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How Efficient is the U.K. Housing Market?

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Non-technical Summary

Research in real estate finance and economics has been dealing with the topic of efficiency in the housing market for over 25 years, mainly for the U.S., Canada, and the U.K. Most recent research on this topic either only examines local markets based on single homes or focuses on structural, sectoral or macro economic methods and models. By contrast, our analysis focuses on univariate analysis, thereby examining the memory of the individual house price series and the information contained in the time series with respect to future house prices. To the best of our knowledge, there does not yet exist any similar study for the housing market in the U.K. built on transaction-only based indices provided by Nationwide, one of the largest building societies in the U.K.

This study examines the behavior of quarterly house price changes for 13 regions in the U.K. and one nationwide index from the fourth quarter of 1973 to the fourth quarter of 2009 incorporating several cycles of both booms and downturns of the U.K. housing market, whereas the amplitude of each cycle differs by region. The conducted analysis provides empirical evidence that house price changes in the U.K. exhibit certain patterns. The results show that the return generating process of U.K. housing markets differs significantly from the theoretical model of the random walk hypothesis. The conducted tests reject the null hypothesis of a random walk for all time series of house price changes and indicate strong mean-aversion processes. Furthermore, trading strategies are implemented as a robustness check and support the findings by generating excess returns in comparison to a buy-and-hold strategy. In general, we can conclude that market participants can use the information which is contained in the time series for their forecast; also, and investors might be likely to earn excess returns by using past information in the U.K. housing market, in particular when short selling or other types of participation in downward-moving markets is allowed and accessible. The identified inefficiencies are much stronger for the southern parts than for the northern parts of the U.K.

Das Wichtigste in Kürze

Die Analyse der Effizienzeigenschaften der Häusermärkte war in den letzten 25 Jahren immer wieder Gegenstand von wissenschaftlichen Untersuchungen. Allerdings beziehen sich die meisten Analysen auf den US-amerikanischen Markt. Die bisherigen Analysen zum britischen Markt konzentrieren sich entweder auf einzelne lokale Märkte und beruhen auf Daten zu Einzelimmobilien oder die Analysen basieren auf sektoralen oder makroökonomischen Modellen. Dagegen liegt der Fokus dieser Untersuchung auf einer univariaten Analyse und untersucht die Persistenz- und Prognoseeigenschaften der regionalen Hauspreisindizes in Großbritannien und Nordirland.

Die 13 regionalen Hauspreisindizes sowie ein nationaler Index bestehen aus transaktionsbasierten Daten und werden von Nationwide, einem der größten Hypothekenfinanzierer in Großbritannien, seit Ende 1973 quartalsweise berechnet. Die Analyse erstreckt sich daher über den Zeitraum von 1974 bis 2009, über den sich mehrere Immobilienpreiszyklen erkennen lassen und somit alle Marktphasen Berücksichtigung finden.

Die durchgeführten parametrischen und nicht-parametrischen Testverfahren liefern empirische Evidenz, dass die Hypothese des Random Walks als Testverfahren auf Markteffizienz für die britischen Häusermärkte auf dem 1 %-Signifikanzniveau mehrheitlich abgelehnt wird. Als zusätzlicher Test auf die Robustheit der Ergebnisse und auf Grund ihrer praktischen Relevanz werden zwei Handelsstrategien implementiert. In Bezug auf die Prognosefähigkeit deuten die Ergebnisse darauf hin, dass Finanzmarktakteure in der Lage sein könnten, – unter Verwendung von auf historischen Kursen beruhenden Informationen – Überrenditen zu erzielen bzw. aus historischen Kursen Informationen zu gewinnen, die sich zur Prognose der zukünftigen Marktentwicklung eignen. Die aufgedeckten Ineffizienzen erweisen sich für die südlichen Regionen – im Gegensatz zu den Regionen im nördlichen Großbritannien – als deutlich ausgeprägter.

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Abstract

Extending the controversial findings from the relevant literature, the results from the quarterly transaction-based Nationwide indices from 1974 to 2009 provide further empirical evidence on the rejection of the weak-form version of efficiency in the U.K. housing market. In addition to conducting parametric and non-parametric tests, we apply technical trading strategies to test whether or not the inefficiencies can be exploited by investors earning excess returns. The empirical findings from the technical trading strategies support the results from the statistical tests and suggest that investors might be able to obtain excess returns from both autocorrelation- and moving average-based strategies compared to a buy-and-hold strategy for 10 out of 14 markets.

Keywords: Housing market, weak-form market efficiency, random walk hypothesis, variance ratio tests, runs test, trading strategies

JEL Classifications: G12; G14; G15; R31

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1 Introduction

Housing markets are typically characterized by high transaction costs, low turnover volumes, carrying costs, specific tax issues, asymmetric information, and unstandardized, heterogeneous commodities, compared in particular to assets on financial markets. These arguments are repeatedly given as reasons why housing markets might be less efficient than other asset markets.

Nevertheless, the topic of market efficiency is of no less significance for housing markets as already emphasized by Gatzlaff and Tirtiroglu (1995). Around half the net wealth of private households in the U.S. and other developed countries like the U.K. consists of real estate, of which the own home constitutes a substantial part. However, the conducted research on the U.K. housing market is much less intensive than for the U.S. housing markets or other asset markets. Furthermore, the origin of the current financial crisis has quite plainly demonstrated the importance of the housing market for the financial system and the economy. Due to the strong implications and consequences the sharp decrease of the U.K. housing prices had for mortgage banks, the financial system, and the economy in the U.K., an increasing number of market participants is interested in forecasting markets and hedging their risk exposure. Therefore, a closer look at the pattern of U.K. house prices is clearly worthwhile. This is particularly necessary because so little is known about identifying turning points in the housing market and about investor’s appropriate reaction. If housing markets are weak-form efficient, investors, homeowners, mortgage bankers, hedge funds, and others do not have to care about these movements and cannot get any further information from analyzing historical prices. However, if there is any indication of inefficiency in the housing markets, historical house prices could contain useful and valuable information with respect to turning points in the markets and to adjusting the real estate position in the asset portfolio.

While efficiency in U.K. real estate markets has already been the focus of a few previous studies, which mainly consider and test house price models with multiple variables, this paper focuses more on analyzing the historical time series of house prices and the information contained therein. Thus, the crucial question is whether historical house prices contain useful information for predicting future prices and to which extent this information can be used by investors to earn excess returns. Willcocks (2009) shows that a univariate analysis of the U.K. housing market is able to generate standardized residuals that were independent and identically distributed, “indicating that ‘there is nothing else left’” (Willcocks, 2009, p. 411).

Compared to relatively complex models with multiple variables as housing market indicators, a univariate analysis has the advantage that the data quality of other time series and the consequences of drawbacks in this data are not relevant. Furthermore, some studies are based on models with very restrictive assumptions, which are questionable. Additionally, the implementation and testing of a trading strategy based on past information of historical house prices only is more intuitive and realizable. This last point is of particular interest since there were, and still are, several attempts to construct both standardized and exchange traded as well as non-standardized and over-the-counter traded derivative products on the housing markets in the U.S. and the U.K in particular. Thus, financial products are provided to investors and market participants with different interests by which they can hedge their risk exposure to the housing market or can participate in the housing market without investing in direct real estate combined with all its well known shortcomings from an investor's perspective.

The positive impact of futures and options on the housing market for many different types of market players has been thoroughly discussed for almost 20 years now. As early as the 1990s, Case et al. (1991, 1995) recommended the introduction of derivatives on the housing market and emphasized the benefits for various market players with different interests such as homeowners, mortgage banks, insurance companies, hedge funds, and other investment groups. After the introduction of derivatives on 11 U.S. housing market indices at the Chicago Mercantile Exchange (CME) in May 2006, Shiller (2008) continues the discussion and emphasizes that "the potential value of such products, once they become established, is seen in consideration of the inefficiency of the market for single family homes" (Shiller, 2008, p. 2). Beside the standardized and exchange-traded options and futures on the Case-Shiller house price indices, according to the homepage of MacroMarkets LLC, there are also various over-the-counter products based on the Case-Shiller indices. The trading opportunities at the CME resulted in standardized products, less capital constraints and lumpiness, lower information dispersion, lower transaction costs, lower carrying costs, and less relevant tax issues compared to trading in the direct housing market.

