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# The Choice of Unsmoothing Coefficients for Real Estate Appreciation Indices: With Notes on Correction Procedures, Appraisal-Smoothing, Nonsynchronous Appraisal, Asset Return Correlation and Market Efficiency

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## Abstract

Due to the smoothing problem with appraisal-based indices, there is uncertainty about the true volatility of value change returns on real estate markets. The selection of unsmoothing procedures proposed in the literature obviously cannot remedy this. The article argues that it is hardly possible to uncover historical latent market values and volatilities, as various sources of error in the compilation of indices may overlap and change over time. These so-called smoothing phenomena are mentioned in various sources in the literature and are discussed in more detail here. The correction methods proposed in the literature are also discussed critically and it is explained that many of these in essence contain a simple correction formula already presented by Blundell & Ward. The results of calculations based on this correction formula and on an innovative approach by Bond & Hwang are therefore presented in the paper.

The article suggests not relying on a point estimate resulting from the application of a selected correction procedure. Instead, an attempt could be made to narrow down plausible value ranges of the time series characteristics (volatility, mean value and asset correlations) relevant to investment decisions. Using the NCREIF Appreciation Index, the paper shows how the volatility of the corrected index returns changes with the level of the unsmoothing coefficient. To find plausible value ranges, it could be considered, for example, that high transaction costs are already an obstacle to market efficiency in real estate markets. The paper therefore illustrates that volatility is already substantially reduced with a low entry of serial correlation in time series.

## 1. Motivation

Appraisal-based indices do not reflect the actual fluctuations in market values. Due to imperfect information on current market values, appraisers include historical information in property valuations. To eliminate the smoothing and autocorrelation that occurs in the time series during the process of property appraisal, correction procedures (so-called "unsmoothing procedures") have been proposed. By applying these to the return series, the true (approximate) market returns are to be obtained. However, the suitability of the unsmoothing procedures has not yet been sufficiently investigated. In some cases, the developers of the procedures do not clearly define themselves when determining the unsmoothing parameters.

This study moves away from the arbitrary choice of an unsmoothing procedure or the value of the unsmoothing coefficient. According to the view expressed here, due to various sources of uncertainty and their dynamics, it is difficult to reconstruct the true market returns. The determination and use of unsmoothing coefficients from the application of correction methods leads to uncertainties about the results derived from them. It is therefore proposed in the study to narrow down the possible or plausible range of values for the volatility of actual market returns. For this purpose, a corrected return series of the appreciation component of the NCREIF Property Index (NPI) is calculated for each value of the sequence of a successively changed unsmoothing coefficient. Value ranges for volatility and the mean value are derived from the bundle of unsmoothed return series. Value ranges of the correlations with the return series of the asset classes equities, bonds and REITs as well as with inflation are also presented.

The essay is structured as follows: The next section classifies the topic in literature. Then the smoothing problem and selected correction methods are described in more detail. In this context, the assumption of market efficiency and other circumstances that lead to uncertainties about the characteristics of true market returns are also discussed. Furthermore, the study design and the analyzed time series data are presented. An interpretation of the results is followed by a summary.

## 2. Literature

In the past, various studies have argued that appraised values tend to reduce volatility in real estate markets, including Geltner (1989a, 1989b, 1991, 1993a, 1993b), Ross and Zisler (1991) and Giacotto and Clapp (1992). Cheng et al. (2011) explain that the theory of appraisal smoothing is mainly based on the simple observation that the NPI shows too little volatility in relation to stocks. This cannot be explained by classical pricing models. Regarding empirical studies on appraisal smoothing, Yiu et al. (2006), p. 322 refer to Ibbotson and Siegel (1984), Miles, Cole and Guilkey (1990), Hendershott and Kane (1995) and Hamilton (1997).

Quan and Quigley (1989, 1991) have presented a theoretical model of the behavior of appraisers in real estate valuations. This shows that valuers include past values in property valuations even if they proceed efficiently. Hypotheses on appraiser behavior were tested by Dewit (1993) and Diaz and Wolverton (1996).

Corgel and de Roos (1999, p. 281) explain: "*We accept the premise that improper allocations to real estate and other assets in mixed-asset portfolios represent the greatest potential consequence of using reported, appraisal-based returns.*" Brown and Ong (2001) explain that "*the most serious implication is that a low and under-estimated real estate return volatility roots to excessive allocation to real estate.*"<sup>1</sup> Gohs, Frömel and Sebastian (2022) explain: "*Related research has shown that reliance on smoothed appraisal-based numbers may adversely affect investment decisions and thus hinder efficient capital allocation (see, e.g., Booth & Matysiak, 2001; Brooks & Kat, 2002; Getmansky et al., 2004; Marcato & Key, 2007).*"

First, Blundell and Ward (1987) proposed unsmoothing the return series of an appraisal-based index by removing autocorrelation. They rely on the theory of market efficiency (in its weak form) by Fama (1970). The market returns on real estate markets that are not directly observable would be free of autocorrelation if information efficiency prevailed.

For the correction of a quarterly updated index, Firstenberg et al. (1988) fitted an autoregressive model with time lags of up to four annual quarters to the returns. Fisher et al. (1994) proposed correcting only the deviation from inflation - understood as the real component - instead of the nominal return values.

As a follow-up, some improvements for correction procedures were proposed. Among other things, the relationships between the latent market values and reporting values were modeled and correction procedures were obtained by reverse-engineering these models. The advantage of these methods is that the critical ex ante assumption of information efficiency can be dispensed with. Geltner (1993a) and Barkham and Geltner (1994) have developed reverse-engineering correction procedures adapted to the situation in the US and UK markets. However, the correction formulas derived in each case do not differ in structure from those of the pioneers Blundell and Ward (1987). In Blundell and Ward (1987), the unsmoothing coefficient is estimated using an autoregressive model. In reverse engineering correction procedures, however, the coefficient value is derived theoretically. However, the developers of the reverse engineering methods do not offer any clear unsmoothing parameters, but only plausible alternative values. Later (more complex) correction procedures are

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<sup>1</sup> Brown and Ong (2001) refer to Webb and Rubens (1987), Firstenberg et al. (1988), Giliberto (1992) and Brown and Schuck (1996).

proposed: But Chaplin (1997) and Lizieri et al. (2012) also adhere to the classic correction formula. In addition, they determine coefficients for different switching regimes.

Bond and Hwang (2007) introduced a substantial innovation. They argue that the effect of appraisal smoothing is transformed during the cross-sectional aggregation of time series of individual real estate assets for index calculation. Therefore, the effect of appraisal smoothing on index returns is captured by the fractional integration parameter of an ARFIMA model rather than the AR parameter of a simple autoregressive model. They explain that this is due to the inconsistent approach to valuations of individual real estate assets. Cheng et al. (2011) also referred to heterogeneous appraiser behavior. They explain that cross-sectional variation results from different access to and interpretation of information. They claim that the variance of transaction-based returns can therefore be higher or lower than the variance of comparable-based returns, depending on the degree of this heterogeneity. Cheng et al. (2011) conclude that “appraisal-based indices may not suffer any smoothing bias.” In contrast, Gohs (2014) inferred from simulation studies that the volatility of the index time series is reduced by appraisal smoothing and other smoothing phenomena.<sup>2</sup>

Multivariate models have also been proposed in the literature that include other time series with information content about the real estate market in addition to the valuation-based index. Ling et al. (2000) proposed a latent variable model to extract the true market returns from several time series. Wang (1998) identified a cointegration relationship between reported and actual market values, which he used for correction purposes.

Ultimately, the user is confronted with a selection of correction procedures proposed in the literature. There are no clear choice criteria and there is a lack of studies to evaluate the quality of the correction procedures. The uncertainty of the user or investor about the true market returns and the risk of real estate investments remains.

Based on the correction rule of Blundell and Ward (1987), this study determines the value ranges of the standard deviation and other properties of corrected index returns and thus possible market returns.<sup>3</sup> These are obtained by calculating results for successively changed unsmoothing coefficients. It is shown that a further narrowing of the plausible value ranges for the characteristics of market returns is possible if the assumption of an absence of information efficiency is considered plausible. It is argued that the assumption of a lack of information efficiency is already plausible due to the high

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<sup>2</sup> Gohs (2014) obtains increased volatility only for extraordinary constellations of the interplay of smoothing phenomena and their parameterization. Gohs (2014) therefore supports the prevailing view that the appraisal-based indices are smoothed towards true market movements.

<sup>3</sup> For comparison purposes, calculations were carried out using the correction procedure of Bond and Hwang (2007). In addition, the time series properties of inflation with increasing unsmoothing were investigated.

transaction costs in real estate transactions. This prevents a reduction of autocorrelation in market returns.

In the past, the prevalence of market efficiency was examined for various spatially defined markets and time periods. Clayton (1988), for example, empirically examines the prices of condominiums in Vancouver (British Columbia) and concludes missing market efficiency. Herath and Maier (2015) conduct a meta-analysis and find "that the use of stock market data and individual-level data rather than aggregate data significantly increases the likelihood that a study will find efficiency." Furthermore, the researchers find no change in the view of market efficiency over the years.

Gatzlaff and Tirtiroglu (1995) review studies on the efficiency of real estate markets. They find that different real estate market segments have different levels of efficiency: "Income property markets are considered more efficient than the residential market, but less efficient than corporate securities markets." Gatzlaff and Tirtiroglu (1995) name transaction costs as the reason for a lack of market efficiency.<sup>4</sup>

Corgel and de Roos (1999) conclude that the weighting of real estate in mixed portfolios (with equities) reacts very sensitively to "recovery".<sup>5</sup> They show how the weighting of real estate assets in the portfolio allocation depends on the volatility of real estate returns and their correlation with equity returns.

### 3. Real estate background

#### 3.1. Real estate market

##### 3.1.1. Perception of real estate as an investment

Properties form a large part of the assets of national economies. Historically, they were built to serve residential or commercial purposes. However, land has also always been regarded as an investment. In general, investments in tangible assets such as real estate have a reputation for offering protection against inflation. As a result of increasing globalization with international capital flows, real estate has gained in importance as an investment in countries with stable political conditions. The establishment of real estate investment trusts (REITs) in the 1960s further contributed to this. REITs allow investors to participate in the performance of real estate without physically acquiring it themselves. The establishment of mortgage-backed securities and collateralized debt obligations also supported

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<sup>4</sup> Gatzlaff and Tirtiroglu (1995) explain: „...transaction costs typically prohibit investors from exploiting the predictable price movements in any of the market segments.“

<sup>5</sup> Corgel & de Roos (1999) rely on the correction procedure of Geltner (1993a), for which they consider an unsmoothing parameter in the range between 0.5 and 0.67 to be plausible, and particularly the coefficient 0.6.

international investments in real estate markets. In the environment of losing monetary policy by central banks in the years following the peak of the financial crisis, the public increasingly focused on real estate as an alternative investment to shares and bonds due to sharp price increases.

### 3.1.2. Attractiveness of real estate in relation to other asset classes

Some studies claim that real estate has a more attractive risk/return profile than other investment classes.<sup>6</sup> In addition, properties are interesting for investors if they offer diversification potential in combination with other investments such as stocks or bonds.<sup>7</sup>

The smoothing problem with appraisal-based indices discussed here is certainly important when assessing the attractiveness of real estate investments. In early studies in particular, the smoothing problem may not be considered adequately or not at all.

### 3.1.3. Appraisal-based indices and smoothing issues

An appraisal-based index, which is intended to reflect the value trends on a real estate market, is created from a mass of expert valuations for properties. However, appraisers usually do not have sufficient up-to-date information (particularly current purchase prices of comparable properties) for valuations of individual properties. Therefore, they also include previous transaction prices and estimated values of the property in question in revaluations - due to the obviously not negligible information content. Appraisal-based indices therefore presumably do not reflect the completely current situation on the real estate market. In the economic literature, the prevailing view is that they do not reflect the actual fluctuations in market values, instead they are smoother.

However, it is not only the volatility that changes with the autocorrelation structure of a time series. (Local) maxima, minima and turning points of the index time series are also shifted compared to the actual situation on the market. This affects calculated correlations with other time series. The mean value of the index returns is hardly considered in studies on the effects of appraisal smoothing. However, even here small deviations in the annual mean returns can lead to large deviations in returns over a long investment horizon.

As an appraisal-based index with a long history (the first index value refers to the end of the fourth quarter of 1977), the NCREIF Property Index (NPI), which represents the US commercial real estate market, is well-known among investors and economists. It is the subject of many studies on the optimal diversification of portfolios (with mixed asset classes) and on the effects of so-called "smoothing phenomena" on the index time series.

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<sup>6</sup> Cf. Hoesli & MacGregor (2000), Hoesli et al. (2004)

<sup>7</sup> Cf. Hoesli et al. (2004)

### 3.1.4. Market efficiency, arbitrage, unsmoothing and real estate markets

The zero-autocorrelation unsmoothing procedures were founded on the market efficiency hypothesis (or information efficiency hypothesis) by Eugene F. Fama (1965):<sup>8</sup> In information-efficient markets, new information is incorporated into price formation as soon as it becomes known. This is supported by temporal arbitrage. Arbitrage means making a profit without taking a risk.<sup>9</sup> Rational market participants would take advantage of the opportunity to engage in arbitrage transactions. The information flowing into the market as a result would support convergence toward market efficiency. In a state of (perfect) market efficiency, arbitrage transactions would no longer be possible.

The market efficiency hypothesis assumes that market participants act rationally and consider all available information.<sup>10</sup> A distinction is made between three levels of information efficiency, which are related to information availability: The weak form refers to historical prices, so that no information advantage can be achieved for the forecast of future price developments by means of technical analysis. The medium-strong form includes all publicly available information (e.g. annual reports), while the strong form also includes insider information.

A common conclusion is that, given prevailing information efficiency, market returns do not exhibit serial correlation that could be used for forecasting purposes. Therefore, no information advantage over other market participants can be achieved by means of time-series-analytical forecasts, which would enable profit (through time-based arbitrage).

Blundell and Ward (1987) assume that the real estate market is indeed information efficient and that all autocorrelation in the valuation-based indices is due to the procedures used in real estate appraisals. They conclude that the actual market returns are obtained from the returns of the appraisal-based indices by subtracting their predictable part (i.e. their autocorrelation).

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<sup>8</sup> Cf. the review articles by Fama (1970, 1991) on capital market efficiency, as well as the studies by Fama and Gibbons (1982) and Fama and Schwert (1977).

<sup>9</sup> The trading strategy of arbitrage differs from speculation (i.e., the deliberate taking of risks).

History has shown us the trading strategy of geographical arbitrage transactions, i.e., profits were achieved by taking advantage of spatial price differences. In contrast, temporal arbitrage is considered here. For a more detailed consideration, however, the question would arise as to whether (substantial) risks can actually be avoided when implementing the temporal arbitrage trading strategy. In fact, geographical trading was not entirely risk-free, so that, for example, the sinking of some ships was included in the calculations.

<sup>10</sup> The assumption that all (relevant) information is taken into account makes more sense for market participants as a whole than for each individual. However, this also explains why information efficiency is more likely to occur on regulated trading platforms or exchanges, where a large number of market participants come together and their information is incorporated into price formation.

In contrast, however, information efficiency is more justified for capital markets where the information of the mass of market participants comes together and is processed immediately in price formation processes. With market efficiency, even an uninformed investor can therefore expect to buy at fair prices.

Empirical studies on information efficiency in markets come to different conclusions.

For stock markets, at least the assumption of weak market efficiency is often confirmed. However, speculative bubbles with strong autocorrelation also form on stock markets at times. Some studies that also refer to spatially and temporally defined real estate markets also support the market efficiency hypothesis. Most arguments and results of empirical studies, however, argue against the efficient processing of information on real estate markets. Among other things, real estate markets differ from capital markets in the following aspects:

- Properties are heterogeneous in terms of their hedonic (i.e. value-determining) characteristics.
- Price negotiations are conducted between buyer and seller (groups) and agreed prices are not necessarily published.
- There may be an asymmetry in the distribution of information between better informed (domestic) sellers of real estate on a local market and potential (nonresident) buyers.
- High transaction costs and long investment horizons, tax holding periods, etc.
- Lack of market liquidity, low transaction volume, etc.

In real estate transactions, transaction costs and periods (plus personnel and opportunity costs, marketing, market analyses, research) are so extensive that short investment periods are not profitable and serial correlation in index time series of lower periodicity (monthly or quarterly indices) is not fully offset.

Appraisal values not only depend on the purchase prices of comparable properties, but also purchase prices depend on appraisal values. These reciprocal relationships also speak in favor of autocorrelation in market values.

Real estate transactions are prepared and processed over longer periods of time and are usually only terminated under exceptional circumstances. Therefore, short-term considerations, such as autocorrelation in quarterly returns, become less important.

As described above, the developers of zero-autocorrelation unsmoothing procedures demand the absence of autocorrelation. However, in the literature, (weak form) information efficiency is sometimes interpreted somewhat more freely. Some scholars explain that even with market efficiency, returns can be temporarily or insignificantly serially correlated.<sup>11</sup> For the application of

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<sup>11</sup> Some authors also refer only to the portion of the market return that exceeds the expected return on a risk-free investment.

correction procedures, this could mean that only significant autocorrelation is calculated out of the return series.

