period 1990-2008, the volatility of hedge funds was slightly higher than half the volatility of stocks. Taking into account our estimate of the volatility for stocks of 20%, we estimate the volatility of hedge funds at 12%, i.e. 11.9%/20.5% multiplied by 20%.

TABLE A.6  
OVERVIEW OF HISTORICAL RISK AND RETURN CHARACTERISTICS FOR HEDGE FUNDS

SOURCE	RISK PREMIUM ON CASH	RISK PREMIUM ON STOCKS	ST. DEV. ANN. ST. DEV. OF MONTHLY RETURNS	DATA	
STOCKS: MSCI US	3.8%		20.5%	14.6%	1990-2008
HEDGE FUNDS: HFRI FOF COMPOSITE	3.8%	0.0%	11.9%	8.9%	1990-2008
AGGRESSIVE ESTIMATE*	2.5%	-1.3%			1990-2008
CONSERVATIVE ESTIMATE*	0.2%	-3.6%			1990-2008
HEDGE FUNDS: HFRI FOF COMPOSITE	7.8%	-7.1%	12.0%	9.0%	1990-1999
HEDGE FUNDS: HFRI FOF COMPOSITE	-0.3%	6.7%	9.9%	8.6%	2000-2008

\* FOR THE CONSERVATIVE ESTIMATE WE SUBTRACT A 2.27% BACKFILL BIAS AND A 1.40% SURVIVORSHIP BIAS FROM THE ARITHMETIC RETURN, THE AGGRESSIVE ESTIMATE USES 0.70% AND 0.63% RESPECTIVELY. NOW THE GEOMETRIC RISK PREMIUMS ON CASH ARE 2.5% AND 0.2% RESPECTIVELY.

## Commodities

An unleveraged investment in commodities is a fully collateralized position which has three drivers of returns: the risk free rate, the spot return and the roll return. Erb and Harvey (2006) point out that the roll return has been a very important driver of commodity returns, but it is unclear what the sign of roll returns will be in the future<sup>2</sup>. In their extensive study they find that the average individual compound excess return of commodity futures was zero. They argue that individual commodities are not homogeneous and that their high volatility and low mutual correlations result in high diversification benefits. The diversification benefit comes from periodically rebalancing the portfolio and is reflected in the high historical performance of the GSCI index compared to the return from individual commodities, as can be seen in Table A.7. We use the GSCI index since it represents the majority of open interest in the future market (Masters 2008) and offers the longest historical return series since 1969. Gorton

<sup>2</sup> The upward or downward sloping term structure of futures prices creates the possibility of a roll return. It arises when an almost expiring future is rolled over to a future with a longer maturity.

and Rouwenhorst (2006) create an equally weighted monthly rebalanced portfolio of commodity futures that had returns like stocks over the period 1959-2004.

TABLE A.7  
OVERVIEW OF HISTORICAL RISK AND RETURN CHARACTERISTICS FOR COMMODITIES

SOURCE	RISK PREMIUM ON CASH	RISK PREMIUM ON STOCKS	ST. DEV. ANN. ST. DEV. OF MONTHLY RETURNS	DATA	
STOCKS: MSCI US	3.1%		18.4%	15.4%	1970-2008
COMMODITIES: GSCI	3.9%	0.8%	25.6%	19.9%	1970-2008
GORTON AND ROUWENHORST (2006)	5.0%	0.0%		12.1%	1959-2004

The historical geometric risk premium for the GSCI commodity index was 3.9% over the period 1970-2008 which exceeds the MSCI US by 0.8%. Erb and Harvey (2006) raise questions to the representativeness of both the equally weighted portfolio and the GSCI index. On the one hand, they show that an equally weighted stock index would by far outperform a market cap weighted index. On the other hand, the GSCI index composition has changed dramatically over time and allocates heavy weights to energy commodities. They suggest that a simple extrapolation of historical commodity index returns might not be a good estimate for future returns. Lummer and Siegel (1993) and Kaplan and Lummer (1998) claim that the long run expected return of commodities equals the return on Treasury bills. Many theories for commodity risk premia exist, but most of those are not measurable<sup>3</sup>. Since we do not find enough support for a forward-looking positive risk premium, we proceed with a commodity return equal to the risk free rate, in line with Kaplan and Lummer (1998).

Erb and Harvey (2006) show that the average annual standard deviation of commodities was 30%. A portfolio of commodities, however, diversifies away part of the risk. We take the volatility of the S&P GSCI index during 1970-2008 as our measure of risk. Therefore, our estimate for the volatility of commodity returns is 26%.