Beside the U.S., there have been several attempts to establish a market for derivatives on the housing market in the U.K. in the past as well. In fact, the first property futures market for both single-family homes and also commercial real estate was launched by the London Futures and Options Exchange (London Fox) in 1991. However, this first period of trading futures on property markets lasted only a few months and ended in a scandal, which defined the following years in which no further efforts were undertaken to launch a property futures market. A review of further launches is given by Shiller (2008), which is briefly summarized in the following. Despite the sobering experience in the early 1990s, the idea of derivatives on real estate markets prevailed. It was not until the beginning of the 21st century that a new attempt launched property futures markets in the U.K. City Index and IG Index launched a spread betting market in single-family homes in 2001 and 2002, respectively. However, the success of the two companies was limited and both markets were closed in 2004. A third attempt at spread betting on U.K. home prices was launched by Cantor Index, but this business was closed in December 2008. Goldman Sachs created a market for covered warrants on U.K. home price indices on the London Stock Exchange in 2003 based on the Halifax home price indices. Hedgestreet.com, on the other hand, launched a further market for betting on the direction of home prices which could provide a hedging instrument for homeowners as it was the idea of the Hedgestreet.com founder. However, the attempts by both Goldman Sachs and Hedgestreet.com showed, once again, quite plainly that it seems "hard to get hedging markets started for real estate" (Shiller, 2008, p. 7). Thus, the futures and options markets on the Case-Shiller home price indices launched by the CME in May 2006 are the only well-known instruments for investors hedging their single-family home market risk exposure at the moment. However, it can also be seen that the idea of introducing a well-functioning market to hedge housing market movements has been alive for almost 20 years and even several hits have not been able to prevent attempts at launching these markets. Therefore, it may be expected that further attempts of launching derivatives on property markets will occur. Furthermore, companies related to the U.K. housing market like mortgage banks, hedge funds, and insurance companies might hedge their risk exposure by products traded over-the-counter and individually constructed products, as it is the case in the U.S. For investors participating in these markets and trading these products and for the pricing process of these products, the characteristics of the underlying indices with respect to their market efficiency in the understanding of Fama (1970) are of particular interest. Thus, the validity of the efficient market hypothesis, the information contained in historical prices series and its implications are crucial for their business.

A widely used test of market efficiency analyzes whether (housing) market indices follow a random walk or exhibit a certain pattern. If market indices show random walk behavior, investors will be unable to persistently earn excess returns because indices are priced at their equilibrium values. By contrast, if market indices do not follow a random walk process, the pricing of capital and risk would be predictable and investors could achieve excess returns.

For the last 25 years, understanding the behavior of stock prices has been a key topic in financial literature, and the efficient market hypothesis and its three versions according to Fama (1970) have been at the core of many empirical studies on traditional asset markets in a wide range of countries for highly developed markets e.g. Summers (1986), Fama and French (1988), Poterba and Summers (1988), Richardson and Stock (1989), and Fama (1991) but also for less developed markets e.g. Errunza and Losq (1985), Barnes (1986), Laurence (1986), Butler and Malaikah (1992), Agbeyegbe (1994), Huang (1995), Urrutia (1995), Grieb and Reyes (1999), Karemera et al. (1999), Ojah and Karemera (1999), Chang and Ting (2000), Abraham et al. (2002), Ryoo and Smith (2002), Smith et al. (2002), and Lim et al. (2009) amongst others. The studies differ mainly by the market analyzed, the considered time period, and the applied methodology for analyzing market efficiency. However, with regard to real estate markets, the number of studies is much smaller. Most research on the securitized real estate sector focuses on the U.S. market, like Mei and Gao (1995), Seck (1996), Graff and Young (1997), Nelling and Gyourko (1998), Kuhle and Alvayay (2000), Kleiman et al. (2002), and Jirasakuldech and Knight (2005). With regard to the U.K. securitized real estate market, Belaire-Franch et al. (2007) provide evidence of the rejection of the efficient market hypothesis. One of the few internationally oriented studies analyzing eleven national real estate stock markets was conducted by Stevenson (2002). Serrano and Hoesli (2009) compared the predictability of securitized real estate returns and stock returns for ten markets. They concluded that securitized real estate returns are more predictable compared to stock returns in matured REIT markets. However, stock returns are more predictable than securitized real estate returns in some of the countries that have only established REIT regimes in the recent past. Schindler et al. (2009) conducted a more comprehensive study by testing the efficient market hypothesis for 14 national real estate stock markets from January 1990 to December 2006. They concluded that real estate stock markets are less efficient than international stock markets and that the empirical findings suggest that investors are likely to earn excess returns by using past information in most of the public real estate markets.

In contrast to the securitized real estate markets, even less empirical evidence exists on the U.K. housing market in its nationwide perspective with respect to the efficient market hypothesis. Many studies focus either on the nationwide housing market or on selected local markets only. However, few studies cover the total market by simultaneously analyzing individual regions with partly very heterogeneous house price developments between the regions. Furthermore, the limitations in data quality are inherent in almost all studies including the following analysis. Thus, conclusions from statistical tests have to be seen in the context of this caveat. A literature review on selected studies related to efficiency in the U.S. and the U.K. housing market is provided in section 2.

The main objectives of this study are (1) to examine the random walk hypothesis for the Nationwide house price indices in 13 regional housing markets in the U.K. and the nationwide index, (2) to test for market efficiency across the selected housing markets, and (3), most importantly, for practical relevance, to derive trading strategies if inefficiencies are detected. With respect to the range of existing products and derivatives on the U.K. housing market, the strategies are tested when short-selling or other instruments of participating in a downward-moving market are available and when these opportunities do not exist.

The remainder of this paper is organized as follows. The next section provides a literature review. Section 3 discusses the weak-form version of market efficiency (Fama, 1965 and 1970) in conjunction with the random walk hypothesis and deals with the methodology of variance-ratio and runs tests. After a data description and descriptive statistics, empirical results of the applied test procedures are presented in section 4. Section 5 tests market efficiency by comparing two trading strategies with a simple buy-and-hold approach. Section 6 draws conclusions and gives an outlook for further research.

2 Literature Review

Although the question of efficiency in housing markets and the resulting implications from market inefficiency are of great importance for professional real estate investors, mortgage bankers, and also for homeowners, the number of empirical studies on this topic has been limited for the last 25 years. However, there are almost innumerable studies considering tests of market efficiency for stock, bond, exchange rate, and commodity markets. The key findings from all analyses are almost similar. In general, the hypothesis at least of weak-form market efficiency by the seminal definition of Fama (1970) is not rejected and even if for some markets and for some time periods the conducted tests reject the efficient market hypothesis, investors trading standardized products on exchanges are not able to exploit these inefficiencies by earning abnormal returns.

Besides the two studies by Gau (1984 and 1985) considering the prices of income-producing properties located in the real estate market of Vancouver, Canada, one of the first studies analyzing the validity of the efficient market hypothesis in real estate markets was conducted by Linneman (1986). Linneman focuses on the efficiency of the housing market of Philadelphia at two points in time (1975 and 1978) using observations on individual homeowner assessments of their house values. By using a hedonic price approach and analyzing the residual information from the estimated model, Linneman (1986) applies this methodology to the Annual Housing Survey for the Philadelphia Standard Metropolitan Statistical Area. From the test results he concludes that the excess returns are insufficient to cover the high transaction costs associated with transacting residential real estate and that no significant arbitrage opportunities exist. Thus, the market can be considered as semi-strong form efficient.

The central study by Case and Shiller (1989) extends previous research in several ways. First, it is the first study that used repeated sales price data on individual homes. Second, the total number of observations of 39,210 and the time span from 1970 to 1986 is unique when compared to previous studies. Third, Case and Shiller (1989) extend the geographical area by using data from the Society of Real Estate Appraisers for Atlanta, Chicago, Dallas, and San Francisco / Oakland. Fourth, and most importantly from a theoretical perspective, the applied statistical methodology shows several improvements over the analysis by Gau (1984, 1985). The methodology improvements concern testing the random walk hypothesis for housing prices by regressing the change in the index on lagged changes in the index. The suggested method is more robust to spurious serial correlation in price changes. In contrast to Gau (1984, 1985) and Linneman (1986), the results by Case and Shiller (1989) reject weak-form market efficiency for housing markets. Additionally, they implement trading strategies to provide further evidence for the rejection of the weak-form market efficiency. However, forecasting individual housing prices turns out to be much more difficult and is swamped out by noise. Thus, Case and Shiller (1989) emphasize doubts about definite proof of whether or not housing markets are efficient.

Based on the same data set used by Case and Shiller (1989), Case and Shiller (1990) conduct a more detailed analysis of market efficiency. The forecastability of excess returns is evaluated by regressing home price changes and excess returns on certain identified forecasting variables. The findings provide further evidence on the inefficiencies in the housing market for single-family homes.

The study by Kuo (1996) focuses mainly on the econometrically and statistically challenging problem of correctly estimating serial correlation and seasonality for infrequently traded assets, as could occur in the real estate market. Kuo (1996) shows that the estimators used by Case and Shiller (1989) are not consistent, that they involve an arbitrary partition of the data set, and that the developed Bayesian approach is superior. However, the results from applying the Bayesian approach confirm the result of serial correlation by Case and Shiller. Thus, the rejection of a random walk is supported by Kuo (1996), who points out, however, that "the estimates are sensitive to different estimation techniques" (Kuo, 1996, p. 160).

More recent research on the predictability of house prices has been conducted by Gu (2002). The study uses the quarterly published CMHPI for all fifty states, the District of Columbia, separate indices for nine Census Divisions and an aggregate index for the U.S. from the first quarter of 1975 to the first quarter of 1999. It is the most comprehensive analysis of market efficiency in the U.S. housing market to date. In comparison to several studies mentioned before, Gu (2002) examines spatial markets instead of individual homes. Thus, the perspective and implications differ to some extent. While in the short run, price changes in all states show variance ratios of less than one, indicating mean reversion, the results from heteroscedasticity-robust variance ratio tests differ across the states when conducting test statistics for more lags and the test statistics become less significant. Similar results can be found when splitting the whole sample into two subsamples and running the variance ratio test for each subsample. Gu (2002) also shows that trading strategies based on estimated autocorrelation are able to generate excess returns supporting the rejection of weak-form market efficiency. However, home values are based on either a sale or an appraisal and for this reason the indices might suffer – at least to some extent – from the same problems as appraisal-based indices.

