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Abstract

The mixed-asset portfolio optimization consists in determining the best allocation among standard financial assets such as money market accounts, bonds, stocks and additionally real estate assets. For this later kind of asset, computing the optimal weight is sometimes a puzzle. First, we have to specificy what kind of real estate is introduced in the portfolio (commercial, industrial, residential, direct , REIT shares...). Second, we have to choose what kind of prices we use to calibrate real estate prices: appraisal values, actual real estate transactions, repeated sales, indices ...In this paper we focus on private residential real estate returns. In this framework, we investigate the optimal weight of the real asset with respect to standard financial assets. Using quarterly data on housing indices for four European countries, namely France, Germany, UK and Spain, we address the question of how the investment in housing affects the composition of an investor's portfolio. We show in particular under which conditions we recover the typical 15%-20% real asset allocation.

JEL classification: G11, G17, D14.

Keywords: Real Estate Investment; European Residential Real Estate; Mixed Asset Portfolio Allocation.

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1 Introduction

For portfolio investing purposes, real estate is usually considered as an alternative investment class. According to specific assumptions about both expected returns and volatilities levels, the mixed-asset portfolio optimization may induce various real estate asset allocation levels. Recall that standard results about mixed-asset portfolios suggest that the allocation to real estate should be about 15-20% (see Hoesli and MacGregor, 2000). Thus, real estate is found to be an effective portfolio diversifier. However, in most countries the share of real estate in portfolios of institutional investors is significantly smaller. For example, according to Clayton (2007) and J.P. Morgan (2007), the share of real estate is about 7.3% for the US and about 8.5% for the UK. As mentioned in Rehring (2012), the difference between theoretical allocations and observed low allocations to real estate in portfolios of institutional investors is viewed as a puzzle in real estate research (see Chun *et al.*, 2004). The usual framework of the mixed asset allocation problem is based on the standard model of Markowitz (1952). Usual portfolio maturities are monthly, quarterly or annual returns.

However, the optimal portfolio allocation depends on the predictability of real estate returns, as illustrated by McKinnon and Al Zaman (2009). These latter authors show also that real estate investment trusts are redundant assets for investors with access to direct real estate as an asset class (nevertheless having a significant role in optimal allocations when direct property investment is not feasible). The choice of the method to calibrate real estate asset prices has also to be examined as emphasized by Wallace and Meese (1997) who compare approaches based on repeat-sales, on hedonic-regression, and hybrid approaches when constructing residential housing price indices. Pagliari (2011) shows also how varying degrees of serial correlation between different asset classes modifies the optimal mixed allocation (see also Rab and Warnung, 2012).

For the European financial market, Fugazza *et al.* (2007) determine the optimal allocation for risk-averse investors who have a long-horizon and diversifies among stocks, bonds, real estate, and cash. They find that introducing real estate assets in optimal portfolio choices lead to weights between 12 and 44 percent. They emphasize that, "the welfare costs of either ignoring predictability or restricting portfolio choices to traditional financial assets only are found to be in the order of 150-300 basis points per year."(see De Roquemaurel and Scaillet (1996) for the French market case).

In this paper, we study residential real estate investment for four major European markets: France, Germany, UK and Spain. More precisely, we address the question of how the investment in housing affects the composition of an investor's portfolio. The other assets available to investment are money market instrument (*i.e.*, an index growing at a three months rate), national aggregate bond index and national stock market index. Quarterly data on housing

indexes are available and our sample spans the period from 1980 (Germany and UK), 1985 (France) and 1991 (Spain) through 2015, depending on the availability of data. The sample covers period of time with different economic conditions. We provide also the information ratio values, which allows to measure and compare the assets performances. Section 2 is devoted to a brief overview of real estate investment vehicles and to the presentation of the financial markets data. Section 3 provides the efficient frontiers for the four countries that are investigated. Some additional empirical analyzes are relegated to the Appendix.

2 Real estate investment and financial markets data

2.1 Real estate investment vehicles

Real estate investment is available through various vehicles. First, we can distinguish between private and public market investment in real estate. Private market is concerned with direct interest in real estate properties. In that case, you own and operate your real estate property (or through a property manager) and receive the rent payments and value changes from that investment. Another option consists of investing in the public real estate market by purchasing a share or unit in a publicly traded real estate company, such as a real estate investment trust (REIT). Real estate securities are issued by companies that own real estate and manage it on behalf of the shareholders of the company. As a result, exposure to the real estate market is more indirect as REIT are traded on a stock exchange. A real estate security pays to its shareholders/unitholders, a dividend which corresponds to the rent payments it receives from renters. Any price appreciation or depreciation in the assets owned by the company should be reflected in its share price although these securities are trading at a discount or a premium to their net asset values (NAVs). Next, a distinction must be made between equity and debt investment. An equity investment represents a residual interest in a property meaning that an equity investor is essentially the owner of the property. Debt investment corresponds to lending funds to an owner or purchaser of real estate. This type of real estate investing resembles bond investing. The most popular instrument of public debt is a mortgage-backed security (MBS).

Table (1) illustrates this typology.

Table 1: Real Estate Investment Typology

	Private	Public
Equity	Direct ownership Private REITs	Publicly traded real estate companies Standard equity REITs
Debt	Private mortgages	Mortgage-backed securities

The return characteristics differ across different investment vehicles. Investments in public real estate companies can be considered as an alternative to private real estate investments with higher liquidity. Nonetheless, early research shows that returns of public real estate resembles more that of the stock market than that of the available private real estate indices. For the French market case, De Roquemaurel and Scaillet (1996) show that using public real estate in an asset portfolio mix does not bring much diversification contrary to private equity real estate.

This lack of diversification comes mainly from the high correlation of quoted real estate with financial markets. More recent studies seem to show that this drawback disappears when longer investment horizons are considered (i.e., McKinnon and Al Zaman, 2009 and Hoesli *et al.*, 2015). On the other hand, Ang *et al.* (2013) show that there exists a common factor explaining public and private returns. Nevertheless, innovations in public real estate indices are correlated with equity and bond market returns which is not the case for private real estate indices. Moreover and perhaps more importantly, public real estate represents only around 10% of global real estate.