Furthermore, it is questionable whether the identification of significant autocorrelation in market returns necessarily leads to immediate transactions and thus to price adjustments and a convergence toward market efficiency. This is because a (risk-free) arbitrage opportunity does not necessarily exist. From another perspective, it can even be doubted that significant autocorrelation precludes information efficiency (in the sense of the weak form concept or another meaningful interpretation of the term).

Experience with previous speculative bubbles (such as the dot-com bubble or those associated with other innovations) and shifts in levels (such as during the years of rising real estate prices in European cities due to rural depopulation in connection with the digital revolution and the ECB's loose monetary policy) show the following: On the one hand, it is unclear for a long time whether it is a shift in levels or a speculative bubble. On the other hand, after a prolonged accumulation of yield gains (which may initially manifest themselves in significant autocorrelation), a sudden bursting of the speculative bubble is likely to be associated with substantial losses. This risk of loss is considered and prevents or delays investment. In general, the question arises as to whether autocorrelation as a side effect of innovation (and not of market friction) should be linked to a lack of information efficiency at all. Since trends and their effects are often difficult to predict and only become apparent gradually, hesitant trading and autocorrelation in market returns are justified.

Chordia et al. (2005) measure convergence toward market efficiency as the time at which a predictability of returns in stock trading disappears again. The question arises as to how these findings can be transferred to real estate markets or markets with a lack of market efficiency. How long does it take for autocorrelation to disappear from a real estate market so that traders cannot exploit it for arbitrage? Given existing frictions, should a longer convergence toward market efficiency be accepted?

Concepts of information efficiency need to be scrutinized. Due to the high risk of loss when a speculative bubble bursts, it should also be acceptable to forecast "excess returns" during an accumulating speculative bubble. The enormous risk associated with high transaction costs is likely to be just as prevalent, if not more so, in innovative processes. How does this contradict a prevailing of market efficiency? Arbitrage means making a profit without risk. But which market is free from risks?

## 3.2. Smoothing phenomena

### 3.2.1. Appraisal smoothing and Quan & Quigley's theoretical model of efficient appraiser behavior

Quan and Quigley (1989, 1991) have presented the relationship between appraisal estimates and transaction prices in a theoretical model.<sup>12</sup> Accordingly, appraisal smoothing occurs even when appraisers take an efficient approach to property valuations due to the consideration of past values. The higher (lower) the dispersion of current transaction prices of comparable properties and the lower (higher) the fluctuation of the time series of historical appraisal values, the higher (lower) the weighing of historical values in revaluations.<sup>13</sup> This is due to the uncertainty caused by the high dispersion.

### 3.2.2. A note on appraisal smoothing: temporal and spatial dynamics

However, both the dispersion of transaction prices and the volatility of historical values are likely to exhibit temporal (and possibly spatial) dynamics that a single "smoothing coefficient" can at best only represent on average. This will probably prevent market values from being back calculable.

### 3.2.3. Non-synchronous appraisals

According to Bond and Hwang (2007), the phenomenon of non-synchronous trading was first recognized by Fisher (1966). It affects appraisal-based real estate indices (in the form of non-synchronous appraisals) when the valuation dates of the properties in an index portfolio diverge.<sup>14</sup> This is because the valuations of the properties by appraisers may not take place on the same date, but on different dates within the appraisal period for whose end date the calculated index value is shown. The index value is shown for the end of the month or quarter, but the valuations are spread over the entire period or over a time span at the end of the period.

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<sup>12</sup> Strictly speaking, transaction prices can also deviate from their underlying latent market values. For the following considerations, however, the subtle difference between the two concepts (market value vs. transaction price) is negligible. A distinction is therefore made here between appraisal estimates on the one hand and market values or transaction prices on the other.

<sup>13</sup> In this context, Yiu et al. (2006), p. 322 also refer to Geltner (1989a, 1991, 1993) and Giaccotto and Clapp (1992), among others.

<sup>14</sup> The index portfolio refers to the mass of properties whose values are used to calculate the index.

### 3.2.4. Taking values from previous periods ("stale appraisal") for index calculation and seasonality in this practice

"Stale Appraisal" refers to an index construction practice in which only a portion of the properties in the index portfolio are revalued in each period (for the end of which an index value is reported).<sup>15</sup> Values from previous periods are taken for the remaining properties.<sup>16</sup> Insofar as (cost-intensive) revaluations by valuers are usually commissioned primarily for transaction projects and not for index compilation, this procedure cannot be completely avoided. However, in some countries, property valuations may also be carried out regularly to fulfill reporting obligations, for tax purposes, etc. In the case of sizeable real estate holdings in the index portfolio, a portion - for which current revaluations are available - may already be representative of the market. It is then not necessary to adopt outdated values for the remaining portion.

In the context of "stale appraisal", "seasonality in appraisals" arises if the numbers of revaluations are not evenly distributed throughout the year. For example, more properties are typically (i.e. systematically) revalued in one quarter of the year than in the other quarters. The index values may then show greater changes in value in the quarters of the year with an above-average share of revaluations than take place in the market.<sup>17</sup>

Regarding the phenomenon of "stale appraisal", similar considerations play a role as with non-synchronicity of appraisals.

Additionally, the terms for smoothing phenomena in literature do not always have the same or definite content. Some authors summarize different phenomena with similar effects under the term "temporal aggregation". It can be assumed here that the term "stale appraisal" is also sometimes used in literature to refer to non-synchronous appraisals. Although stale appraisals (in the closer sense) have a significantly higher impact than non-synchronous appraisals, both effects are comparable.

### 3.2.5. Non-synchronicity and stale appraisals: discussion of dynamics and impact

It can be assumed that the effects of non-synchronous appraisals (including "stale appraisal") have changed compared to the early years of the NPI index calculation (or the 1980s) and may even have lost relevance. This is supported by the following hypotheses, which are not examined in detail in this

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<sup>15</sup> cf. Gohs (2014)

<sup>16</sup> For example, Investment Property Databank (IPD) publishes monthly, quarterly and annual indices for the United Kingdom market. However, not all properties are revalued monthly or are considered for each index.

<sup>17</sup> cf. Gohs (2014)

study. Overall, however, the arguments suggest that it is unlikely that the impact of non-synchronicity has remained constant over the decades of index calculation (concerning NPI or other appreciation indices and markets):

- The problem should (nowadays) only affect the valuation portion associated with on-site property inspections, i.e. the material value. The results of on-site inspections are now better analyzed, documented and tracked (remotely) using digital technologies. The effects of ever-changing market conditions (interest rates, inflation, labor market, etc.) on all property values in the portfolio can be updated or simulated simultaneously as part of desktop valuations. The tenant pool can also be managed remotely and centrally to a large extent.
- The ratio of the substance values of properties to the land values has changed (in the metropolitan areas) over the decades of index calculation. The substance value, which can be determined locally by experts, may therefore have lost significant weight as a value component. The substance value changes slowly, is hardly volatile, and developments for individual properties are easier to predict than in the case of macroeconomic market conditions. Substance values relate more to the idiosyncratic value component of a property than to the market, so that their influence is largely diversified out in the index calculation. Substance values are positively correlated with land values, as investments in profitable properties in attractive regions are more likely to pay off.
- The number and market capitalization of the properties included in the calculations of the NPI index values has grown over time. Therefore, a subset of the index properties for which up-to-date values are available may already be representative of the market.<sup>18</sup>
- Temporal changes in market conditions (cf. the arguments in the context of appraisal smoothing) are also likely to change the non-synchronicity of valuations: The timeliness of real estate valuations may have a reciprocal relationship with transaction numbers and the dispersion of transaction prices.

Under these circumstances, up-to-date desktop valuations are likely to provide a highly accurate indication of the current property value.

### 3.2.6. Influence of combined smoothing phenomena and empirical evidence

Influences of a variety of smoothing causes are incorporated into the reported values for individual properties. These combined effects are also transformed during the cross-sectional aggregation of individual time series (or individual values for each point in time) of a mass of properties to calculate the index. The isolated effects of the smoothing phenomena on the properties (with a particular

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<sup>18</sup> The question of the extent to which specific appraisal-based indices over their entire history are representative of their market was not examined for this study.

focus on volatility as a measure of risk for an investment) of reported values for individual properties or valuation-based indices for a real estate market are therefore difficult to reconstruct. They can hardly be separated from other effects that influence the dynamics of market values.

Gohs (2014) examined the isolated and combined effects of the smoothing phenomena on reported values of individual properties and index time series as part of simulation studies. In doing so, he assumed different combinations of the effects of the NPI and the monthly UK-IPD. For the NPI scenario, it was shown that appraisal smoothing in isolation reduces the standard deviation of quarterly returns by 22.2% to 48.8%. When non-synchronous valuations are added (without stale appraisals), the quarterly standard deviation is reduced by 27.8% to 51.8%. If additional valuations from previous quarters (i.e. stale appraisals) are used to calculate current index values and seasonality is included in the valuations, the quarterly standard deviation is reduced further, by a total of -54.6% to -72.3%. However, the effects of the smoothing phenomena decrease with a higher periodicity of the time series. Therefore, for longer investment horizons, the presence of smoothing phenomena has a diminishing effect on the return measured using appraisal-based indices. The standard deviation of annual index returns is reduced by the combined smoothing phenomena (NPI scenario) by only 30.1% to 54.6%.

### 3.3. Unsmoothing procedures (correction procedures)

#### 3.3.1. Criteria for the choice of correction procedures

In literature, e.g. on the optimization of mixed portfolios with investments from different asset classes, the return series of appraisal-based real estate indices are used in their original form or corrected. Various criteria can play a role in the choice of a correction procedure:

- The plausibility of the presentation of the correction procedure and the results obtained from its application.
- The compatibility of the correction procedure with the appraisal-based index: On the one hand, this concerns the periodicity of the index time series. For example, the Firstenberg, Ross and Zissler (1988) and Fisher, Geltner and Webb (1994) unsmoothing procedures are suitable for quarterly index time series. For the present study, the NPI index returns were corrected in annual periodicity, although the NPI is updated quarterly. Secondly, compatibility concerns the smoothing phenomena influencing the index, which can vary depending on the (appraisal) circumstances in the country's markets.
- The user-friendliness of the correction procedure could be particularly relevant for users from the non-scientific field. In addition to the understandability (or complexity) of the correction procedure described in the literature, this also concerns the availability of any software to be used if an econometric method is to be used for the correction.

- The interests of the user regarding the presentation of the attractiveness of real estate investments. This is because the universe of correction procedures opens scope for shaping the characteristics of the corrected index returns received (cf. Gohs, 2014). If a provider of real estate wants to present it as a low-risk investment, it would select a “correction” procedure that hardly increases or even reduces the volatility of the corrected index returns compared to the original index time series.

Overall, it can be stated that the choice of a correction procedure does not only have to be aimed at obtaining true market returns. Furthermore, although the literature offers a certain selection of correction procedures, research on the quality of individual correction procedures and any selection rules derived from them for users is rare. This leaves users uncertainty about the true (latent) market returns.

### 3.3.2. Zero autocorrelation unsmoothing procedures

#### 3.3.2.1. *The Blundell & Ward correction procedure*

Blundell and Ward (1987) first presented a zero-autocorrelation unsmoothing procedure and applied it to the annual returns of the Jones-Lang-Wootton Index for UK commercial real estate.

The zero-autocorrelation unsmoothing procedures are based on the assumption of efficient processing of information in the corresponding real estate market. Accordingly, the market returns that cannot be measured directly are free of (significant) autocorrelation.<sup>19</sup> And all autocorrelation in the index time series representing the real estate market results from property valuation and index construction processes. The core of zero-autocorrelation unsmoothing procedures is therefore the extensive removal of autocorrelation from index returns.

Blundell and Ward (1987) regress index returns of annual periodicity on their past values lagged by one period. In doing so, the unsmoothing coefficient  $\hat{\beta}$  is estimated as the AR(1) parameter of an autoregressive model fitted to the index returns  $r_t$ :

$$r_t = \alpha + \beta r_{t-1} + \varepsilon_t$$

for all years  $t = 2, \dots, T$

The proportion equal to the value of the estimated regression coefficient  $\hat{\beta}$  of the respective preceding return values is then subtracted from the current return values,  $r_t - \hat{\beta} \cdot r_{t-1}$ . No corrected return value is obtained as a counterpart for the first return value  $r_{t=1}$  of the original time series due to the absence of a preceding value. Furthermore, the difference is weighed with the factor  $1/(1-\hat{\beta})$  so that the expected value of the corrected return series corresponds to that of the original. Blundell and Ward (1987) thus calculate the unsmoothed returns  $r_t^{BW}$  using the following correction rule:

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<sup>19</sup> Cf. Fama (1970, 1991) on information efficiency.

$$r_t^{BW} = \frac{r_t - \hat{\beta} \cdot r_{t-1}}{1 - \hat{\beta}}$$

where

- $r_t$  is the index return of the year  $t$
- $r_t^{BW}$  is the unsmoothed index return of the year  $t$
- $\hat{\beta}$  is the estimated unsmoothing coefficient

**This first correction method by Blundell and Ward (1987) is the focus of the present study.**

The expected values of the unsmoothed and original index returns are in the relationship

$$E(r_t^{BW}) = \frac{E(r_t) - \hat{\beta} \cdot E(r_{t-1})}{1 - \hat{\beta}} = E(r_t)$$

The following applies to the variance:

$$V(r_t^{BW}) = \frac{1 - \hat{\beta}^2}{(1 - \hat{\beta})^2} V(r_t)$$

#### 3.3.2.2. Notes on the Blundell & Ward correction method

The equality of the expected values of the BW-unsmoothed and the original return series presented by the equation above is consistent with the widespread assumption that the smoothing phenomena – as the term suggests – smooth volatility. The expected return is not changed by smoothing, and so it should not be changed by unsmoothing either.

The following correction methods proposed in the literature are often based on this principle or use a correction rule adapted (e.g. to the periodicity of the available index time series).

#### 3.3.2.3. The Firstenberg, Ross & Zisler correction procedure

Firstenberg et al. (1988) proposed a zero-autocorrelation unsmoothing procedure to fit an index published at quarterly frequency. This includes the adjustment of an autoregressive AR(4) model to the quarterly return series. If revaluations take place on a market on a quarterly basis and the index is updated on a quarterly basis, it makes sense to model these economic facts in the corresponding periodicity:<sup>20</sup>

$$r_t^{FRZ} = \frac{r_t - \sum_{q=1}^4 \hat{\beta}_q \cdot r_{t-q}}{1 - \sum_{q=1}^4 \hat{\beta}_q}$$

for all quarters  $t = 5, \dots, T$

#### 3.3.2.4. Notes on the Firstenberg, Ross & Zisler correction procedure

The autocorrelation structure of a time series can be processed (manipulated) more precisely with quarterly periodicity than with annual periodicity. Therefore, the result of Gohs et al. (2022) is

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<sup>20</sup> However, the effects of the non-synchronicity of the valuations would have to be formulated in working-day periodicity, in which the index is not available (cf. Gohs, 2014).

plausible that the volatility of the return series  $r_t^{FRZ}$  corrected with the procedure of Firstenberg et al. (1988) is still somewhat higher than the volatility of the index returns  $r_t^{BW}$  corrected with the Blundell & Ward (1987) method. Although, the increase factor of the volatility of the FRZ-corrected index returns related to the volatility of the original NPI returns is lower in annual periodicity (for which periodicity as well BW-unsmoothed returns are calculated) than in quarterly periodicity. This results from diminishing autocorrelation (including the influence of smoothing phenomena) in higher periodicity of an index time series.<sup>21</sup> It can therefore be assumed that the deviations in the results of the methods of Blundell & Ward on the one hand and Firstenberg et al. (1988) on the other are negligible for practice-oriented investment horizons.

#### 3.3.2.5. *The correction procedure of Fisher, Geltner & Webb*

Fisher et al. (1994) have also developed an unsmoothing procedure for appraisal-based indices with a quarterly periodicity. However, they only correct for the autoregressive terms of the first (previous quarter) and fourth (previous year's quarter) lags.<sup>22</sup> In doing so, they move away from the idea that all autocorrelation in the index results from valuation processes and index construction or that the true market returns are free of serial correlation. Fisher et al. (1994) explain the occurrence of first and fourth lag autocorrelation as effects of appraisal smoothing and the seasonality of revaluations. Further, Fisher et al. (1994) suggest correcting only the real component of the return series of an appraisal-based index, i.e. assuming non-predictability only for this component. They suggest reducing the index returns by inflation to obtain real returns. An AR(1,4) model is then fitted to these returns to estimate the parameters of the zero-autocorrelation unsmoothing procedure. After correcting the autocorrelation structure of the real returns, inflation is added back in. In addition, the authors propose a volatility adjustment of the corrected series, as discussed in the following section.

#### 3.3.2.6. *Notes on the Fisher, Geltner & Webb correction procedure*

Gohs (2014) argues that the real component of appraisal-based indices is nevertheless not obtained by deducting inflation (specifically logarithmic returns of a suitable consumer price index). Since surveyor value in nominal and not in real terms, the inflation component of the index time series is also distorted by the smoothing phenomena and does not correspond to inflation. Strictly speaking, the deviation of the index returns from inflation would therefore be corrected.

Another critical aspect of this approach is the implicit assumption that the performance of the real estate market includes inflation. And the choice of a suitable consumer price index is critical, as the

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<sup>21</sup> The analysis in a higher periodicity is consistent with an increased investment horizon.