Schindler (2010) exhibits a similar analysis as Gu (2002). However, the former circumvents the problems inherent in appraisal-based indices by using the transaction-only based Case-Shiller indices, and tests the random walk hypothesis by conducting parametric as well as non-parametric tests. He finds strong evidence for the rejection the null hypothesis of market efficiency. Furthermore, trading strategies based on the Case-Shiller indices for which derivatives are traded at the CME, are presented and generate excess returns compared to a buy-and-hold strategy.

Besides the U.S., there are only a few empirical studies analyzing predictability in housing prices and testing market efficiency in other countries whereas studies on regional markets in

Canada (e.g. Hosios and Pesando (1991), Clayton (1988)) and the U.K. are very common. With respect to the U.K. housing market, most analyses which focus on price formation and house price determinants are based on a theoretical model of house price determinants such as Pain and Westaway (1997) and Muellbauer and Murphy (1997). Other studies, such as the ones conducted by MacDonald and Taylor (1993), Alexander and Barrow (1994) or Ashworth and Parker (1997), among others, analyze long-run relationships and short-run dynamics between the regional house prices in the U.K. as well as macroeconomic variables in the case of Ashworth and Parker (1997). The results indicate cross-regional spatial dependence and can be seen as indicative of rejecting the semi-strong form of market efficiency. Furthermore, it is shown that causality is in the direction from South East to the North, which is often called the ripple effect. However, none of these studies analyzes the information contained in historical house prices for future house prices of the same region.

The framework of analyzing semi-strong form efficiency is applied by Barkham and Geltner (1996) who examine the linkages between the housing market and the stock market. As a result, the stock market leads the housing market up to two years and inefficiencies seem to be stronger in the housing market than in the commercial real estate market. However, Barkham and Geltner (1996) also mention limitations in data quality. The simulations by Meen (2000) also detect inefficiencies in the U.K. housing market by simulating housing cycles and housing models. However, Meen (2000) also points out, that the findings do not necessarily imply that there are exploitable trading rules if the covered inefficiencies result from high transaction costs. A more recent analysis of efficiency in owner-occupied housing markets was conducted by Rosenthal (2006), extending the scope to a nationwide, but locally more precise and county-specific, examination from 1991 to 2001. Rosenthal (2006) concludes that – at a spatially disaggregated level – the results from the employed autoregressive framework are not indicative of a rejection of the weak-form version of efficiency in the owner-occupied housing market of the U.K. By comparing the three studies on the U.K. housing market, it can be seen how conclusions from testing efficiency in the housing market differ. However – as in the case for the U.S. – the tested version of efficiency, statistical methodologies, covered time periods, geographical focus, and level of data aggregation, among other factors, are different. Thus, the overall result may not differ much when the framework of the two studies has been adjusted. In addition, Meen (2002) emphasizes that the U.K. housing market is analyzed in much less detail compared to the U.S. housing market and thus the evidence from previous research on the efficiency of the

U.K. housing market is much weaker, which provides further motivation for a detailed analysis of this topic.

In conclusion, all previous research on the topic of efficiency in the housing market shows that there is no unanimous conclusion and that further research is essential to gain more insight into the housing markets and their characteristics, in particular against the background of ongoing innovations in housing market derivatives and the fact that the recent financial crises originated in the housing market. To our knowledge, as yet no study exists on predicting housing markets and testing the weak-form version of market efficiency based on quarterly transaction-based indices which cover regional and national U.K. housing markets and testing trading strategies for exploiting inefficiencies. The following analysis concentrates exactly on this topic.

3 Methodology

In its weak form, the efficient market hypothesis proposes that price changes are unpredictable. Thus, a frequently employed test of market efficiency examines whether or not prices follow a random walk. Under the random walk hypothesis, a non-predictable random mechanism generates the behavior of price changes. In the simplest version of a random walk model, the actual index I_t equals the previous index I_{t-1} plus the realization of a random variable ε_t,

$$I_t = I_{t-1} + \varepsilon_t, \qquad (1)$$

where I_t is the natural logarithm of the index and ε_t is a random disturbance term at time t, which satisfies $E[\varepsilon_t] = 0$ and $E[\varepsilon_t\varepsilon_{t-h}] = 0$, $h \neq 0$ for all t. If the expected index changes are given by $E[\Delta I_t] = E[\varepsilon_t] = 0$, the best linear estimator for index I_t is the previous index value I_{t-1}. Under the assumption that expected index changes μ are constant over time, the random walk model expands to a random walk with drift (μ = drift parameter)

$$I_t = I_{t-1} + \mu + \varepsilon_t \text{ or } \Delta I_t = \mu + \varepsilon_t \qquad \varepsilon_t \sim \text{i.i.d.}(0, \sigma^2). \qquad (2)$$

The random walk implies uncorrelated residuals and hence, uncorrelated returns, ΔI_t; $\varepsilon_t \sim \text{i.i.d.}(0, \sigma^2)$ denotes that the increments ε_t are independently and identically distributed (i.i.d.) with $E[\varepsilon_t] = 0$ and $E[\varepsilon_t^2] = \sigma_\varepsilon^2$.

In general, the weak-form version of market efficiency and the random walk hypothesis are not equivalent. Nevertheless, if indices are found to follow a random walk process, then the housing market is considered weak-form efficient (Fama, 1970). Consequently, the random walk properties of index returns are considered to be an outcome of the efficient market hypothesis.

3.1 Variance Ratio Tests of Random Walk

The traditional random walk tests on the basis of serial correlation and unit roots are vulnerable to errors due to autocorrelation induced by non-synchronous and infrequent trading. A discussion on real estate indices with a small sample size can be found in Case and Shiller (1989) and in Kuo (1996), respectively. To resolve this shortcoming (for financial time series), Lo and MacKinlay (1988, 1989) developed tests for random walks based on variance ratio estimators.

The variance of the increments of a random walk is linearly time-dependent. Thus, if the natural logarithm of index I_t follows a pure random walk with drift (Equation (2)), then the variance of index changes should increase proportionally to the observation interval q. Suppose a series of $nq + 1$ price observations (P_0, P_1, P_2, …, P_{nq}) measured at uniform intervals is available. If this time series follows a random walk, the variance of the qth difference would correspond to q times the variance of first differences. Following the models of Equations (1) and (2), the variance of the first differences, denoted as $\hat{\sigma}^2[I_t - I_{t-1}]$ and $\hat{\sigma}^2[r_t]$ respectively, grows linearly over time so that the variance of the qth difference is

$$\hat{\sigma}^2[I_t - I_{t-q}] = q \cdot \hat{\sigma}^2[I_t - I_{t-1}] \quad \text{or} \quad \hat{\sigma}^2[r_t(q)] = q \cdot \hat{\sigma}^2[r_t]. \tag{3}$$

For the qth lag in I_t, where q is any integer greater than one, the variance ratio, VR(q), is defined as

$$VR(q) \equiv \frac{\hat{\sigma}^2[r_t(q)]}{q \cdot \hat{\sigma}^2[r_t]} = 1 + 2\sum_{h=1}^{q-1}\left(1 - \frac{h}{q}\right) \cdot \hat{\rho}(h), \tag{4}$$

where $\hat{\sigma}^2[\cdot]$ is an unbiased estimator of the variance. The expected value of VR(q) is one under the null hypothesis of a random walk for all values of q. While I_t describes the logarithmic price process, $r_t(q)$ is a q period continuously compounded return with $r_t(q) \equiv r_t + r_{t-1} + \ldots + r_{t-q+1} = I_t - I_{t-q}$. $\hat{\rho}(h)$ is the estimator of the hth serial correlation coefficient. Alternatively, values for VR(q) greater than one imply mean aversion, while values smaller than one imply mean reversion. Equation (4) shows that VR(q) is a particularly linear combination of the first h-1 autocorrelation coefficients with linearly declining weights. If q behaves as a random walk, VR(q) = 1 because $\hat{\rho}(h) = 0$ for all h ≥ 1 (Campbell et al., 1997).

Under the null hypothesis of a homoscedastic increments random walk, Lo and MacKinlay (1988) derive an asymptotic standard normal test statistic for the VR. The standard z-test statistic is

$$Z_2(q) = \frac{VR(q) - 1}{\sqrt{\hat{\theta}_1(q)}} = \frac{M_r(q)}{\sqrt{\hat{\theta}_1(q)}} \overset{a}{\sim} N(0,1), \tag{5}$$

where $\hat{\theta}_1(q) = \frac{2(2q-1)(q-1)}{3q(nq)}$, and $\overset{a}{\sim}$ denotes that the distributional equivalence is asymptotic.