In our study, we rely on private equity residential real estate returns. For this investment class, there exists two main methodologies for index construction: the appraisal-based indices and the transaction-based indices.

- Appraisal-based indices use valuation of properties by appraisers. For income producing properties, the most common method used by appraisers is the capitalization rate (net income from a property divided by its price) approach. Another more technical approach relies on discounted cash flow methodology which is equivalent to the DDM methodology for stocks. The appraisal process introduces a bias due to appraisers seeking to dampen or to smooth volatility in their price estimates.

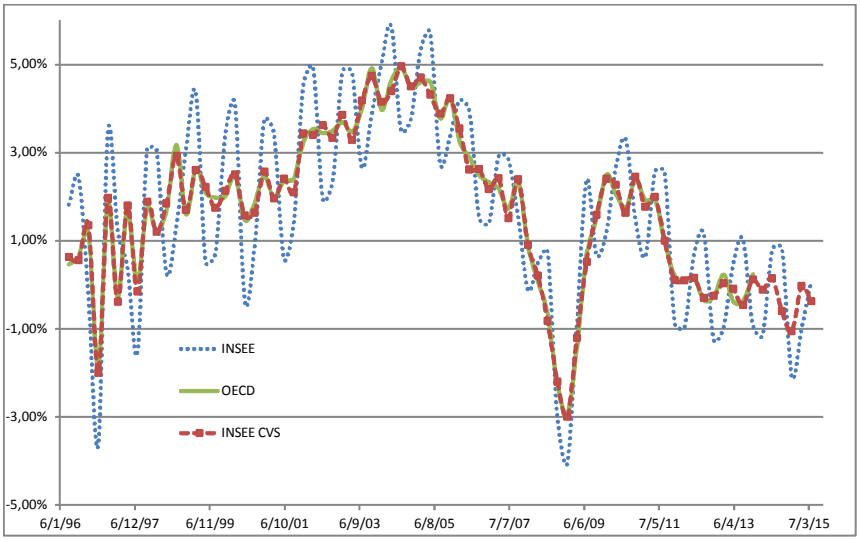
  Therefore, appraisal-based indices average past and current values, resulting in a moving average process. In order to correct for this appraisal smoothing and to extract the true market volatility and correlations, some "unsmoothing" techniques have been introduced in the literature. Usually, volatilities of appraisal-based indices are underestimated.

- On the other hand, indices can be based on observed transaction prices. Transaction-based indices must accommodate the lack of comparability of transacted properties by either applying repeat-sales measures, a method which uses information on properties which have been sold more than once, or hedonic index techniques which regresses property prices on the properties characteristics and derives the price of a hypothetical standard property. For instance, the INSEE index for sales of existing dwellings (all types of dwellings, whole country) is build on a stratified hedonic regression method. This index reflects the private residential real estate investment performance for France.

Figure (1) displays historical returns of the INSEE raw and seasonally-adjusted as well the OECD residential real estate indexes.

We notice that the OECD index is the INSEE seasonally-adjusted index. It is important to consider the seasonally adjusted one instead of the raw one since the volatility of the latter is biased due to the cyclicality of the quarterly returns. In our study, we rely on the OECD real estate series for the four countries considered.

Figure 1: Residential Real Estate Return: OECD and INSEE



2.2 Financial Markets Data and Statistics

For comparison purpose, we use the same source of data for the three type of financial assets considered in our study, namely: stocks, bonds, 3-month T-bills. The performance of the four stock markets are obtained through the MSCI Total return Indexes which accounts for dividend reinvestment. The performance of the bond market is given by the Datastream 10 year total return government indexes.

2.2.1 Statistics for France

Quarterly data Table 2 provides summary statistics on the quarterly french data. We build the Residential Real Estate nominal return series by adding the OECD (which is the INSEE) index on of sales of existing dwellings[1] and the calculated index on rent obtained from the index series of price to rent ratio provided by OECD[2]. For our sample period, the average annual return for the MSCI index is 12.46 percent, the average Bond index return is 8.81 percent, the average money market return is 4.77 percent and the average Real Estate index return is 9.66 percent. The volatility, defined as the annualized standard deviation of returns, for the MSCI index is 22.46 percent, 6.65 percent for the bond index, 1.67 percent for the money market and 3.14 percent for the Real Estate. Thus, real estate dominates in a mean-variance sense bonds. We will see later that volatility depends heavily on the frequency of calculation and that not all assets are affected in the same way when the frequency is changed.

Table 2: Descriptive Statistics, France - Quarterly Returns

	1985:1 to 2015:1			
	MSCI	Bond	Money Market	Real Estate
Mean	12.46%	8.81%	4.77%	9.67%
Volatility	22.46%	6.65%	1.67%	3.14%
Skewness	-0.367	0.013	0.418	-0.4614
Kurtosis	4.366	3.636	1.956	2.625

We use the information ratio[3] to rank the assets. The higher the ratio, the more the asset is "efficient", meaning that it provides a good mean-variance trade-off compared to the reference asset, the money market asset. The results are reported in Table (3):

[1] For this index all types of dwellings, whole country.and seasonally-adjusted data are considered.

[2] The methodology used can be found in the Appendix 1.

[3] The Information ratio is similar to a Sharpe ratio where both assets are risky. It is the ratio of the excess return of an asset over the money market return and of the tracking-error of this asset with respect to the money market return. The tracking-error is defined as follows: $T^2 = \sigma^2 (R_i - R_f) = \sigma_i^2 + \sigma_f^2 - 2\rho\sigma_i\sigma_f$, where i denotes an asset (Stocks, Bonds or Real estate) and f denotes the money market and ρ is the coefficient of correlation between the retrun of asset i and f. Thus, $IR = \frac{(R_i - R_f)}{T}$.

Table 3: Information Ratio, France - Quarterly Returns

	Information ratio
MSCI	0.341
Bond	0.614
Real Estate	1.120

We see that the most "efficient" asset is the real estate investment then the bonds and finally the stocks.

