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Consistent commercial real estate market indicators: Methodology and an application to the German office market*

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Abstract

We develop a statistical-methodological framework for a set of core commercial real estate market indicators, which consists of a market price index, a gross rent index, and a net rental yield index as well a vacancy rate. We argue that the indicators should be (macro-)consistent, meaning that the asset valuation relation between the market price, rental income, yield and vacant space of an individual property carries over to the macro indicators. In case of a bottom-up compilation of all indicators, macro-consistency is met if (1) target universes are common, (2) the granular data source is complete and (3) price and rental yield indices are weighted with capital value shares while the rent index and the aggregate vacancy rate are weighted by rental income shares. We exemplify the established statistical-methodological framework by compiling a consistent set of annual indicators of the German office market using appraisal data from a real estate consulting company.

JEL classification: C43, R33

Keywords: price index, rent index, rental yield index, vacancy rate

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1 Introduction

The urgent demand for frequent, timely and high-quality real estate statistics has been expressed by policymakers since the Global Financial Crisis of 2007-08. The detrimental interlinkages between abrupt declines in real estate prices, excessive lending, and fallacious mitigation of risks caused the Great Recession and severely threatened financial stability in many parts of the world. In order to implement effective macroprudential monitoring and policy, existing information gaps have had to be filled. Macroprudential authorities identified missing data in both residential and commercial real estate markets. Price and rent indices, transaction volumes and construction activity as well as lending indicators (e.g. credit volumes, loan-to-value ratios, debt service-to-income ratios) were among the indicators most urgently needed.

Data collection, methodological development and indicator compilation have been initiated and/or advanced on the basis of international initiatives such as the G20 Data Gaps Initiative (Heath and Goksu, 2016) or the recommendations of the European Systemic Risk Board (ESRB) on closing real estate data gaps (European Systemic Risk Board, 2016, 2019). The latter have shaped the statistical efforts in European countries with regard to the development of indicators for commercial real estate (CRE) markets. In the 2019 amendment to the initial recommendation, the Statistical Office of the European Union (Eurostat) "is recommended to propose Union legislation establishing a common minimum framework for the development, production and dissemination of a database on indicators on the physical CRE market" (European Systemic Risk Board, 2019, Recommendation F).[1] This triggered coordinated action in and among European statistical offices and central banks as well as other institutions with the aim of making progress in this statistical field.[2]

Of primary interest for macroprudential authorities in Europe is a set of CRE market indicators consisting of price, rent, and yield indices as well as vacancy rates and activity indicators such as building starts. The former three are usually dealt with as closely related indicators. While the number of building starts is definitely statistical information of a different nature, the vacancy rate plays an intermediate role. On the one hand, it is linked to activity indicators as a measure of tension or slack in real estate markets. On the other hand, vacant space affects rental income and yields, suggesting that the vacancy rate is connected to price, rent, and rental yield indices. In this paper, we show that by integrating the vacancy rate, the demand-side view of the space market, focusing on an observable rent concept, is reconciled with the investors' perspective on the investment market. In particular, we suggest the set of core CRE market indicators consisting of a market price index, a gross rent index, a net rental yield index, and a vacancy rate.

At the level of individual properties, these four indicators are mathematically directly connected by the income approach to asset valuation. When developing CRE market indicators, one aim worth considering is to ensure that this mathematical link carries over to the macro

[1] In the ESRB recommendations and related literature, the attribute "physical" is used to distinguish price, rent and rental yield indices as well as vacancy rates, building starts, transactions and so on from lending indicators or financial information. In the remainder of this paper, we refer to the multitude of non-financial indicators using the term "CRE market indicators".

[2] In Europe, CRE market indicators generally fall within the remit of statistical offices. Depending on the country-specific distribution of statistical competences, however, central banks play different roles, ranging from users to (co-)compilers, because of (joint) responsibility for these statistics.

level (henceforth called macro-consistency), as users might be puzzled if this property is not met. This target may or may not be feasible as regards available data sources. For the time being, we observe that macro-consistency is of less practical relevance for statistical offices, as they usually struggle with patchy data, meaning it is only possible to proceed following an indicator-by-indicator approach (European Commission, 2023).

Eurostat (2017) is perhaps the most recent and comprehensive document for the compilation of CRE market indicators.[3] The focus is on the statistical-methodological treatment of price indices. The other indicators are only touched upon. Interconnections between them are sketched, viewing the economic rather than the statistical dimension. A discussion about macro-consistency is missing altogether. In the academic literature, there are several papers that deal with the compilation of price indices. Among the price indices discussed in Fisher, Geltner, and Webb (1994), Diewert and Shimizu (2015), and Diewert, Fox, and Shimizu (2016) are some examples that build on the ratio between net operating income and the capitalisation rate. The income approach is thus applied to the construction of indices. However, consistency is ensured by imposing it at the macro level. Thus, it does not emerge as a result of a bottom-up approach using granular data.

In this paper, we show that macro-consistency requires core CRE market indicators be defined on a common target universe and be compiled using a data source comprising complete and consistent information about prices, rental income and vacant space. This collection is available, preferably, at the level of transacted individual properties or, at least, in a partly aggregated and stratified manner. Additionally, we prove that macro-consistency is ensured if price and rental yield indices are weighted by capital value shares, whereas rent indices and vacancy rates are weighted by rental income shares. This result is valid irrespective of the index formula type (e.g. Laspeyres, Lowe) as long as it is applied to each individual indicator in exactly the same way. Weight updating procedures are included in this uniformity requirement, too. As a consequence, macro-consistent core CRE market indicators can also be constructed using chain-linked Laspeyres-type indices with an annual updating of weights, which is common practice in price and house price statistics (Eurostat, 2013, 2018).[4]

The paper includes an empirical illustration of the proposed weighting scheme using data for the German office market. We use annual information on prices, rents, and vacancy rates in 125 German towns and cities. Each town and city represents one stratum. Information refers to a typical property for each stratum. The dataset is provided by the real estate consulting agency bulwiengesa. Information on prices and rents represents market values assessed by experts and refers to a typical property in the respective stratum. Object quality of the representative property is held constant over time. bulwiengesa additionally provides annual information on floor space and vacant floor space of office buildings in these German towns and cities. The available dataset suits the compilation exercise at hand insofar as pricing information at the city level serves consistent stratum data, which are aggregated by means of the proposed index formulae.

3 For an in-depth discussion of the issues raised in this report, see Hill and Steurer (2020).

4 In terms of practical index compilation, we consider the upper level of aggregation (i.e. the level from which weighting information is available) while, for the lower level of aggregation, we (implicitly) assume that (sub-)indices are aggregated by any formula which maintains consistency at the level of individual properties. The granular information might be aggregated by a (weighted) geometric mean, for instance.

The resulting macro-consistent core indicators for the German office market are useful for real estate and financial stability analyses. The exercise is also valuable from a statistical-methodological point of view, as it illustrates empirical differences between a consistent and an inconsistent indicator compilation. Yet, bulwiengesa data cannot be considered a source for physical CRE index compilation, which is compliant with the ESRB recommendation, as the information is not transaction-based, not available on a quarterly frequency and does not cover Germany as a whole (Knetsch, 2021, p. 457).

The remainder of the paper is organised as follows. In Section 2, we focus on individual properties and outline the income approach to the valuation of an individual commercial property. In Section 3, we introduce the concept of macro-consistency of core CRE market indicators and lay down the requirements in terms of target universe and data source. We then switch to the stratum level and derive formulae to be applied to a bottom-up compilation of aggregate indicators. In Section 4, we apply these formulae to exemplify macro-consistent core CRE market indicators using data for office markets in 125 German towns and cities. In the final section, we draw conclusions.

2 Income approach to the valuation of individual CRE

Market value and price. Let the market value x_t of a property at the end of period t be represented by:

$$x_t = p_t \, q, \tag{1}$$

where p_t is the market price per square metre and q is the floor space in square metres. The floor space is assumed to exhibit constant quality over time, i.e. the property does not depreciate due to wear and tear or economic obsolescence.

Rent. The property is assumed to generate rental income. When the property is rented out, rental income is the revenue the landlord receives from the tenant(s), usually by means of monetary transactions. Owing to the complexity of rent agreements, there is no unambiguous approach to characterise the rent. The literature distinguishes various forms. Eurostat (2017) lists four rent concepts: asking rents, contract rents, consideration rents, and net effective rents.

Asking rents are perhaps most easily measurable, as they are often disclosed when rental space is advertised. However, asking rents poorly proxy contractual rents. Apart from the regular payment, rent agreements may include rent-free periods, pre-specified rent changes, indexation and so on. Wheaton and Torto (1994) propose looking at the consideration rent, which includes all components whose payable amounts are determined in the contract,[5] calculating the undiscounted sum and dividing it by the term of the agreement. The consideration rent ignores the timing of the payments. Webb and Fisher (1996) suggest adopting a present value approach. In their concept of a net effective rent, they go beyond the consideration rent in terms of scope, too, by balancing all cash inflows and outflows which are agreed upon in the contract.

[5] When rents are indexed to a price index, rent graduations are not considered in the consideration rent, as they are unknown a priori.

Eurostat (2022b) draws a distinction between gross rents and different types of net rents. The different rental concepts reflect differences in to the costs that tenants have to bear vis-a-vis the commercial lessor. Gross rents include all costs associated with the property. Single net rents exclude property taxes. Double net rents exclude property taxes and insurance. Triple net rents exclude property taxes, insurance, maintenance, and repair costs. Eurostat (2022a) argues that the net rent should be informative of a landlord's income after operating expenses have been deducted.