Many time series have time-varying volatilities, with returns deviating from normality. When index changes are conditionally heteroscedastic over time, there may not exist a linear relation over the observation intervals. Hence, Lo and MacKinlay (1988) suggest a second test statistic $Z_2(q)$ with a heteroscedasticity-consistent variance estimator $\hat{\theta}_2(q)$:

$$Z_2(q) = \frac{VR(q) - 1}{\sqrt{\hat{\theta}_2(q)}} = \frac{M_r(q)}{\sqrt{\hat{\theta}_2(q)}} \overset{a}{\sim} N(0,1), \tag{6}$$

with $\hat{\theta}_2(q) = \sum_{j=1}^{q-1} \left[\frac{2(q-j)}{q} \right]^2 \cdot \hat{\delta}(j)$ and $\hat{\delta}(j) = \frac{\sum_{t=j+1}^{nq} (I_t - I_{t-1} - \hat{\mu})^2 (I_{t-j} - I_{t-j-1} - \hat{\mu})^2}{\left[\sum_{t=1}^{nq} (I_t - I_{t-1} - \hat{\mu})^2 \right]}$.

If the null hypothesis is true, then the modified heteroscedasticity-consistent test statistic in Equation (6) has an asymptotic standard normal distribution (Liu and He, 1991). The $Z_2(q)$-statistic is robust to heteroscedasticity as well as to non-normal disturbance terms and it allows for a more efficient and powerful test than the tests of Box and Pierce (1970) or of Dickey and Fuller (1979, 1981) (Lo and MacKinlay, 1989).

The variance ratio test of Lo and MacKinlay (1988) considers one VR for a single aggregation interval q by comparing the test statistics $Z_1(q)$ and $Z_2(q)$ with the critical value of a standard normal distribution. By contrast, the random walk model requires that $VR(q) = 1$ and hence $VR_r(q) = VR(q)-1 = 0$ for all selected aggregation intervals q simultaneously. Neglecting the joint nature of the hypothesis may lead to inaccurate inferences. To solve this problem, Chow and Denning (1993) suggest a multiple variance ratio (MVR) test. It is based on a multiple comparison similar to a classical joint F-test. In conjunction with a set of primary Lo and MacKinlay test statistics, $\{Z_1(q_i) \mid i = 1, \ldots, m\}$ and $\{Z_2(q_i) \mid i = 1, \ldots, m\}$, the random walk hypothesis is rejected if any of the estimated VRs differs significantly from one. For this test, it is only necessary to consider the maximum absolute value of the test statistics (Chow and Denning, 1993):

$$Z_1^*(q) = \max_{1 \le i \le m} |Z_1(q_i)| \quad \text{and} \quad Z_2^*(q) = \max_{1 \le i \le m} |Z_2(q_i)|. \tag{7}$$

The multiple variance ratio approach controls the size of the joint test and defines a joint confidence interval for the $VR(q_i)$ estimates by applying the Studentized Maximum Modulus (SMM) distribution theory. The upper α point is used instead of the critical values of the standard normal distribution,

$$SMM(\alpha, m, \infty) = Z_{\alpha^+/2}, \tag{8}$$

where $\alpha^+ = 1 - (1-\alpha)^{1/m}$.

According to equation (8), the asymptotic SMM critical value can be calculated from the conventional standard normal distribution for a large number of observations. In essence, the Chow and Denning's test is conservative by design (i.e., the critical values are larger), but even so, it has the same, or even more, power than the conventional unit root tests against an AR(1) alternative. At the same time, the MVR-test is robust with respect to many forms of heteroscedasticity and non-normality of the stochastic disturbance term.

3.2 Runs Test of Market Efficiency

Both autocorrelation and VR tests are based on the assumption of a linear return generating process. Thus, both approaches test for linear dependencies in the price series by definition when challenging the random walk hypothesis and the hypothesis of weak-form market efficiency. Consequently, even if the efficient market hypothesis is not rejected by autocorrelation and VR tests, it does not necessarily imply market efficiency. Thus, it is important to apply a direct test of the weak-form version of market efficiency. The non-parametric runs test investigates the independence of successive returns and does not require normality or a linear return generating process. These characteristics of testing methods are especially useful for investigating returns of house price indices, which are frequently non-normally distributed.

A runs test determines whether the total number of runs in the sample is consistent with the hypothesis that changes are independent. If the return series exhibit a greater tendency of change in one direction, the average run will be longer and, consequently, the number of runs will be lower than generated by a random process. In the Bernoulli case, the total number of runs is referred to as N_{Runs} and the total expected number of runs is given by

$$E[N_{Runs}] = 2n\pi(1-\pi) + \pi^2 + (1-\pi)^2, \quad (9)$$

where $\pi = \Pr(r_t > 0) = \Phi\left(\frac{\mu}{\sigma}\right)$, μ is the expected index change, and σ is the standard deviation of index changes. For large sample size ($N > 30$) the sampling distribution of $E[N_{Runs}]$ is approximately normal, and a continuity correction is produced.

When the actual number exceeds (falls below) the expected runs, a positive (negative) Z-value is obtained. Consequently, a positive (negative) Z-value indicates a negative (positive) serial correlation in the series of index changes.

Table 1 summarizes the conclusions of the various test approaches which are applied to test for weak-form market efficiency and predictability of price changes in the U.K. housing market.

Table 1: Null and Alternative Hypotheses of Weak-Form Market Efficiency Tests

Significance Test	**Autocorrelation Coefficient**	**Variance Ratio**	**Runs**
Random Walk	$\rho(h) = 0 \ \ for\ h \neq 0$	$VR(h) = 1 \ \ for\ h \neq 0$	$Z = 0$
Mean Aversion	$\rho(h) > 0 \ \ for\ h \neq 0$	$VR(h) > 1 \ \ for\ h \neq 0$	$Z < 0$
Mean Reversion	$\rho(h) < 0 \ \ for\ h \neq 0$	$VR(h) < 1 \ \ for\ h \neq 0$	$Z > 0$

4 Empirical Results of Weak-Form Market Efficiency Tests

4.1 Data

The data set used in this study is built on the transaction-only based Nationwide house price indices for the United Kingdom. The indices are reported quarterly for 13 regions covering the U.K. in total, and on a countrywide level. In addition to Northern Ireland, Scotland, and Wales, regional indices are provided for the following areas in England: the North, the North West, Yorkshire & Humberside, East Anglia, the East Midlands, the West Midlands, the South West, the Outer South East, the Outer Metropolitan, and London. More information on sub-regional details is provided by the website of Nationwide. However, due to its partly small number of transactions, more detailed sub-regions and monthly indices, as provided by, e.g., Land Registry, are not considered. The Nationwide indices are based on lending data for properties at the post-approval stage and are published on a quarterly base dated back to the fourth quarter of 1973. Thus, Nationwide provides much longer time series on transaction-only based data than other data and index providers such as Land Registry or Halifax. Due to the index construction shortcomings of monthly data when there are few transactions and a small sample size only, the analysis is conducted at a quarterly data frequency. The problems arising from sparse data sets are well-discussed by Sommervoll (2006). Furthermore, Nationwide indices are mix-adjusted to track a representative house price over time better than the simple average price. While Rosenthal (2006) emphasizes that investors and homeowners in particular are heavily interested in the housing market most closely related to their own property, and brings forward the argument that homeowners do not benefit from information on broader markets, the analysis on housing market efficiency in this paper is based on regional data for two reasons – despite the qualified facts mentioned by Rosenthal (2006). First, the number of house transactions is rather small for some sub-regions, even when quarterly data are considered. However, when focusing on the 13 regions mentioned above, the sample size is sufficiently large to construct statistically reliable, representative, and meaningful housing price indices. Second, the topic of market efficiency and potential housing market forecasts combined with its consequences might not be of interest only for homeowners, but also for insurance companies, institutional investors, as well as mortgage financiers and banks which are well diversified across sub-regions and are more focused on broader markets than on rather narrow ones. This perspective also applies when banking and insurance companies as well as other investors search for hedging opportunities of their systematic risk exposure to the housing market while they are hedged towards their unsystematic risk by a well-diversified portfolio. Thus, the focus on regional levels is sufficient and reliable for the analysis of market efficiency in the U.K. housing market in this context.

Compared to hedonic or appraisal-based house price indices, transaction-based indices represent the actual market situation much more closely and adjust faster to changing market conditions. Thus, transaction-based data are predominant when analyzing housing markets and the efficiency of these markets. Wood (2005) conducted a comprehensive summary and comparison of the seven most relevant U.K. residential house price indices and discussed the conceptual and practical problems from constructing house price indices. As the Federal Housing Finance Agency (FHFA) and Conventional Mortgage Home Price Indices (CMHPI) data for the U.S. market, the Nationwide data set is limited to house prices and transactions financed by mortgages, but their samples exclude cash purchases. However, Wood (2005) concludes that the "Nationwide indices use the broadest quality-adjustment techniques and a dataset that, for measuring final transacted prices, represents a good trade-off between accuracy and timeliness" (Wood, 2005, p. 227).

The analyzed data set includes quarterly house price indices from the fourth quarter of 1973 to the fourth quarter of 2009. There are indices for 13 regions and one aggregate index for the U.K. The different regional indices and their covered sub-regions are presented in Table 2. Thus, the indices offer an appropriate representation of the regional U.K. housing markets relevant for investors and institutional institutions.