Annual Data Table 4 provides summary statistics for France based on annual data. The volatility of Money market and Real Estate returns are approximately doubled. For this two asset classes, the square root rule previously used to annualize the quarterly data is misleading. Indeed, this rule relies on the assumption that changes in log price are independently and identically distributed, which is clearly not the case. The high level of auto-correlation in those two latter series (see Appendix 2) precludes to use the square root rule. Instead, we should have relied on the following rule[4]:

$$\sigma_n = \sigma_1 \sqrt{n + 2\sum_{k=1}^{n-1}(n-k)\rho(k)}.$$

Table 4: Descriptive Statistics, France - Annual Returns

	1985 to 2014			
	MSCI	Bond	Money Market	Real Estate
Mean	12.83%	9.13%	4.94%	10.22%
Volatility	25.53%	8.48%	3.46%	6.29%
Skewness	-0.319	-0.325	0.393	-0.205
Kurtosis	2.404	2.766	1,841	2.058

The information ratios computed on annual data are given in Table 5. The sharp decrease of the real estate IR (approximately divided by 2) is simply the consequence of the doubling of the volatility of cash and real estate returns.

Table 5: Information Ratio, France - Annual Returns

	Information ratio
MSCI	0.309
Bond	0.509
Real Estate	0.600

[4] See Rab and Warnung (2012).

2.2.2 Statistics for Germany

Quarterly data The real estate data for Germany are provided through OECD by the Deutsche Bundesbank. For annual data, it is the index of residential property prices in Germany and for quarterly series only the index price for owner-occupied apartments in 7 cities is available. It is worth noting that real estate in Germany exhibits a small historical average return as well as a very low volatility, which makes it very comparable to money market return.

Table 6: Descriptive Statistics, Germany - Quarterly Returns

	1980:1 to 2014:4			
	MSCI	Bond	Money Market	Real Estate
Mean	11.96%	7.32%	4.58%	5.06%
Volatility	22.73%	6.84%	1.48%	1.57%
Skewness	-0.803	0.273	0.645	0.670
Kurtosis	4.787	4.725	2.880	2.709

Table (7) reports the information ratio of stocks, bonds and real estate for Germany. As for France, Bonds have an higher IR than stocks although here the dominance is weaker. But here, real estate seems not very appealing with the lowest IR.

Table 7: Information Ratio, Germany - Quarterly Returns

	Information ratio
MSCI	0.322
Bond	0.397
Real Estate	0.226

Annual Data Table 8 provides summary statistics for Germany based on annual data. As previously, the volatility of money market and Real Estate returns are approximately doubled due to the high level of auto-correlation in those two series.

Table 8: Descriptive Statistics, Germany - Annual Returns

	1980 to 2014			
	MSCI	Bond	Money Market	Real Estate
Mean	13.05%	7.53%	4.70%	5.19%
Volatility	27.12%	7.41%	3.08%	2.97%
Skewness	-0.073	-0.108	0.665	0.490
Kurtosis	3.418	2.199	2.865	1.998

The information ratios computed on annual data are given in table 9. Again, we observe a sharp decrease of the Real estate IR (approximately divided by 2) due to the doubling of the volatility of cash and real estate returns.

Table 9: Information Ratio, Germany - Annual Returns

	Information ratio
MSCI	0.303
Bond	0.368
Real Estate	0.118

2.2.3 Statistics for UK

Quarterly data The real estate data for UK are provided through OECD by the Department for Communities and Local Government. The index is established on sales of newly-built and existing residential dwellings, all type of dwellings, whole country and is available quarterly. Table 10 provides summary statistics on the quarterly UK data. Real estate in UK has a high average returns as well as a low volatility. It dominates in a mean-variance sense the bond asset.

Table 10: Descriptive Statistics, UK - Quarterly Returns

	1980:1 to 2014:4			
	MSCI	Bond	Money Market	Real Estate
Mean	12.68%	10.34%	6.61%	10.99%
Volatility	16.25%	8.78%	2.12%	4.48%
Skewness	-0.598	0.480	0.263	0.349
Kurtosis	3.983	4.557	2.244	4.913

Table (11) reports the information ratio of stocks, bonds and real estate for UK. The ranking is the same that for France and Germany.

Table 11: Information Ratio, UK - Quarterly Returns

	Information ratio
MSCI	0.378
Bond	0.437
Real Estate	0.917

Annual Data Table 12 provides summary statistics for UK based on annual data. As previously, the volatility of Money market and Real Estate returns are approximately doubled due to the high level of auto-correlation in those two series. Here, the annual volatility

is smaller than the annualized quarterly volatility because of a negative auto-correlation of order 2 in quarterly returns and negligible auto-correlation of order 1, 3 and 4 (see previous formula).

Table 12: Descriptive Statistics, UK - Annual Returns

	1980 to 2014			
	MSCI	Bond	Money Market	Real Estate
Mean	13.02%	10.86%	6.84%	11.65%
Volatility	15.60%	11.08%	4.46%	8.40%
Skewness	-0.890	1.338	0.262	0.245
Kurtosis	3.323	7.573	2.200	3.964

The information ratios computed on annual data are given in Table 13. Again, we observe a sharp decrease of the Real estate IR (approximately divided by 2) due to the doubling of the volatility of cash and real estate returns. But here, the stocks IR are now higher than the bonds IR.

Table 13: Information Ratio, UK - Annual Returns

	Information ratio
MSCI	0.419
Bond	0.389
Real Estate	0.537

2.2.4 Statistics for Spain

Quarterly data The real estate data for Spain are provided through by OECD. The index is established on sales of newly-built and existing residential dwellings, all type of dwellings, whole country and is available quarterly. Table 14 provides summary statistics on the quarterly ESP data. No asset is a dominating one in a mean-variance sense.

Table 14: Descriptive Statistics, ESP - Quarterly Returns

	1991:1 to 2014:4			
	MSCI	Bond	Money Market	Real Estate
Mean	13.64%	9.75%	4.57%	7.84%
Volatility	24.21%	8.31%	1.77%	5.03%
Skewness	0.347	-0.414	1.103	-0.311
Kurtosis	3.466	3.043	3.196	2.601

Table (11) reports the information ratio of stocks, bonds and real estate for Spain. Contrary to other countries, the Bond IR is slightly higher than the real estate IR.

Table 15: Information Ratio, ESP- Quarterly Returns

	Information ratio
MSCI	0.375
Bond	0.642
Real Estate	0.620

Annual Data Table 16 provides summary statistics for Spain based on annual data. As previously, the volatility of Money market and Real Estate returns are approximately doubled due to the high level of auto-correlation in those two series. Notice, that bond volatility is also significantly increased.