### High yield and credits

Table A.8 shows historical risk premia for high yield and credits. According to Elton e.a. (2001) the credit spread comprises the following three components: default risk compensation, tax premium and systematic risk premium. Additionally, de Jong and Driessen (2005) also find a liquidity premium in credit spreads. High yield bonds require a higher default risk premium than corporate bonds due to lower creditworthiness of the issuers or subordinate debt.

<sup>3</sup> See Erb and Harvey for a literature overview on commodity market theories.

We estimate the risk premium of credits over government bonds at 0.75% as we think findings of Altman (1998) are far closer to the true premium than the historical excess return findings in Barclays indices. Altman (1998) also examines the return from US high yield bonds compared to US treasuries over the period 1978-1997. The excess return of high yield (over Treasuries) during the 20-year period 1978-1997 is 2.47%. We believe that this figure significantly overstates the risk premium of high yield. At the start of the sample period the high yield market was still immature, which leaves room for liquidity problems and biases. Our sample period from 1984 to 2008 even has a negative risk premium for high yield. Obviously, ex-ante this can not be the case. We proceed with a 1.75% premium over government bonds.

Barclays indices show that the volatility of corporate bonds and high yield has been higher than that of government bonds. This study moves forward with a 9% volatility for credits, as seen in the period 1973-2008. This is 2% higher than for bonds. High yield has shown a substantially higher standard deviation than bonds and credits. The difference between the standard deviation of annual returns and monthly returns is large. We therefore also attach weight to the annualized monthly data. We take 11% volatility as our proxy.

TABLE A.8  
OVERVIEW OF HISTORICAL RISK AND RETURN CHARACTERISTICS FOR HIGH YIELD AND CREDITS

SOURCE	RISK PREMIUM ON CASH	RISK PREMIUM ON BONDS	ST. DEV. ANN. OF MONTHLY RETURNS	ST. DEV.	DATA
BARCLAYS GOVERNMENT BONDS US	2.2%		6.5%	5.4%	1973-2008
BARCLAYS CREDITS US	1.9%	-0.3%	9.2%	7.4%	1973-2008
ALTMAN (1998) HIGH GRADE CORPORATE US*		0.8%		5.4%	1985-1997
BARCLAYS GOVERNMENT BONDS US	3.6%		6.3%	5.0%	1984-2008
BARCLAYS CREDITS US	3.6%	0.0%	7.3%	5.7%	1984-2008
BARCLAYS HIGH YIELD US	2.8%	-0.8%	14.0%	8.4%	1984-2008
ALTMAN (1998) HIGH YIELD US*		2.5%		5.20%	1978-1997

\* ARITHMETIC RISK PREMIA

### Inflation linked bonds

The interest rate on inflation linked bonds is comprises the real interest rate and the realized inflation. This differs from the return on bonds which consists of a real interest rate, expected inflation and an inflation risk premium. The cost of insurance for inflation shocks should be reflected by a discount on the risk premium for inflation linked bonds relative to nominal bonds. Theoretically, the inflation risk premium should be positive.

TABLE A.9  
OVERVIEW OF HISTORICAL RISK AND RETURN CHARACTERISTICS FOR INFLATION LINKED BONDS

SOURCE	RISK PREMIUM ON CASH	INFLATION RISK PREMIUM	ST. DEV. ANN. RETURNS	ST. DEV. OF MONTHLY RETURNS	DATA
BARCLAYS GOVERNMENT BONDS US	3.2%		5.3%	4.8%	1998-2008
BARCLAYS INFL. LINKED BONDS US	3.2%	0.0%	5.8%	6.1%	1998-2008
HAMMOND (1999)		0.5%			-
GRISCHENKO AND HUANG (2008)		0.1%			2004-2006

Over the last eleven years the inflation risk premium has been absent, see Table A.9. Grishchenko and Huang (2008) point to liquidity problems in the TIPS market as the reason for the negative inflation risk premium they document. After adjusting for liquidity in TIPS they find an inflation risk premium of 0.14% over the period 2004-2006. Hammond (1999) estimates the risk premium at 0.5%. On the basis of these findings we estimate the inflation risk premium at 0.25%.

Over the sample period, government bonds were slightly less volatile than inflation linked bonds, but forward looking volatilities should not differ much. Therefore, we estimate the volatility of inflation linked bonds at 7%, equal to government bonds.

Table 1 provides an overview of all expected returns and standard deviations for the asset classes discussed above. As we use the parameters in a one period mean-variance analysis, we also show the Sharpe ratio based on the arithmetic return.