Table 2: List of the Nationwide Regional Indices on the U.K. Housing Market

Region	Index	Sub-Regions
East Anglia	EA	Cambridgeshire, Norfolk, Peterborough, Suffolk
East Midlands	EM	Derby, Derbyshire, Leicestershire, Mid Lincolnshire, Northampton Town, Northamptonshire, Nottingham, Nottinghamshire, South Lincolnshire
London	LO	Barking and Dagenham, Barnet, Bexley, Brent, Bromley, Camden, Croydon, Ealing, Enfield, Greenwich, Hackney, Hammersmith and Fulham, Haringey, Harrow, Havering, Hillingdon, Hounslow, Islington, Kingston upon Thames, Lambeth, Lewisham, Merton, Newham, Redbridge, Richmond upon Thames, Southwark, Sutton, Tower Hamlets, Waltham Forest, Wandsworth, Westminster
North	NO	County Durham, Cumbria, Northumberland, Teeside, Tyne and Wear
North West	NW	Cheshire, City of Manchester, Greater Manchester, Lancashire, Merseyside, Warrington & Halton
Outer Metropolitan	OM	Bracknell Forest, Central Kent, East Surrey, Hart & Rushmoor, Hertfordshire, Luton, Medway, North Surrey, Reading, Slough, South Buckinghamshire & Chilterns, South Essex, St Albans, West Kent, West Surrey, West Sussex (North), Windsor & Maidenhead, Wokingham
Outer South East	OS	Basingstoke & Deane, Bedford, Brighton & Hove, Central Bedfordshire, East Kent, East Sussex, Isle of Wight, Mid Hampshire, Milton Keynes & Aylesbury, New Forest, North Essex, Oxfordshire, Portsmouth Area, Southampton Area
South West	SW	Bath, Bournemouth, Bristol, Cheltenham, Cornwall and Isles of Scilly, Dorset, Gloucestershire, North Devon, Plymouth, Poole, Somerset, South Devon, South Gloucestershire, Swindon, Wiltshire
West Midlands	WM	Birmingham, Coventry, Greater Birmingham, Herefordshire, Shropshire, Staffordshire, Warwickshire, Worcestershire
Yorkshire & Humberside	YH	Bradford, East Yorkshire, Leeds, North Lincolnshire, North Yorkshire, Sheffield, South Yorkshire, West Yorkshire, York
Northern Ireland	NI	City of Belfast, Northern Ireland (North East), Northern Ireland (South East), Northern Ireland (West)

Table 2 continues on the next page

Region	Index	Sub-Regions
Scotland	SC	Aberdeen City, Aberdeenshire & Moray, Dunbartonshire & North Lanarkshire, Dundee & Angus, Edinburgh City, Fife, Glasgow City, Highlands & Islands, Lothian & Falkirk, Perthshire & Stirling, Renfrewshire & Inverclyde, South Lanarkshire, Southern Scotland
Wales	WA	Cardiff, Mid & West Wales, North Wales, South Wales (East), South Wales (West)
United Kingdom	UK	all 13 regions

4.2 Descriptive Statistics

The descriptive statistics for the quarterly returns of the Nationwide indices are presented in Table 3 and are based on continuously compounded quarterly returns from 1974 to 2009.[1] The southern regions around London, such as London itself, Outer Metropolitan, and the South West show the highest average quarterly returns while the lowest average return can be found in northern regions like the North and Yorkshire & Humberside as well as in Wales. However, compared to the U.S., the heterogeneity between the regions in the U.K. is much less distinctive than for the U.S. (see Schindler, 2010). The most volatile U.K. housing markets are in East Anglia, the North and Yorkshire & Humberside as well as Northern Ireland. The North West, Outer Metroplitan, and Scotland exhibit the least volatile housing markets. With respect to the higher moments, all regional housing markets are characterized by a slight excess kurtosis while the results on skewness are mixed. According to the test statistic by Jarque and Bera (1980), the null hypothesis of normally distributed returns is rejected for five out of the 13 considered markets at the 1 % level of significance.

Considering simple Sharpe ratios, the housing markets in London, the Outer Metropolitan, the South West, the North West, and Scotland have the best risk-return profile, while East Anglia, the North, Yorkshire & Humberside, and Northern Ireland exhibit the least beneficial risk-return characteristics.

[1] Log differences of prices are used because, for small changes, they approximately equal the rate of return from continuous compounding.

Table 3: Descriptive Statistics of Quarterly Index Returns

Index	Mean	Min.	Max.	Std.dev.	Skewness	Kurtosis	J.-B.
EA	0.0193	-0.1023	0.1392	0.0375	0.0378	4.0604	6.7806
EM	0.0192	-0.0617	0.1554	0.0327	0.5768	5.0132	**32.3024**
LO	0.0213	-0.0640	0.1115	0.0335	-0.2605	3.0944	1.6827
NO	0.0188	-0.0713	0.1259	0.0355	0.1631	3.2315	0.9597
NW	0.0199	-0.0601	0.1077	0.0296	0.2823	3.7156	4.9842
OM	0.0201	-0.0678	0.1215	0.0314	-0.2535	3.7335	4.7699
OS	0.0199	-0.0626	0.1085	0.0337	-0.1752	3.3910	1.6538
SW	0.0203	-0.0747	0.1503	0.0332	0.1245	5.3644	**33.9147**
WM	0.0190	-0.0832	0.1656	0.0332	0.7154	6.1475	**71.7248**
YH	0.0185	-0.0804	0.1306	0.0355	0.2504	3.8874	6.2298
NI	0.0198	-0.1371	0.1244	0.0422	-0.5528	4.7509	**25.7267**
SC	0.0191	-0.0706	0.0922	0.0280	-0.2934	4.0672	8.9007
WA	0.0189	-0.0937	0.1432	0.0348	0.2990	4.5704	**16.9423**
UK	0.0195	-0.0549	0.1050	0.0271	-0.0202	3.9594	5.5327

Notes: Bold figures indicate rejection of the null hypothesis of normally distributed returns at a 1 % significance level.

4.3 Results of Autocorrelation Tests

The efficient market hypothesis in its weak-form version states that asset returns are not time-dependent and are thus not autocorrelated. However, at least in the short-run, positive autocorrelations are a well-studied phenomenon for asset market returns; various possible explanations such as common risk factors of stocks (systematic risk) have been proposed, amongst others, by Lo and MacKinlay (1988) as well as French and Roll (1986).

As can be gathered from Table 4, the results from estimating autocorrelations of the quarterly index changes show significant coefficients for all markets and all considered lags indicating a general upward trend and mean aversion processes, at least up to twelve quarters. In particular, the short-run autocorrelations are very high, have a positive sign and are highly significant. In the long-run, persistence weakens slightly but is still significant. The exception is the lag of six quarters for which East Anglia, Yorkshire & Humberside, Northern Ireland, Scotland, and Wales exhibit slightly negative autocorrelation and partly persist for higher lags. The lowest first order autocorrelation is found for the North (0.2607) and Scotland

(0.2507) while the North West, the regions in the southern part of the U.K., and London exhibit the highest autocorrelation. In general, according to the autocorrelation analysis, housing markets in the U.K. exhibit a highly significant positive autocorrelation; this indicates both a short- and a long-run mean aversion and thus suggests a rejection of the efficient market hypothesis in its weak-form version. Due to the large sample size for quarterly data and predominantly normally distributed house price returns (see Table 3), the often cited deficiencies of autocorrelation analysis such as spurious autocorrelation do not apply to the U.K. housing market data. However, the following tests, the non-parametric runs test in particular, can be seen as an additional robustness check on the findings from autocorrelation.

Table 4: Autocorrelation of Quarterly Index Returns

Index	ρ_1	ρ_2	ρ_3	ρ_4	ρ_6	ρ_8	ρ_{12}
EA	0.4904	0.3786	0.3094	0.3163	-0.0084	0.1061	0.1111
EM	0.5576	0.4219	0.3336	0.2496	0.1112	0.0911	0.0287
LO	0.5715	0.4300	0.3337	0.3250	0.1051	0.0743	0.0841
NO	0.2607	0.3110	0.2984	0.1493	0.0341	0.1591	-0.0169
NW	0.6020	0.4534	0.4448	0.3343	0.0454	0.1155	0.0059
OM	0.6957	0.4860	0.3404	0.3254	0.0742	0.1454	0.1285
OS	0.6480	0.4412	0.3755	0.3718	0.0394	0.1340	0.1096
SW	0.5720	0.3173	0.3221	0.3709	0.0116	0.1732	0.1151
WM	0.4311	0.3037	0.2767	0.3354	0.0365	0.0439	0.0110
YH	0.4893	0.3949	0.2172	0.2180	-0.0515	0.0801	0.0941
NI	0.3537	0.3451	0.2886	0.1709	-0.1514	-0.0108	0.0184
SC	0.2507	0.0915	0.2032	0.2552	-0.1630	0.1710	0.1645
WA	0.3731	0.4365	0.2498	0.1489	-0.0115	-0.0349	-0.0089
UK	0.6846	0.4151	0.3809	0.3690	0.0270	0.1443	0.1186

Notes: All autocorrelation coefficients for lag h are significant at the 1 % significance level with critical values from the χ^2 distribution with h degrees of freedom.