Table 16: Descriptive Statistics, ESP - Annual Returns

	1980 to 2014			
	MSCI	Bond	Money Market	Real Estate
Mean	14.28%	10.89%	4.79%	8.04%
Volatility	25.91%	12.93%	3.71%	9.31%
Skewness	-0.090	0.529	1.114	-0.227
Kurtosis	2.272	3.083	3.059	2.580

The information ratios computed on annual data are given in table 17. Again, we observe a sharp decrease of the Real estate IR (approximately divided by 2) due to the doubling of the volatility of cash and real estate returns.

Table 17: Information Ratio, ESP - Annual Returns

	Information ratio
MSCI	0.368
Bond	0.502
Real Estate	0.319

3 Efficient Portfolios with four asset classes

In this section, we derive optimal portfolios, in a mean-variance sense, invested in our four asset classes. Our objective is to assess the benefit of adding real estate investment to a standard diversified portfolio (*ie*, stocks, bonds and cash). For that purpose, we run an mean-variance optimization program with a positivity constraint on portfolio weights in accordance with common professional practice. Data are available for the four markets analyzed from 1980 to 2014.

3.1 Efficient Portfolios for France

3.1.1 Quarterly data

Table (18) reports the coefficient of correlations between quarterly returns of the four asset classes. On this historical observation period, real estate returns exhibit a positive correlation with stock market returns and a negative correlation with bond returns.

Table 18: Correlations, France - Quarterly Returns, 1985-2014

	MSCI	**Bond**	**Money Mkt**	**Real Estate**
MSCI	1.000	0.0144	-0.004	0.172
Bond	0.0144	1.000	0.167	-0.111
Money Mkt	-0.004	0.167	1.000	0.086
Real Estate	0.172	-0.111	0.086	1.000

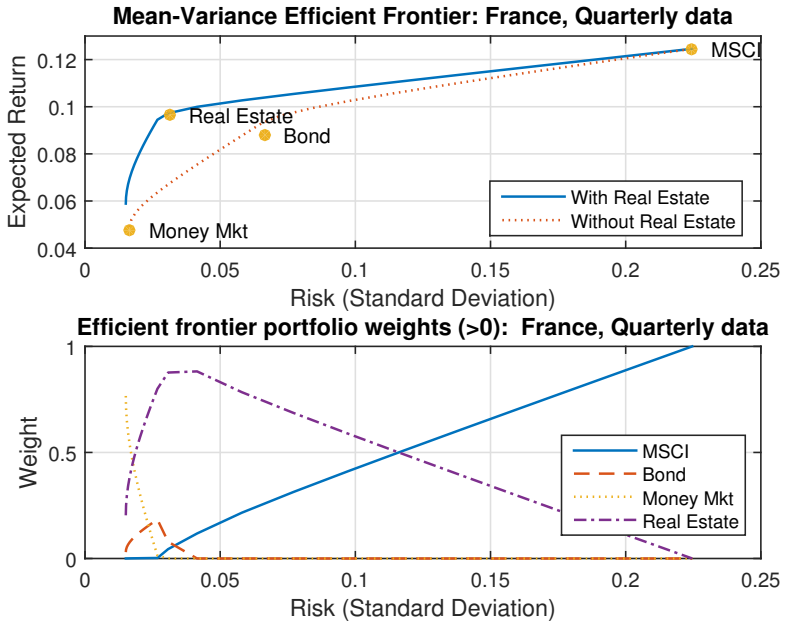
The upper part of figure (2) shows two efficient frontiers: one obtained without the real estate asset and one taking account of real estate. The lower part of this figure displays the holdings of the efficient portfolios as a function of portfolio risk.

The distance between the two efficient frontiers can be analyzed as a measure of the benefit of introducing the real estate asset into the portfolio optimization problem. This benefit is the most significative for volatility between 2% and 8% with a maximal increase in returns of near 3% for the same level of risk. As volatility increases, cash and bonds are eliminated from optimal portfolios. At the same time, there is a sharp rise of the weight invested in real estate. For a level of risk higher than 4 %, the share of real estate decreases and the share of stocks increases. This is quite natural as highly risky portfolios are achieved with highly risky assets, namely stocks here.

3.1.2 Annual Data

Table (19) reports the coefficient of correlations between annual returns of the four asset classes. On this historical observation period, real estate returns exhibit a positive correlation

Figure 2: Efficient Frontier with and without Real Estate and Portfolio Weights, France (quarterly data,1985-2014)



with stock market returns and a negative correlation with bond returns. Nevertheless, real estate returns have the lowest average correlation of the four asset classes. Low correlations of real estate returns with returns of other asset classes are usually the key point for introducing real estate investments into a well diversified portfolio.

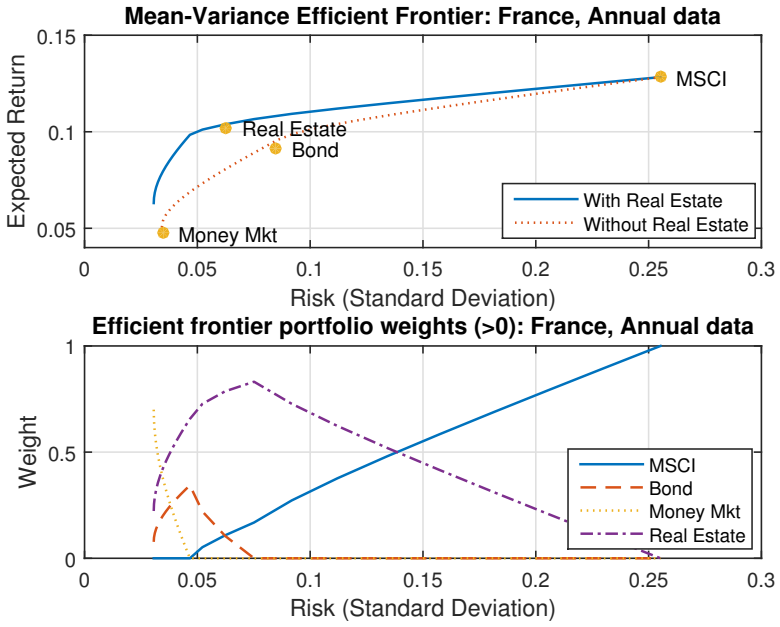
Table 19: Correlations, France - Annual Returns, 1985-2014

	MSCI	**Bond**	**Money Mkt**	**Real Estate**
MSCI	1	0.1754	0.0595	0.2267
Bond	0.1754	1	0.2760	-0.1636
Money Mkt	0.0595	0.2760	1	0.0618
Real Estate	0.2267	-0.1636	0.0618	1

The figure (3) is similar to figure (2) but for annual data.