## Correlations

In a study with  $n$  asset classes the correlation matrix consists of  $(n(n-1))/2$  different entries, or 36 in this study. We derive all correlation estimates from historical correlations, but in order to fill the complete correlation matrix we have to make assumptions at some point. This is mainly the case for asset classes with short sample periods like private equity and inflation linked bonds, and to a lesser extent for hedge funds. We focus mainly on correlations of annual returns. However, we also attach weight to the correlations of monthly returns.

Correlations are time-varying, see for example Li (2002) who documents time-varying correlations in a study that covers G7 countries from 1958-2001. Over this period, the average correlation between stocks and government bonds was approximately 0.2, similar to the 0.17 that we observe for the period 1973-2008 as shown in Table A.10. We take 0.2 as the estimate for the correlation between stocks and government bonds, see Table A.11.

Private equity experienced a high correlation with stocks, a fact that is also supported by Ibbotson (2007). Looking forward, we estimate the correlation between private equity and stocks at 0.8.

Because of the strong correlation between stocks and private equity, we assume similar individual correlations with other asset classes. This is supported by correlations of monthly returns.

TABLE A.10  
OVERVIEW OF HISTORICAL CORRELATIONS OF ANNUAL RETURNS (LOWER LEFT PART OF THE MATRIX) AND MONTHLY RETURNS (UPPER RIGHT PART). THE EFFECTIVE PERIOD FOR EACH CORRELATION STARTS WITH THE DATE OF THE SHORTEST DATASET

	STOCKS (1970)	PRIVATE EQUITY (1998)	REAL ESTATE (1972)	HEDGE FUNDS (1990)	COMMODITIES (1970)	HIGH YIELD (1984)	CREDITS (1973)	BONDS (1973)	INFLATION LINKED BONDS (1998)
STOCKS (1970)	1.00	0.76	0.55	0.54	0.02	0.57	0.35	0.14	-0.01
PRIVATE EQUITY (1998)	0.76	1.00	0.62	0.62	0.21	0.68	0.16	-0.26	0.11
REAL ESTATE (1972)	0.56	0.36	1.00	0.26	0.04	0.60	0.38	0.16	0.28
HEDGE FUNDS (1990)	0.58	0.90	0.41	1.00	0.29	0.41	0.30	0.01	0.09
COMMODITIES (1970)	-0.09	0.32	-0.17	0.39	1.00	0.08	-0.05	-0.07	0.27
HIGH YIELD (1984)	0.70	0.65	0.71	0.56	0.00	1.00	0.50	0.15	0.28
CREDITS (1973)	0.48	-0.17	0.45	0.32	-0.19	0.60	1.00	0.87	0.79
BONDS (1973)	0.17	-0.91	0.11	-0.15	-0.21	0.18	0.82	1.00	0.71
INFLATION LINKED BONDS (1998)	-0.18	-0.21	0.29	0.07	0.58	0.19	0.75	0.35	1.00

We estimate the correlation of stocks and real estate at 0.6, in line with the reported historical average of 0.56. For stocks and hedge funds we also estimate the correlation at 0.6, again in line with the 0.58 that we observed over the period 1990-2008. This correlation is the result of the exposure of hedge funds to the stock market. The mutual correlation of real estate and hedge funds was lower at 0.41. Therefore, we estimate the correlation at 0.4.

High yield and credits both showed somewhat higher correlations with stocks than government bonds did, and this may be attributable to the credit risk embedded in these bonds. Going forward, we expect correlations of 0.6 and 0.4 respectively. Over the period 1998-2008, inflation linked bonds showed a slightly lower correlation with stocks than government bonds did, both on annual and monthly returns. In a forward looking context, we therefore consider a correlation of 0.0 between stocks and inflation linked bonds justified.

Commodities had close to zero correlation with all asset classes, other than hedge funds and inflation linked bonds. An explanation for the positive relationship with hedge funds could be their investment positions in commodities. The positive relationship with inflation linked bonds can be explained by their common driver unexpected inflation. As Table A.11 shows, we take this into account in our estimated correlations. The correlation between commodities and private equity was driven solely by 2008. As mentioned before, we assume similar correlation for stocks and private equity with other asset classes.

For high yield and credits we mostly round the annual correlations to get our estimates. For bonds we round the correlation with real estate, for the correlation with hedge funds and inflation linked bonds we also take the monthly correlations into account. For the last two remaining cells of the correlation matrix, the correlation of inflation linked bonds with real estate and hedge funds, we round the annual correlations as they are in line with the monthly correlations.