4.4 Results of Variance Ratio Tests

The variance ratios are computed in intervals of two, three, and four quarters as well as for eight and twelve quarters. All regional housing markets exhibit systematically increasing (with the exception of Northern Ireland) and highly significant variance ratios for all considered lags, which confirms mean aversion and the rejection of the weak-form version of market efficiency (see Table 5). The empirical findings of both homoscedasticity- and heteroscedasticity-robust variance ratio tests as well as multiple variance ratio tests are basically consistent with the results from autocorrelations. While the North of the U.K. and Scotland show the lowest variance ratios, they also exhibit the lowest first-order autocorrelation coefficient. By contrast the highest variance ratios are found for the regions with the highest autocorrelation, namely the North West, Outer Metropolitan, and Outer South East as well as for the U.K. in total.

The results from comparing homoscedasticity- and heteroscedasticity-consistent test statistics indicate the rejection of the random walk hypothesis at the same assumed level of significance. However, the differences in the values of the test statistics suggest that all the analyzed housing markets are characteristized by heteroscedasticity in the time series of house price changes.

Table 5: Variance Ratio Estimates and Variance Ratio Test Statistics for Quarterly Index Returns

Index	Number q of Base Observations (Lags) Aggregated to form Variance Ratio					SMM for *m* = 5
	q = 2	q = 3	q = 4	q = 8	q = 12	max $Z_1^*(2,\ldots, 12)$ max $Z_2^*(2,\ldots, 12)$
EA	1.51	1.96	2.36	3.53	4.08	
	(6.12)***	(7.71)***	(8.72)***	(10.27)***	(9.85)***	(10.27)***
	[3.97]***	[5.17]***	[6.06]***	[7.74]***	[7.80]***	[7.80]***
EM	1.58	2.08	2.53	3.72	4.29	
	(6.95)***	(8.71)***	(9.80)***	(11.02)***	(10.54)***	(11.02)***
	[3.88]***	[5.14]***	[6.11]***	[7.96]***	[8.21]***	[8.21]***
LO	1.59	2.10	2.55	3.91	4.76	
	(7.12)***	(8.89)***	(9.94)***	(11.81)***	(12.03)***	(12.03)***
	[5.13]***	[6.58]***	[7.53]***	[9.66]***	[10.42]***	[10.42]***
NO	1.28	1.60	1.93	2.71	3.12	
	(3.32)***	(4.80)***	(5.93)***	(6.93)***	(6.77)***	(6.93)***
	[2.62]***	[3.83]***	[4.77]***	[5.72]***	[5.78]***	[5.78]***
NW	1.62	2.16	2.69	4.08	4.72	
	(7.49)***	(9.36)***	(10.81)***	(12.51)***	(11.91)***	(12.51)***
	[4.74]***	[6.07]***	[7.18]***	[9.13]***	[9.43]***	[9.43]***
OM	1.72	2.31	2.81	4.19	5.01	
	(8.62)***	(10.55)***	(11.59)***	(12.93)***	(12.85)***	(12.93)***
	[5.72]***	[7.28]***	[8.28]***	[10.15]***	[10.72]***	[10.72]***
OS	1.67	2.21	2.70	4.12	4.87	
	(8.05)***	(9.78)***	(10.92)***	(12.66)***	(12.66)***	(12.66)***
	[5.38]***	[6.79]***	[7.85]***	[9.83]***	[10.09]***	[10.09]***
SW	1.59	2.03	2.44	3.64	4.23	
	(7.12)***	(8.28)***	(9.21)***	(10.70)***	(10.32)***	(10.70)***
	[4.49]***	[5.54]***	[6.50]***	[8.25]***	[8.28]***	[8.28]***
WM	1.45	1.83	2.18	3.29	3.74	
	(5.41)***	(6.66)***	(7.56)***	(9.27)***	(8.78)***	(9.27)***
	[3.04]***	[4.04]***	[4.93]***	[7.20]***	[7.46]***	[7.46]***
YH	1.51	1.97	2.33	3.15	3.51	
	(6.12)***	(7.81)***	(8.55)***	(8.72)***	(8.04)***	(8.72)***
	[3.94]***	[5.13]***	[5.77]***	[6.39]***	[6.15]***	[6.39]***
NI	1.36	1.74	2.09	2.55	2.03	
	(4.27)***	(5.94)***	(7.01)***	(6.29)***	(3.29)***	(7.01)***
	[2.61]***	[3.61]***	[4.29]***	[4.04]***	[2.19]**	[4.29]***
SC	1.27	1.43	1.64	2.11	2.25	
	(3.20)***	(3.49)***	(4.07)***	(4.50)***	(4.00)***	(4.50)***
	[3.12]***	[3.31]***	[3.78]***	[4.16]***	[3.81]***	[4.16]***

Table 5 continues on the next page

Index	Number q of Base Observations (Lags) Aggregated to form Variance Ratio					SMM for *m* = 5 max $Z_1^*(2,\ldots,12)$ max $Z_2^*(2,\ldots,12)$
	q = 2	q = 3	q = 4	q = 8	q = 12	
WA	1.39	1.84	2.21	3.03	3.30	
	(4.70)***	(6.74)***	(7.75)***	(8.24)***	(7.38)***	(8.24)***
	[2.99]***	[4.45]***	[5.29]***	[6.22]***	[5.96]***	[6.22]***
UK	1.71	2.25	2.74	4.08	4.70	
	(8.50)***	(10.07)***	(11.18)***	(12.48)***	(11.86)***	(12.48)***
	[5.45]***	[6.71]***	[7.72]***	[9.51]***	[9.62]***	[9.62]***

Notes: ***, **, * indicate significance at the 99 %, 95 %, and 90 % confidence level (rejection of the RWH). One month is taken as a base observation interval; the varaince ratios, VR(q)'s, are reported in the main rows. The homoscedasticity- and heteroscedasticity-consistent test results are reported in parentheses ($Z_1(q)$, $Z_1^*(q)$) and brackets [$Z_2(q)$, $Z_2^*(q)$], respectively. The critical values for multiple variance ratio tests $Z_1^*(q)$ and $Z_2^*(q)$ at the 1 %, 5 % and 10 % significance level are 3.089, 2.569 and 2.311, respectively, according to Hahn and Hendrickson (1971) and Stoline and Ury (1979).

4.5 Results of Runs Tests

As mentioned above, both the autocorrelation tests and the variance ratio tests contain some shortcomings when applying these tests to the analysis of market efficiency. Moreover, if the return generating process is non-linear, the autocorrelation coefficients and variance ratio tests are not a reliable measure to detect market (in-) efficiency. Therefore, a direct test for market efficiency is employed that requires neither the assumption of normality of the underlying distribution nor a linear return generating process. The results of the non-parametric runs test of independence between successive events in the time series of quarterly index changes are presented in Table 6.

According to the runs test, all indices show highly significant negative test statistics with the exception of the North, Yorkshire & Humberside, and Scotland. This indicates a mean aversion process because the number of observed runs is below the statistically expected number. The insignificant test statistic for the North and the only slightly significant test statistic for Scotland are in line with the findings from the autocorrelation analysis and the variance ratio tests. Both regions show the lowest first-order autocorrelation coefficients and the lowest variance ratio for lags up to four quarters. Furthermore, beside Northern Ireland, both regional housing markets exhibit the lowest test statistics from multiple variance ratio tests (see Table 5). On the other hand, the Outer Metropolitan, the Outer South East, and the South West have the highest test statistic in absolute value. These regions also exhibit relatively high first-order autocorrelation coefficients and variance ratios. Thus, the different tests are consistent and coincide by trend. For all analyzed housing markets in the U.K., the statistical tests tend to result in the rejection of the random walk hypothesis and thus of weak-form market efficiency.

Table 6: Results from the Runs Test for Quarterly Index Returns

Index	Runs actual N_{Runs}	Runs expected E[Runs]	Probability π	Test Statistics
EA	39	61	0.6961	-3.2106***
EM	39	59	0.7209	-2.7218***
LO	35	56	0.7373	-2.9668***
NO	55	61	0.7023	-0.7042
NW	35	55	0.7489	-2.7145***
OM	25	56	0.7389	-4.3951***
OS	31	58	0.7228	-3.8627***
SW	29	57	0.7301	-3.9996***
WM	36	59	0.7166	-3.2526***
YH	47	61	0.6992	-1.9550*
NI	44	63	0.6809	-2.7390***
SC	41	54	0.7527	-1.7590*
WA	41	60	0.7062	-2.7176***
UK	29	53	0.7644	-3.2389***

Notes: ***, ** and * indicate significance at the 99 %, 95 %, and 90 % confidence level; critical values for the runs test at the 1 %, 5 % and 10 % significance level are derived from standard normal distribution.

5 Implications for Trading Strategies

The strong (mainly positive) autocorrelation suggests that there might be a pattern of house price movements and that investors would therefore be able to develop some trading strategies to exploit the pattern and to earn excess returns compared to a buy-and-hold strategy. However, following the definition by Fama (1970), even if the efficient market hypothesis is rejected by statistical tests, and housing prices do not reflect all relevant market information, (housing) markets can be weak-form efficient from a more practical perspective. Thus, the rejection of the weak-form version of market efficiency by itself does not postulate market inefficiency. Although inefficiencies seem to be statistically detected, they might be too small for investors yielding excess returns by implementing trading strategies based upon historical price information. This means that autocorrelation is not necessarily contradictory to the efficient market hypothesis as long as the implementation of a trading strategy is not beneficial. Thus, further methods must be introduced to evaluate particular strategies and to provide more direct evidence of market inefficiencies. Technical analysis can therefore serve as a control of, or complement, the earlier statistical testing methods.