<sup>22</sup> So they do not see any cause in possible autocorrelation to lags of two and three periods in the discussed smoothing phenomena.

development of asset values deviates from that of consumer prices.<sup>23</sup> Even if real estate investments offer inflation protection, consumer prices and asset values do not necessarily move in tandem but adjust to each other with a time lag. The results of this study show that the correlation between inflation and returns on direct investments in real estate is at most medium.

The pioneers Blundell and Ward (1987) compensate with the factor  $1/(1-\hat{\beta})$  when calculating corrected returns. In this way, they compensate for the change in the expected value of the expression  $r_t - \hat{\beta} \cdot r_{t-1}$  compared to that of the original return series  $r_t$ . This principle is also adopted by Firstenberg et al. (1988), who, however, consider the influences of all four preceding annual quarters via estimated AR(1,2,3,4) coefficients due to the correction of quarterly returns.

Fisher et al. (1994) do not follow this idea but weigh the resulting return series so that it has a volatility that corresponds to half the volatility of the country's stock market. Specifically, they rely on the Standard & Poor's 500 index.<sup>24</sup> The target volatility is set by multiplying by the factor  $\sigma_{S\&P} / 2\sigma_{r_t - \hat{\beta} \cdot r_{t-1}}$ . With this alternative approach, however, the expected value of the corrected index returns can deviate significantly from that of the original index returns. This contradicts the general view that the smoothing phenomena change the volatility of a time series (in addition to the autocorrelation structure) and at best only slightly change the expected value.<sup>25</sup> In addition, even minor changes in the arithmetic mean can lead to an index time series calculated from corrected returns drifting sharply away from the original index due to the accumulation of deviations (see figure 3 in Gohs et al. 2022). However, it is realistic to assume that the latent market values and appraisal estimates, or index values influence each other and are co-integrated.<sup>26</sup> Applications of the correction procedures of Fisher et al. (1994) and Cho et al. (2003) therefore provide little insight into the true market returns: The target volatility is imposed and the corrected (manipulated) index drifts. In addition, the half of the annual volatility of the Dow Jones index returns does not exceed the volatility of the NCREIF Appreciation Index returns in the period under consideration in this study. This can be seen at least for the overall period of the index time series and for the period up to 2007. Volatility would increase for the period of annual returns from 2010 to 2020. In this respect, the

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<sup>23</sup> Cf. Piketty (2014)

<sup>24</sup> It is assumed here that the authors use the term volatility to mean the standard deviation and not the variance.

<sup>25</sup> To avoid a change in the mean value, it is proposed here to correct the mean-adjusted return series and then add back the mean return when using a correction procedure with specification of the target volatility. This applies both to the procedure for correcting nominal returns and to correction procedures with differentiated treatment of real and inflation components.

<sup>26</sup> Cf. Wang (1998) who proposes a correction procedure based on cointegration relationships.

proposed volatility adjustment could lead to a reduction in the volatility of the corrected NPI returns compared to the original NPI returns. However, this contrasts with the majority view that volatility is reduced rather than increased by the smoothing phenomena.

The specification of a target volatility is also not unproblematic, as Fisher et al. (1994) call for an exclusive correction of the real component of the appraisal-based index. However, this would require complicated calculations of the volatility of the real component to obtain the target volatility of the nominal corrected returns. Gohs (2014) therefore proposes a correction procedure that incorporates the autocorrelation structure of inflation. But this procedure only changes the volatility of the real component so that the corrected nominal index returns adopt the target volatility.

Gohs (2014) and Gohs et al. (2022) compare various correction procedures. They also calculate a variant (referred to there as "FRZ-14") in which only the autocorrelation to the time lags of one and four periods is eliminated.<sup>27</sup>

For this study, however, it is considered plausible that both the specification of a target volatility and the exclusive correction of the real part of the index returns tend to (significantly) limit the range of results from the application of the correction methods. This was certainly also the intention, as the corrected index returns without inflation adjustment showed an unrealistically high volatility. Thus, the results using Blundell and Ward's weighting factor  $1/(1-\beta)$  should cover the plausible value ranges of the key figures (i.e. volatilities of a corrected return series and correlations).

### 3.3.3. Reverse engineering correction procedures

#### 3.3.3.1. *The correction procedures of Geltner and Barkham & Geltner*

Alternative correction procedures that do not require the assumption of an information-efficient market ex ante have been developed by Geltner (1993b) and Barkham and Geltner (1994) by means of "reverse engineering". This involves modeling the relationship between the reported values and their underlying non-directly observable market values of real estate. The "reverse engineering" correction procedures are then obtained by reversing these models. In both studies, complex relationships between appraisal estimates and market values are first established. In doing so, the authors consider the approaches used by appraisers in real estate appraisals and the effects of smoothing phenomena. By making suitable assumptions, however, the developers succeed in

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<sup>27</sup> In the descriptive statistics tables, the correction method is referred to as FRZ-14, i.e. in contrast to the Firstenberg et al. (1988) method, no autocorrelation to the lags of two and three periods is considered. In contrast to Fisher et al. (1994), neither a target volatility is specified nor is there a differentiated treatment of the real and inflation components of the index returns.

reducing these to a simple correction rule:<sup>28</sup> This includes the partial factoring out of autocorrelation. Essentially, a proportion of the return values from previous periods is subtracted from the current return values. This corresponds to the correction rule of Blundell and Ward (1987). The difference lies in the level of the unsmoothing coefficient used and its calculation. In both studies, the unsmoothing coefficient is derived from theoretical considerations about valuation practice in the respective country markets (UK and USA).

If the theoretically derived unsmoothing coefficient corresponds to the estimated AR(1) coefficient of the zero-autocorrelation method, the assumption of an information-efficient real estate market would be confirmed. In this case, the return series corrected using reverse engineering are largely free of autocorrelation. If it is smaller than the estimated AR(1) parameter of the BW method, this would support the assumption that market returns already contain autocorrelation.<sup>29</sup>

#### 3.3.3.2. *Notes on reverse engineering correction procedures*

Developers succeed in significantly reducing complexity and transferring the complex relationships between report values and market values into a simple correction rule. This is not only justified, but also necessary, as the imprecise information situation would not allow a complex model to be fed up with data.

However, the authors cannot provide a clear value for the remaining unsmoothing coefficient of their simple correction rule. Instead, Barkham and Geltner (1994) propose a range of values or two alternative unsmoothing coefficients that they consider plausible.

#### 3.3.4. Bond & Hwang: the consideration of the transformation of appraisal smoothing in the cross-sectional aggregation of individual time series for index calculation

##### 3.3.4.1. *The Bond & Hwang correction procedure*

Bond and Hwang (2007) developed analytical relationships between the reported returns of individual property assets or appraisal-based indices and their underlying latent market returns. The researchers considered the influences of appraisal smoothing and nonsynchronous appraisal. In addition, for the development of a correction procedure, they considered the fact that smoothing in

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<sup>28</sup> Suitable assumptions for reducing the complexity of the correction methods (in general, not just in relation to the Barkham and Geltner (1994) model) are sometimes necessary, as the detailed information for filling the models is not known.

<sup>29</sup> Incidentally, only positive unsmoothing coefficients are plausible. A coefficient of zero would mean that the original index time series is used. In the application, however, it cannot be ruled out that negative AR(1) coefficients are also estimated.

the index time series shows a different form than in the time series for individual property assets. They correct the quarterly time series of the NCREIF index for the USA and the monthly Investment Property Databank IPD for the UK.

The authors explain that the return series of individual real estate assets can be represented as ARMA processes. The AR term captures the appraisal smoothing and the MA term the non-synchronicity in the appraisals.<sup>30</sup>

However, the effects of appraisal smoothing are also transformed during index construction by cross-sectional aggregation of individual property time series. Therefore, the appraisal smoothing in index returns is captured by the parameter  $d$  of the fractional integration of a fitted ARFIMA(0,d,1) model.<sup>31</sup>

The fractional differentiation by the estimated parameter value  $\hat{d}$  then corresponds to unsmoothing, i.e. removing the effect of appraisal smoothing. After further correction of the effect of non-synchronicity in the valuations by removing the MA component, the series representing the market returns of an average property in the market is obtained.

If the user assumes a lack of information efficiency in the market, this can supposedly be considered by including AR terms, i.e. fitting an ARFIMA(p,d,1) model to the index returns.

#### 3.3.4.2. *Notes on the Bond & Hwang correction procedure*

A critical point is that the returns obtained by applying the Bond and Hwang (2007) correction method for various time series (ranges) sometimes show lower volatility than the original index returns. This contradicts the view predominantly held in the literature that appraisal smoothing causes a smoothing of the index time series.

The analytical relationships between market values and reported values at the level of an individual property on the one hand and the index for the whole market on the other are shown by Bond and Hwang (2007). The consideration of the changing effects of smoothing in the cross-sectional aggregation of individual time series for index calculation further increases the complexity of the model.

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<sup>30</sup> A detailed explanation of the phenomenon of non-synchronous property valuations can be found in Gohs (2014). At the level of an individual property, this corresponds to non-equidistant valuations.

<sup>31</sup> Most of the literature holds the view that the return series of appraisal-based indices are smoothed in relation to the true market returns, i.e. their volatility is reduced by the smoothing phenomena. Accordingly, the correction procedures are often referred to as "unsmoothing procedures". In fact, they commonly cause an increase in the volatility of the unsmoothed return series. However, Bond and Hwang (2007) achieve corrected return series with their procedure that have a lower volatility than the original time series. In this paper, I use the term "unsmoothing procedure" rather in the context of the "zero-autocorrelation" procedures, which cause a significant increase in volatility, and in general the term "correction procedure".

However, the autocorrelation of market values (in the absence of information efficiency) is already overlaid at the level of individual real estate assets by the autocorrelation arising in appraisal processes. Subsequent separation of the two combined and in the index transformed effects by cross-sectional aggregation is critical. The temporal and spatial dynamics in the possibly mutually dependent market values and reported values would also make it difficult to separate the two effects retrospectively and to identify orders of magnitude.

In general, the estimation of the fractional integration coefficient is very sensitive and requires an even longer time series (preferably 200 observations) than the adjustment of simple ARMA models (approx. 30 observations).

Bond and Hwang (2007) explain that the random arrival of information is modeled using Weibull distribution. They transfer this to the modeling of non-synchronous appraisal days. However, appraisals are not purely random but planned events. In the IPD, the appraisers are given leeway for appraisals of several working days. Gohs (2014) assumes that the appraisers perform valuations evenly distributed over their working days.

### 3.3.5. Regime switching in the real estate market and appraiser behavior

#### 3.3.5.1. *The correction procedures of Chaplin and Lizieri, Satchell & Wongwachara*

Real estate markets are subject to the changing market conditions of economies, which are reflected in index time series with such a long history as the NPI (since the end of 1977). Chaplin (1997) proposed a correction method that takes multiple regimes into account. He bases this on changing market conditions and shows how, according to Quan and Quigley's model, the unsmoothing coefficient changes depending on "market noise" and "transaction noise". Chaplin (1997) gives thresholds and unsmoothing parameters for several regimes and discusses effects on asset allocation. Lizieri et al. (2012) explain that regime switching can affect not only the dynamics of market values, but also the appraiser behavior (adapted to the market). They therefore propose model variants that can in principle capture both types of regimes.

#### 3.3.5.2. *Notes on the correction procedures of Chaplin and Lizieri, Satchell & Wongwachara*

It makes sense to consider the dynamics of the market as well as the adjusted behavior of appraisers (due to changed market conditions or other causes). However, the changes over time can take all possible courses; instead of abrupt (regime) changes, gradual changes may emerge, especially in the case of adapted appraiser behavior. It is also assumed here that structural breaks are more likely to occur in the market and that there are hardly any regime switches. Structural breaks are often obvious at times of historical events. Regime switches tend to require a well-founded explanation.

However, these correction procedures considering switching regimes adopt the basic principle of Blundell and Ward's (1997) simple correction rule, too. Only different unsmoothing coefficients are derived for the various regimes. For this study, it was obvious to analyze the two time periods of the NCREIF time series before and after the peak of the financial crisis. Firstly, because of the significant peaks in 2008 and 2009, which caused an interruption in the time series. Secondly, due to the changed market conditions before and after this event, particularly the loose monetary policy of the central banks after the peak of the financial crisis. On the one hand, the impact in the two years itself influences the estimated parameter values when fitting a time series model to the overall time series. On the other hand, the analyses for both sub periods show differences in the estimated coefficients due to the changed market conditions.

### 3.4. Evaluation of correction procedures

Up to now, attempts have been made to prove the quality of correction procedures by comparing the characteristics (particularly volatility) of the corrected index time series with those of the original index time series. Academic papers have also presented the trends of the index time series calculated from the corrected returns. It has been argued that these match the timing of historical events better than the original indices.

Gohs (2014) simulated the influences of various smoothing phenomena on time series using random processes. He then treated the manipulated time series with various correction methods. He found that both the standard deviations of the manipulated series and those of the subsequently corrected series deviated considerably from the original ones.

Gohs et al. (2022) have shown that unstable results are obtained when some correction procedures are applied to different (rolling or growing) time series sections. Specifically, the standard deviation of the corrected time series sometimes changes abruptly if the time series section is changed slightly. If new index values are published and the extended index time series is corrected, the corrected values for previous periods would often be completely different. However, the true market returns must be unchanged.

According to Gohs et al. (2022), there is a general need for further studies on the quality of correction methods.

#### 4. Time series data and discussion of descriptive statistics

The NCREIF Property Index (NPI) represents the United States commercial real estate market. Index values are published on a quarterly basis. The first index value relates to the end of the fourth quarter of 1977, while the last index value included in the study relates to the end of the fourth quarter of 2020. This study focuses on the appreciation component of the NPI, which is intended to reflect the performance of properties and is compiled from appraisal estimates. The index component of rental income is not considered here.

The 43 value change returns of the NPI for the years 1978 to 2020 are corrected using the method of Blundell and Ward (1987). No predecessor value is available for the correction of the first return value of the NPI time series; accordingly, no counterpart of the Blundell and Ward ('BW')-corrected return series exists. Therefore, BW returns are obtained for the years 1979 to 2020 as well as corrected index values for the years 1978 (=100) to 2020.

In addition, an alternative method of correcting annual returns was used, in which the standard deviation of the unsmoothed time series is specified as 10 percent ('Vola10'). The specification also changes the mean and quantile values compared to the properties of the BW returns, but not the autocorrelation structure of the corrected time series or its correlation with other time series (see table 1.1).

Pairwise Pearson correlation coefficients were calculated between the returns of the original or unsmoothed NPI Appreciation Index on the one hand and each time series listed below on the other hand:

- US Dow Jones Industrials Share Price Index (EP) NADJ
- US CPI - All Urban: All Items SADJ
- FTSE NAREIT All REITs \$ - Total Return Ind.
- US Yield 10-Year Government Bonds NADJ

Descriptive statistics for the annual returns of the index time series are also given in Table 1.1 (in percent in each case).

Due to the strong impact of the financial crisis on returns in 2008 and 2009 and possible changes in market conditions thereafter, analyses are also carried out for the two sub-periods of the years before (1979 to 2007) and after (2010 to 2020) (see Tables 2.1 and 3.1). Due to the loss of the first return value, only BW-corrected return values for the years 2011 to 2020 are available for the later sub-period.

Over the entire period (1979 to 2020), the standard deviation of the corrected BW returns ( $12.374/7.095=$ ) is 1.74 times as high as that of the NPI returns. The factor ( $18.954/6.011=$ ) 3.15 is calculated for the sub-period before the financial crisis (1979 to 2007) and the factor ( $8.648/3.153=$ )

2.74 for the sub-period afterwards (2011 to 2020).<sup>32</sup> The autocorrelation of NPI returns to time lags of up to three years is significantly higher in the period before the financial crisis (0.768, 0.447, 0.151) than over the entire period (0.496, -0.005, -0.132) and thereafter (0.398, 0.215, 0.135). In addition to the break in the time series at the height of the financial crisis, this could also be due to increased market efficiency afterwards. The changed characteristics (volatility, mean values, autocorrelation structure) of the time series included in the study, in addition to the break itself, argue for a separate analysis of the two sub-periods. However, the number of observations in the period after the peak of the financial crisis is very low, so the quality of the results is questionable. In addition to the NPI time series, inflation also exhibits a high autocorrelation. In the case of inflation, however, a higher persistence is observed for the overall period (0.666, 0.364, 0.169) than for the earlier sub-period (0.657, 0.312, 0.105). Thereafter, the time series shows a significantly lower autocorrelation (0.236, -0.155, -0.387). The volatility of inflation decreased in the period from 2011 to 2020 (0.784% compared to 2.678%). However, the CPI tends to reflect the development of consumer prices. The development of asset prices can deviate from that of consumer prices both in individual periods and in the long term (i.e. also on average).

The index returns of the Dow Jones and the REITs show hardly any autocorrelation over the entire period and the previous period. This supports the assumption of efficient information processing on the US capital markets. For the period 2010 to 2020, both the Dow Jones (-0.466) and the REITs (-0.450) show a negative autocorrelation with a time lag of one year.