TABLE A.11  
OVERVIEW OF ESTIMATED CORRELATIONS

	STOCKS	PRIVATE EQUITY	REAL ESTATE	HEDGE FUNDS	COMMODITIES	HIGH YIELD	CREDITS	BONDS	INFLATION LINKED BONDS
STOCKS	1.0								
PRIVATE EQUITY	0.8	1.0							
REAL ESTATE	0.6	0.6	1.0						
HEDGE FUNDS	0.6	0.7	0.4	1.0					
COMMODITIES	0.0	0.1	0.0	0.4	1.0				
HIGH YIELD	0.6	0.7	0.7	0.6	0.0	1.0			
CREDITS	0.4	0.4	0.4	0.3	0.0	0.5	1.0		
BONDS	0.2	0.2	0.1	-0.1	0.0	0.2	0.8	1.0	
INFLATION LINKED BONDS	0.0	0.1	0.3	0.1	0.3	0.3	0.8	0.6	1.0

Graybill (1983) argues that a correlation matrix is either positive definite or positive semi-definite, since the variance of a vector is always greater than or equal to zero. Moreover, the correlation matrix is positive definite (i.e. the eigenvalues of the correlation matrix are positive) if there are no linear dependencies among the primary variables. It is therefore of crucial importance to verify whether the correlation matrix used satisfies these conditions. According to Ong and Ranasinghe (2000), a consequence of ignoring this requirement is that the determinant of the correlation matrix can be negative. This implies in turn that the derived variance of the portfolio can somehow be negative. We therefore checked our correlation matrix and found it to be positive definite.

## Appendix B: Market portfolio

We derive the market portfolio from a variety of sources that we consider best in providing an assessment of the market size of an asset class. As most markets were rather depressed in 2008, we estimate the market size over the period 2006-2008 to illustrate the dynamic character of the market portfolio.

For stocks we use the market capitalization of the MSCI All Countries Index, summing the standard index and the small cap index. We then subtract the weight of REITs as they are part of the real estate asset category in this study. At the end of 2008 we estimate the market capitalization of stocks at USD 20.510 billion<sup>4</sup> as shown in Table B.1. In contrast, McKinsey Global Institutes (2008)<sup>5</sup> estimates far higher figures for stocks in the previous years than we derive from MSCI. For example, they come up with a capitalization of USD 54 trillion at the end of 2006, while we estimate the market size at that moment at USD 34 trillion. The difference arises when McKinsey does not adjust the figures for free float, and this is what makes MSCI values more representative for the investable universe in this study. Ibbotson (2006) estimates stocks at USD 29.1 trillion in its market value approach, which is close to MSCI market capitalizations.

TABLE B.1  
ESTIMATE OF THE MARKET PORTFOLIO FROM 2006 TO 2008 (USD BLN)

	2006	2007	2008
STOCKS	33752	36071	20510
PRIVATE EQUITY	1105	1044	355
REAL ESTATE	3960	3649	2025
HEDGE FUNDS	1500	1900	1400
COMMODITIES	237	330	452
HIGH YIELD	1020	996	612
CREDITS	9582	11017	11555
BONDS	12755	13728	15913
INFLATION LINKED BONDS	995	1229	1222
TOTAL MARKET CAPITALIZATION	64906	69964	54043

The fixed-income estimates result from market capitalizations of Barclays indices (previously Lehman indices). The Barclays Multiverse Index comprises all fixed income asset classes. Within this universe we use the market capitalization of the Barclays Multiverse Government Index minus inflation linked bonds as a proxy for government bonds. This amounts to USD 15.913 billion at the end of 2008. The market capitalization of the Barclays Global Inflation Linked Index was USD 1.222 billion at the end of 2008, a figure that we use for our estimate of the size of the inflation linked bonds market. For high

<sup>4</sup> This number contains some double counting as private equity and hedge funds also have positions in stocks. In the case of private equity, the double counting is likely negligible. Hedge funds are private pools of capital, which makes correction impossible.

<sup>5</sup> McKinsey (2007) also estimates other market values for bonds, but due to the lack of transparency of these figures this study uses other sources.

yield this is USD 612 billion, derived from the Barclays Global High Yield Index. The remaining market value within the Barclays Multiverse Index consists primarily of corporate debt and mortgage backed securities (MBS), which we assign to the asset class credits and has a worth of USD 11.555 billion. Ibbotson (2006) applies a geographical composition of the bond market and values the total market at USD 21.4 trillion which is somewhat smaller than our estimate of USD 24.4 trillion of the total fixed income market at the end of 2006 in this study.

For private equity we use the 2006 year end estimate by McKinsey (2007). As we lack other data sources, we adjust this figure for 2007 and 2008, multiplying it by the cumulative performance of the LPX50, a global index that measures the performance of 50 listed private equity companies. We estimate the size of the private equity market at USD 355 billion at the close of 2008. The observed presence of private equity in financial markets is greater because of their high leverage. This also applies to hedge funds for which we use data from Hedge Fund Research. They estimate the unleveraged assets under management at USD 1.4 trillion at the end of 2008.