In order to analyze the profitability of trading strategies compared to a simple buy-and-hold strategy, we apply two different methodologies. First, a trading strategy based on the estimated autocorrelations of the indices is considered as suggested by Gu (2002). Second, trading strategies based on moving averages are tested. The latter one is built on less crucial assumptions. While the strategy suggested by Gu (2002) explicitly assumes linear return generating processes and is afflicted with problems from estimating autocorrelations, the application of moving averages does not require any assumption on linearity in returns and is thus less restrictive. Both trading strategies are of simple construction, allow for out-of-sample analysis, and are thus well-suited as a basis for investors' strategies. Tax effects and transaction costs are not considered in either strategy. These arguments might mainly be decisive if the number of transactions indicated by the strategies is very high and direct real estate is sold and bought. However, if the market is replicated by derivatives, transaction costs should not substantially influence the comparison of buy-and-hold and the applied trading strategy. Furthermore, both tax effects and transactions costs are highly investor-specific and thus, they are hardly to consider from a general perspective.

Two scenarios are considered for both trading strategies. In the first case, short-selling is not allowed since, to our knowledge, derivatives exist neither on the regional nor on the U.K. countrywide house price indices, which are listed and traded at standardized exchanges at the moment. Thus, investors are not able to participate in a downward-moving housing market. However, there have been several attempts in the past to introduce such instruments for the U.K. housing market, and there might come some time when these products will be listed again following the traded products based on the Case-Shiller house price indices for the U.S. Furthermore, there may already be over-the-counter products such as hedging instruments and swaps based on the U.K. housing market which allow participation in downward-moving housing markets for institutional investors who have access to OTC-products or hedge their risk exposure to the housing market like mortgage banks or insurance companies. Therefore, it is interesting to expand the conducted technical trading strategies to a market environment allowing for opportunities of taking short positions in the market or participating in downward-moving markets by other products. With regard to the implemented strategies, this case is incorporated by assuming short-selling instead of zero returns for periods in which the trading signal recommends selling the market. Hence, the investor is not neutral in such cases but actively engaged in the market.

5.1 Results of Autocorrelation-based Trading Strategy

The empirical results of applying the trading strategy suggested by Gu (2002) and of extending it by seizing short-selling opportunities are shown in Table 7. For the purpose of comparison only, the total nominal returns from a buy-and-hold strategy are presented as well. The starting point of implementing the trading strategy is the first quarter of 1977, because data are available since the first quarter of 1974, and 12 quarterly returns are needed in advance in order to have a basis. When comparing the results from the trading strategy and the buy-and-hold strategy, two dimensions have to be considered.

First, the findings differ by region. As can be seen in Table 7, the regional markets which are characterized by low autocorrelation, low variance ratios, and the lowest test statistics from runs test in absolute values (the North, Yorkshire & Humberside, Northern Ireland, Scotland, and Wales) also show the worst performance from the trading strategy compared to a buy-and-hold strategy and do not outperform passive market investments. By contrast, the two regions Outer Metropolitan and Outer South East, which are characterized by the highest autocorrelation, the highest variance ratios, and for which the random walk hypothesis is strongly rejected by the runs test, exhibit the highest benefit from the application of the trading strategy compared to the buy-and-hold strategy. The outperformance for both markets based on first-order autocorrelation is 53.02 % for Outer Metropolitan and 46.04 % for Outer South East, respectively. With the exception of the five regions mentioned above, market inefficiencies can be exploited by at least one strategy, especially where short-term indicators are used. However, excess returns seem to be higher for markets in the southern parts of the U.K. than for the northern regions.

Second, the results differ in the order of autocorrelation on which the strategy is based. The results from different autocorrelation patterns remarkably indicate that the outperformance of the trading strategy shrinks rigorously when it is built on higher-order autocorrelation. For lags of twelve quarters, the strategy is not able to generate positive performance for any market as opposed to a buy-and-hold strategy, and even for lags of eight quarters, there are only two markets, namely Outer South East and the entire U.K., for which the trading strategy is beneficial. Thus, it can be concluded that excess returns are negatively related to the applied order of autocorrelation for the trading strategy.

Due to the negative autocorrelation in the case of the North (lag 12), Northern Ireland (lag 8), and Wales (lag 8 and lag 12) the strategy is reversed for these lag structures. This means that negative (positive) index changes indicate a buying (selling) signal. However, as can be seen in Table 7, when applying this strategy, excess returns are not possible.

When short-selling is allowed, the results show the same tendency related to the buy-and-hold strategy as before, but the development is accelerated and strengthened in each direction. While the total nominal return for Outer Metropolitan is around 2,133 % during the sample period when short-selling is not allowed and the trading strategy is based on first-order autocorrelation, the total nominal return jumps up to over 3,139 % when the participation in a downward-moving market is possible. In the other direction, the same phenomenon occurs. The total nominal return based on the regional market in the North shrinks from around 519 % to 221 % compared to a return of 1,006 % from the buy-and-hold strategy. For lag structures to which the reversed strategy is applied, the strategy results in highly negative absolute returns which are close to a total loss in the case of Wales.

Table 7: Total Nominal Returns from Buy-and-Hold Strategy Compared to Trading Strategies Based on Autocorrelation Pattern

Index	Buy-and-Hold	AR(1)	AR(2)	AR(4)	AR(8)	AR(12)
EA	1,271.05 %	1,345.85 % *1,339.33 %*	1,356.76 % *1,368.35 %*	1,412.29 % *1,498.74 %*	1,093.85 % 906.93 %	1,029.21 % *799.09 %*
EM	1,206.64 %	1,325.42 % *1,450.35 %*	1,302.81 % *1,340.21 %*	1,284.45 % *1,376.85 %*	1,185.57 % *1,213.85 %*	869.72 % *636.80 %*
LO	1,716.86 %	1,979.52 % *2,176.45 %*	1,715.21 % *1,649.88 %*	1,783.70 % *1,786.16 %*	1,266.21 % *896.48 %*	1,371.24 % *1,055.38 %*
NO	1,006.27 %	518.77 % *221.19 %*	636.06 % *360.09 %*	538.90 % *238.54 %*	698.18 % *439.57 %*	79.93 % *-75.10 %*
NW	1,297.37 %	1,323.19 % *1,324.15 %*	984.47 % *722.73 %*	1,030.04 % *795.18 %*	1,183.22 % *1,063.73 %*	1,224.22 % *1,135.29 %*
OM	1,394.21 %	2,133.44 % *3,139.48 %*	1,719.21 % *2,053.99 %*	1,335.91 % *1,253.38 %*	1,086.64 % *822.57 %*	1,244.89 % *1,080.75 %*
OS	1,436.96 %	2,098.53 % *2,921.28 %*	1,689.06 % *1,911.00 %*	1,656.59 % *1,847.02 %*	1,463.33 % *1,470.44 %*	1,380.53 % *1,301.70 %*
SW	1,405.22 %	1,671.33 % *1,930.04 %*	1,412.26 % *1,372.17 %*	1,458.79 % *1,469.38 %*	1,369.57 % *1,307.93 %*	1,301.25 % *1,172.83 %*
WM	1,150.39 %	1,315.63 % *1,501.11 %*	1,041.99 % *923.59 %*	1,237.08 % *1,366.04 %*	1,066.70 % *1,007.49 %*	984.52 % *852.35 %*
YH	985.77 %	775.12 % *561.05 %*	830.23 % *645.54 %*	651.26 % *381.32 %*	812.99 % *646.31 %*	789.06 % *586.31 %*
NI	893.33 %	760.34 % *567.08 %*	728.16 % *536.13 %*	851.54 % *768.49 %*	45.24 % *-83.32 %*	553.06 % *311.44 %*
SC	940.17 %	657.54 % *436.15 %*	546.69 % *289.35 %*	627.42 % *395.44 %*	744.27 % *564.89 %*	669.86 % *461.70 %*
WA	1,066.15 %	936.07 % *784.27 %*	1,055.62 % *1,005.40 %*	706.75 % *419.22 %*	11.43 % *-91.43 %*	18.44 % *-90.07 %*
UK	1,227.81 %	1,583.72 % *1,993.59 %*	1,110.50 % *972.01 %*	1,176.89 % *1,103.60 %*	1,131.18 % *1,027.01 %*	1,153.75 % *1,068.75 %*

Notes: The results from allowing for short selling are shown in italic letters.

5.2 Results of Moving Average-based Trading Strategy

To further check robustness of the rejection of the hypothesis of housing market efficiency in section 4, and to test for possible spurious autocorrelation and the assumption of linear return-generating processes, we implement a technical analysis based on simple moving averages for the 14 housing markets. Moving averages are applied to distinguish between long-term trends and short-term oscillations, thus acting as trend indicators. In practice, the average index price is calculated from past index prices. The number of relevant historical index values depends on the period examined. Moving averages do differ with respect to the length of time (e.g., four, eight, twelve quarters). In addition to the long-term twelve-quarter window, moving averages for four and eight quarters are calculated. This might be an advantage for indices that are more volatile and less persistent.