The NPI returns are strongly correlated with their unsmoothed BW counterparts, particularly over the entire period (0.861) and over the period after the peak of the financial crisis (0.853). For the earlier sub-period, the correlation is not quite as strong (0.595); this is consistent with the high (removed) autocorrelation (0.768, see above). Over the entire period, returns on direct investments in real estate are weakly correlated with bond returns (NPI: 0.149, BW: 0.138). When looking at the sub-periods before (NPI: 0.268; BW: 0.289) and after (NPI: 0.374; BW: 0.351) the financial crisis, a somewhat stronger correlation between real estate investments and bonds is observed. A weak to medium-strong correlation can be observed between direct investments and REITs for the overall period (NPI: 0.268; BW: 0.438) and for the period after the financial crisis (NPI: 0.393; BW: 0.219). The two investment classes are hardly correlated over the earlier sub-period (NPI: 0.052; BW: 0.224). REITs and equities have a medium correlation (0.47). Without taking the two crisis years into account, the correlation is lower and roughly the same in both sub-periods (before: 0.251, after: 0.29).

Considering the results from applying the correction procedure of Bond and Hwang (2007), it can be seen that the standard deviation of 6.574% of the corrected index returns is lower than that of the

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<sup>32</sup> Cf. Gohs et al. (2022).

original NPI (7.05% for the years from 1978 to 2020 and the ARFIMA(0,d,1) model with  $\hat{d} = 0.4537$  and  $\hat{\theta} = -0.255$ ). However, if the fractional integration parameter is varied and the MA parameter is kept constant, the standard deviation would not increase above 12.758%. When fitting an ARFIMA(0,d,0) model with  $\hat{d} = 0.4914$ , a standard deviation of 7.3% is received. When varying the parameter d, this does not rise above 13.86% (for d = 0). For the ARFIMA(4,d,1) with  $\hat{d} = 0.0000534$  and  $\hat{\theta} = -0.5281$ ), a standard deviation of 6.6411% is obtained. This means that even with exceptional parameterization of the ARFIMA model, the calculated standard deviation of manipulated NPI returns does not exceed 12.758% to 13.86%. This corresponds approximately to the standard deviation of 12.404% calculated in the present study when unsmoothing using the Blundell & Ward procedure and the standard deviation of 13.37% reported by Gohs et al. (2022) for the NPI returns corrected using the Firstenberg et al. (1988) procedure.

## 5. Study

### 5.1. Design

Several of the correction procedures proposed in the literature in core are based on the correction rule of Blundell and Ward (1987):

$$r_t^u = \frac{r_t - \beta \cdot r_{t-1}}{1 - \beta}$$

They differ in the determination of the coefficient value  $\beta$  for calculating the corrected  $r_t^u$  from the original index returns  $r_t$ . For this study, it was investigated how the properties (including volatility) of the unsmoothed index time series change when the unsmoothing parameter  $\beta$ , starting from the value zero (corresponding to the original index time series), is successively increased (with a step size of 0.01) up to the value (rounded to the second decimal place) of the estimated AR(1) coefficient  $\hat{\beta}$  of an autoregressive model adjusted to the annual return series (corresponds to the Blundell and Ward (1987) unsmoothing procedure). For comparison purposes, corrections were made according to Bond and Hwang (2007). The fractional integration parameter d was estimated on the one hand and successively changed between 0 and 1 on the other. The estimated MA parameter value  $\hat{\theta}$  was kept constant. The results show a range of possible values of the standard deviation, the mean, the median and the autocorrelation remaining in the time series (for the time lag of one period) of the market returns that are not directly observable. Correlations of the index returns of direct investments in commercial real estate on the US market with index returns of bonds, equities, REITs and inflation are also shown. If users believe in pre-existing autocorrelation in the latent market returns (i.e. a non-information-efficient real estate market), it is possible to further narrow the value ranges of statistical measures for plausible unsmoothing coefficients. Users can use these plausible

values directly for investment decisions. It is not necessary to deal with the details of different correction methods. If users nevertheless apply a correction procedure, it is possible (for the plausibility check) to compare the resulting statistical key figures with the value ranges presented here.

## 5.2. Software

The calculations were carried out using the free software R.

The AR(1) models were estimated based on the maximum likelihood (ML) function. Alternative R functions for estimating parameters were also run; no deviations were found or only in the second decimal place of the estimated parameter values.

# 6. Description and interpretation of the results

## 6.1. Time series properties

### 6.1.1. Blundell & Ward scenarios

For increasing unsmoothing coefficients in the interval  $\beta \in [0, 0.51]$ , corrected return series were calculated (successively with a step size of 0.01) and Figure 1.1 was plotted: The front edge shows the original return series (corresponding to  $\beta = 0$ ), in the z-coordinate direction the unsmoothing parameter increases up to the value  $\beta = 0.51$  (corresponding to  $\hat{\beta}$  of the Blundell & Ward procedure). Corresponding calculations and illustrations were carried out for the time periods 1979 to 2007 ( $\hat{\beta} = 0.82$ , Figure 2.1) and 2011 to 2020 ( $\hat{\beta} = 0.73$ , Figure 3.1). As can be seen in Figures 1.1, 2.1 and 3.1, among others, the corrected return series change increasingly with increasing unsmoothing coefficients and a strong approximation to  $\hat{\beta}$ . Changes are particularly evident at extreme return values and turning points. This is also shown in Figures 1.2, 2.2 and 3.2 of the index values calculated from the returns. For the index calculations, the first index value for the end of 1978 (or 2010 in Figure 3.2) was set to 100. The front edge in Figures 1.2, 2.2 and 3.2 shows the original index time series, while the rear edge shows the BW-unsmoothed index time series. When calculating the index for the entire period, (corrected) index values in the range between 182.03 and 200.16 were received for 2020. This deviation of 10% is acceptable in relation to the overall period of over 40 years. It is also partly due to the situation at the current margin, i.e. the coronavirus year. This is also relevant, as a suitable correction procedure should meet the requirement of producing plausible results. This includes ensuring that the corrected time series does not increasingly diverge from the original time series.<sup>33</sup> In addition, literature predominantly holds the view that the average return is not or only insignificantly changed by smoothing phenomena. This should also be reflected in the accumulated

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<sup>33</sup> Wang (1988) assumes a cointegration relationship between reported returns and market returns.

index values. The level of the unsmoothing coefficient or, from the other perspective, the smoothing phenomena therefore have a limited impact: Depending on the level of the unsmoothing coefficient, the allocation of market changes to periods does vary, but there is an equalization over time. Particularly for long investment periods and for purchases and sales of the investment during quiet market phases (i.e. not during strong swings or at market turning points), the changes in value shown are hardly dependent on the selected unsmoothing coefficient. This means that the original index time series can simply be used.

The changes in relevant time series properties of the NCREIF Appreciation Index were also analyzed with increasing unsmoothing, i.e. an increase in the unsmoothing coefficient from  $\beta = 0$  (corresponds to the original time series) to  $\beta = \hat{\beta}$  (corresponds to the BW-unsmoothed return series) (see Tables 1.2, 2.2 and 3.2 as well as Figures 1.3 to 1.5, 2.3 to 2.5 and 3.3 to 3.5):

Over the entire period, the standard deviation of the NPI returns is 7.1% and rises progressively to 12.4% with the level of the de-smoothing coefficient in the interval between 0 and 0.51. However, it is plausible to assume that the commercial real estate market is not information efficient. Market returns should already be autocorrelated due to high transaction costs. If autocorrelation in the index is only partially caused by smoothing in valuation processes, only a portion would have to be deducted. If a plausible unsmoothing coefficient  $\beta < 0.4$  is assumed, the standard deviation of the true market returns is between 7.1% and 10.2%. If a higher unsmoothing coefficient is selected, the autocorrelation remaining in the time series decreases at slightly increasing rates and almost proportionally. The autocorrelation is not completely eliminated even when using the Blundell & Ward method (i.e. with  $\beta = \hat{\beta} = 0.51$ ).

When looking at the time series section before the financial crisis, starting from a standard deviation of the original time series of 6%, this is increased to 19.2% when the unsmoothing coefficient is increased ( $\hat{\beta} = 0.82$ , Table 2.2, Figure 2.3). If existing serial correlation is assumed in the market returns, the plausible value range of the standard deviation can be significantly narrowed down. For example, the volatility is at most 9.3% if a plausible unsmoothing coefficient of less than 0.6 is selected.

In the years following the peak of the financial crisis (2011 to 2020), the standard deviation of the NCREIF returns is 3.2% and 8.8% for the Blundell & Ward unsmoothing coefficient ( $\hat{\beta} = 0.73$ , Table 3.2, Figure 3.3). If a plausible unsmoothing coefficient between 0 and 0.6 is selected, the standard deviation is below 6.1% (Table 3.2). If a BW unsmoothing coefficient of 0.73 is selected, the autocorrelation remaining in the time series becomes negative.

As Figures 1.3, 2.3 and 3.3 show, the standard deviation of the corrected index returns is between 0 and  $\hat{\beta}$  in an interval constrained by the volatilities of the original and BW-corrected index returns for

any given unsmoothing coefficient. Figures 1.4, 2.4 and 3.4 show the same for the arithmetic mean. However, the median also lies partly outside the interval spanned by the values at the edges. Over the entire period, the average annual return on value change on the real estate market according to the NPI is 1.65%. It falls at increasing rates to 1.43% as the unsmoothing coefficient increases (Figure 1.4). The plausible value range of the arithmetic means of annual returns on real estate investments can be narrowed down to 1.65 to 1.56, for example, if inertia in the processing of information on the market is assumed (unsmoothing coefficient 0 to 0.3). In relation to the long index history or a long investment period or high investment volumes, even this small range can have a significant impact on the assessment of the average change in value on the market.

For the subperiod before the financial crisis, it can be seen (Figure 2.4) that the arithmetic mean increases progressively with the size of the unsmoothing coefficient, starting from 2.2% according to the original NPI time series to 2.6% when the BW coefficient is chosen. For the period from 2011 onwards, the arithmetic means decreases progressively from 3.7% of the original returns to 1.4% with Blundell & Ward unsmoothing. This high range must be interpreted considering the low number of annual values and the market movement at the current margin (corona crisis in 2020). The standard deviation and arithmetic mean thus change with the level of the selected unsmoothing coefficient at absolutely increasing rates. They therefore change only slightly with already high autocorrelation in the market returns due to the additional influences of the smoothing phenomena. From the other perspective, the volatility of the time series is hardly increased when a low unsmoothing coefficient is applied. However, if information efficiency prevails on the real estate market in the initial state, the volatility would be significantly reduced even if a low serial correlation arises due to transaction costs or the smoothing phenomena. Again, from the other perspective, volatility is only significantly increased during unsmoothing if the coefficient is close to that estimated by applying the Blundell and Ward method.

The calculated skewness of the return distributions for the analyzed time series sections is negative (Table 1.2, 2.2, 3.2 and Figures 1.5, 2.5, 3.5). The kurtosis of the overall time series and the earlier time series section is greater than 3. For the returns from 2011 to 2020, the kurtosis is less than 3.

Depending on the size of the unsmoothing coefficient, the skewness and the kurtosis are also partly outside the ranges spanned by their respective values for the unsmoothing coefficients 0 and  $\hat{\beta}$ . The autocorrelation remaining in the return series to the time lag of one year decreases with decreasing rates as the volatility increases due to unsmoothing (Figure 1.6).

With extensive unsmoothing using BW, autocorrelation remains in the corrected return series for the entire period (Figure 1.3). This remaining autocorrelation is high for the returns of the earlier period

(0.319, Table 2.2, Figure 2.3) and negative for those of the later subperiod (-0.057, Table 3.2, Figure 3.3).

#### 6.1.2. Scenarios when a target volatility is specified

If the volatility of the corrected returns is set (here at 10%), the mean and median are also changed compared to the calculations according to the Blundell & Ward correction method (Table 4.2). If the standard deviation of 10% is used for the BW correction, the range of the arithmetic mean values and the calculated index values are reduced (see Tables 4.2 and 1.2). However, the range of the medians calculated for all possible unsmoothing coefficients increases. Skewness and kurtosis do not change. The correlations described below also remain unchanged when the target volatility is set compared to the strict correction according to Blundell & Ward.

### 6.2. Correlations of asset returns

#### 6.2.1. REITs

The return correlation between direct real estate investments and REITs is weak to medium. Over the entire period, the correlation of REIT and NPI returns is  $\rho = 0.268$  and increases with the level of the selected unsmoothing coefficient at slightly decreasing rates, i.e. approximately linear. For a de-smoothing coefficient of 0.51 according to Blundell & Ward, a correlation of  $\rho = 0.438$  is obtained. A correlation of  $\rho = 0.052$  is calculated for the earlier sub-period up to 2007, which also increases approximately linearly to  $\rho = 0.224$  for  $\beta = 0.82$ . For the years 2011 to 2020, a medium-strong correlation coefficient  $\rho = 0.393$  is again calculated for the NPI returns with REITs. As the de-smoothing factor increases to  $\beta = 0.73$ ,  $\rho$  falls to 0.217. Using the correction method of Bond & Hwang (2007), a medium-strong correlation coefficient  $\rho = 0.48$  (ARFIMA(0,d,1) with  $\hat{d} = 0.4537$  and  $\hat{\theta} = -0.255$ ) is estimated. A weak ( $\rho = 0.212$ ) to medium-strong ( $\rho = 0.547$ ) correlation is calculated across all possible fractional integration parameters  $d$  (between 0 and 1) and when the MA coefficient is kept constant. Overall, uncertainty about the true correlation results not only from not knowing the influence of smoothing, but also from possible changes in the correlation over time. Due to the consideration of the different time series sections and plausible unsmoothing coefficients, it seems reasonable to use a value range of the correlation coefficient rather than a point value, e.g.  $\rho = [0.22, 0.45]$ , when considering portfolio diversification.

#### 6.2.2. Stocks

The correlation between direct real estate investments and equities is weak at best. No linear correlation is found between NPI and Dow Jones over the entire period, precisely  $\rho = 0.079$ . However, the calculated correlation increases almost linearly with the unsmoothing coefficient  $\beta$  to  $\rho = 0.177$ . For the early period up to 2007, a correlation between Dow Jones and NPI index returns between

$\rho = -0.058$  and  $\rho = -0.075$  is calculated. For the more recent time range of returns from 2011 onwards, a weak negative correlation is calculated, which varies slightly between  $\rho = -0.204$  and  $\rho = -0.184$ . For selected  $\beta$  it lies slightly outside the interval spanned by the correlation coefficients at the points  $\beta = 0$  and  $\beta = \hat{\beta}$ . The NPI returns corrected according to Bond & Hwang support the result of a weak correlation ( $\rho = 0.23$  for the ARFIMA(0,d,1) model with  $\hat{d} = 0.4537$  and  $\hat{\theta} = -0.255$ ) between equities and direct investments in real estate.

### 6.2.3. Inflation

Returns on real estate assets are (at times) weak to moderate or not at all correlated with inflation. Over the entire period, NPI returns correlate weakly with inflation ( $\rho = 0.273$ ). For increasing unsmoothing coefficients up to  $\beta = \hat{\beta} = 0.51$ , the correlation decreases with slightly increasing rates and almost linearly up to  $\rho = 0.159$ .

Over the earlier period up to 2007, a medium-strong correlation  $\rho = 0.351$  is calculated for the NPI returns with inflation. This decreases with increasing rates as the unsmoothing coefficient increases to  $\rho = 0.088$  for  $\beta = 0.82$ . For the later period from 2011 to 2020, the returns on direct investments in real estate are not correlated with inflation. The calculated correlation coefficient barely increases from  $\rho = -0.013$  for  $\beta = 0$  to  $\rho = -0.005$  for  $\beta = 0.73$ . The application of Bond & Hwang's correction method would also confirm at best a weak correlation ( $\rho = 0.156$  for the ARFIMA(0,d,1) model with  $\hat{d} = 0.4537$  and  $\hat{\theta} = -0.255$ ) between inflation and direct investments in real estate. The assumption that direct investments in real estate serve as a hedge against inflation is more likely to be confirmed for the earlier period (and only if a low unsmoothing coefficient is assumed or, from the other perspective, if already a high autocorrelation in market returns is assumed). However, the consumer price index reflects consumer prices and not necessarily changes in asset values.

### 6.2.4. Long-term government bonds

Over the entire period, the returns on direct investments in real estate correlate weakly with those on bonds. They hardly vary between approximately  $\rho = 0.15$  and  $\rho = 0.138$  across all possible unsmoothing coefficients. Applying the Bond & Hwang correction method would produce a similar result ( $\rho = 0.171$ ). Over the earlier time range of the years up to 2007, the correlation ranges between  $\rho = 0.268$  and approximately  $\rho = 0.313$ . For the period from 2011 to 2020, correlation coefficients between approximately  $\rho = 0.379$  and  $\rho = 0.35$  are calculated for various unsmoothing coefficients  $\beta$ . Overall, the results indicate a weak to medium-strong correlation between bond returns and those of direct real estate investments. Although the correlation coefficient hardly depends on the selected unsmoothing coefficient, it does change over time. Significantly lower correlation coefficients were calculated for the overall period covering the two years 2008 and 2009. This could be interpreted

positively in terms of a diversification effect if bonds and real estate assets did not lose ground in tandem over the two years.

## 7. Summary

Market conditions and the (adjusted) weighting of information in real estate appraisals change over time. Index construction also changes over the decades due to technological progress in data collection, processing, etc. and the changing effects of smoothing phenomena. The weights of these various dynamics change. The possibility of uncovering latent market returns therefore appears unrealistic, even with the use of sophisticated time series analysis methods.