The reading of both graphs is similar, except that the share of real estate in the optimal portfolios increases up to a portfolio's volatility of about 8% and is still at 50% for portfolio's risk of 14%.

Figure 3: Efficient Frontier with and without Real Estate and Portfolio Weights, France (annual data,1985-2014)



3.2 Efficient Portfolios for Germany

3.2.1 Quarterly data

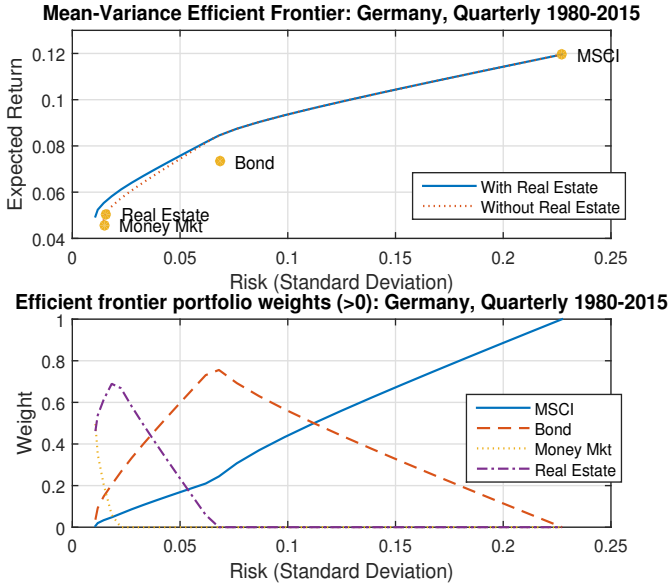
Table (20) reports the coefficient of correlations between quarterly returns of the four asset classes. For the German markets, real estate returns exhibit a near zero correlation with stock market returns and a negative correlation with bond returns. Contrary to other countries, the average correlation of real estate is not the lowest with a value of -0.027 where the average correlation for stocks is equal to -0.081, the one for bonds is -0.142 and the one for cash is 0.016.

Table 20: Correlations, Germany - Quarterly Returns, 1980-2014

	MSCI	**Bond**	**Money Mkt**	**Real Estate**
MSCI	1.000	-0.196	-0.066	0.018
Bond	-0.196	1.000	0.069	-0.142
Money Mkt	-0.066	0.069	1.000	0.044
Real Estate	0.018	-0.142	0.044	1.000

The upper part of figure (4) shows two efficient frontiers: one obtained without the real estate asset and one taking account of real estate. The lower part of this figure displays the holdings of the efficient portfolios as a function of portfolio risk.

Figure 4: Efficient Frontier with and without Real Estate and Portfolio Weights, Germany (quarterly data,1980:1-2014:4)



In the German case, it is clear that real estate brings not too much to the portfolio mix: the two efficient frontiers are very close to each other. Real estate seems to be a close substitute of Money Market in terms of average return and risk, but not in terms of correlation: the average correlation of real estate with other markets is -0.027 where it is 0.016 for money market.

As volatility increases, cash and real estate are eliminated from optimal portfolios. But real estate is still present in portfolios up to a volatility level of bout 7%.

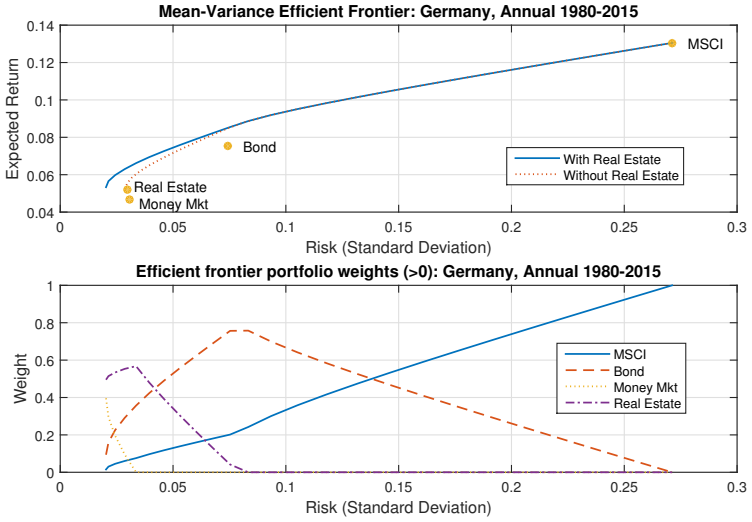
3.2.2 Annual Data

Table (21) reports the coefficient of correlations between annual returns of the four asset classes.

Table 21: Correlations, Germany - Annual Returns, 1980-2014

	MSCI	**Bond**	**Money Mkt**	**Real Estate**
MSCI	1.000	-0.071	-0.087	-0.072
Bond	-0.071	1.000	0.110	-0.166
Money Mkt	-0.087	0.110	1.000	0.051
Real Estate	-0.072	-0.166	0.051	1.000

Figure 5: Efficient Frontier with and without Real Estate and Portfolio Weights, Germany (Annual data,1980-2014)



The upper part of figure (5) shows two efficient frontiers: one obtained without the real estate asset and one taking account of real estate. The lower part of this figure displays the holdings of the efficient portfolios as a function of portfolio risk.

We obtain the same shape as with quarterly returns. Notice that the real estate weight is equal to zero for a portfolio volatility slightly higher and equal to about 8%.