The ESRB recommendation defines the rent as "the amount of money actually paid by the tenant to the owner of the property, net of any incentives (e.g. rent-free periods, contributions to refurbishment) and charges" (European Systemic Risk Board, 2016). A rent index employing this definition approximately tracks the evolution of rental payments, thereby taking the tenants' perspective. This follows the practice of statistical offices in the construction of residential rent indices by European statistical offices (Eurostat, 2018) and the Bureau of Labor Statistics (Adams, Loewenstein, Montag, and Verbrugge, 2022). Ambrose, Coulson, and Yoshida (2015) also take the tenants' perspective when calculating a repeat rent index. The literature commonly employs this perspective and the resulting interpretation of the term rent when estimating the effect of object-specific characteristics such as the height of a building (Koster, van Ommeren, and Rietveld, 2014) or its energy efficiency (Eichholtz, Kok, and Quigley, 2010) on office rents.

Apart from considering rents from the tenants' perspective, it is also possible to take the investors' perspective (Eurostat, 2022a; Ambrose, Coulson, and Yoshida, 2023). This perspective is particularly relevant in the context of CRE. Investment decisions are evaluated on the basis of discounted future cash flows (Geltner, 1990). The cash flow is given by net operating income which is gross rental income net of total costs. In formal terms, the net operating income generated by a property in period t may be written as:

$$n_t \, q = [r_t - c_t] \, q \ , \tag{2}$$

where n_t denotes net operating income, r_t gross rental income and c_t total costs, with all flow variables being measured in value terms per square metre.

The major cost components in CRE are vacancy and operating costs.[6] In the remainder, we express these costs as percentages of rental income and may thus write:

$$c_t = [vr_t + or_t] \, r_t \ , \tag{3}$$

where vr_t denotes the vacancy rate of the property and or_t the fraction of rental income that is eaten up by operating costs. The vacancy rate of an individual property may be measured as the fraction of total to vacant floor space.

Rental yield. The ESRB recommendation defines the rental yield as the "ratio of annual rents to the market value of the immovable property" (European Systemic Risk Board, 2016). Following this interpretation, if the concept of net operating income is employed, the rental yield is conceptually close to the capitalisation rate (or cap rate).

[6] Operating costs may consist of maintenance costs, administrative expenses, and other operating costs that cannot be apportioned to tenants.

In general, given a constant discount factor, the cap rate y_t of the property in period t is derived using an asset pricing approach assuming future net operating income to be constant at its initial level over the whole useful life T: $n_{t+\tau} = n_t$, $\tau = 1, ..., T$. The market price of the property in period $t-1$ can therefore be expressed by the discounted sum of future net income flows:

$$p_{t-1} = \frac{n_t}{1+y_t} + \frac{n_{t+1}}{[1+y_t]^2} + ... + \frac{n_{t+T}}{[1+y_t]^{T+1}}. \tag{4}$$

The cap rate equals the rental yield if the useful life approaches infinity:

$$y_t = \frac{n_t}{p_{t-1}} \quad \text{for} \quad T \to \infty. \tag{5}$$

This relationship between market price, net operating income and cap rate is of crucial importance in CRE valuation. For instance, practitioners tend to assess the market price of a property in terms of n_t and y_t.

Relationship between core CRE indicators. The mathematical relationship between the market price, the (gross) rent, the rental yield and the vacancy rate at the level of individual properties can be described by

$$y_t = \frac{[\alpha - vr_t]\, r_t}{p_{t-1}}. \tag{6}$$

It results from plugging (2) and (3) into (5). The fraction of operating costs is assumed to be constant over time, i.e. $or_t = or$ and $\alpha = 1 - or$ with $0 \ll \alpha < 1$.

3 Deriving macro-consistent CRE market indicators

We conceptualise macro-consistency of core CRE market indicators by imposing three requirements. First, target universes need to be common to the individual indicators. Second, available granular data need to be complete as regards the information about market prices (including price-determining variables) and the rental situation (i.e. rental income, vacant space). Third, index formulae need to be of the same type, with capital value weights being applied to the price and rental yield indices and rental income weights to the rent index and the vacancy rate.

In Section 3.1, we lay down the framework conditions regarding target universes and data sources. In Section 3.2, we derive index formulae and weighting schemes for consistent sets of core CRE market indicators of Lowe type. Section 3.3 presents formulae for sets of chain-linked Laypeyres-type indices.

3.1 Target universes and data sources

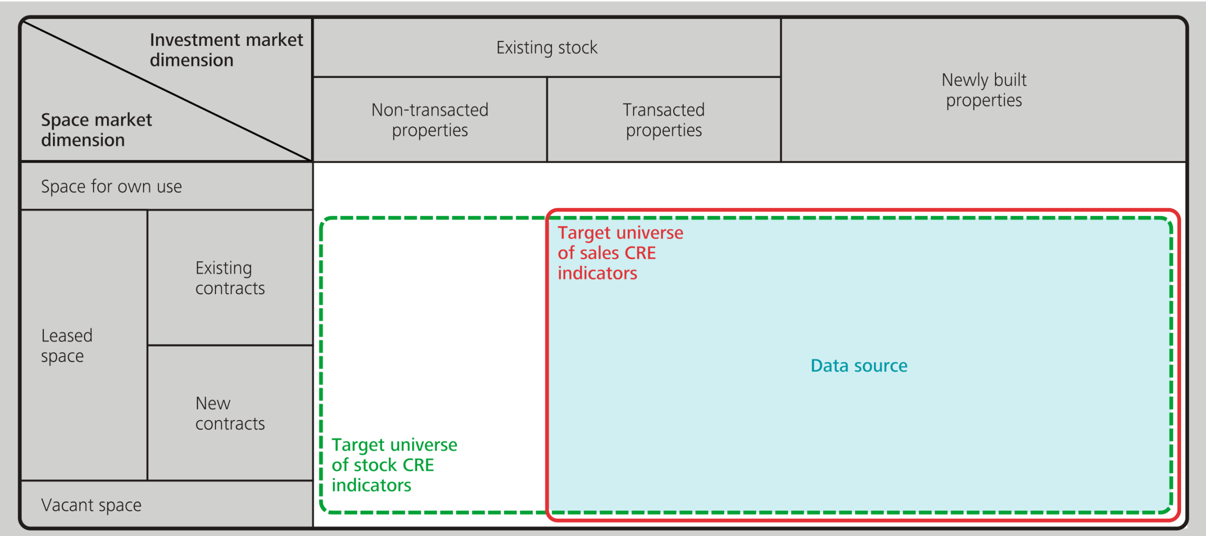
One approach to the compilation of core CRE market indicators is to consider them as unrelated statistical entities, each of which serves individual purposes or user interests and poses different challenges as regards the availability of data sources. One example is a rent index which is intended to be used in national accounts and is thus conceptually similar to a producer price index for the sector “Renting and operating of own and leased real estate; non-residential”

(68.20.2).[7] Diewert and Shimizu (2017) calculating commercial property price indices for the compilation of the System of National Accounts is a further example. These indices distinguish between the price of the structure and the price of land. The (usual) definition of the vacancy rate as a percentage of vacant marketable floor space to total marketable floor space measured is another example. With square meterage as the measurement unit for the constituents of the vacancy rate, the vacancy rate is an indicator of real estate market tensions which is very closely related to activity indicators (such as building permits and starts) rather than to price, rent, and rental yield indices.

An alternative approach takes the valuation of individual CRE as a starting point, based on the reasoning that the relationship between the market price, the gross rent, the net rental yield and the vacancy rate, derived for an individual property in (6), should carry over to the respective macro indicators. In this line of argument, the respective macro indicators are not only aggregates of a sample of observations measured at different points in time. Instead, they reflect price, rent and rental yield developments as well as the ratio of vacant space for a representative property of the CRE market. Except for in a few very exceptional cases, an individual, perhaps hypothetical, property can only be representative in a single target universe. Hence, the core CRE market indicators must share the same target universe in this approach.

Figure 1

Target universe and data source of core CRE market indicators



Deutsche Bundesbank S4PR0046A.Chart

We derive the common target universe from the overlap of the maximum target universes of price indices and rent indices. These target universes are defined along orthogonal dimensions, as illustrated in Fig. 1. In general, each property may be classified as non-transacted, transacted or newly built. These are categories of the investment market which are relevant for prices. At the same time, each property, or even each separate unit thereof,[8] may be grouped into a space

[7] In the German version of the current statistical classification of economic activities (*Klassifikation der Wirtschaftszweige, Ausgabe 2008*), the NACE Rev. 2 sector 68.20 is further broken down into residential and non-residential real estate. NACE is the acronym of the respective European classification called *Nomenclature statistique des activités economiques*.

[8] For the sake of simplification, we do not distinguish the degree of granularity between the investment and

market category. It may be classified as non-leased, leased or vacant. Leased properties may be further broken down into those rented out under an existing or new contract.

The maximum target universe of a price index consists of all non-transacted, transacted and newly built properties. A rent index can, at most, cover all leased and vacant properties. The intersection represents the common target universe of price and rent indices and, as a corollary, it applies to rental yield indices and vacancy rates, too.

The availability of data is usually another factor that may shrink the coverage of the indicators if the condition of macro-consistency is to be met. In a bottom-up calculation using granular data, macro-consistency will only be achieved if the price and the rental situation are observed for each and every property in the dataset. If we further require observations be solely transaction-based, we are able to compile macro-consistent indicators on the basis of transacted properties that are rented out. The dataset is expandable to newly built properties that are (intended to be) rented out.