The study proposes considering (plausible) value ranges for time series characteristics such as volatility and asset correlations. This approach is intended to support market participants in assessing the attractiveness of real estate investments and in diversifying portfolios with mixed asset classes. This overcomes the uncertainty inherent in deciding on (only) one specific correction procedure or selecting a point value as an unsmoothing coefficient. If correction procedures are nevertheless used, the consideration of a plausible range of values offers an opportunity to classify or compare the results achieved.

There are alternative ways of dealing with the results presented here. For example, studies that provide information on the reduction in volatility can also be used as a guide. If, for example, the estimate by Gohs (2014) is followed that the combined smoothing phenomena reduce the annual standard deviation of NPI returns of 7.095% stated there by 30% to 54.6%, a volatility of market returns of 10.14% to 15.63% would be concluded. Then the tables and figures in this paper can be used for plausibility checks. If the user believes in the BW correction formula, the other time series properties and asset correlations can also be read accordingly.

Starting from the original return series, the volatility initially changes only slightly when the selected unsmoothing coefficient is increased. However, the volatility of the corrected time series increases disproportionately (i.e. at increasing rates) with the level of the unsmoothing coefficient. The slope is highest for the unsmoothing coefficient that corresponds to the estimated  $\hat{\beta}$  from the Blundell & Ward correction procedure, i.e. for market efficiency.

If the market efficiency hypothesis is rejected and existing autocorrelation in the market returns is suspected, it is possible to remove autocorrelation that only corresponds to a proportion of the estimated BW unsmoothing coefficient  $\hat{\beta}$ . If, for example,  $\hat{\beta} = 0.51$  is estimated (as determined for the overall time series), but an unsmoothing coefficient in the interval  $\beta \in [0; 0.4]$  is assumed due to autocorrelation already present in the market returns, the plausible value range of the standard deviation of market returns can be narrowed down considerably.

If index returns are available with a quarterly or even lower periodicity, even finer manipulation of the autocorrelation structure is possible.<sup>34</sup> This means that with the market efficiency assumption, there is still scope for shaping volatility via the selection of the correction procedure. Gohs et al. (2022) obtain a standard deviation of 2.03% for the NPI returns in quarterly periodicity. Using the Firstenberg et al. (1988) unsmoothing procedure, the volatility is 6.05%. Thus, the quarterly standard deviation of the corrected FRZ returns is higher by a factor of 2.98 ( $= 6.05 / 2.03$ ). If only the autocorrelation to the lags around the previous quarter and the previous year's quarter is removed, the volatility is 5.16% (factor 2.54  $= 5.16 / 2.03$ ),<sup>35</sup> with the Fisher, Geltner & Webb method it is 3.94% (factor 1.94). When analyzing the return series with an annual periodicity, a standard deviation of 7.05% is calculated for the NPI. For the Blundell and Ward (1987)-corrected returns, the standard deviation is 12.37% (factor 1.75). The annual standard deviation of the returns corrected in quarterly periodicity according to the method of Firstenberg et al. (1994) is 13.37% (factor 1.9). The annual standard deviation of the FRZ-14 variant is 12.36% (factor 1.75) and that of the FGW method is 9.87% (factor 1.4). The slightly higher volatility of the FRZ-corrected returns compared to the BW-corrected returns results from the more precise processing of the return series in quarterly compared to annual periodicity.

As can be seen from the figures, even the introduction of low autocorrelation would significantly reduce volatility in an initial state of prevailing information efficiency. Due to the high transaction costs in real estate markets, it would be plausible if (even with an otherwise high level of efficiency) a certain degree of autocorrelation is not reduced. In addition, there are costs for time spent on personnel (research costs, marketing, contract negotiations, etc.). The consideration of short-term investment periods and serial correlation when analyzing quarterly return series therefore loses relevance for realistic transaction plans. At higher periodicity, however, the autocorrelation decreases regardless of its source (inertia in information processing or induced by smoothing phenomena). This means that the effects of appraisal smoothing on the autocorrelation structure of the reporting values also disappear at higher periodicity. If transactions take place in tranquil market phases and assets are held over a longer period, the chosen unsmoothing coefficient has less impact, so the original index can be used to assess performance.

Regarding the correlation of returns on direct investments in real estate with other asset classes or inflation, there is also a lack of clarity. However, this results not only from the choice of a suitable unsmoothing coefficient, but also from changes in market conditions over time. In addition,

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<sup>34</sup> It would make sense to correct a time series in the periodicity and at the level at which the errors occur, provided the details for a corresponding correction were known.

<sup>35</sup> process variant referred to as FRZ14 in Gohs et al. (2022)

autocorrelated time series also produce a range of results for different investment horizons. Overall, intervals rather than point values of plausible volatilities, mean values and correlation coefficients should be considered for portfolio diversification. The dynamic changes in market conditions over time (including market efficiency), investment horizon and plausible unsmoothing coefficients should be considered in a common context for investment decisions.

The study provides general insights into information efficiency on markets. The inflation time series was also smoothed as an example. Volatility is highest with (approximate) market efficiency. Even the introduction of low autocorrelation causes a significant reduction in volatility. This means that in an approximately efficient market, the introduction or change of autocorrelation (e.g. through marginal changes in transaction costs) significantly changes volatility. This means that even barely perceptible friction in the market may cause continuous changes in volatility over time and support the formation of volatility clusters. It is plausible that (temporary) serial correlation arises when appraisers (or market participants in general) look back, for example to reduce uncertainty by considering past values.

In future, innovative investment vehicles based on digital technologies, among other things, may enable the pro rata acquisition with rapid settlement of (heterogeneous) assets such as individual properties or works of art. It remains to be seen how innovations can generate high-frequency market data and increase efficiency.

## 8. Appendix

### I. Time series: years 1978 to 2020

#### I.1. Overview

**Table 1.1 Descriptive Statistics of Annual Index Returns from 1979 to 2020**

	CPI	LTGvtBds	Dow	REITs	NPI	BW	Vola10
<b>Std.Dev.</b>	2,483	22,657	13,764	16,540	7,095	12,374	10,000
<b>Mean</b>	3,220	-5,533	8,662	11,177	1,652	1,427	1,492
<b>Min.</b>	0,400	-73,105	-41,305	-44,519	-24,964	-38,485	-30,764
<b>25%-Q.</b>	1,862	-18,489	2,147	3,268	-0,801	-1,679	-1,018
<b>50%-Q.</b>	2,589	-5,579	10,827	11,130	2,600	2,138	2,067
<b>75%-Q.</b>	3,570	7,347	19,746	23,091	6,120	7,289	6,230
<b>Max.</b>	11,904	47,584	28,857	34,302	12,012	38,027	31,071
<b>ACF-Lag1</b>	0,666	-0,054	-0,132	-0,005	0,496	0,162	0,162
<b>ACF-Lag2</b>	0,364	-0,220	-0,054	-0,182	-0,005	-0,265	-0,265
<b>ACF-Lag3</b>	0,169	-0,044	0,187	-0,064	-0,132	-0,115	-0,115
<b>Cor-CPI</b>	1,000	0,304	-0,090	0,063	0,273	0,160	0,160
<b>Cor-Bonds</b>	0,304	1,000	0,029	0,054	0,149	0,138	0,138
<b>Cor-Dow</b>	-0,090	0,029	1,000	0,470	0,079	0,177	0,177
<b>Cor-REITs</b>	0,063	0,054	0,470	1,000	0,268	0,438	0,438
<b>Cor-NPI</b>	0,273	0,149	0,079	0,268	1,000	0,861	0,861
<b>Cor-BW</b>	0,160	0,138	0,177	0,438	0,861	1,000	1,000

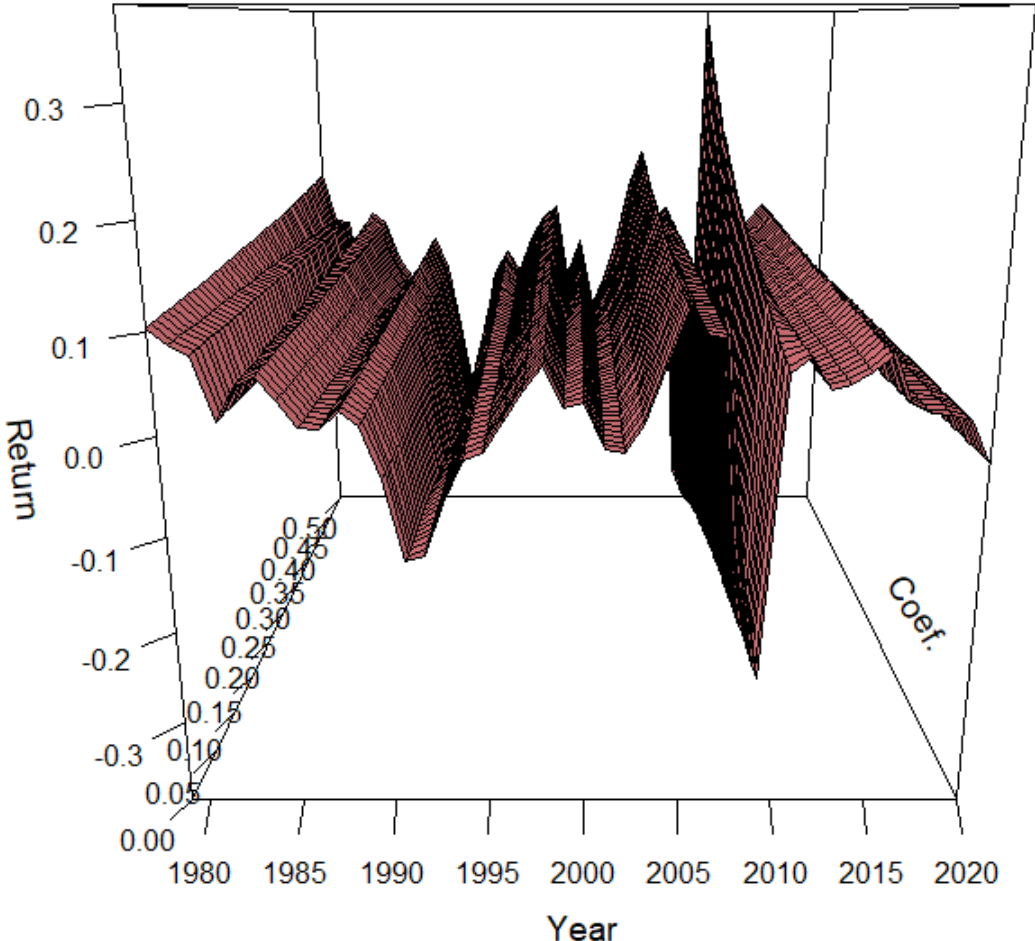
An AR(1) coefficient of  $\hat{\beta} = 0.5088$  is estimated for the annual returns.

**Table 1.2 Characteristics of the corrected time series depending on the unsmoothing coefficient  $\beta$  - Annual returns 1979 to 2020**

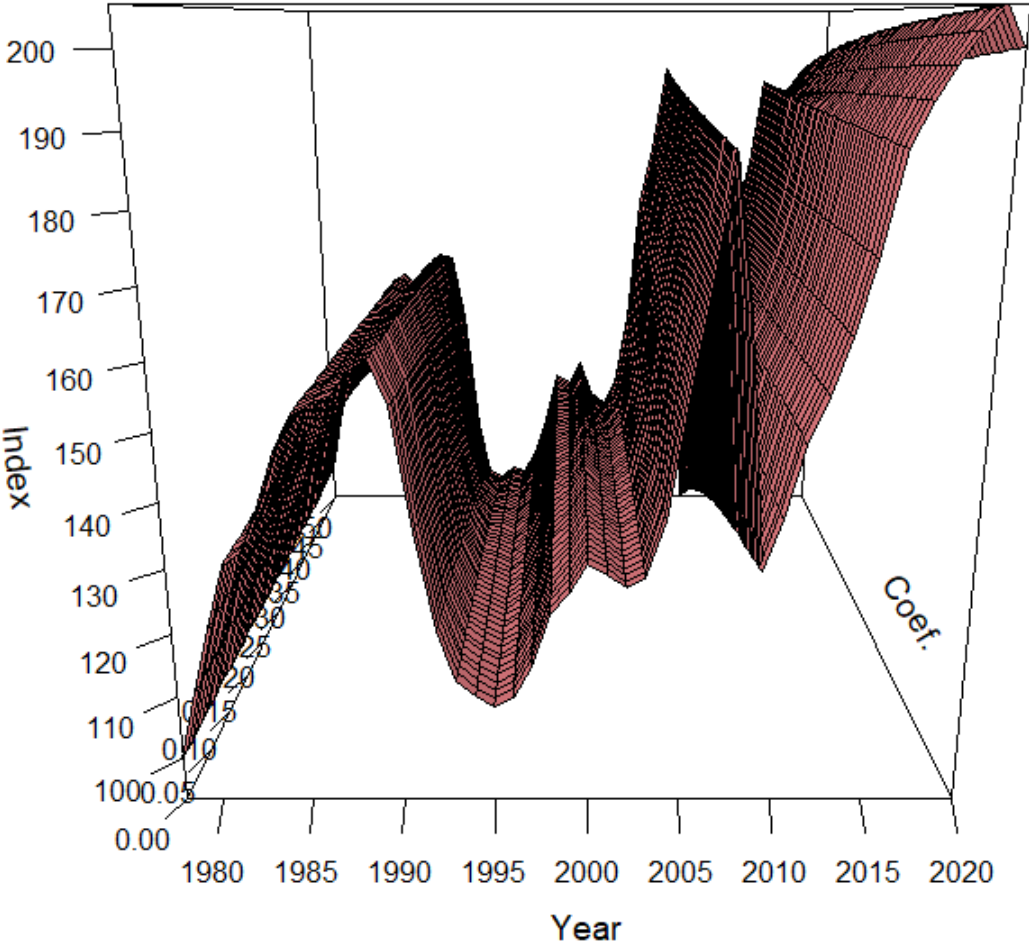
Unsm.Coef.	0	0.1	0.2	0.3	0.4	0.51
<b>Index-end 2020</b>	200,2	198,1	195,6	192,5	188,3	182,0
<b>Std.Dev.</b>	7,095	7,506	8,096	8,953	10,221	12,404
<b>ACF-Lag1</b>	0,496	0,442	0,379	0,309	0,237	0,161
<b>Mean</b>	1,652	1,628	1,598	1,559	1,507	1,426
<b>Median</b>	2,600	2,422	2,039	2,391	2,255	2,149
<b>Skewness</b>	-1,610	-1,618	-1,570	-1,439	-1,208	-0,832
<b>Kurtosis</b>	6,412	6,411	6,341	6,279	6,356	6,772
<b>Cor-NPI/REITs</b>	0,268	0,304	0,340	0,375	0,408	0,438
<b>Cor-NPI/Dow</b>	0,079	0,098	0,118	0,138	0,157	0,177
<b>Cor-NPI/Bonds</b>	0,149	0,150	0,150	0,148	0,145	0,138
<b>Cor-NPI/CPI</b>	0,273	0,259	0,240	0,218	0,192	0,159

I.2. Index

Figure 1.1 Return series of the NCREIF Appreciation Index for the years 1979 to 2020 (front edge) and unsmoothed with increasing coefficient  $\beta$  (0 to 0.51)



**Figure 1.2 NCREIF Appreciation Index for the years 1978 (=100) to 2020 (front edge) and unsmoothed with increasing coefficient  $\beta$  (0 to 0.51)**



I.3. Descriptive statistics

Figure 1.3 Change in standard deviation and autocorrelation remaining in the return series when increasing the unsmoothing coefficient  $\beta$  (0 to 0.51)

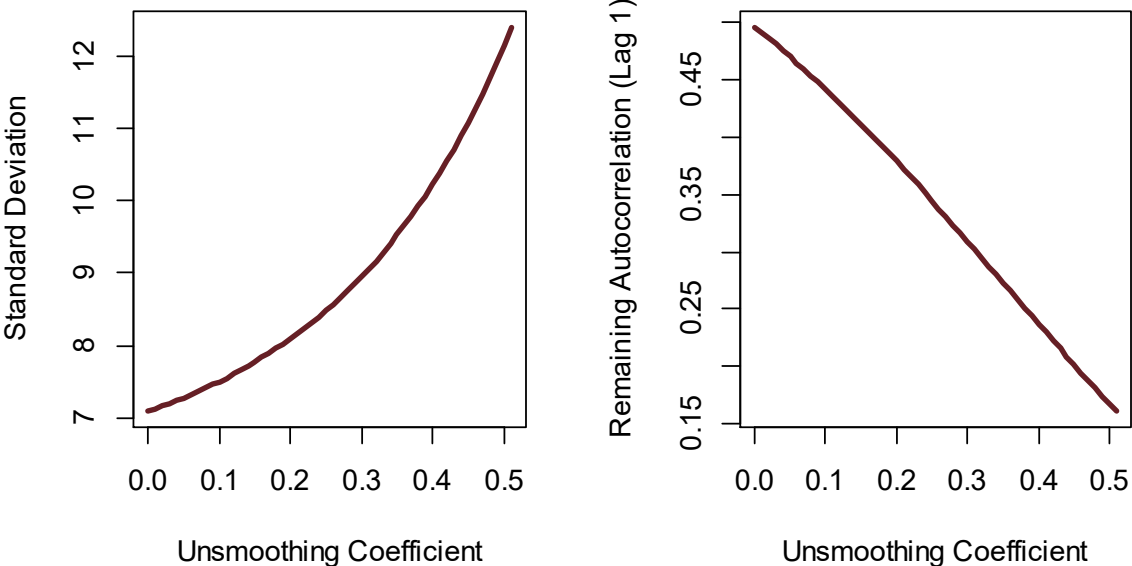


Figure 1.4 Change in arithmetic mean and median of the corrected return series when increasing the unsmoothing coefficient  $\beta$  (0 to 0.51)