3.3 Efficient Portfolios for UK

3.3.1 Quarterly data

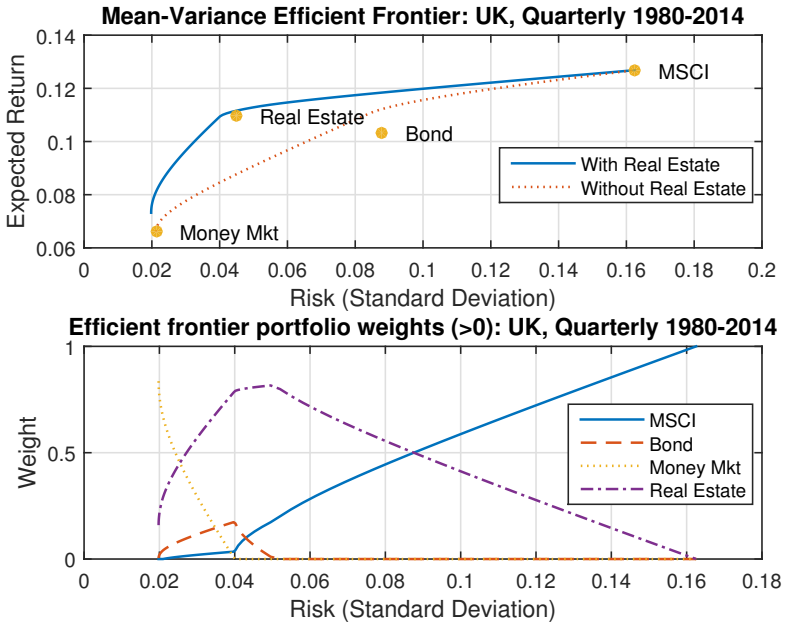
Table (22) reports the coefficient of correlations between quarterly returns of the four asset classes. The stock index is positively correlated with the three other markets with the same magnitude. Bond and cash market have the highest correlation. The real estate index is nearly uncorrelated with both bond and cash. It has the lowest average correlation: 0.079 (stocks: 0.15, bonds 0.125, cash: 0.157).

Table 22: Correlations, UK - Quarterly Returns, 1980-2014

	MSCI	**Bond**	**Money Mkt**	**Real Estate**
MSCI	1.000	0.149	0.148	0.154
Bond	0.149	1.000	0.232	-0.007
Money Mkt	0.148	0.232	1.000	0.090
Real Estate	0.154	-0.007	0.090	1.000

The upper part of figure (6) shows two efficient frontiers: one obtained without the real estate asset and one taking account of real estate. The lower part of this figure displays the holdings of the efficient portfolios as a function of portfolio risk.

Figure 6: Efficient Frontier with and without Real Estate and Portfolio Weights, UK (quarterly data,1980:1-2014:4)



The UK case is rather similar to the French one. Holdings in real estate increase up to a portfolio volatility of 5% and then begin to decrease. Again, weights in cash and bonds converge to zero for portfolio volatility of respectively 4% and 5%.

3.3.2 Annual Data

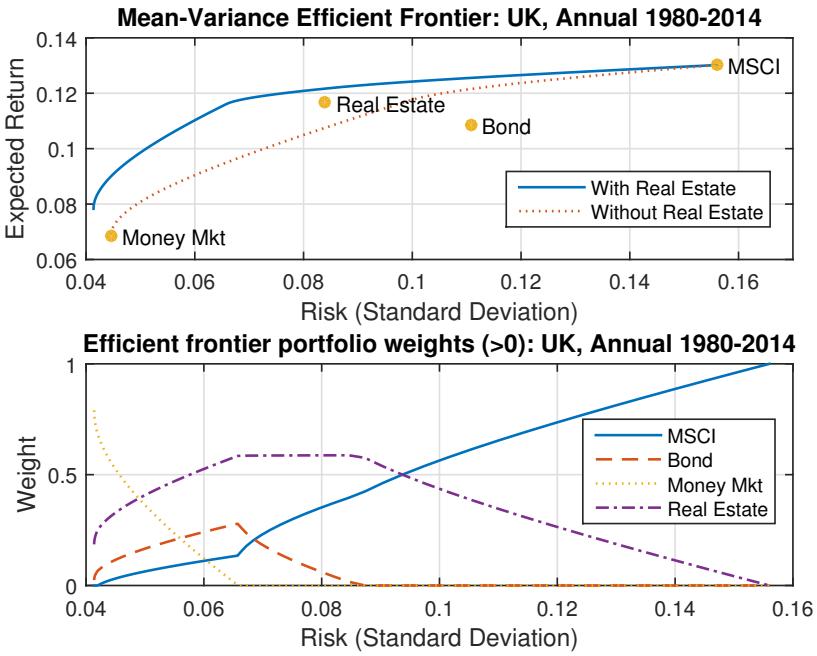
Table (23) reports the coefficient of correlations between annual returns of the four asset classes for the UK market. The same qualitative results as in the quarterly case apply.

Table 23: Correlations, UK - Annual Returns, 1980-2014

	MSCI	**Bond**	**Money Mkt**	**Real Estate**
MSCI	1.000	0.187	0.331	0.142
Bond	0.187	1.000	0.365	-0.007
Money Mkt	0.331	0.365	1.000	0.137
Real Estate	0.142	-0.007	0.137	1.000

The upper part of figure (7) shows two efficient frontiers: one obtained without the real estate asset and one taking account of real estate. The lower part of this figure displays the holdings of the efficient portfolios as a function of portfolio risk.

Figure 7: Efficient Frontier with and without Real Estate and Portfolio Weights, UK (Annual data,1980-2014)



The resulting portfolio weights are different from those obtained with quarterly data. The weight invested in bonds (resp. cash) is equal to zero for higher portfolio volatility: 8.3% and. 6.3%. The weight of real estate is now bounded from above at 59%.