In CRE price statistics, a distinction is generally made between indices for sales and stocks (see Eurostat, 2017, Section 4.6). For the former, the restriction on transactions is conceptually adequate whereas, for the latter, the application of transaction-based information on prices and rental income to the non-transacted part of the real estate stock is reasoned by the argument that this information is the best source for market valuations (i.e. assessing the value of the property if it were being sold at the market). In this sense, the coverage of the price index can be extended to the complete real estate stock.

For rent and rental yield indices as well as the vacancy rate, a two-step argumentation is needed to use the information about the rental income and vacant space of transacted properties with the aim of covering the complete real estate stock. First, the observations from the transacted properties may be taken as the best information base to proxy the rental income and vacant space of the non-transacted real estate stock. Second, as rental income is actually earned only when the property is rented out, an expansion of the information to the non-leased part of the real estate stock requires imputation. It is a matter of the index concept whether imputations should be included.

From the discussion so far, we conclude that a bottom-up compilation of macro-consistent core CRE market indicators can only be based on granular data about the price and the rental situation of transacted, leased properties. With some additional assumptions, it is nonetheless possible to construct indices covering the complete real estate stock.

3.2 Formulae for Lowe indices

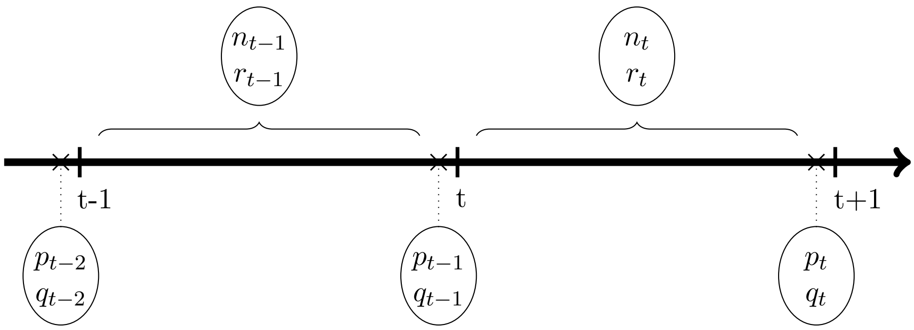
In this section, we derive formulae for a bottom-up compilation of macro-consistent core CRE market indicators, assuming that target universes are common and the granular dataset is complete. The formulae refer to the stock of properties, which is either rented out or vacant. First, we derive Lowe index formulae for price, rent and rental yield indices. Then, we augment this set of three indicators by the vacancy rate.

the space markets though it turns out to realistically feature CRE markets. As any separate unit is generally rentable and saleable, we continue to denote the granular unit by property in both dimensions.

In the following, we switch from looking at individual objects to looking at strata. Let I denote the number of strata which are designed to group each and every individual property in a territory, with the set of strata $\{i : i = 1, 2, ..., I\}$ meeting the following conditions. First, each stratum contains objects, which are, or better: are made uniform with regard to all characteristics.[9] Second, strata do not overlap and cover the universe as a total. Let us denote the price, gross rent, net operating income, and the rental yield, which are representative for stratum i in period t, by $p_t(i)$, $r_t(i)$, $n_t(i)$, and $y_t(i)$, respectively. Let us further denote total floor space of stratum i in period t by $q_t(i)$.

Figure 2 illustrates the timing of events. At the end of a period, the investment market opens. Properties are transacted and we observe strata-specific prices and quantities. After the investment market has closed, a new period begins and the space market opens. Properties that are available at the space market in period t correspond to quantities on the investment market at end of period $t-1$. In the space market, properties either are rented out or remain vacant in the respective period. We observe period t gross rents, net operating income, and vacancies. After the space market has closed, the investment market opens and period t quantities are determined, which represent the quantities available on the space market in period $t+1$. Given this timing and the definitions in Section 2, the rental yield of period t represents the return in period t on an investment in period $t-1$.

Figure 2: Timing of events



Price indices. Following Eurostat (2017), let us define a price index for stocks of commercial properties using a Lowe index:

$$P_t^{Lo} = \frac{\sum_{i=1}^{I} p_t(i) q_b(i)}{\sum_{i=1}^{I} p_0(i) q_b(i)}, \tag{7}$$

where t denotes the reporting period, 0 the price reference period and b the weight reference period. As price and weight reference periods do not change over time in a set of Lowe indices, in the following, we abstain from indicating these two time-invariant reference periods for simplicity.

[9] CRE data are usually adjusted for potential variation in the quality of observed properties. Hedonic theory postulates that the price of a good can be decomposed into the contributions of its characteristics (Rosen, 1974). Establishing comparability of properties via a hedonic price function has therefore been a popular approach ever since (King and Mieszkowski, 1973; Linneman, 1980; Eurostat, 2013) and has been recommended for CRE (Eurostat, 2017). For residential real estate in Germany, this approach has been applied, for example, by the Federal Statistical Office of Germany(Dechent, 2008), vdpResearch, and Bauer, Feuerschütte, Kiefer, an de Meulen, Micheli, Schmidt, and Wilke (2013). Alternative approaches include the comparison of repeated sales prices of individual objects (Case and Shiller, 1987) and the comparison of typical objects, which is employed by bulwiengesa (Deutsche Bundesbank, 2020), e.g. by using narrowly defined strata.

The Lowe price index (7) may be written as a weighted sum of price relatives:

$$P_t^{Lo} = \sum_{i=1}^{I} w_P^{Lo}(i) \frac{p_t(i)}{p_0(i)} \quad \text{and} \quad w_P^{Lo}(i) = \frac{p_0(i) q_b(i)}{\sum_{j=1}^{I} p_0(j) q_b(j)}, \tag{8}$$

where $w_P^{Lo}(i)$ is henceforth called the Lowe price weight of stratum i. Lowe price indices are transitive and may thus be calculated by updating from one period to the next using the formula:

$$\frac{P_t^{Lo}}{P_{t-1}^{Lo}} = \sum_{i=1}^{I} \tilde{w}_P^{Lo}(i, t-1) \frac{p_t(i)}{p_{t-1}(i)} \quad \text{and} \quad \tilde{w}_P^{Lo}(i, t-1) = \frac{p_{t-1}(i)\, q_b(i)}{\sum_{j=1}^{I} p_{t-1}(j)\, q_b(j)}, \tag{9}$$

where $\tilde{w}_P^{Lo}(i, t-1)$ is the updated Lowe price weight of stratum i. This weight is time-dependent. It results from evaluating period b quantities at period $t-1$ market prices and is equivalent to price-updating the market value of CRE in stratum i from the weight reference period b to period $t-1$.

Rent and net operating income indices. Paralleling the construction of price indices, we define a Lowe gross rent index:

$$R_t^{Lo} = \frac{\sum_{i=1}^{I} r_t(i) q_b(i)}{\sum_{i=1}^{I} r_0(i) q_b(i)} = \sum_{i=1}^{I} w_R^{Lo}(i) \frac{r_t(i)}{r_0(i)} \quad \text{and} \quad w_R^{Lo}(i) = \frac{r_0(i) q_b(i)}{\sum_{j=1}^{I} r_0(j) q_b(j)}. \tag{10}$$

It can also be written in recursive form:

$$R_t^{Lo} = R_{t-1}^{Lo} \sum_{i=1}^{I} \tilde{w}_R^{Lo}(i, t-1) \frac{r_t(i)}{r_{t-1}(i)} \quad \text{and} \quad \tilde{w}_R^{Lo}(i, t-1) = \frac{r_{t-1}(i)\, q_b(i)}{\sum_{j=1}^{I} r_{t-1}(j)\, q_b(j)}, \tag{11}$$

where $\tilde{w}_R^{Lo}(i, t-1)$ is the Lowe rent weight of stratum i updated to period $t-1$. It results from rent-updating gross rental income generated by CRE in stratum i.

In the same way, we define a Lowe index for net operating income:

$$N_t^{Lo} = \frac{\sum_{i=1}^{I} n_t(i) q_b(i)}{\sum_{i=1}^{I} n_0(i) q_b(i)} = \sum_{i=1}^{I} w_N^{Lo}(i) \frac{n_t(i)}{n_0(i)} \quad \text{and} \quad w_N^{Lo}(i) = \frac{n_0(i) q_b(i)}{\sum_{j=1}^{I} n_0(j) q_b(j)}. \tag{12}$$

In its recursive form, it reads:

$$N_t^{Lo} = N_{t-1}^{Lo} \sum_{i=1}^{I} \tilde{w}_N^{Lo}(i, t-1) \frac{n_t(i)}{n_{t-1}(i)} \quad \text{and} \quad \tilde{w}_N^{Lo}(i, t-1) = \frac{n_{t-1}(i)\, q_b(i)}{\sum_{j=1}^{I} n_{t-1}(j)\, q_b(j)}\ , \tag{13}$$

where $\tilde{w}_N^{Lo}(i, t-1)$ is the Lowe net operating income weight of stratum i updated to its period $t-1$ value.