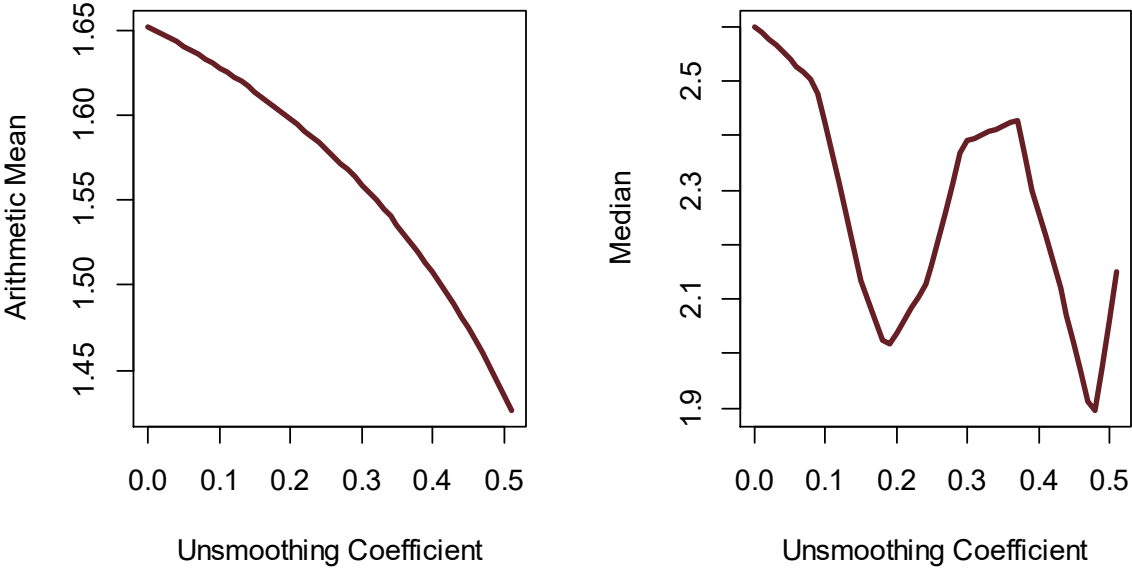


Figure 1.5 Change in skewness and kurtosis of the corrected return series when increasing the unsmoothing coefficient  $\beta$  (0 to 0.51)

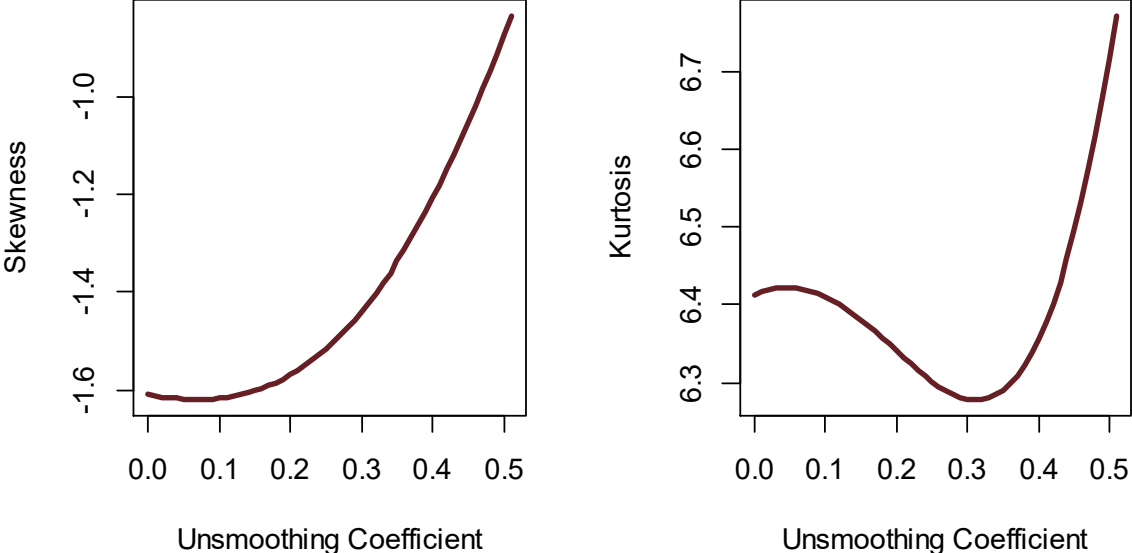
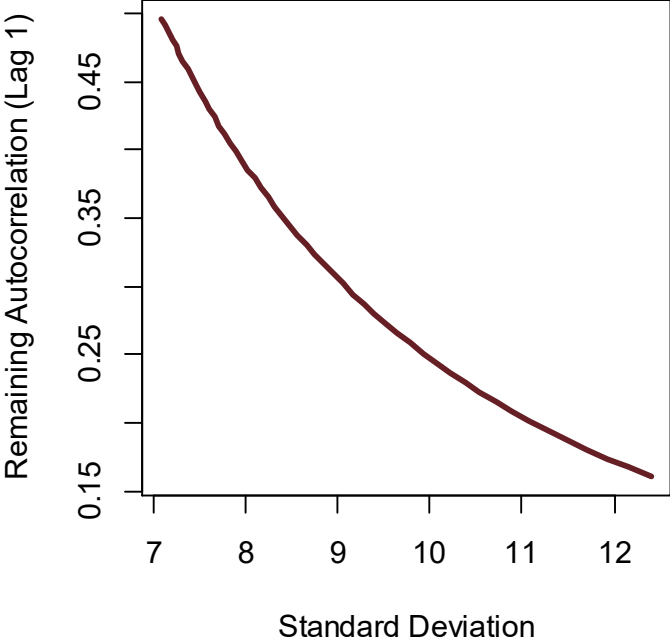
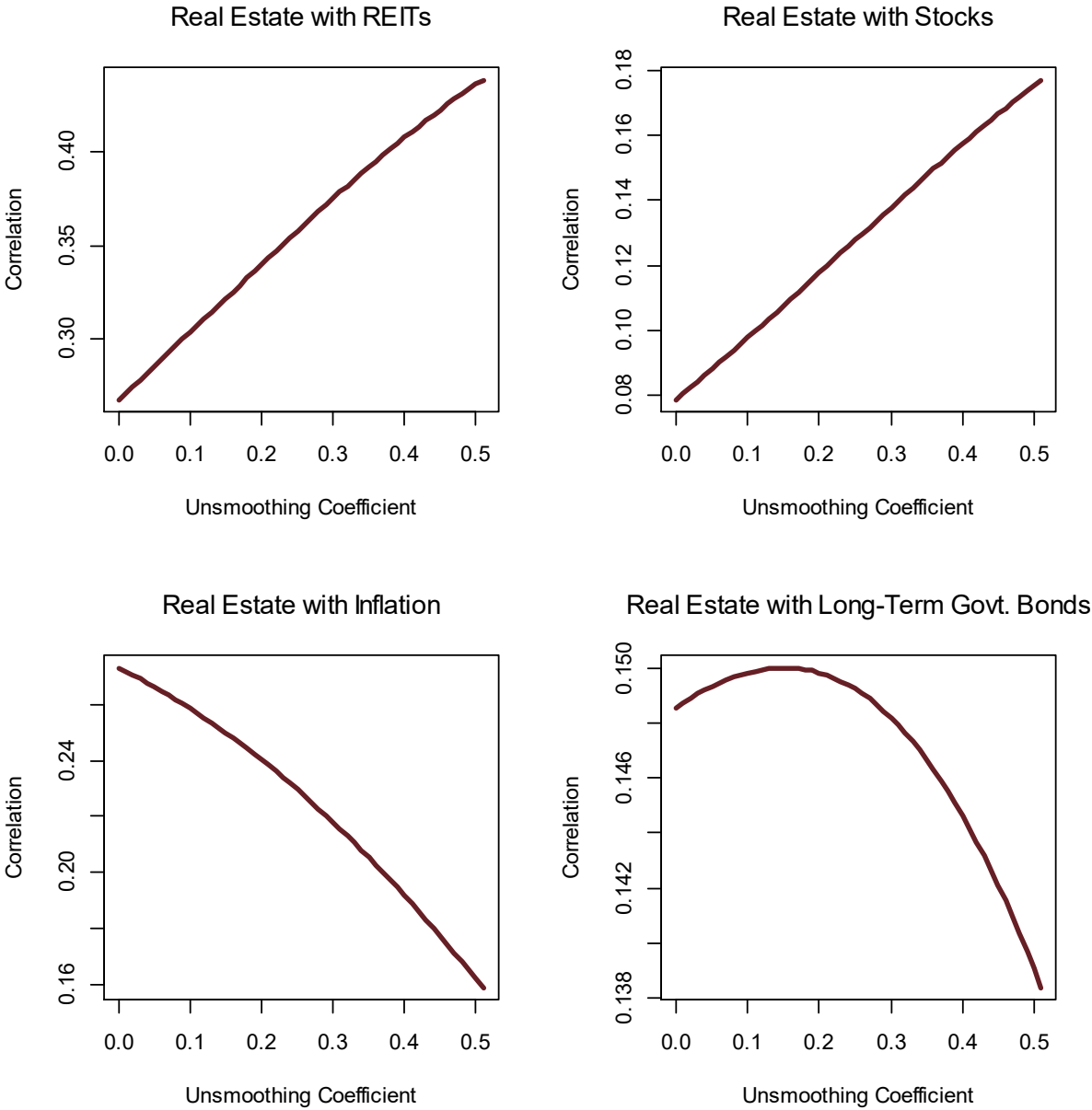


Figure 1.6 Remaining autocorrelation in the corrected return series when the standard deviation is increased by unsmoothing



**Figure 1.7** Calculated correlation of the appreciation returns of US commercial real estate direct investments with returns of other asset classes or inflation depending on the selected unsmoothing coefficient  $\beta$  (0 to 0.51)



## II. Early time series section (before the peak of the financial crisis): years 1978 to 2007

### II.1. Overview

**Table 2.1 Descriptive Statistics of Annual Index Returns from 1979 to 2007**

	CPI	LTGvtBds	Dow	REITs	NPI	BW
<b>Std.Dev.</b>	2,678	17,014	12,338	14,960	6,011	18,954
<b>Mean</b>	3,922	-2,509	9,662	13,669	2,168	2,601
<b>Min.</b>	1,337	-29,546	-18,347	-22,918	-12,518	-49,766
<b>25%-Q.</b>	2,570	-15,446	2,118	5,363	-1,296	-6,708
<b>50%-Q.</b>	3,183	-2,681	12,859	15,113	2,435	3,554
<b>75%-Q.</b>	4,217	7,358	20,362	23,201	6,630	16,731
<b>Max.</b>	11,904	33,486	28,857	34,302	12,012	36,073
<b>ACF-Lag1</b>	0,657	-0,327	-0,086	-0,084	0,768	0,321
<b>ACF-Lag2</b>	0,312	-0,086	0,059	-0,106	0,447	-0,031
<b>ACF-Lag3</b>	0,105	0,040	0,108	-0,113	0,151	-0,283
<b>Cor-CPI</b>	1,000	0,414	-0,215	-0,045	0,351	0,090
<b>Cor-Bonds</b>	0,414	1,000	-0,194	-0,142	0,268	0,289
<b>Cor-Dow</b>	-0,215	-0,194	1,000	0,251	-0,058	-0,075
<b>Cor-REITs</b>	-0,045	-0,142	0,251	1,000	0,052	0,224
<b>Cor-NPI</b>	0,351	0,268	-0,058	0,052	1,000	0,595
<b>Cor-BW</b>	0,090	0,289	-0,075	0,224	0,595	1,000

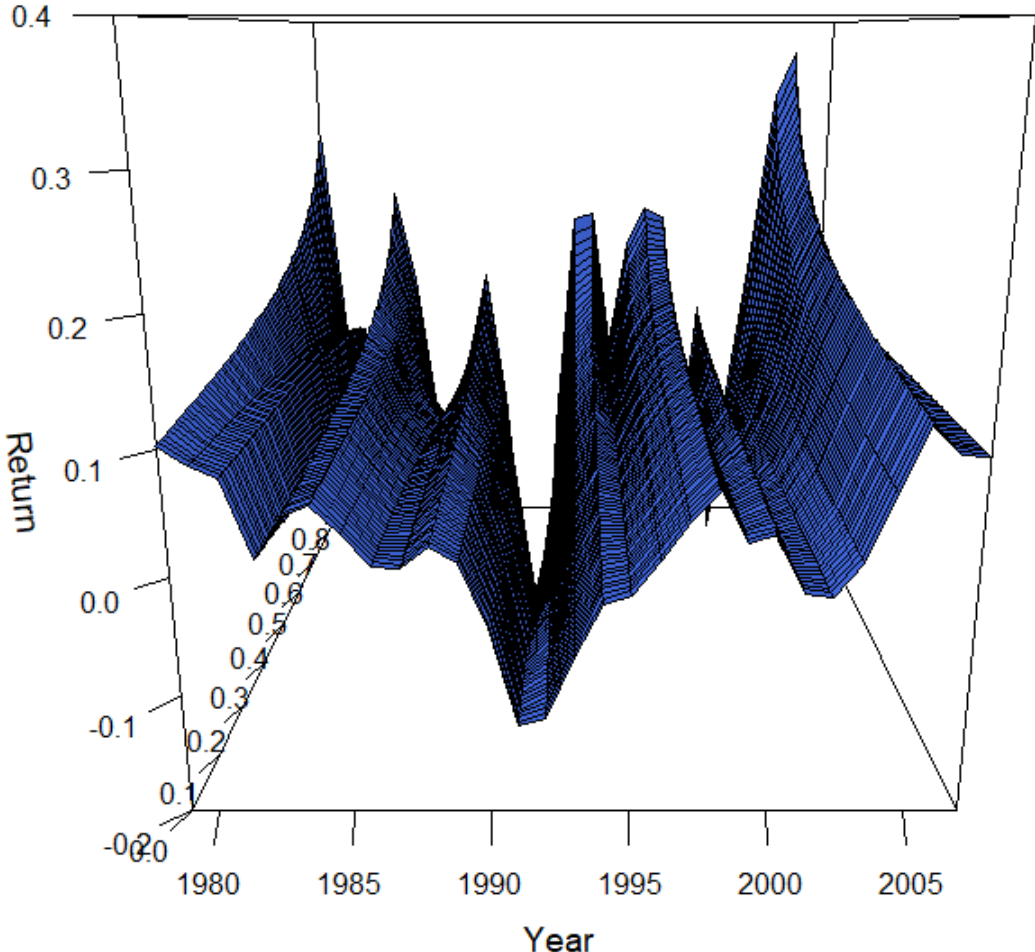
An AR(1) coefficient of  $\hat{\beta} = 0.8172$  is estimated for the annual returns.