3.4 Efficient Portfolios for Spain

3.4.1 Quarterly data

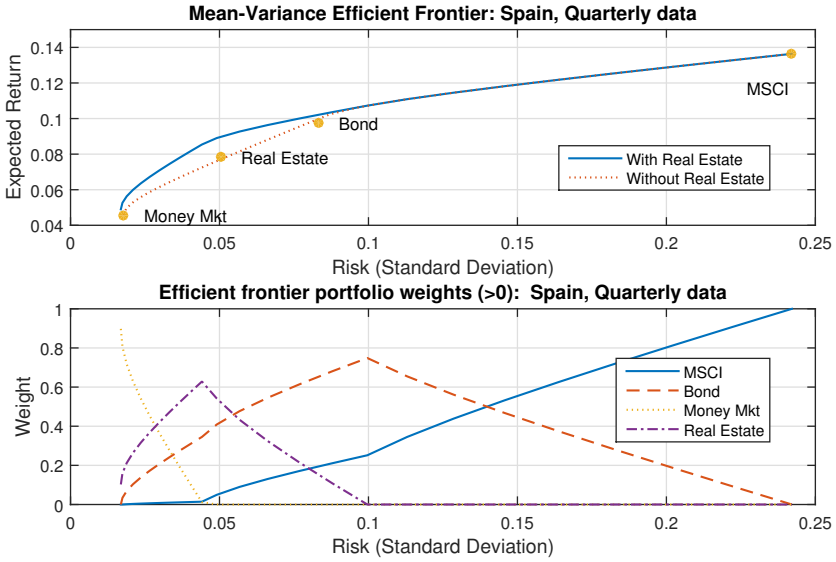
Table (24) reports the coefficient of correlations between quarterly returns of the four asset classes. All coefficients value are positive. Some correlations are non significative: Stocks and Real estate with Cash and Bonds with real estate. Stocks and Bonds have the highest correlation. The real estate index has the lowest average correlation: 0.067 (stocks: 0.176, bonds 0.184, cash: 0.107).

Table 24: Correlations, ESP - Quarterly Returns, 1980-2014

	MSCI	Bond	Money Mkt	Real Estate
MSCI	1.000	0.310	0.054	0.164
Bond	0.310	1.000	0.236	0.006
Money Mkt	0.054	0.236	1.000	0.032
Real Estate	0.164	0.006	0.032	1.000

The upper part of figure (8) shows two efficient frontiers: one obtained without the real estate asset and one taking account of real estate. The lower part of this figure displays the holdings of the efficient portfolios as a function of portfolio risk.

Figure 8: Efficient Frontier with and without Real Estate and Portfolio Weights, ESP (quarterly data,1991:1-2014:4)



Here, the real estate has positive weight in optimal portfolios up to a level of volatility of 10%. Then it is completely replaced by the Bond index.

3.4.2 Annual Data

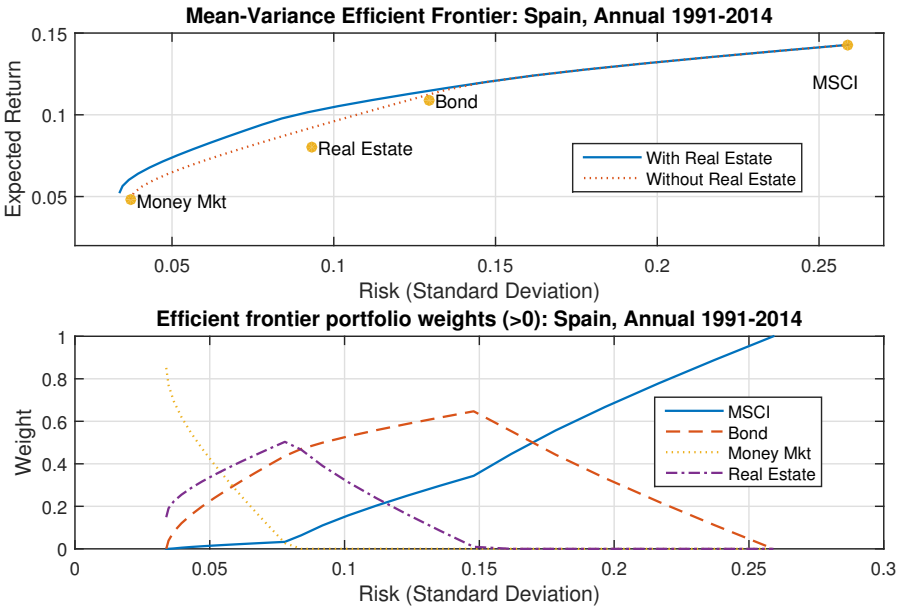
Table (25) reports the coefficient of correlations between annual returns of the four asset classes for the Spanish market.

Table 25: Correlations, ESP - Annual Returns, 1980-2014

	MSCI	Bond	Money Mkt	Real Estate
MSCI	1.000	0.187	0.331	0.142
Bond	0.187	1.000	0.365	-0.007
Money Mkt	0.331	0.365	1.000	0.137
Real Estate	0.142	-0.007	0.137	1.000

The upper part of figure (7) shows two efficient frontiers: one obtained without the real estate asset and one taking account of real estate. The lower part of this figure displays the holdings of the efficient portfolios as a function of portfolio risk.

Figure 9: Efficient Frontier with and without Real Estate and Portfolio Weights, Spain (Annual data,1991-2014)



The same shape is obtained. But real estate weight is now positive up to an optimal portfolio volatility of 15%.

4 Conclusion

We have analyzed diversified portfolio investment in stocks, bonds, cash and real estate over the period 1980 to 2014 for Germany and UK, 1985 to 2015 for France and 1991 to 2014 for Spain with both quarterly and annual data. Our study shows that Residential Private Real Estate enhances significantly the mean-variance trade-off for three of the four markets considered: France, UK and Spain. This is no more true for the German market where real estate experiments poor performance and is not really interesting in terms of correlation. Note also that the optimal weight on the real asset is always first increasing then decreasing with respect to the volatility level of the portfolio (for example, for France, UK and Spain, the real asset weight reaches its maximum when the portfolio volatility lies between 5% and 7%).

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Appendix 1: Determination of the rent component of the real estate return series

We rely on a study by Duajrdin *et al. (2016)* to determine the rent component of the real estate return series.