Aggregate rental yields and rental yield indices. In deriving a formula for the aggregate rental yield, we start from the idea of measuring the performance of a time-invariant portfolio of assets. In particular, the portfolio considered is representative of the CRE stock in period b, i.e. $q_b(1), q_b(2), ...q_b(I)$. The market value of this portfolio at the end of period $t-1$ is $\sum_{i=1}^{I} p_{t-1}(i)\ \ q_{t-1}(i)$. Net operating income of this portfolio in period t is given by

$\sum_{i=1}^{I} n_t(i)\ q_{t-1}(i)$. The portfolio's rental yield Y_t^{Lo} in period t is

$$Y_t^{Lo} = \frac{\sum_{i=1}^{I} n_t(i) q_b(i)}{\sum_{i=1}^{I} p_{t-1}(i) q_b(i)} \ , \tag{14}$$

where the superscript Lo indicates that quantities of the weight reference period b are used. Expanding the numerator in (14) by $p_{t-1}(i)$, applying the definition of the cap rate (5) to the strata level and using the definition of price updated weights (9), we end up with the compact expression:

$$Y_t^{Lo} = \frac{\sum_{i=1}^{I} [n_t(i)/p_{t-1}(i)]\ [p_{t-1}(i)\ q_b(i)]}{\sum_{i=1}^{I} [p_{t-1}(i)\ q_b(i)]} = \sum_{i=1}^{I} \tilde{w}_P^{Lo}(i, t-1)\, y_t(i) \ . \tag{15}$$

The aggregate rental yield is equivalent to the weighted sum of rental yields over all strata, if the weights of the chain-linking formula of Lowe price indices (9) are used. Hence, the aggregate rental yield is based on capital value share weights.

Changes in a rental yield index are constructed on the basis of the ratio (Y_t^{Lo}/Y_{t-1}^{Lo}). This yield index is consistent with the Lowe price index (7) and the Lowe index for net operating income (12) in the sense that the definition of an individual property's cap rate (5) carries over to the aggregate framework:

$$Y_t^{Lo}/Y_{t-1}^{Lo} = \frac{N_t^{Lo}/N_{t-1}^{Lo}}{P_{t-1}^{Lo}/P_{t-2}^{Lo}}. \tag{16}$$

This implies that, at the aggregate level, the change of the rental yield in percent is approximately equal to the percentage change of net operating income net of the percentage change in the market price.

Aggregate vacancy rate. In the following, we augment this set of three indicators – a price, a rent, and a rental yield index – by a vacancy rate. For the mathematical relationship on the individual property level to carry over to the aggregate level, the aggregate vacancy rate requires a specific definition and weighting scheme.

On the level of individual properties, the relationship between net operating income, the gross rent and the vacancy rate results from combining (2) and (3). Assuming the fraction of operating costs to be constant over time and across strata, this relation for stratum i reads

$$n_t(i)\ q_b(i) = \alpha\ r_t(i)\ q_b(i) - vr_t(i)\ r_t(i)\ q_b(i) \ . \tag{17}$$

Aggregating over all strata yields an expression for the relation on the aggregate level

$$\sum_{i=1}^{I} n_t(i)\, q_b(i) = \sum_{i=1}^{I} \alpha\, r_t(i)\, q_b(i) - \sum_{i=1}^{I} vr_t(i)\, r_t(i)\, q_b(i) \ . \tag{18}$$

The aggregate net operating income in period t of the population of properties in the weight reference period b is equivalent to the gross rental value less operating expenses and less forgone profit due to vacancies.

For a set of Lowe indices, we define the aggregate vacancy rate as

$$VR_t^{Lo} = \sum_{i=1}^{I} \frac{r_t(i)q_b(i)}{\sum_{j=1}^{I} r_t(j)q_b(j)} \, vr_t(i) \; . \tag{19}$$

The superscript *Lo* indicates that the vacancy rate uses the same weight reference period as the Lowe indices for prices and gross rents. The weighting scheme underlying the aggregate vacancy rate is based on rental income shares, as in the case of the gross rent index. The only difference to the rental income weight in (11) is that rental income is price updated to period t instead of period $t-1$.

Dividing (18) by (18) for the observation period $t = 0$ yields an expression linking the Lowe index for the gross rent to the one for net operating income via the vacancy rate.[10]

$$N_t^{Lo} = \frac{\alpha - VR_t^{Lo}}{\alpha - VR_0^{Lo}} \; R_t^{Lo} \tag{20}$$

The evolution of a net rental yield index can be described by changes in the price and the gross rent index as well as a vacancy rate between two time periods. Eliminating net operating income in (16) using (20), the rental yield index evolves according to

$$Y_t^{Lo}/Y_{t-1}^{Lo} = \frac{\alpha - VR_t^{Lo}}{\alpha - VR_{t-1}^{Lo}} \; \frac{R_t^{Lo}/R_{t-1}^{Lo}}{P_{t-1}^{Lo}/P_{t-2}^{Lo}}. \tag{21}$$

Discussion. There are different ways to measure vacancies. Vacancies could, for example, be measured in terms of properties, floor space, the market value of properties, or the value on the rental market. Eurostat (2022a) argues that the general consensus is to measure vacancies in terms of vacant floor space and suggests using this measure. However, the integration of the vacancy rate into a set of macro-consistent CRE market indicators requires the valuation of vacant space by their value on the rental market. Compared to weighting vacancies by buildings or floor space, relatively expensive CRE markets get a higher weight than relatively cheap ones.

Measuring vacancies with their value on the rental market is based on two economic arguments. First, whether commercial space is vacant or occupied is per se value-neutral. What is interesting, however, is the way vacant commercial space affects commercial lessors, for example. A rent-weighted aggregate vacancy rate enables us to calculate foregone profit, which might be useful with respect to the assessment of financial soundness of commercial lessors. Second, taking differences in the quality of properties into account, which rents are indicative of, simplifies the calculation of productive capital.

3.3 Formulae for chain-linked Laspeyres-type indices

In this section, we derive annually chain-linked macro-consistent core CRE market indicators. Here, price and rent indices are of Laspeyres-type, which is the concept usually applied in official price statistics in Europe.[11] In contrast to Section 3.2, the rental yield index here measures the performance of a time-varying portfolio of assets.

[10] For a derivation of (20), see Section A.1 in Appendix A.

[11] Given a quarterly frequency, annual expenditure shares would have to be price updated to the fourth quarter.

In particular, prices and quantities are determined in the investment market and settle at the end of the period. A chain-linked price index tracks the evolution of price changes for a portfolio that is representative of quantities at the time of investment.

Gross rents and net operating income are determined in the market for office space. This market opens at the beginning of a period. For example, in period t, gross rents and net operating income represent the values from renting out the property over period t. Available office space for lease in period t has been determined in the investment market at the end of period $t-1$. The quantities therefore refer to period $t-1$.

The index formulae that track changes in gross rents (23) and net operating income (24) of a Laspeyres-type form are shifted by one period due to the timing convention. Quantities therefore refer to period $t-2$ instead of period $t-1$.[12]

$$P_t^{CL} = P_{t-1}^{CL} \sum_{i=1}^{I} w_P^{t-1}(i,t-1) \frac{p_t(i)}{p_{t-1}(i)} \quad \text{and} \quad w_P^{t-1}(i,t-1) = \frac{p_{t-1}(i) q_{t-1}(i)}{\sum_{j=1}^{I} p_{t-1}(j) q_{t-1}(j)}, \tag{22}$$

$$R_t^{CL} = R_{t-1}^{CL} \sum_{i=1}^{I} w_R^{t-2}(i,t-1) \frac{r_t(i)}{r_{t-1}(i)} \quad \text{and} \quad w_R^{t-2}(i,t-1) = \frac{r_{t-1}(i) q_{t-2}(i)}{\sum_{j=1}^{I} r_{t-1}(j) q_{t-2}(j)}, \tag{23}$$

$$N_t^{CL} = N_{t-1}^{CL} \sum_{i=1}^{I} w_N^{t-2}(i,t-1) \frac{n_t(i)}{n_{t-1}(i)} \quad \text{and} \quad w_N^{t-2}(i,t-1) = \frac{n_{t-1}(i) q_{t-2}(i)}{\sum_{j=1}^{I} n_{t-1}(j) q_{t-2}(j)}. \tag{24}$$

The weights' superscript indicates the weight reference period; the second term in parenthesis indicates the observation period of prices and rents that is used to evaluate the respective quantities.

A rental yield index in a set of chain-linked indices results from chaining changes in the rental yield based on a coherent weighting scheme. Given the definition of the rental yield (14), the evolution of a rental yield index can be described by

$$Y_t^{CL} = Y_{t-1}^{CL} \frac{N_t^{CL} / N_{t-1}^{CL}}{P_{t-1}^{CL} / P_{t-2}^{CL}}. \tag{25}$$

Vacancy rate index. Similar to Section 3.2, we augment this three-variables set by an indicator for the vacancy rate. In the context of chain-linked Laspeyres-type indices, the aggregate vacancy rate reads

$$VR_t^{t-2} = \sum_{i=1}^{I} \frac{r_t(i) q_{t-2}(i)}{\sum_{j=1}^{I} r_t(j) q_{t-2}(j)} \, vr_t(i) = \sum_{i=1}^{I} w_R^{t-2}(i,t) \, vr_t(i) \; . \tag{26}$$

The subscript indicates the observation period of the vacancy rate; the superscript indicates the weight reference period. The weighting scheme is based on rental income shares. Similar to (19), the weight resembles that of the gross rent, but rental income is updated to period t instead of period $t-1$.