**Table 2.2 Characteristics of the corrected time series depending on the unsmoothing coefficient  $\beta$  - Annual returns 1979 to 2007**

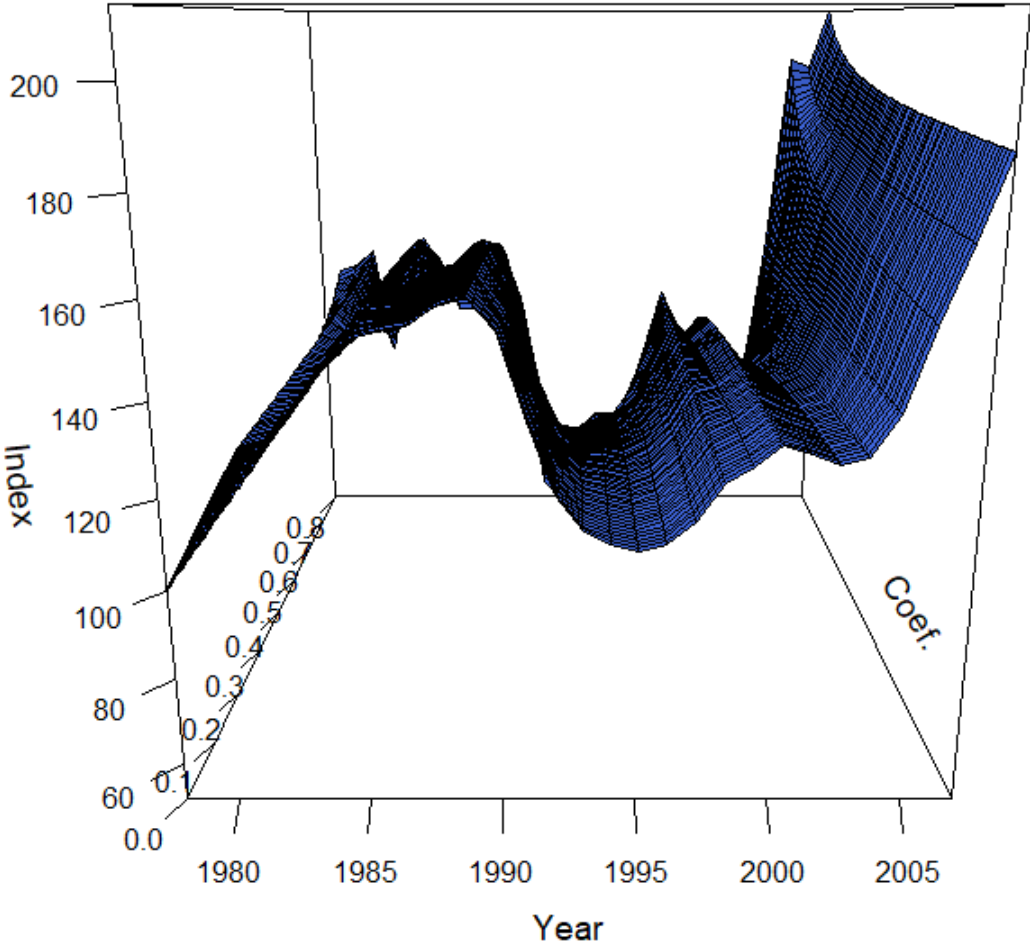
Unsm.Coef.	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.82
<b>Index-end 2007</b>	187,5	188,1	188,8	189,8	191,1	192,9	195,6	200,2	213,1
<b>Std.Dev.</b>	6,011	6,154	6,363	6,678	7,166	7,956	9,307	11,830	19,244
<b>ACF-Lag1</b>	0,768	0,747	0,717	0,677	0,624	0,559	0,482	0,402	0,319
<b>Mean</b>	2,168	2,179	2,192	2,209	2,232	2,265	2,313	2,394	2,609
<b>Median</b>	2,435	2,320	2,036	2,476	2,958	3,871	4,363	5,118	3,474
<b>Skewness</b>	-0,688	-0,690	-0,694	-0,703	-0,717	-0,732	-0,744	-0,735	-0,671
<b>Kurtosis</b>	3,326	3,407	3,521	3,671	3,847	4,010	4,080	3,956	3,490
<b>Cor-NPI/REITs</b>	0,052	0,067	0,084	0,103	0,126	0,150	0,175	0,200	0,224
<b>Cor-NPI/Dow</b>	-0,058	-0,061	-0,064	-0,068	-0,071	-0,074	-0,076	-0,077	-0,075
<b>Cor-NPI/Bonds</b>	0,268	0,278	0,287	0,297	0,306	0,312	0,313	0,307	0,289
<b>Cor-NPI/CPI</b>	0,351	0,341	0,328	0,310	0,286	0,254	0,212	0,161	0,088

II.2. Index

Figure 2.1 Return series of the NCREIF Appreciation Index for the years 1979 to 2007 (front edge) and unsmoothed with increasing coefficient  $\beta$  (0 to 0.82)



**Figure 2.2 NCREIF Appreciation Index for the years 1978 (=100) to 2007 (front edge) and unsmoothed with increasing coefficient  $\beta$  (0 to 0.82)**



II.3. Descriptive statistics

Figure 2.3 Change in standard deviation and autocorrelation remaining in the return series when increasing the unsmoothing coefficient  $\beta$  (0 to 0.82)

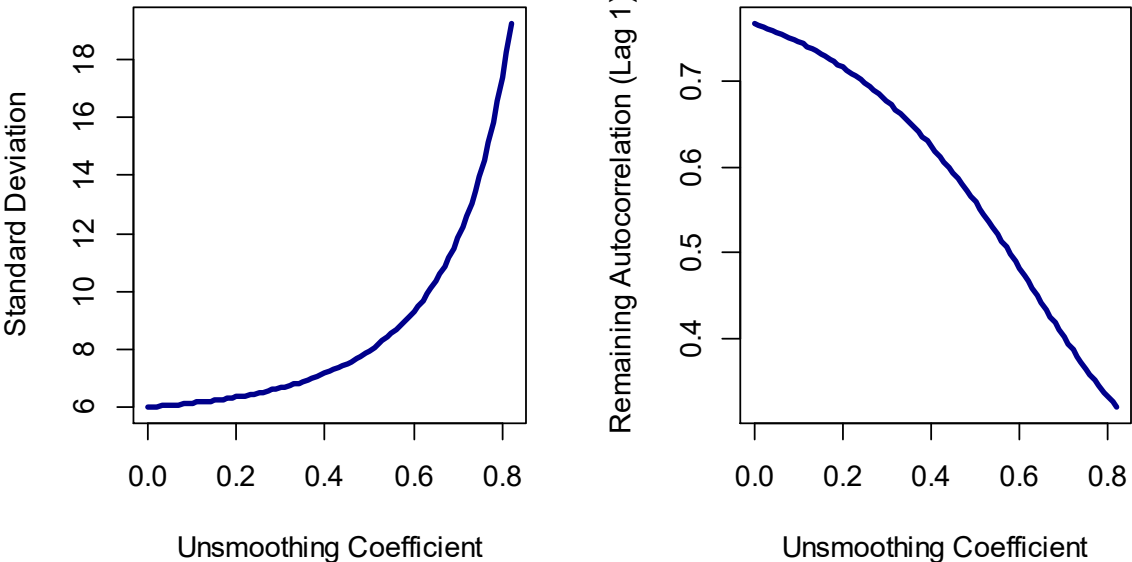


Figure 2.4 Change in arithmetic mean and median of the corrected return series when increasing the unsmoothing coefficient  $\beta$  (0 to 0.82)

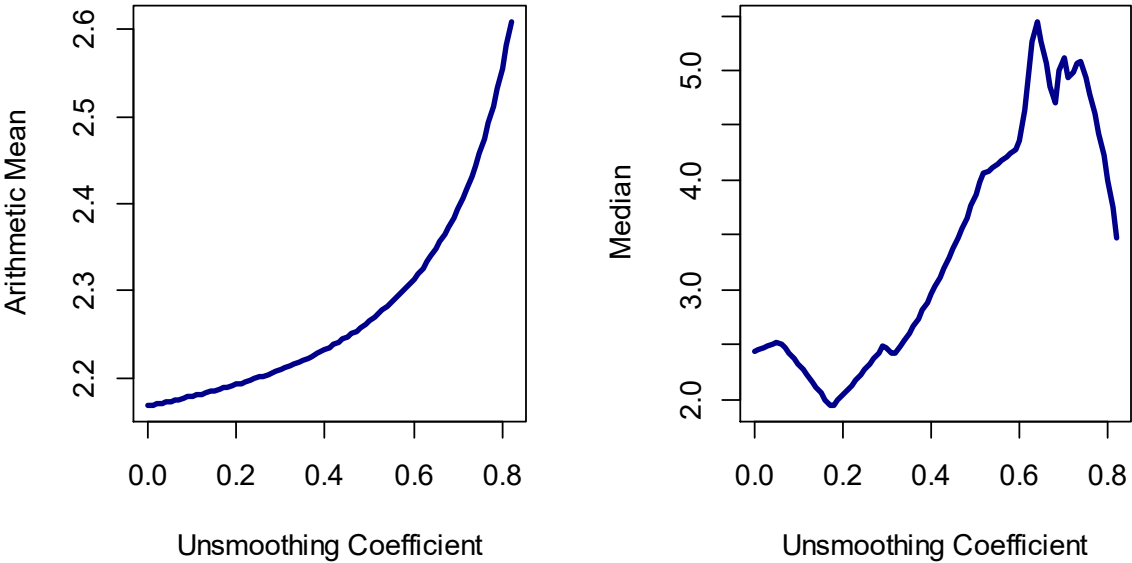


Figure 2.5 Change in skewness and kurtosis of the corrected return series when increasing the unsmoothing coefficient  $\beta$  (0 to 0.82)

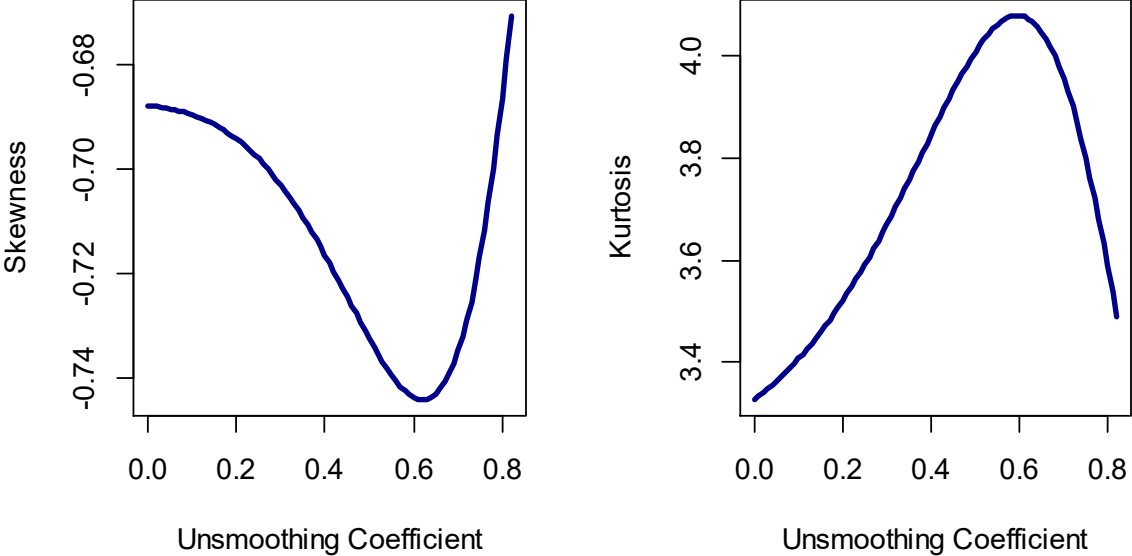
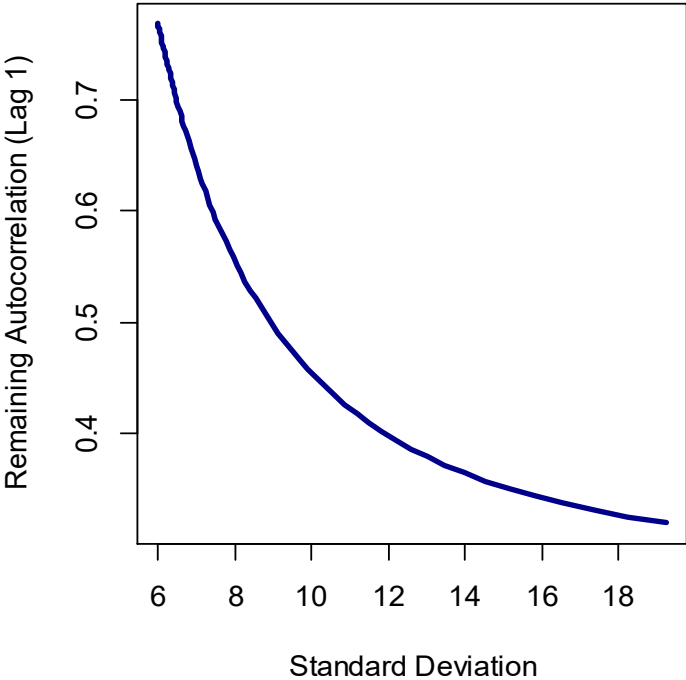
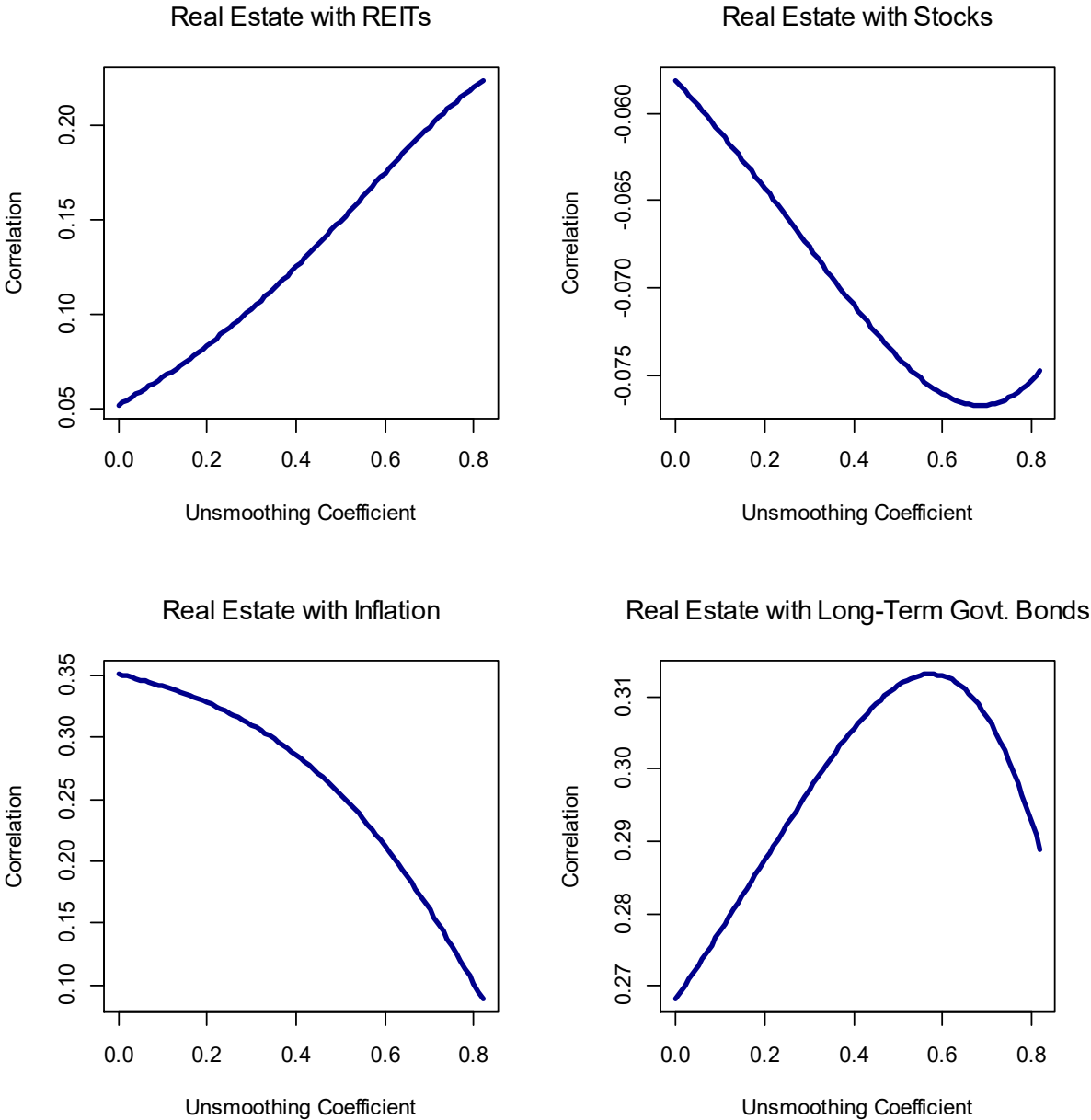


Figure 2.6 Remaining autocorrelation in the corrected return series when the standard deviation is increased by unsmoothing



**Figure 2.7** Calculated correlation of the appreciation returns of US commercial real estate direct investments with returns of other asset classes or inflation depending on the selected unsmoothing coefficient  $\beta$  (0 to 0.82)



## III. Later time series section: years 2010 to 2020

## III.1. Overview

**Table 3.1 Descriptive statistics of annual index returns from 2011 to 2020**

	<b>CPI</b>	<b>LTGvtBds</b>	<b>Dow</b>	<b>REITs</b>	<b>NPI</b>	<b>BW</b>
<b>Std.Dev.</b>	0,784	35,722	9,953	11,376	3,153	8,648
<b>Mean</b>	1,722	-11,990	9,721	8,420	3,742	1,494
<b>Min.</b>	0,400	-73,105	-5,795	-13,861	-2,530	-13,232
<b>25%-Q.</b>	1,201	-29,837	5,785	2,407	2,097	-2,594
<b>50%-Q.</b>	1,838	-11,097	7,128	9,655	3,787	0,923
<b>75%-Q.</b>	2,072	7,313	18,269	10,977	5,890	8,451
<b>Max.</b>	3,290	47,584	23,507	26,023	7,874	12,384
<b>ACF-Lag1</b>	0,236	0,124	-0,466	-0,450	0,398	-0,054
<b>ACF-Lag2</b>	-0,155	-0,302	-0,277	0,152	0,215	-0,060
<b>ACF-Lag3</b>	-0,387	-0,085	0,261	0,045	0,135	-0,003
<b>Cor-CPI</b>	1,000	-0,104	0,068	-0,041	-0,013	-0,006
<b>Cor-Bonds</b>	-0,104	1,000	0,106	0,166	0,374	0,351
<b>Cor-Dow</b>	0,068	0,106	1,000	0,290	-0,204	-0,184
<b>Cor-REITs</b>	-0,041	0,166	0,290	1,000	0,393	0,219
<b>Cor-NPI</b>	-0,013	0,374	-0,204	0,393	1,000	0,853
<b>Cor-BW</b>	-0,006	0,351	-0,184	0,219	0,853	1,000

An AR(1) coefficient of  $\hat{\beta} = 0.7255$  is estimated for the annual returns.