The real estate market needs further discussion. Within the real estate market, a first distinction can be made when it comes to commercial and residential real estate. The residential market would be much bigger than the commercial market, were it not for the fact that a large portion of this market is the property of the occupiers or residents. Hordijk and Ahlqvist (2004), as an extreme example, estimate that only five percent of all residential real estate in the UK is available to investors. Added to investability constraints, most individual investors already have an exposure to residential real estate that exceeds the money they have available for investments, simply because they own a home. Therefore, this study focuses on commercial real estate only. Going forward there are three measures for the size of the market. The broadest measure comprises all real estate, both investment grade and non-investment grade. The investable universe then consists of all investment grade real estate, and includes real estate that is owner occupied. The invested universe, the smallest one, differs from investable, because it measures the market that is actually in the hands of investors. Liang and Gordon (2003) estimate the investable market at USD 12.5 trillion.

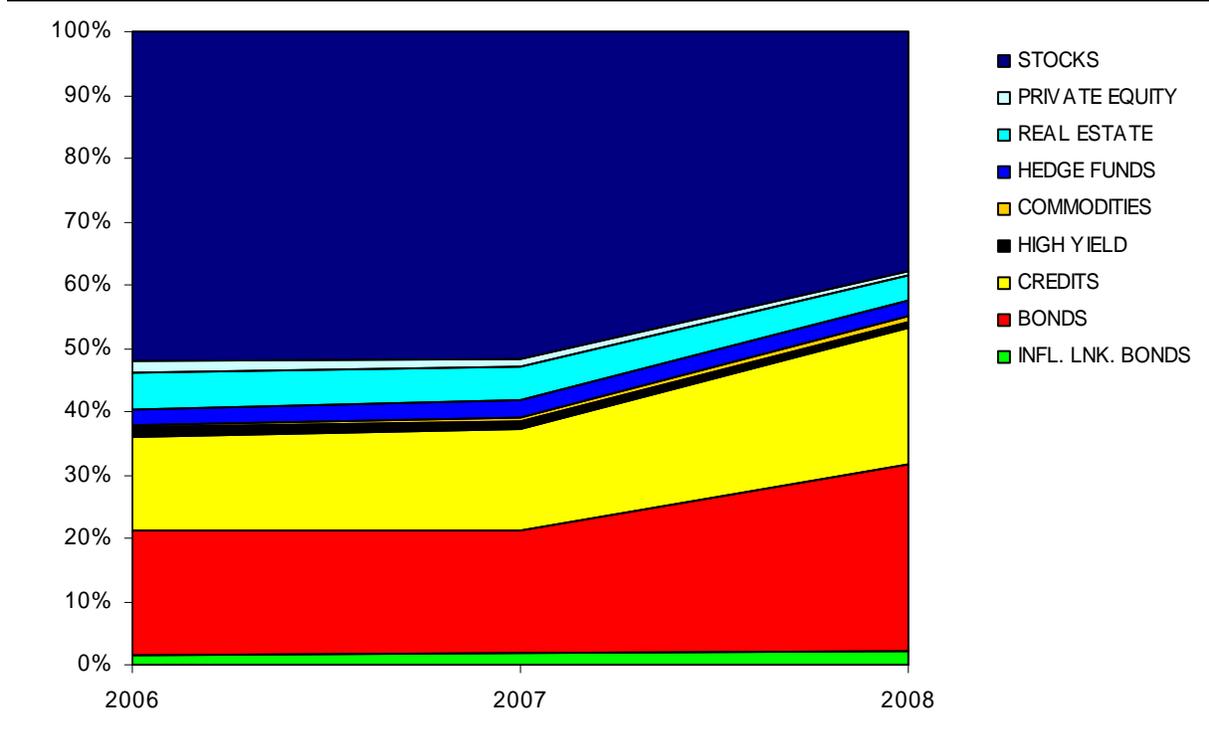
The commercial real estate market is valued by using data from RREEF Real Estate Research, see Hobbs (2007). As different to other sources, RREEF divides the market estimate of real estate into the four quadrants of public equity, private equity, public debt and private debt. At the end of 2006, they estimate the investable and invested markets at USD 16.0 and 9.8 trillion respectively. The 9.8 trillion estimate is the total market and includes both equity and debt. The equity component of invested real estate, which is the universe suitable for comparison in this framework, is USD 4.0 trillion. The estimate is close to the figure given by Ibbotson (2006), who estimates this measure of the real-estate market at USD 4.6 trillion. Real estate debt, such as MBS, can be considered as part of the fixed

income asset class and is in fact largely captured by the estimate for credits. We obtain the figures for 2007 and 2008 by adjusting the 2006 figure for the change in the global market capitalization of REITs, as measured by MSCI.