Dividing (18) for the observation period t and the weight reference period $b = t-2$ by (18) for the same weight reference period and the observation period $t-1$ yields an expression linking

[12] Using period $t-1$ quantities would imply a Paasche index, as $t-1$ quantities are only determined at the end of the period and refer to the quantities that are available for lease in period t.

chain-linked Laspeyres-type indices for the gross rent to net operating income via the vacancy rate.[13]

$$\frac{N_t^{CL}}{N_{t-1}^{CL}} = \frac{\alpha - VR_t^{t-2}}{\alpha - VR_{t-1}^{t-2}} \, \frac{R_t^{CL}}{R_{t-1}^{CL}} \tag{27}$$

Using (27) to eliminate net operating income from (25), the evolution of a net rental yield index can be described by

$$Y_t^{CL}/Y_{t-1}^{CL} = \frac{\alpha - VR_t^{t-2}}{\alpha - VR_{t-1}^{t-2}} \, \frac{R_t^{CL}/R_{t-1}^{CL}}{P_{t-1}^{CL}/P_{t-2}^{CL}}. \tag{28}$$

Chain-linked Laspeyres-type indices compare the evolution of a variable using the same weight reference period (chain link) and link these changes to an index. In the three-variable case, prices, rents, and rental yields are linked multiplicatively, which only requires information on the change in the respective aggregate to construct a set of indicators.

Vacancy rates, however, are subtracted from the fraction of rental income that remains after operating expenses have been deducted. We therefore cannot use a growth rate similar to prices, rents, and rental yields, but require a vacancy rate for two time periods using the same weight reference period to describe the evolution of a net rental yield index.

One way to circumvent this issue is to simplify the relation (28) by employing an approximation. Substituting the first fraction on the right-hand side by its first-order approximation, we can rewrite (28) as

$$Y_t^{CL}/Y_{t-1}^{CL} \approx \left(1 - \frac{\Delta VR_t^{CL}}{\alpha - VR}\right) \, \frac{R_t^{CL}/R_{t-1}^{CL}}{P_{t-1}^{CL}/P_{t-2}^{CL}} \, , \tag{29}$$

where VR represents the steady state vacancy rate.[14] The steady state vacancy rate is the rate in the long run equilibrium, which would occur in the absence of shocks. Due to frictions, it may, for example, take time to find a new tenant after the previous one has left the building, while some offices remain vacant even in the absence of shocks. $\Delta VR_t^{CL} = VR_t^{t-2} - VR_{t-1}^{t-2}$ is the change in the aggregate vacancy rate for the weight reference period $t-2$ for the observation period t in percentage points. An indicator for the vacancy rate results from chaining changes in the vacancy rate with a common weight reference period.

4 Application to the German office market

This section presents a case study for the construction of a macro-consistent set of core CRE market indicators using the example of the market for office space in Germany.

In the following subsection, we provide an overview of the data used to compile the indicators. In Subsection 4.2, we present a macro-consistent set of four indicators, consisting of a price, a gross rent, and a net rental yield index as well as a vacancy rate. In Subsection 4.3, we compare the macro-consistent version of the indicators to alternative specifications proposed in the literature or used in practice.

[13] For a derivation of (27), see Section A.2 in Appendix A.

[14] We abstract from variation in the steady state vacancy rate due to changing weights.

4.1 Dataset

This paper uses a dataset provided by bulwiengesa, a real estate consulting agency for stakeholders in the German real estate market. We have annual information on prices, gross rents, and vacancy rates for office space in 125 German towns and cities. Each town and city represents one stratum.[15] Information on prices and rents is based on assessments of market experts for a typical property in the respective stratum. Our dataset starts in 1995. Especially for towns and cities in the former German Democratic Republic, office markets required several years to adjust after the German reunification. The last year of observations is 2023.

Prices and gross rents refer to prime properties. Prices reflect net purchase prices per square metre in the respective year and exclude ancillary acquisition costs such as land transfer taxes, administrative expenses (notary and registration fees), as well as expert and broker fees. Rents represent monthly square metre rents that could be obtained under a new lease starting in the respective year. We annualise this monthly information. Rents correspond to the contractually agreed starting rent regardless of incentives, incidental expenses, and taxes. Rents track the evolution of contract rents, therefore represent gross rents.

Vacancy rates are calculated as the ratio of marketable vacant office space to total marketable office space in the respective town or city. Total office space is the sum of the net usable area in square metres of existing offices and office space under construction that will be available for occupancy within three months.[16] Vacant office space is the sum of the vacant net usable area in square metres that is available for sale or letting and ready for occupancy within three months.[17] The reporting date for these space indicators is the end of the year.

Net operating income is calculated as gross rents less operating expenses and forgone profit associated with vacancies. We assume a constant operating cost rate of 20% of the gross market rent across cities and over time. Gross and net yields are calculated dividing gross rents and net operating income by prices.

Table 1 reports summary statistics for unweighted averages across the 125 strata and the standard deviation for the different indicators. Our dataset contains observations for 125 towns and cities in 29 years, which implies a maximum of 3,625 observations per indicator. On average, the square metre price of an office building in the reference year 2015 was €$1,517$. Over the sample period, prices increased by about 0.9% per year. The annual gross rent was about €136 per square metre, which is equivalent to about €11 per month. On average, gross rents increased by about 0.7% per year, which is substantially less than the growth rate of office prices. About 5.8% of office space was vacant in the observation period, which is roughly equal to the vacancy rate in the reference period 2015 (6.1%). Office space increased over time in our sample, on average by about 0.9% per year. In 2015, office space averaged $1,461$k m^2 per town or city.

Using prices, gross rents, and vacancy rates, we calculate net operating income and net rental yields at the city level. Net operating income is substantially less than the gross rent. In 2015,

[15] For the list of the 125 strata, see Table B.1 in the Appendix.

[16] Information on the stock of office space in 1995 is based on a complete count for some cities or an estimate based on the number of office workers for others. If there is no new complete count available, the stock of office space is updated based on information on additions and disposals.

[17] This is based on information by market participants, market observers, and portals for marketing vacant office space.

Table 1: Unweighted descriptive statistics

	mean (2015)	transformation	N	median	mean	SD
Price	€1,517	growth rate:	3,500	1.2%	0.9%	7.3
Gross annual rent	€136	growth rate:	3,500	0.0%	0.7%	4.6
Vacancy rate	6.1%		3,625	4,7%	5.8%	4.2
Office space	1,461k m^2	growth rate:	3,500	0.5%	0.9%	1.5
Annual net operating income	€101	growth rate:	3,500	0.6%	0.7%	5.1
Gross rental yield	10.9%		3,625	9.7%	10.1%	3.2
Net rental yield	8.0%		3,625	7.2%	7.4%	2.0

net operating income was €101 per square metre on average. In our sample, its mean growth rate was 0.7% per year. As vacancies in the first and the last year of our sample were roughly equal, the gross rent and net operating income expanded at a similar average rate. The average gross yield in our sample was 10.1%. The average net rental yield was substantially lower (7.4%).

4.2 Macro-consistent core CRE market indicators

Using the dataset provided by bulwiengesa, we compile macro-consistent sets of core CRE market indicators for office markets in the years from 1995 to 2023. We calculate aggregate indicators for 125 towns and cities, as well as for the seven largest cities.[18] This city group is a good proxy for the metropolitan areas in Germany and has played a prominent role in real estate market analysis for many years. Information on floor space is available at the same time as information on prices and rents. The exposition in this subsection is restricted to Laspeyres indices.

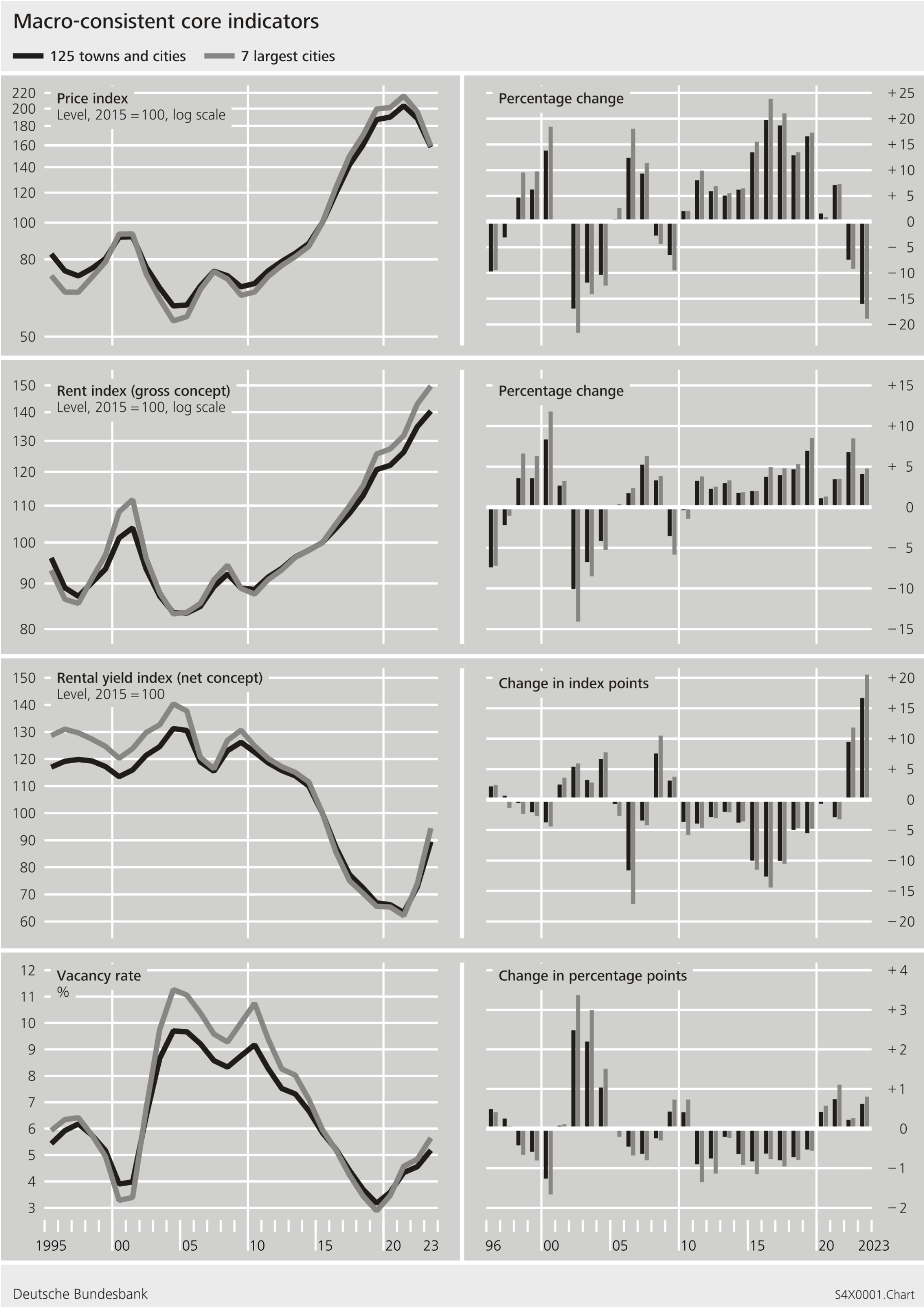
In Figure 3, the time series of the price, the gross rent and the net rental yield indices as well as the aggregate vacancy rate are displayed for the 125 towns and cities as well as for the seven largest cities. Comparing the two city groups with each other, the core indicators generally show a rather similar development in qualitative terms. However, there are differences with respect to quantitative changes. In general, absolute changes for the seven largest cities are larger than for the 125 towns and cities.