**Table 3.2 Characteristics of the corrected time series depending on the unsmoothing coefficient  $\beta$  - Annual returns 2011 to 2020**

<b>Unsm.Coef.</b>	<b>0</b>	<b>0.1</b>	<b>0.2</b>	<b>0.3</b>	<b>0.4</b>	<b>0.5</b>	<b>0.6</b>	<b>0.7</b>	<b>0.73</b>
<b>Index-end 2020</b>	145,4	144,0	142,3	140,2	137,4	133,5	128,0	119,2	115,5
<b>Std.Dev.</b>	3,153	3,336	3,578	3,907	4,370	5,049	6,114	7,953	8,786
<b>ACF-Lag1</b>	0,398	0,357	0,308	0,252	0,188	0,117	0,042	-0,034	-0,057
<b>Mean</b>	3,742	3,648	3,530	3,378	3,175	2,892	2,466	1,757	1,442
<b>Median</b>	3,787	3,352	2,903	2,625	2,255	1,737	1,382	1,025	0,903
<b>Skewness</b>	-0,469	-0,433	-0,394	-0,355	-0,321	-0,298	-0,295	-0,320	-0,333
<b>Kurtosis</b>	2,645	2,657	2,638	2,582	2,486	2,354	2,202	2,052	2,013
<b>Cor-NPI/REITs</b>	0,393	0,380	0,364	0,344	0,321	0,294	0,263	0,228	0,217
<b>Cor-NPI/Dow</b>	-0,204	-0,205	-0,205	-0,204	-0,202	-0,199	-0,193	-0,186	-0,184
<b>Cor-NPI/Bonds</b>	0,374	0,377	0,379	0,379	0,377	0,373	0,365	0,354	0,350
<b>Cor-NPI/CPI</b>	-0,013	-0,012	-0,011	-0,010	-0,010	-0,008	-0,007	-0,006	-0,005

IV. Time series: years 1978 to 2020 - correction with target volatility of 10%

IV.1. Overview

The estimated AR(1) coefficient corresponds to that given in Appendix I.).

The standard deviation of the corrected return series is set at 10 percent.

As a result, arithmetic means and medians also change compared with the scenarios in I.).

**Table 4.2 Characteristics of the corrected time series depending on the unsmoothing coefficient  $\beta$  - Annual returns 1979 to 2020**

<b>Unsm.Coef.</b>	<b>0</b>	<b>0.1</b>	<b>0.2</b>	<b>0.3</b>	<b>0.4</b>	<b>0.51</b>
<b>Index-end 2020</b>	196,2	194,3	192,4	190,5	188,8	187,1
<b>Std.Dev.</b>	10,000	10,000	10,000	10,000	10,000	10,000
<b>ACF-Lag1</b>	0,496	0,442	0,379	0,309	0,237	0,161
<b>Mean</b>	1,605	1,582	1,558	1,535	1,513	1,492
<b>Median</b>	2,941	2,640	2,103	2,464	2,245	2,075
<b>Skewness</b>	-1,610	-1,618	-1,570	-1,439	-1,208	-0,832
<b>Kurtosis</b>	6,412	6,411	6,341	6,279	6,356	6,772
<b>Cor-NPI/REITs</b>	0,268	0,304	0,340	0,375	0,408	0,438
<b>Cor-NPI/Dow</b>	0,079	0,098	0,118	0,138	0,157	0,177
<b>Cor-NPI/Bonds</b>	0,149	0,150	0,150	0,148	0,145	0,138
<b>Cor-NPI/CPI</b>	0,273	0,259	0,240	0,218	0,192	0,159

V. Time series: years 1978 to 2020 - Bond & Hwang correction procedure

V.1. Overview

In Bond and Hwang's (2007) correction procedure, the first time series value of the original time series is also offset by a corrected value. An ARFIMA(0,d,1) model is adjusted to the quarterly returns of the NCREIF Appreciation Index. The fractional integration parameter of  $\hat{d} = 0.4537$  and the MA(1) term of  $\hat{\theta} = -0.2552$  are estimated.

The following table shows the time series properties analyzed in annual periodicity:

**Table 5.1 Descriptive statistics of annual index returns from 1978 to 2020**

	<b>CPI</b>	<b>LTGvtBds</b>	<b>Dow</b>	<b>REITs</b>	<b>NPI</b>	<b>Bond &amp; Hwang</b>
<b>Std.Dev.</b>	2,585	22,602	13,719	16,366	7,050	6,574
<b>Mean</b>	3,344	-5,057	8,386	11,313	1,767	1,724
<b>Min.</b>	0,400	-73,105	-41,305	-44,519	-24,964	-20,829
<b>25%-Q.</b>	1,865	-18,479	0,754	3,384	-0,305	0,134
<b>50%-Q.</b>	2,592	-4,027	10,457	11,155	2,765	2,531
<b>75%-Q.</b>	3,780	8,245	19,330	23,026	6,379	4,717
<b>Max.</b>	11,904	47,584	28,857	34,302	12,012	19,482
<b>ACF-Lag1</b>	0,764	-0,033	-0,123	0,007	0,510	0,285
<b>ACF-Lag2</b>	0,494	-0,196	-0,061	-0,182	0,012	-0,251
<b>ACF-Lag3</b>	0,271	-0,027	0,211	-0,068	-0,116	-0,203
<b>Cor-CPI</b>	1,000	0,330	-0,126	0,077	0,291	0,156
<b>Cor-Bonds</b>	0,330	1,000	0,010	0,061	0,161	0,171
<b>Cor-Dow</b>	-0,126	0,010	1,000	0,458	0,064	0,232
<b>Cor-REITs</b>	0,077	0,061	0,458	1,000	0,272	0,480
<b>Cor-NPI</b>	0,291	0,161	0,064	0,272	1,000	0,797
<b>Cor-B&amp;H</b>	0,156	0,171	0,232	0,480	0,797	1,000

A stepwise increase of the fractional integration parameter  $d$  from 0 to 1 is performed. The estimated MA(1) parameter  $\hat{\theta} = -0.255$  is kept constant.

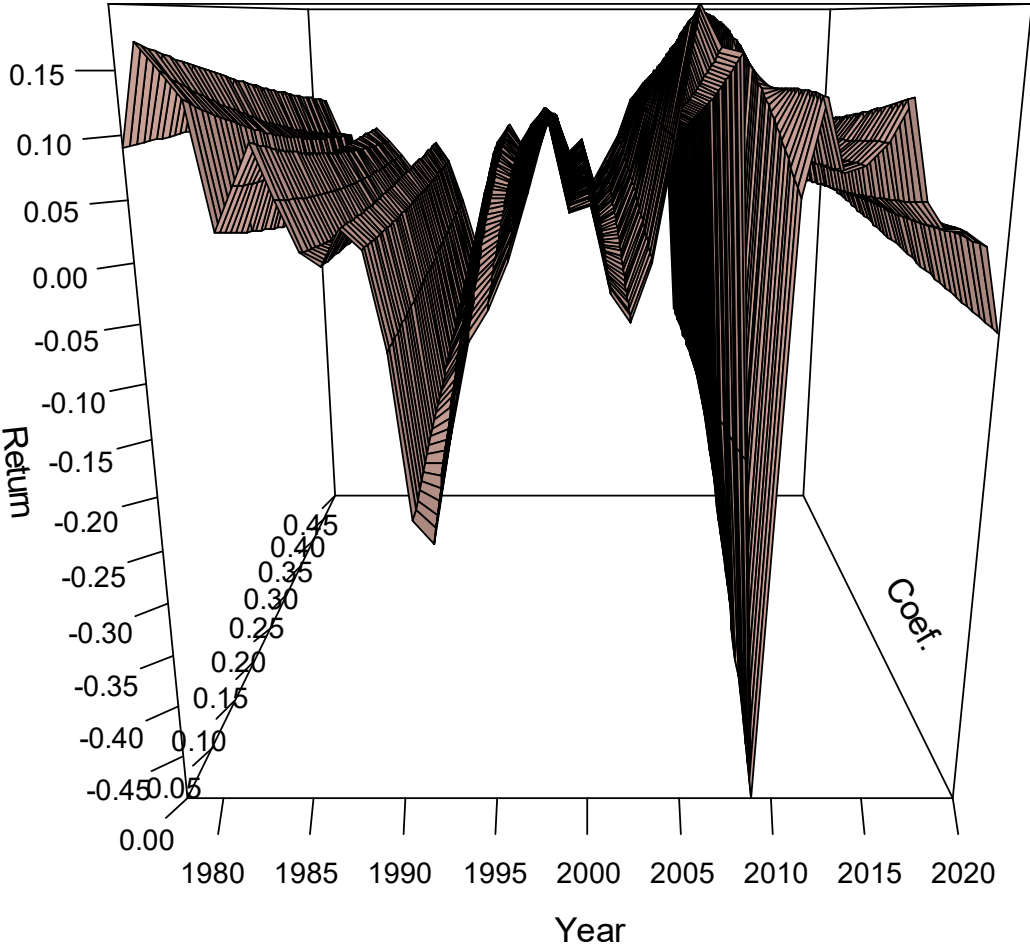
**Table 5.2 Properties of the corrected time series as a function of the fractional integration parameter  $d$  (0 to 1) and  $\hat{\theta} = -0.255$ , annual returns 1978 to 2020**

Unsm.Coef.	0	0.1	0.2	0.3	0.4	0.45
Index-end 2020	214,8	212,7	211,3	210,4	210,0	209,9
Std.Dev.	12,758	10,803	9,248	8,008	7,019	6,603
ACF-Lag1	0,516	0,462	0,410	0,360	0,311	0,287
Mean	1,778	1,755	1,740	1,730	1,725	1,724
Median	3,982	2,911	2,219	2,853	2,955	2,558
Skewness	-1,788	-1,785	-1,656	-1,427	-1,158	-1,035
Kurtosis	7,592	7,397	6,717	6,068	6,052	6,400
Cor-NPI/REITs	0,212	0,276	0,340	0,400	0,455	0,479
Cor-NPI/Dow	0,022	0,068	0,116	0,164	0,209	0,230
Cor-NPI/Bonds	0,140	0,147	0,154	0,160	0,167	0,171
Cor-NPI/CPI	0,295	0,267	0,237	0,206	0,174	0,157

Unsm.Coef.	0.5	0.6	0.7	0.8	0.9	1
Index-end 2020	209,9	210,0	210,4	210,9	211,6	212,3
Std.Dev.	6,233	5,615	5,135	4,766	4,486	4,274
ACF-Lag1	0,262	0,214	0,164	0,112	0,059	0,005
Mean	1,724	1,726	1,730	1,736	1,743	1,750
Median	2,568	2,129	1,646	1,823	1,659	1,778
Skewness	-0,932	-0,819	-0,841	-0,957	-1,084	-1,133
Kurtosis	6,979	8,586	10,154	10,983	10,865	10,145
Cor-NPI/REITs	0,500	0,535	0,557	0,565	0,561	0,547
Cor-NPI/Dow	0,250	0,287	0,317	0,340	0,356	0,366
Cor-NPI/Bonds	0,174	0,182	0,189	0,196	0,202	0,207
Cor-NPI/CPI	0,141	0,108	0,077	0,049	0,024	0,003

V.2. Index

Figure 5.1 Return series of the NCREIF Appreciation Index for the years 1978 to 2020, unsmoothed with increasing fractional integration parameter  $d$  (0 to 0.45) and  $\hat{\theta} = -0.255$



VI. Unsmoothing the time series of the consumer price index using the Blundell & Ward procedure: years 1978 to 2020

VI.1. Overview

Inflation was calculated from the consumer price index as a continuous return (i.e. first differences of the logarithmic CPI) (analogous to the procedure for calculating NPI returns).

An AR(1) coefficient of  $\hat{\beta} = 0.8361$  is estimated for the annual inflation.

**Table 6.1 Descriptive Statistics of US-Inflation (original and Blundell & Ward-unsmoothed log-Returns from Consumer Price Index) from 1979 to 2020**

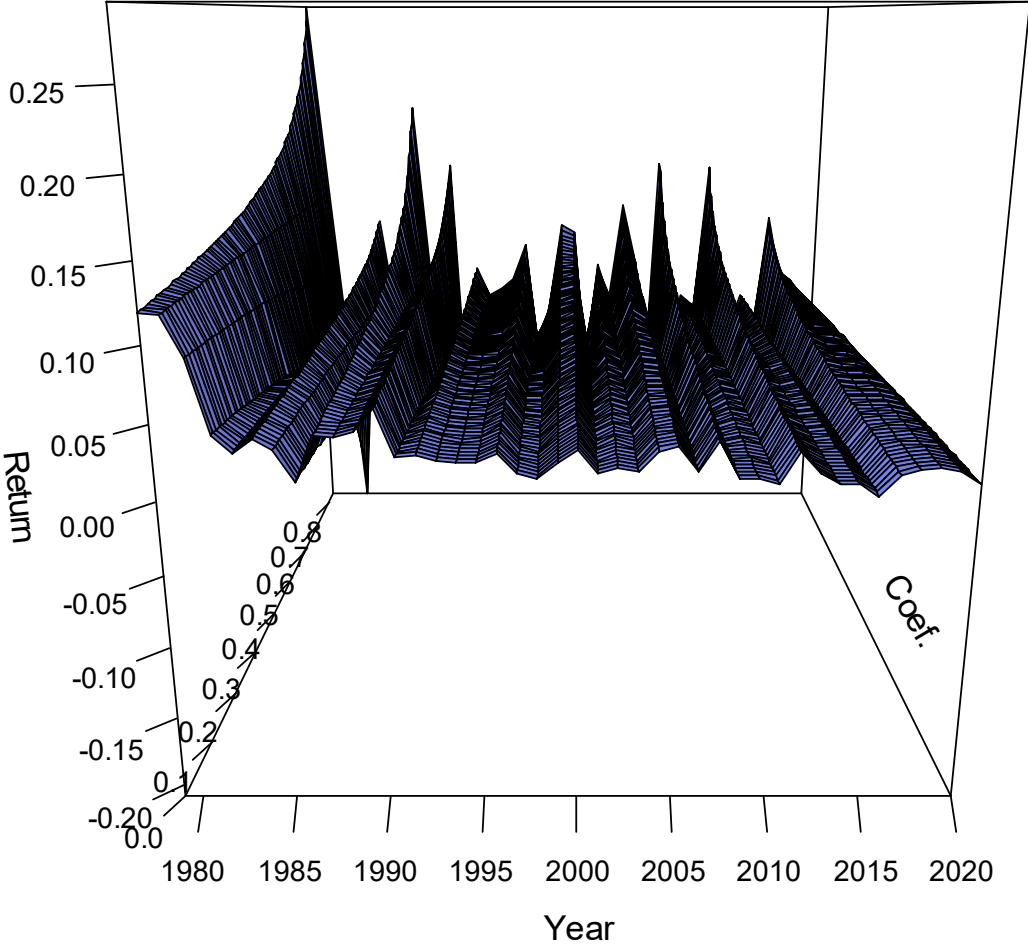
	CPI	BW (CPI)
<b>Std.Dev.</b>	2,483	8,882
<b>Mean</b>	3,220	2,327
<b>Min.</b>	0,400	-20,159
<b>25%-Q.</b>	1,862	-2,856
<b>50%-Q.</b>	2,589	1,400
<b>75%-Q.</b>	3,570	7,143
<b>Max.</b>	11,904	28,999
<b>ACF-Lag1</b>	0,666	-0,094
<b>ACF-Lag2</b>	0,364	-0,176
<b>ACF-Lag3</b>	0,169	-0,150
<b>Cor-CPI</b>	1,000	0,495
<b>Cor-Bonds</b>	0,304	0,329
<b>Cor-Dow</b>	-0,090	-0,064
<b>Cor-REITs</b>	0,063	-0,040
<b>Cor-NPI</b>	1,000	0,495
<b>Cor-BW (CPI)</b>	0,495	1,000

**Table 6.2 Characteristics of the corrected time series depending on the unsmoothing coefficient  $\beta$  - Annual returns 1979 to 2020**

Unsm.Coef.	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.84
<b>Index-end 2020</b>	386,6	383,5	379,6	374,7	368,2	359,2	346,3	325,7	288,2	262,9
<b>Std.Dev.</b>	2,483	2,531	2,605	2,723	2,914	3,234	3,799	4,873	7,245	9,106
<b>ACF-Lag1</b>	0,666	0,619	0,557	0,476	0,375	0,254	0,124	0,005	-0,077	-0,095
<b>Mean</b>	3,220	3,200	3,176	3,145	3,103	3,045	2,957	2,812	2,520	2,301
<b>Median</b>	2,589	2,582	2,564	2,444	2,469	2,402	2,435	2,308	1,643	1,374
<b>Skewness</b>	2,307	2,277	2,222	2,126	1,970	1,733	1,397	0,970	0,495	0,305
<b>Kurtosis</b>	8,309	8,288	8,186	7,954	7,533	6,877	6,013	5,097	4,377	4,191
<b>Cor-CPI/REITs</b>	0,063	0,057	0,050	0,042	0,031	0,017	0,002	-0,016	-0,034	-0,041
<b>Cor-CPI/Dow</b>	-0,090	-0,091	-0,092	-0,093	-0,092	-0,090	-0,085	-0,078	-0,068	-0,063
<b>Cor-CPI/Bonds</b>	0,304	0,317	0,331	0,345	0,357	0,365	0,367	0,359	0,339	0,328
<b>Cor-CPI/CPI</b>	1,000	0,998	0,989	0,971	0,938	0,884	0,802	0,690	0,550	0,489

VI.2. Index

Figure 6.1 Inflation from 1979 to 2020 (leading edge) and unsmoothed with increasing coefficient  $\beta$  (0 to 0.84)



Annotations

This paper is based on the dissertation by Gohs (2014), which was written in German. The translation of particular statements was carried out in consultation with the translator DeepL.

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