The growth of commodity markets in recent years is evident and observable, but unfortunately hard to qualify. According to Doyle, Hill and Jack (2007) from the FSA Markets Infrastructure Department, even the most important market participants were unable to accurately measure the commodity market. Masters (2008) uses open interest in commodity futures as a proxy for the market value. We use these data and estimate the commodity market at USD 452 million in 2008.<sup>6</sup>

Figure B.1 shows the market portfolio from 2006 to 2008.

FIGURE B.1  
ESTIMATE OF THE MARKET PORTFOLIO FROM 2006 TO 2008



<sup>6</sup>Although this study does not treat derivatives as an asset class, the commodity market is gauged with the futures market since that is the only investment proposition for this asset class. The estimate is an average of the daily value of open interest during 2006 and 2007, adjusted for the stake of physical hedgers in Masters (2008). Note that it concerns the average dollar value daily of open interest in stead of year end estimates that we have for the other asset classes. We derive the 2008 estimate from the first quarter of 2008 figure from Masters (2008) by multiplying it with the cumulative performance of the GSCI, the same methodology as for private equity.

## Tables and figures

TABLE 1  
OVERVIEW OF CAPITAL MARKET EXPECTATIONS FOR ALL ASSET CLASSES

	GEOMETRIC RISK PREMIUM	VOLATILITY	ARITHMETIC RISK PREMIUM*	GEOMETRIC SHARPE RATIO	ARITHMETIC SHARPE RATIO
STOCKS	4.75%	20%	6.8%	0.24	0.34
PRIVATE EQUITY	4.75%	30%	9.3%	0.16	0.31
REAL ESTATE	3.75%	16%	5.0%	0.23	0.31
HEDGE FUNDS	1.25%	12%	2.0%	0.10	0.16
COMMODITIES	0.00%	26%	3.4%	0.00	0.13
HIGH YIELD	2.50%	11%	3.1%	0.23	0.28
CREDITS	1.50%	9%	1.9%	0.17	0.21
BONDS	0.75%	7%	1.0%	0.11	0.14
INFLATION LINKED BONDS	0.50%	7%	0.7%	0.07	0.11

\* WE DERIVE ARITHMETIC DATA BY USING THE EQUATION  $R_A = R_G + 0.5 \cdot \text{VARIANCE}$

TABLE 2  
OPTIMAL PORTFOLIO FOR A TRADITIONAL PORTFOLIO AND FOR AN ALL ASSETS PORTFOLIO

ASSET CLASS	PORTFOLIO WEIGHT	DESCRIPTIVE STATISTICS	
<u>TRADITIONAL</u>			
STOCKS	59.2%	VARIANCE	1.6%
BONDS	40.8%	STANDARD DEVIATION	12.7%
		EXPECTED RISK PREMIUM	4.4%
		GEOMETRIC RETURN	3.6%
		SHARPE RATIO	0.346
<u>ALL ASSET CLASSES</u>			
STOCKS	26.4%	VARIANCE	1.0%
PRIVATE EQUITY	0.0%	STANDARD DEVIATION	10.1%
REAL ESTATE	25.7%	EXPECTED RISK PREMIUM	4.0%
HEDGE FUNDS	0.0%	GEOMETRIC RETURN	3.5%
COMMODITIES	12.7%	SHARPE RATIO	0.396
HIGH YIELD	6.6%		
CREDITS	0.0%		
BONDS	28.6%		
INFLATION LINKED BONDS	0.0%		

TABLE 3  
 SENSITIVITY ANALYSIS OF THE OPTIMAL PORTFOLIO FOR THE MEAN-VARIANCE ANALYSIS  
 INCREASE OF VOLATILITY OF A FIFTH\*

	DEFAULT	STOCKS	PRIVATE EQUITY	REAL ESTATE	HEDGE FUNDS	COMMODITIES	HIGH YIELD	CREDITS	BONDS	INFL. LNK. BONDS
STOCKS	26.4%	17.2%	26.4%	29.4%	26.4%	26.4%	27.7%	26.3%	28.8%	26.3%
PRIVATE EQUITY	0.0%	2.6%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
REAL ESTATE	25.7%	28.9%	25.8%	15.4%	25.8%	25.7%	28.8%	25.7%	27.6%	25.7%
HEDGE FUNDS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
COMMODITIES	12.7%	13.0%	12.7%	13.3%	12.7%	12.7%	13.0%	12.7%	13.8%	12.7%
HIGH YIELD	6.6%	7.3%	6.6%	13.5%	6.6%	6.6%	0.0%	6.7%	7.7%	6.6%
CREDITS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BONDS	28.6%	31.0%	28.5%	28.5%	28.5%	28.5%	30.3%	28.6%	22.0%	28.6%
INFL. LNK. BONDS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