From 1995 to 2015, the price and rent indices fluctuated in approximately two full cycles without drifting clearly upwards or downwards. In the build-up of the dot-com bubble and prior to the outbreak of the Global Financial Crisis, office prices somewhat increased. During the following recessions, office prices dropped slightly below the respective pre-build-up level. The latest upswing in the German office market began in 2010 and lasted for about one decade. Since 2022, office prices have declined, picking up pace in 2023.

In the beginning of our observation period, gross rents developed similarly to prices, more or less mimicking the cyclical pattern, albeit with a smaller amplitude. The prolonged increase in rental prices started in the early 2010s. In contrast to office prices, the upward trend in the rental market for offices remains intact until the end of the sample period. Rents have continued to increase, even after the COVID-19 pandemic.

[18] The seven city aggregate consists of indicators for Berlin, Dusseldorf, Frankfurt am Main, Hamburg, Cologne, Munich, and Stuttgart.

Figure 3



Macro-consistent core indicators
125 towns and cities
7 largest cities
Price index
Level, 2015 = 100, log scale
Percentage change
Rent index (gross concept)
Level, 2015 = 100, log scale
Percentage change
Rental yield index (net concept)
Level, 2015 = 100
Change in index points
Vacancy rate
%
Change in percentage points
1995 00 05 10 15 20 23
96 00 05 10 15 20 2023
Deutsche Bundesbank
S4X0001.Chart

Net rental yields were rather stable in the first half of our observation period. With prices accelerating in the early 2010s, rental yields declined substantially. Since the trough in 2021, rental yields have picked up substantially due to declining prices and increasing rents.

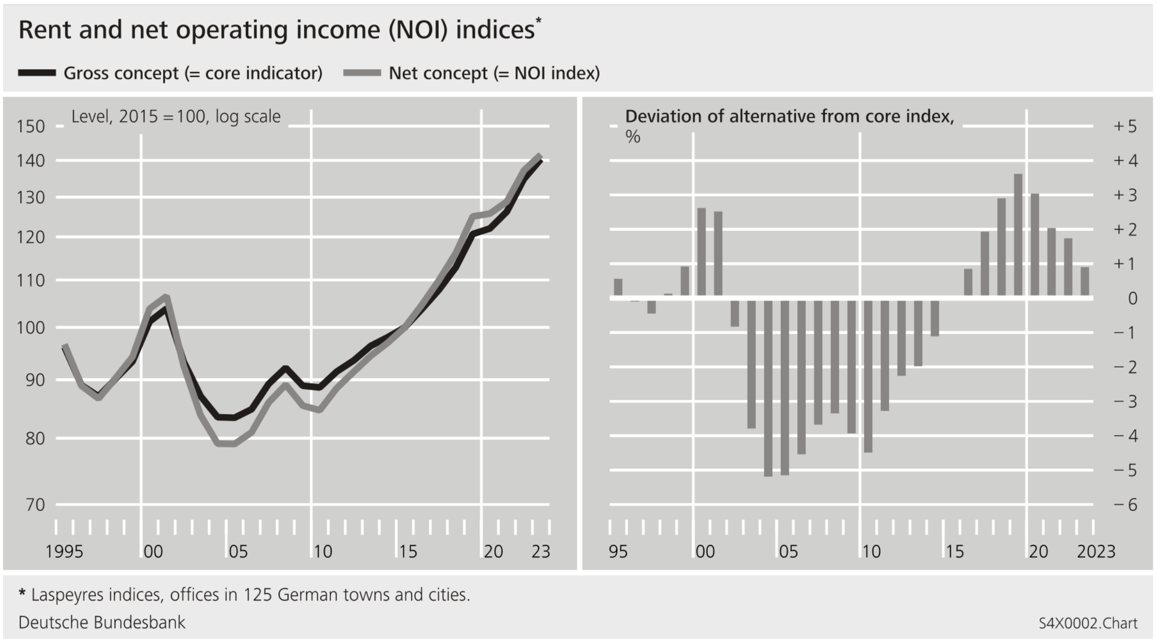
Vacancy rates for offices declined during the build-up of the dot-com bubble. After the bubble had burst, vacancy rates increased substantially and remained elevated till the early 2010s and the start of the latest property price cycle. Prior to the pandemic, vacancy rates dropped below the levels prior to the dot-com bubble. With the pandemic affecting the demand for office space, vacancy rates started to increase in 2020.

4.3 Comparison of macro-consistent core CRE market indicators with alternative choices

The core CRE market indicators need to be designed specifically in order to meet the conditions of macro-consistency. In this subsection, we compare macro-consistent indicators for the 125 towns and cities with alternative specifications of the indicators.

Figure 4 compares the gross rent and the net operating income indices to illustrate similarities and differences in the evolution of the two rent indicators. As we compare indices, differences in the level of the two indicators are driven by the choice of the base year. We therefore compare the changes in the two indices. The general trend of both indicators is rather similar. However, there are distinguishable differences with respect to quantitative changes. From 2000 to 2004 net operating income declined substantially more than the gross rent. From then until 2019, net operating income expanded substantially more than the gross rent, by about 13%.

Figure 4



The differences between the rental yield indices, displayed in Figure 5, reflect the differences in the rent indices, albeit with the opposite sign. Gross rental yields exhibit a higher volatility in comparison to the core indicator. The intuition is straightforward. During, say, an upswing in the office market, prices typically increase more than rents as prices reflect increased revenue in not just one period but the entirety of a property's remaining lifetime. Moreover, the vacancy rate decreases if the market is running hot. This decreases the wedge between gross rents and net rental income, implying a higher growth rate of net operating income.

Figure 5

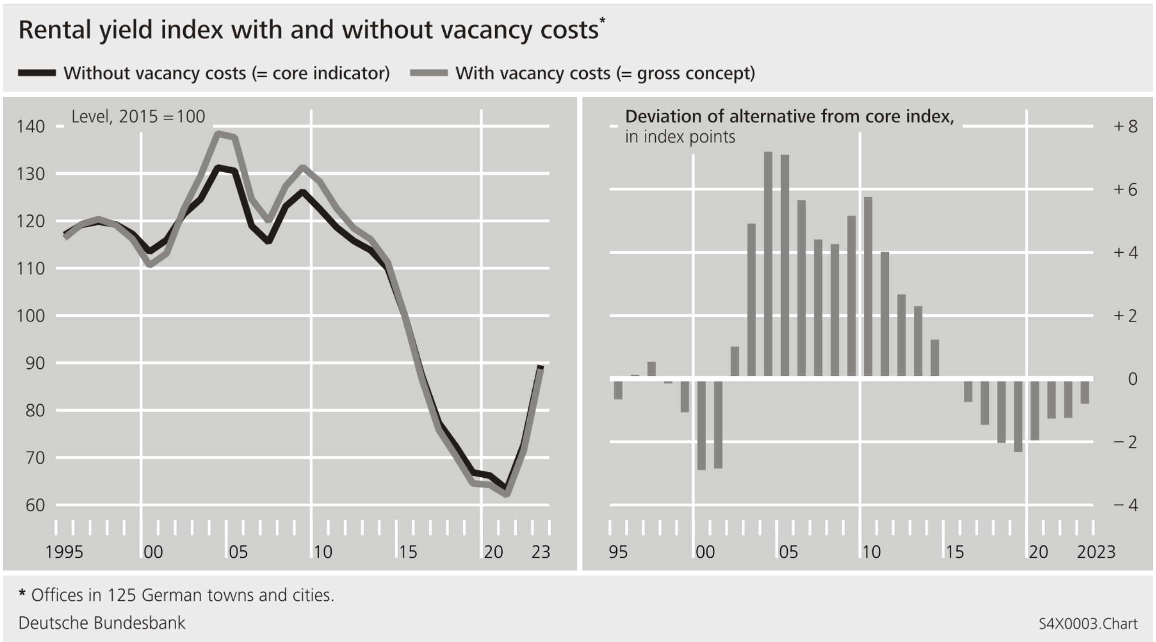


Figure 6 compares a rental income-weighted vacancy rate to a floor space-weighted one. In our sample, the core indicator is substantially more volatile than a floor space-weighted indicator. The intuition is similar to the one for the rental yield index. In an office market boom, vacancy rates go down due to an increased demand for office space. Demand for high quality (and expensive) office space typically increases disproportionately, so that value-weighted vacancy rates decrease more than floor space-weighted vacancy rates, in which space of high and low quality is weighted equally.