The sample period ranges from the fourth quarter of 1973 to the fourth quarter of 2009, identical to the sample for the tests of the random walk hypothesis. The time period from the fourth quarter of 1973 to the third quarter of 1976 is required to compute the moving average based on the twelve-quarter line. Therefore, the moving averages of the third quarter of 1976 serve as starting points and decision criteria for the positioning.

A trading signal occurs immediately at the breakthrough of the moving average line. A buying signal occurs when the index value breaks through its moving average bottom-up; a selling signal occurs when the moving average is breached top-down. Again, the chart-technical model is compared with the buy-and-hold strategy. The technical model is of advantage when it generates higher returns than a simple buy-and-hold strategy.

The total nominal returns of both strategies, the one in which short selling is not allowed and the one in which short-selling is possible, are shown in Table 8. With the exception of the housing markets in Wales and the regions in the northern part of the U.K. (the North, Northern Ireland, and Scotland), all analyzed housing market indices show higher returns for all strategies based on moving averages than for a continuous market investment. It is also obvious that strategies built on short-term indicators (four-quarter and eight-quarter moving averages) perform better than long-term oriented indicators for the vast majority of housing markets. An exception is the housing market in the North West for which a twelve-quarter moving average strategy is superior to the eight-quarter moving average strategy which in turn dominates the four-quarter moving average strategy and still results in positive excess returns compared to a buy-and-hold strategy. One reason for this phenomenon might be the low volatility of this market (see Table 3). However, the difference in total nominal returns between the three approaches is small when calculating annual returns in particular. Again, the housing markets in London, Outer Metropolitan, and Outer South East exhibit the highest absolute nominal returns from trading strategies, while the markets in the northern parts feature the lowest returns for the sample period. This finding is even more pronounced when short-selling is implemented into the trading strategy.

In summary, the results of the two trading strategies are similar in quality. They correspond to each other and to the results of the statistical tests on the random walk hypothesis. First, strategies based on short-term trend indicators perform better than long-term oriented strategies. Second, housing markets in the southern parts of the U.K. exhibit higher excess returns than housing markets located in the northern parts and Wales. Third, allowing short-selling further strengthens the advantageousness and disadvantageousness, respectively, of the trading strategy, compared to a buy-and-hold strategy. However, there are also some quantitative differences. The results of strategies based on moving averages seem to be more stable and less dependent on the applied time structure. Furthermore, the practical application and implementation is easier and its assumptions are less restrictive. In support of the trading strategy based on autocorrelation patterns, it has to be mentioned that excess returns are more pronounced for the well-performing markets in the southern parts of the U.K. when allowing for short-selling in particular. This argument applies to the underperformance of the northern parts of the U.K. as well. Nevertheless, the two strategies are built on different sets of information and assumptions. Therefore, a direct comparison of the advantageousness of the two strategies is nontrivial and almost impossible. However, the difference of one quarter in the time span can be neglected and is not crucial for the performance.

Nonetheless, even if all results strongly support the rejection of the efficient market hypothesis, there are still some limitations on a final judgment of housing market (in-) efficiency in the U.K. from a practical perspective. The trading strategies in particular assume that derivatives on the indices are tradable (and short-selling is possible). This argument might apply for institutional investors (mortgage banks, insurance companies) which are interested in overall market movements for purposes such as hedging their risk exposure or hedging market cycles. Private households do not have access to such products at present and even if they have access, they could use it for hedging systematic market risk only, but not for hedging the risk of their own property.

Table 8: Total Nominal Returns from a Buy-and-Hold Strategy Compared to Trading Strategies Based on Moving Averages (MA)

Index	Buy-and-Hold	4-Quarter MA	8-Quarter MA	12-Quarter MA
EA	1,298.98 %	1,815.87 % *2,395.95 %*	1,565.52 % *1,795.62 %*	1,530.75 % *1,731.41 %*
EM	1,235.88 %	1,572.38 % *1,938.09 %*	1,495.29 % *1,761.96 %*	1,407.14 % *1,564.85 %*
LO	1,739.60 %	2,019.34 % *2,238.86 %*	2,162.99 % *2,582.37 %*	2,030.38 % *2,289.83 %*
NO	1,056.71 %	812.99 % *593.18 %*	959.53 % *841.65 %*	958.61 % *843.46 %*
NW	1,339.17 %	1,401.22 % *1,443.50 %*	1,480.26 % *1,602.42 %*	1,506.52 % *1,665.17 %*
OM	1,407.63 %	2,020.45 % *2,790.42 %*	1,946.89 % *2,598.51 %*	1,626.16 % *1,832.21 %*
OS	1,444.19 %	2,012.23 % *2,667.87 %*	2,142.90 % *3,056.93 %*	1,834.26 % *2,259.55 %*
SW	1,412.66 %	1,520.84 % *1,581.49 %*	1,785.57 % *2,184.20 %*	1,521.94 % *1,606.58 %*
WM	1,176.71 %	1,289.17 % *1,380.06 %*	1,400.38 % *1,623.34 %*	1,322.03 % *1,451.45 %*
YH	1,010.94 %	1,078.05 % *1,091.35 %*	1,046.60 % *1,051.73 %*	1,071.44 % *1,105.83 %*
NI	923.83 %	893.44 % *809.29 %*	1,047.60 % *1,120.73 %*	903.98 % *853.80 %*
SC	960.75 %	793.81 % *639.35 %*	888.64 % *813.81 %*	869.69 % *779.44 %*
WA	1,090.36 %	935.19 % *764.49 %*	964.85 % *822.22 %*	1,073.55 % *1,018.89 %*
UK	1,251.11 %	1,631.35 % *2,075.78 %*	1,499.58 % *1,758.58 %*	1,288.72 % *1,308.44 %*

Notes: The results from allowing for short selling are shown in italic letters.

6 Conclusion

Research in real estate finance and economics has been dealing with the topic of efficiency in the housing market for more than 25 years. However, most past research has focused mainly on the U.S. housing market, and the studies which focus on regional housing markets in the U.K. analyze efficiency in the context of (lagged) dependences and linkages between house prices and economic variables. These studies challenge the hypothesis of semi-strong form market efficiency. To our knowledge, there is no study on the U.K. market exhibiting a univariate analysis concentrating on the information contained in the own time series on challenging the hypothesis of weak-form market efficiency.

While in general, the efficient market hypothesis deals with the question of whether or not prices fully reflect all the information available at a specific point in time, the study tests the weak-form efficient market hypothesis focusing on the set of information of historical index series or index changes. As a further robustness check, and because the rejection of the random walk hypothesis based on autocorrelation analysis and (multiple) variance ratio tests does not necessarily imply inefficiency in a market, a non-parametric runs test for market efficiency is also conducted. Variance ratio tests benefit from also allowing the random walk hypothesis to be tested jointly for all observation intervals. Additionally, the practical relevance of rejecting the efficient market hypothesis is tested by implementing trading strategies based on results of autocorrelation tests as well as on moving averages.

This study examines the behavior of quarterly house price changes for 13 regional and one nationwide index for the period from the fourth quarter of 1973 to the fourth quarter of 2009. The conducted analysis gives empirical evidence that house price changes in the U.K. exhibit certain patterns. The results show that the price changing generating process of U.K. housing markets differs significantly from the theoretical model of the random walk hypothesis. With few exceptions in the northern parts of the U.K., the conducted tests reject the null hypothesis of a random walk for all time series of house price changes. Furthermore, the implemented trading strategies support these findings by generating excess returns as opposed to a buy-and-hold strategy. In general, we can conclude that investors might be likely to earn excess returns by using past information in the U.K. housing market, in particular when standardized derivatives of the indices are traded on exchange markets. The information might also be useful in the prediction of market cycles.

Compared to previous research on the U.S. housing market e.g. by Case and Shiller (1989), Gu (2002), and Schindler (2010), findings for the housing market in the U.K. are similar. Yet, each study focuses on different areas and markets; the studies differ in their focus on markets or single houses, apply different methodologies and data frequencies, partly use appraisal data, and are conducted over different time periods. Hence, general qualitative conclusions might be comparable, but not the quantitative results.

Knowing about the inefficiencies of the U.K. housing market, the next step for investors interested in exploiting these inefficiencies or in hedging their risk exposure to the regional housing markets is focusing on the construction of appropriate products through which the markets can be replicated and through which investors can participate in the market and the pricing process of these derivatives. Analyzing the implications of the inefficiency for the pricing process of products being built on the housing market of the U.K. would give further empirical evidence on whether inefficiencies in the U.K. housing market are exploitable or whether they are incorporated into the pricing process of tradable products and can thus not be exploited by investors. This work is left for further research. Following the work of Tsolacos (2006) for the rental market, a further research topic for future work is the evaluation of the forecasting quality of econometric models compared to univariate time series analysis and consensus forecast. Willcocks (2009) shows that univariate analysis of house prices in the U.K. results in standardized residuals which are independent and identically distributed "indicating that 'there is nothing else left'" (Willcocks, 2009, p. 411). Our results could also be seen as an indication that forecasting cycles and future market developments by univariate time series and technical analysis results in useful information.

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