DECREASE OF VOLATILITY WITH A FIFTH\*

	DEFAULT	STOCKS	PRIVATE EQUITY	REAL ESTATE	HEDGE FUNDS	COMMODITIES	HIGH YIELD	CREDITS	BONDS	INFL. LNK. BONDS
STOCKS	26.4%	41.5%	25.0%	19.6%	26.3%	26.3%	19.9%	26.0%	22.4%	26.3%
PRIVATE EQUITY	0.0%	0.0%	2.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
REAL ESTATE	25.7%	20.5%	26.1%	42.7%	25.7%	25.7%	14.8%	23.6%	22.6%	25.7%
HEDGE FUNDS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
COMMODITIES	12.7%	12.0%	12.7%	11.2%	12.7%	12.7%	11.0%	12.7%	11.0%	12.7%
HIGH YIELD	6.6%	1.3%	5.0%	0.0%	6.6%	6.7%	32.6%	2.0%	4.9%	6.6%
CREDITS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	29.8%	0.0%	0.0%
BONDS	28.6%	24.7%	28.9%	26.5%	28.6%	28.6%	21.7%	5.9%	39.1%	28.6%
INFL. LNK. BONDS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

\* EVERY COLUMN SHOWS THE OPTIMAL PORTFOLIO WHEN THE VOLATILITY OF THE ASSET CLASS IN THE FIRST ROW IS CHANGED, CETERIS PARIBUS

TABLE 4

OPTIMAL PORTFOLIO FOR DIFFERENT TRACKING ERROR CONSTRAINTS AND A MAXIMUM TURNOVER CONSTRAINT OF 25% (SINGLE COUNT), AND THE NO CONSTRAINTS OPTIMAL PORTFOLIO THAT REPRESENTS THE RESULTS OF THE MEAN-VARIANCE ANALYSIS

	MARKET PORTFOLIO	0.5% TE	1.0% TE	1.5% TE	NO CONSTRAINTS
STOCKS	38.0%	37.4%	36.3%	35.9%	26.4%
PRIVATE EQUITY	0.7%	0.6%	0.5%	0.7%	0.0%
REAL ESTATE	3.7%	6.0%	8.7%	11.2%	25.7%
HEDGE FUNDS	2.6%	0.0%	0.0%	0.0%	0.0%
COMMODITIES	0.8%	2.8%	4.0%	5.8%	12.7%
HIGH YIELD	1.1%	3.2%	3.8%	0.8%	6.6%
CREDITS	21.4%	21.0%	16.8%	16.1%	0.0%
BONDS	29.4%	29.0%	29.9%	29.4%	28.6%
INFLATION LINKED BONDS	2.3%	0.0%	0.0%	0.0%	0.0%
EXPECTED RISK PREMIUM	3.64%	3.76%	3.81%	3.87%	3.99%
STANDARD DEVIATION	10.3%	10.3%	10.2%	10.3%	10.1%
SHARPE RATIO	0.354	0.364	0.372	0.378	0.396
TRACKING ERROR (TE)	0.0%	0.5%	1.0%	1.5%	4.4%
TURNOVER (SINGLE COUNTED)	0.0%	12.5%	22.4%	25.0%	78.7%