Figure 6

In the period from about 2003 to 2013, the rental income-weighted core vacancy rate was substantially higher than the floor space-weighted one. The difference amounted to up to 1.1 percentage points, implying that office markets in cities with high prices had especially high vacancy rates. With office markets running hot, vacancy rates fell substantially, especially in structurally high-priced markets. Prior to the pandemic in 2019, the core vacancy rate index was about 0.3 percentage points lower than its floor space-weighted equivalent. This implies that there are non-negligible differences between the two weighing schemes. Floor space weights underestimate the value of offices not utilised in the productive process due to vacant space.

Finally, we investigate the effect of different weighting schemes on rental yields. We argue that to be integrated in a consistent set of indicators, rental yields should be weighted by capital value shares. Apart from this weighting scheme, one might also, in principle, consider a weighting scheme based on the numerator, net operating income, or an average of the two weighting schemes.

Figure 7

Figure 7 illustrates how the weighting scheme affects the rental yield index. The general trend of the three indices is very similar. However, some non-negligible differences remain. Weighting yields with capital value shares, as in the core indicator, results in an index that is slightly more volatile. Capital value shares give markets with high-quality properties, the big cities where prices fluctuate more, a higher weight than the other weighting schemes. The difference in the weighting scheme accumulates to up to twelve index points.

5 Conclusions

In this paper, we have developed a statistical-methodological framework for the bottom-up compilation of macro-consistent core CRE market indicators. The set consists of a market price index, a gross rent index, a net rental yield index as well as a vacancy rate. Consistency requires, first, that the target universe be common and, second, that the granular dataset be complete as regards the information about market prices (including price-determining characteristics) and the rental situation (i.e. rental income, vacant space). The third condition refers to weighting schemes. The price index and the net rental yield index must be based on capital value shares whereas the gross rent index and the vacancy rate must be based on rental income shares.

We have compiled a consistent set of indicators for the German office market. The compilation is based on annual appraisal data for 125 towns and cities provided by bulwiengesa. This application can illustrate the benefits of macro-consistent CRE indicators. From 1995 to about 2010, office prices in Germany went through two cycles. However, these cycles were mild in comparison to the prolonged increase in prices since 2010. This raises the question as to whether the price index adequately captures the price development during the first two cycles. The other CRE indicators can be used to cross-check the development of the price index. First, the rental price index shows a similar pattern to the price index. Second, rental yield indices based on the other CRE indicators seem to be in line with the evolution of interest rates. This cross check also makes us confident that the divergent development of price and rent indices at the current edge adequately captures market developments. Even though rental yield indices have increased substantially in the last two years, they remain well below the levels observed prior to the low interest rate period. However, these indicators cannot fulfil at least two important user needs, namely that they are at quarterly frequency and are based on granular transaction-based information.

The granular CRE transaction data currently available are often rather patchy in the price or rent dimension or both. While it may not be advisable to follow a bottom-up approach under these circumstances, it is nonetheless worthwhile considering how to configurate the core set of CRE market indicators and to impose macro-consistency. For instance, a two-step procedure might be applied. The first step would be to compile the market price index, the gross rent index and the vacancy rate using the individually most appropriate, albeit not necessarily uniform, datasets. The second step would be to infer the net rental yield index by applying the income approach to asset valuation at the aggregate level. This is definitely a second-best solution but probably viable in many instances of current statistical practice.[19]

Further efforts are needed to develop granular data sources in order to make them fit for the bottom-up compilation of quarterly core CRE market indicators. From this paper, we conclude that the data requirements are high. In particular, the market price and price-determining characteristics as well as rental income and vacant space must be available for each and every transacted property. Such a full-information transaction database is difficult to collate with data from notaries and other administrative sources because information about the rental situation is missing. In addition, share deals are not covered. Transaction databases arising from the lending business of banks are perhaps better suited provided that they capture sales activity to a sufficient degree.[20]

Apart from macro-consistency, we have identified conceptual issues which are to be further discussed between compilers and users of CRE market statistics. For example, a sharpening

[19] In manuals and recommendations, statistical methods are often given a rating of A, B or C in order to signal compilers whether the method is preferred (A), acceptable (B) or prohibited (C). Adopting this, we could assign an A rating to the fully fledged bottom-up approach while the alternative could be given a B.

[20] In Germany, such a transaction database is maintained by vdpResearch.

of definitions is welcome, particularly as regards the space market variables. To enhance the interpretation, it should be clarified what exactly constitutes rental income and which cost components are to be deducted from income.

References

Adams, B., L. Loewenstein, H. Montag, and R. Verbrugge (2022). Disentangling rent index differences: Data, methods, and scope. Working Paper 55, Bureau of Labor Statistics.

Ambrose, B. W., N. E. Coulson, and J. Yoshida (2015, 12). The repeat rent index. *The Review of Economics and Statistics 97*(5), 939–950.

Ambrose, B. W., N. E. Coulson, and J. Yoshida (2023). Housing rents and inflation rates. *Journal of Money, Credit and Banking 55*(4), 975–992.

Bauer, T. K., S. Feuerschütte, M. Kiefer, P. an de Meulen, M. Micheli, T. Schmidt, and L.-H. Wilke (2013). Ein hedonischer Immobilienpreisindex auf Basis von Internetdaten: 2007–2011 [A hedonic real estate price index based on internet data: 2007–2011]. *AStA Wirtschafts- und Sozialstatistisches Archiv 7*(1), 5–30.

Case, K. E. and R. J. Shiller (1987). Prices of single family homes since 1970: New indexes for four cities. Working Paper 2393, National Bureau of Economic Research.

Dechent, J. (2008). Hauserpreisindex – Projektfortschritt und erste Ergebnisse für bestehende Wohngebäude [House price index – Project progress and first results for the stock of residential properties]. *Wirtschaft und Statistik 1*(2008), 69–81.

Deutsche Bundesbank (2020). Qualitätsbericht zu den Preisindizes für Wohnimmobilien auf Grundlage der Preisangaben der bulwiengesa AG [Quality report on price indices for residential real estate based on price information by bulwiengesa AG].

Diewert, E. and C. Shimizu (2017). Alternative approaches to commercial property price indexes for tokyo. *Review of Income and Wealth 63*(3), 492–519.

Diewert, W., K. Fox, and C. Shimizu (2016). Commercial property price indexes and the system of national accounts. *Journal of Economic Surveys 30*(5), 913–943.

Diewert, W. and C. Shimizu (2015). A conceptual framework for commercial property price indexes. *Journal of Statistical Science and Application 3*(9-10), 131–152.

Eichholtz, P., N. Kok, and J. M. Quigley (2010). Doing well by doing good? Green office buildings. *American Economic Review 100*(5), 2492–2509.

European Commission (2023). Final progress report on commercial real estate statistics. Commission Staff Working Document 434.

European Systemic Risk Board (2016). Recommendation of the European Systemic Risk Board on closing real estate data gaps. (ESRB/2016/14), 31 October 2016.

European Systemic Risk Board (2019). Recommendation of the European Systemic Risk Board amending recommendation ESRB/2016/14 on closing real estate data gaps. (ESRB/2019/3), 21 March 2019.

Eurostat (2013). *Handbook on Residential Property Price Indices (RPPIs)*. Luxemburg: Publication Office of the European Union.

Eurostat (2017). *Commercial property price indicators: Sources, methods and issues*. Luxemburg: Publication Office of the European Union.

Eurostat (2018). *Harmonised Index of Consumer Prices (HICP)*. Methodolocigal Manual 2018. Luxemburg: Publication Office of the European Union.

Eurostat (2022a). *Indicators of CRE market*, Chapter 4. Draft chapter 4 of the manual on commercial real estate indicators – June 2022. last checked: 02.05.2023.

Eurostat (2022b). *Methods for compiling CRE indicators*. Draft chapter 7 of the manual on commercial real estate indicators – June 2022. Luxemburg. last checked: 02.05.2023.

Fisher, J. D., D. M. Geltner, and R. B. Webb (1994). Value indices of commercial real estate: A comparison of index construction methods. *The Journal of Real Estate Finance and Economics 9*, 137–164.

Geltner, D. (1990). Return risk and cash flow risk with long-term riskless leases in commercial real estate. *Real Estate Economics 18*(4), 377–402.

Heath, R. M. and E. B. Goksu (2016). G-20 Data Gaps Initiative II: Meeting the policy challenge. *IMF Working Papers 2016*(043).

Hill, R. J. and M. Steurer (2020). Commercial Property Price Indices and Indicators: Review and Discussion of Issues Raised in the CPPI Statistical Report of Eurostat (2017). *Review of Income and Wealth 66*(3), 736–751.

King, A. T. and P. Mieszkowski (1973). Racial discrimination, segregation, and the price of housing. *Journal of Political Economy 81*(3), 590–606.

Knetsch, T. A. (2021). Compilation of commercial property price indices for Germany tailored for policy use. *Jahrbücher für Nationalökonomie und Statistik 241*(4), 437–461.

Koster, H. R., J. van Ommeren, and P. Rietveld (2014). Is the sky the limit? High-rise buildings and office rents. *Journal of Economic Geography 14*(1), 125–153.