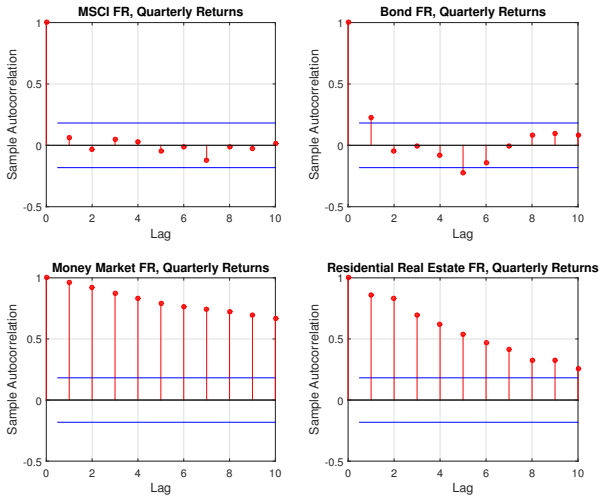
Indeed, the index series of price to rent ratio provided by OECD[5] does not allow to obtain this nominal rent component by considering its inverse, *i.e.* ratio of rent to price. Indeed, the ratio of rent to price depends on the date chosen for the Index base 100. What is needed is data in €/m^2 for the price index and the rent index series, then the total nominal return for the real estate asset is obtained by adding the growth rate of the index and the ratio of rent index to price index. Dujardin *et al. (2016)* determine the €/m^2 price and rent at a specific date and then recover the whole series. This method is an approximation but which seems to work well, according to the authors.

We are interested in the net return, meaning that we must subtract the operational expenses from the rent. There exists no such series. Accordingly, we rely on the work of Friggit (2007) and make the assumption than 37% of the rent perceived are paid as operational expenses for the 5 countries of our study.

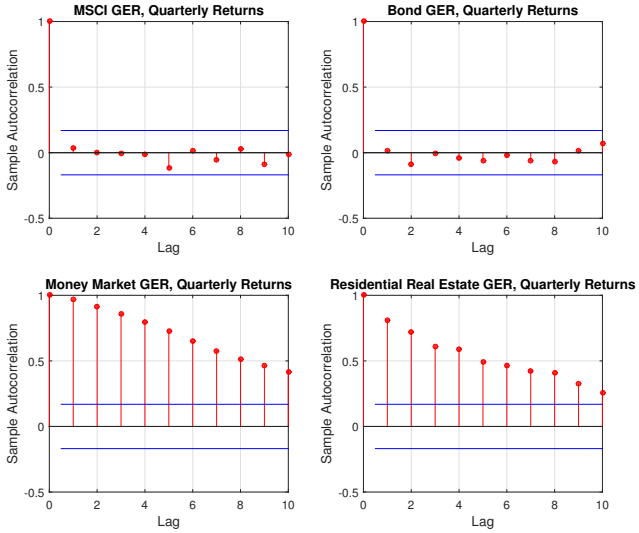
As mentioned by Friggit (2007), these calculations are only approximations but "Nevertheless, we have checked, by using other rental income series, that the impact of these approximations on the average return and the volatility is acceptable for the use we make of them ...it does not change significantly the volatility of our property investment index, which is determined much more by the volatility of the capital gain than by the volatility of the rental income."

[5] OECD relies itself on data provided by National Institute of Statistics of every country.

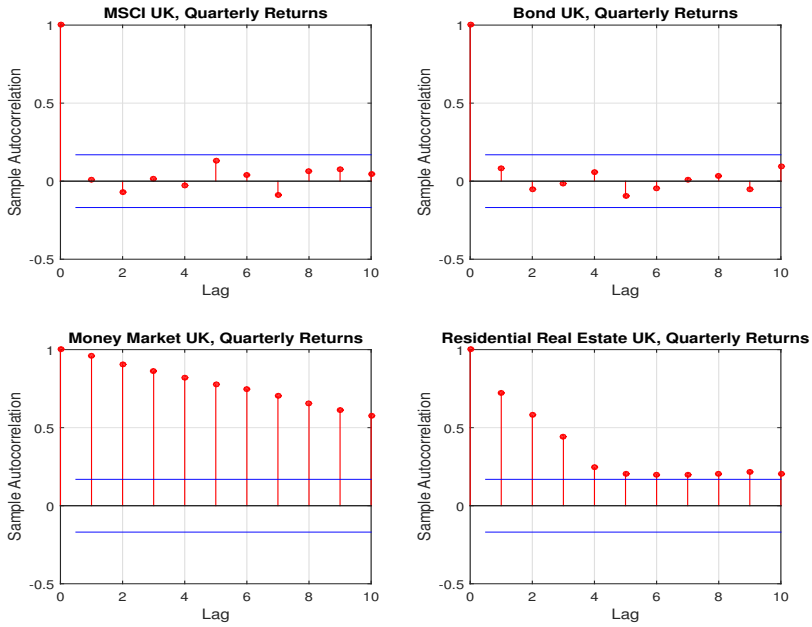
Appendix 2: Auto correlation function of quarterly returns



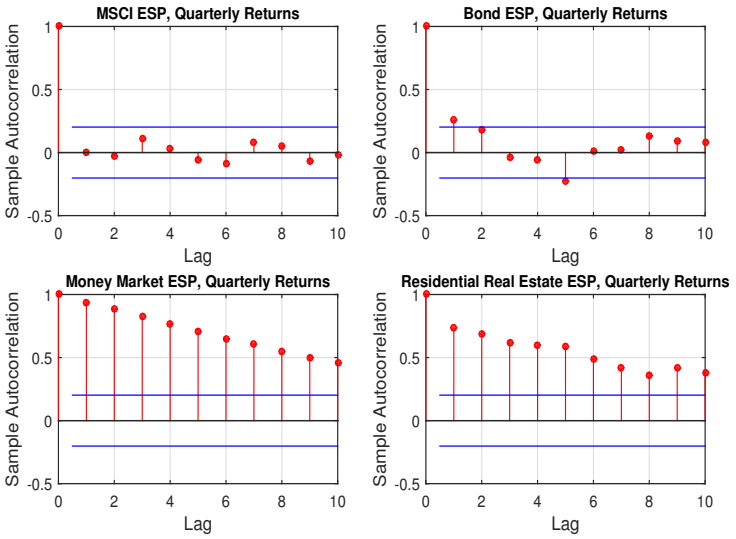
ACF Quarterly Returns France (Q1:1985 to Q4:2014)



ACF Quarterly Returns Germany (Q1:1980 to Q3:2014)



ACF Quarterly Returns UK (Q1:1980 to Q3:2014)



ACF Quarterly Returns Spain (Q1:1991 to Q4:2014)