FIGURE 1  
EFFICIENT FRONTIER FOR DIFFERENT PORTFOLIOS

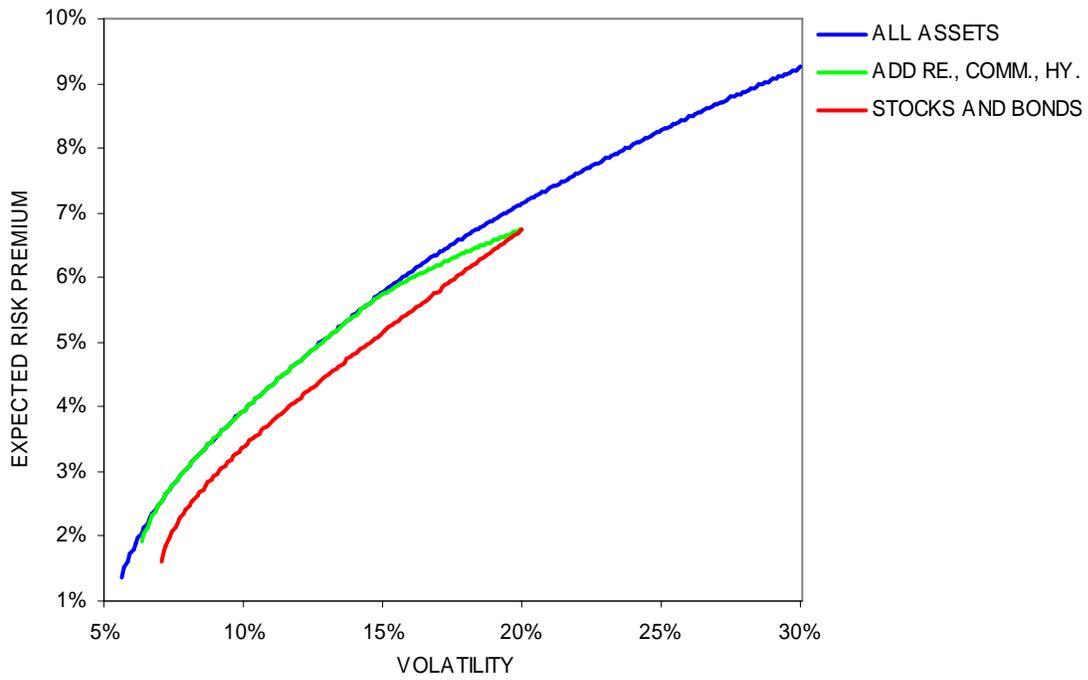


FIGURE 2  
ASSET ALLOCATION ON THE EFFICIENT FRONTIER IN AN ALL ASSETS PORTFOLIO

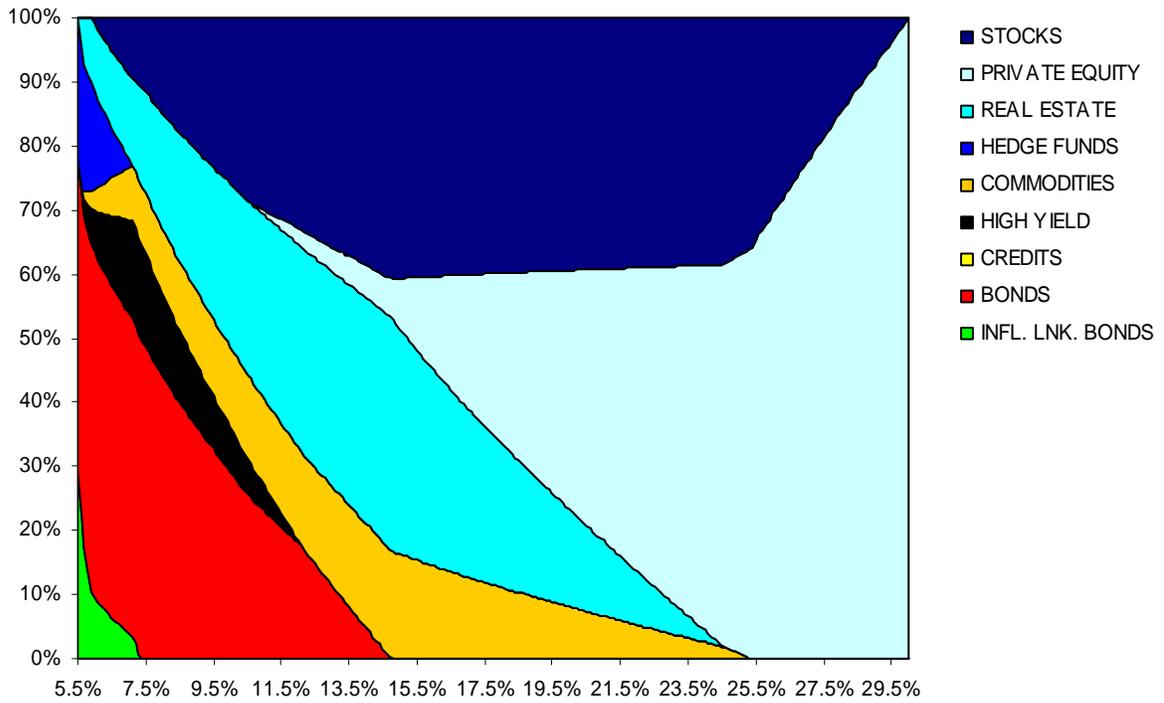


FIGURE 3  
PIE CHART OF THE MARKET PORTFOLIO AT THE END OF 2008

---