Linneman, P. (1980). Some empirical results on the nature of the hedonic price function for the urban housing market. *Journal of Urban Economics 8*(1), 47–68.

Rosen, S. (1974). Hedonic prices and implicit markets: Product differentiation in pure competition. *Journal of Political Economy 82*(1), 34–55.

Webb, R. and J. D. Fisher (1996). Development of an effective rent (lease) index for the Chicago CBD. *Journal of Urban Economics 39*(1), 1–19.

Wheaton, W. C. and R. G. Torto (1994). Office rent indices and their behavior over time. *Journal of Urban Economics 35*(2), 121–139.

Appendix

A Derivations

This section presents the derivation of equations (20) and (27).

A.1 Derivation of (20)

Dividing (18) by (18) for the observation period $t = 0$ yields:

$$\frac{\sum_{i=1}^{I} n_t(i)\, q_b(i)}{\sum_{i=1}^{I} n_0(i)\, q_b(i)} = \frac{\sum_{i=1}^{I} \alpha\, r_t(i)\, q_b(i) - \sum_{i=1}^{I} vr_t(i)\, r_t(i)\, q_b(i)}{\sum_{i=1}^{I} \alpha\, r_0(i)\, q_b(i) - \sum_{i=1}^{I} vr_0(i)\, r_0(i)\, q_b(i)} \tag{A.1}$$

Using (12), we can rewrite the left side of (A.1) as N_t^{Lo}. Expanding the right side by $\sum_{i=1}^{I} r_0(i)\, q_b(i)$, we can rewrite (A.1) as

$$N_t^{Lo} = \frac{\frac{\sum_{i=1}^{I} \alpha\, r_t(i)\, q_b(i)}{\sum_{i=1}^{I} r_0(i)\, q_b(i)} - \frac{\sum_{i=1}^{I} vr_t(i)\, r_t(i)\, q_b(i)}{\sum_{i=1}^{I} r_0(i)\, q_b(i)}}{\frac{\sum_{i=1}^{I} \alpha\, r_0(i)\, q_b(i)}{\sum_{i=1}^{I} r_0(i)\, q_b(i)} - \frac{\sum_{i=1}^{I} vr_0(i)\, r_0(i)\, q_b(i)}{\sum_{i=1}^{I} r_0(i)\, q_b(i)}} \tag{A.2}$$

Using that α does not depend on the individual stratum i, using (10), and expanding the second fraction in the numerator by $\sum_{i=1}^{I} r_t(i)\, q_b(i)$, we can rewrite this expression as

$$N_t^{Lo} = \frac{\alpha\, R_t^{Lo} - \frac{\sum_{i=1}^{I} vr_t(i)\, r_t(i)\, q_b(i)}{\sum_{i=1}^{I} r_t(i)\, q_b(i)} \frac{\sum_{i=1}^{I} r_t(i)\, q_b(i)}{\sum_{i=1}^{I} r_0(i)\, q_b(i)}}{\alpha - \frac{\sum_{i=1}^{I} vr_0(i)\, r_0(i)\, q_b(i)}{\sum_{i=1}^{I} r_0(i)\, q_b(i)}} \tag{A.3}$$

Given the definition of the aggregate vacancy rate for Laspeyres indices (19) and again using (10), (A.3) simplifies to

$$N_t^{Lo} = \frac{\alpha\, R_t^{Lo} - VR_t^{Lo}\, R_t^{Lo}}{\alpha - VR_0^{Lo}} \,, \tag{A.4}$$

which can easily be rearranged to yield (20) in the main text.

A.2 Derivation of (27)

Dividing (18) for the observation period t and the weight reference period $b = t - 2$ by (18) for the same weight reference period and the observation period $t - 1$ yields:

$$\frac{\sum_{i=1}^{I} n_t(i)\, q_{t-2}(i)}{\sum_{i=1}^{I} n_{t-1}(i)\, q_{t-2}(i)} = \frac{\sum_{i=1}^{I} \alpha\, r_t(i)\, q_{t-2}(i) - \sum_{i=1}^{I} vr_t(i)\, r_t(i)\, q_{t-2}(i)}{\sum_{i=1}^{I} \alpha\, r_{t-1}(i)\, q_{t-2}(i) - \sum_{i=1}^{I} vr_{t-1}(i)\, r_{t-1}(i)\, q_{t-2}(i)} \tag{A.5}$$

Using (24), we can rewrite the left side of (A.5) as $\frac{N_t^{CL}}{N_{t-1}^{CL}}$. Expanding the right side by

$\sum_{i=1}^{I} r_{t-1}(i)\, q_{t-2}(i)$, we can rewrite (A.5) as

$$\frac{N_t^{CL}}{N_{t-1}^{CL}} = \frac{\frac{\sum_{i=1}^{I} \alpha\, r_t(i)\, q_{t-2}(i)}{\sum_{i=1}^{I} r_{t-1}(i)\, q_{t-2}(i)} - \frac{\sum_{i=1}^{I} v r_t(i)\, r_t(i)\, q_{t-2}(i)}{\sum_{i=1}^{I} r_{t-1}(i)\, q_{t-2}(i)}}{\frac{\sum_{i=1}^{I} \alpha\, r_{t-1}(i)\, q_{t-2}(i)}{\sum_{i=1}^{I} r_{t-1}(i)\, q_{t-2}(i)} - \frac{\sum_{i=1}^{I} v r_{t-1}(i)\, r_{t-1}(i)\, q_{t-2}(i)}{\sum_{i=1}^{I} r_{t-1}(i)\, q_{t-2}(i)}} \tag{A.6}$$

Using that α does not depend on the individual stratum i, using (23), and expanding the second fraction in the numerator by $\sum_{i=1}^{I} r_t(i)\, q_{t-2}(i)$, we can rewrite this expression as

$$\frac{N_t^{CL}}{N_{t-1}^{CL}} = \frac{\alpha\, \frac{R_t^{CL}}{R_{t-1}^{CL}} - \frac{\sum_{i=1}^{I} v r_t(i)\, r_t(i)\, q_{t-2}(i)}{\sum_{i=1}^{I} r_t(i)\, q_{t-2}(i)} \frac{\sum_{i=1}^{I} r_t(i)\, q_{t-2}(i)}{\sum_{i=1}^{I} r_{t-1}(i)\, q_{t-2}(i)}}{\alpha - \frac{\sum_{i=1}^{I} v r_{t-1}(i)\, r_{t-1}(i)\, q_{t-2}(i)}{\sum_{i=1}^{I} r_{t-1}(i)\, q_{t-2}(i)}} \tag{A.7}$$

Given the definition of the aggregate vacancy rate for chain-linked indices (19) and again using (23), (A.7) simplifies to

$$\frac{N_t^{CL}}{N_{t-1}^{CL}} = \frac{\alpha\, \frac{R_t^{CL}}{R_{t-1}^{CL}} - VR_t^{t-2}\, \frac{R_t^{CL}}{R_{t-1}^{CL}}}{\alpha - VR_{t-1}^{t-2}}\ , \tag{A.8}$$

which can easily be rearranged to yield (27) in the main text.

B Tables

Table B.1: Definition of city-groups and towns and cities covered

City Group	Explanation	List of towns and cities
7 largest cities	Originally introduced by bulwiengesa; meanwhile adapted by other compilers (e.g. Federal Statistical Office of Germany, Deutsche Bundesbank, vdp)	Berlin, Dusseldorf, Frankfurt (Main), Hamburg, Cologne, Munich, Stuttgart
Large cities excluding 7 largest cities	BBSR definition of a large city: at least 100,000 inhabitants	Aachen, Augsburg, Bergisch Gladbach, Bielefeld, Bochum, Bonn, Bottrop, Braunschweig, Bremen, Bremerhaven, Chemnitz, Darmstadt, Dortmund, Dresden, Duisburg, Erfurt, Erlangen, Essen, Freiburg (Breisgau), Fürth, Gelsenkirchen, Göttingen (City), Hagen, Halle (Saale), Hamm, Hannover, Heidelberg, Heilbronn, Herne, Hildesheim (City), Ingolstadt, Jena, Karlsruhe, Kassel, Kiel, Koblenz, Krefeld, Leipzig, Leverkusen, Lübeck, Ludwigshafen, Magdeburg, Mainz, Mannheim, Moers, Mönchengladbach, Mülheim (Ruhr), Münster, Neuss (City), Nuremberg, Oberhausen, Offenbach (Main), Oldenburg, Osnabrück, Paderborn (City), Pforzheim, Potsdam, Recklinghausen (City), Regensburg, Remscheid, Reutlingen (City), Rostock, Saarbrücken, Siegen (City), Solingen, Trier, Ulm, Wiesbaden, Wolfsburg, Wuppertal, Würzburg
Medium-sized towns	BBSR definition of a medium-sized town: at least 20,000, but below 100,000 inhabitants	Albstadt, Aschaffenburg, Bamberg, Brandenburg (Havel), Coburg, Cottbus, Dessau-Roßlau, Detmold, Düren (City), Eisenach, Flensburg, Frankfurt (Oder), Friedrichshafen, Fulda (City), Gera, Gießen (City), Görlitz, Greifswald, Gütersloh (City), Halberstadt, Hanau, Kaiserslautern, Kempten (Allgäu), Konstanz (City), Landshut, Lüdenscheid, Lüneburg (City), Marburg, Minden, Neubrandenburg, Neumünster, Offenburg, Passau, Plauen, Ratingen, Ravensburg (City), Rosenheim, Salzgitter, Schwerin, Stralsund, Suhl, Tübingen (City), Villingen-Schwenningen, Weimar, Wilhelmshaven, Witten, Zwickau