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Estimating regional house price levels

Methodology and results of a pilot project with Spain

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Abstract

While indices tracing the ***evolutions*** of regional house prices are increasingly available, this is less the case for similar data on ***house price levels***. And where data on house price levels exist, they are not necessarily consistent with the patterns observed from house price indices. Yet, consistent regional statistics on house price levels are fundamental to assess housing affordability, potential barriers to labour mobility across regions, and for the design of housing policies. This article puts forward a method to compile regional house price levels that are consistent with the evolutions given by quality-adjusted house price indices, representative of the underlying stock of dwellings, and based on the information on house price levels that is available at all dates rather than in a single reference year. This method could be scaled up to different countries. The results obtained with Spanish data show that the decline in house prices following the global financial crisis of 2008-09 initially reduced the dispersion in house prices across Spanish regions, but this dispersion has increased again afterwards, and since 2016, it exceeds the one recorded in 2008. A comparison of price-per-m² to regional-income ratios shows that the relative housing affordability in the region of Madrid deteriorated compared to all other Spanish regions in the last decade. Monitoring whether shifts in housing demand following the COVID-19 pandemic will reverse this trend will be key.

Keywords: House price indices, House price levels, Regional statistics, Spain.

JEL Classification: R31, R32, C32, C43.

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Résumé

De plus en plus d'indices de prix permettent de suivre les ***évolutions*** des prix de l'immobilier au niveau régional, mais il existe peu de données similaires sur les ***niveaux de prix*** de l'immobilier. Et lorsque ces données existent, elles ne sont pas forcément cohérentes avec les évolutions données par les indices de prix. Néanmoins, disposer de statistiques régionales cohérentes sur les prix de l'immobilier est fondamental pour apprécier si les prix des logements sont accessibles, s'il existe des barrières à la mobilité de la main d'œuvre entre régions, et pour élaborer des politiques de logement. Cet article propose une méthode pour calculer des niveaux de prix régionaux de l'immobilier cohérents avec les évolutions données par les indices de prix ajustés de la qualité, représentatifs du stock de logements, et utilisant toute l'information disponible sur les niveaux de prix plutôt qu'uniquement celle d'une année de référence. Cette méthode pourrait être appliquée à différents pays. Les résultats obtenus à partir de données espagnoles montrent que le déclin des prix de l'immobilier après la crise financière de 2008-09 a tout d'abord réduit la dispersion des prix entre les régions espagnoles, mais cette dispersion a recommencé à augmenter par la suite. Depuis 2016, elle excède celle qui était observée en 2008. Une comparaison des ratios de prix au m² sur les revenus régionaux montre que la possibilité d'acheter un logement dans la région de Madrid s'est dégradée par rapport à toutes les autres régions espagnoles au cours de la dernière décennie. Il sera important d'observer si des modifications de la demande de logements suite à l'épidémie de COVID-19 vont venir renverser cette tendance.

Mots clés : Indices de prix de l'immobilier, Niveaux de prix de l'immobilier, Statistiques régionales, Espagne.

Classification JEL : R31, R32, C32, C43.

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1. Introduction

1. Concerns about the sustainability of the global house price boom that was observed in the late 1990s and early 2000s, as well as the global financial crisis of 2008-09 whose origin is closely related to the financing of a housing bubble in the United States, have called for the development of official and reliable house price indices (HPIs). This move has been facilitated by the publication of international statistical guidelines on HPIs in 2013[2] and, in the case of European countries, by the adoption of a statistical regulation on the production of such indices in 2016.[3] The current increase in real house prices in most OECD countries since the COVID-19 pandemic, fuelled by very low interest rates and savings accumulated during lockdown periods further reinforces the interest for house price developments and HPIs.

2. These indices measure the rate at which the prices of residential properties purchased by households change over time. They adjust for quality differences between dwellings sold in the current period, relative to the reference period.[4] In other words, they aim at measuring pure price changes. These prices include the price of the land on which residential buildings are located.

3. Nowadays, official statistical agencies in all OECD countries release at least one national house price index compiled according to international statistical standards. In most cases, an aggregated index covering all types of dwellings (houses and apartments, new and existing dwellings) is available and gives a comprehensive picture of the national real-estate market.

4. A growing number of OECD countries have also started to develop similar indices at subnational level, in order to capture the heterogeneity in house price developments across regions and cities within countries.[5] For example, the Spanish National Statistics Institute (INE) provides HPIs for all autonomous communities (i.e. NUTS-2 regions) in Spain. These indices show large discrepancies in house price developments across Spanish regions (Figure 1.1). For example, while house prices in Navarra declined by 44% between 2008 and 2015 (vs. -32% for Spain as a whole), they also recovered less strongly than the national average between 2015 and 2020 (+13% vs. +28% for Spain as a whole). By contrast, house prices in the capital region of Madrid closely followed the national average between 2008 and 2015 but exhibited the strongest growth of all regions since then with an increase of more than 40% between 2015 and 2020.

5. In recent decades, at least until the COVID-19 pandemic, an "urban resurgence" phenomenon (Glaeser, 2020[1]), driven in part by better-paid jobs within cities, the willingness to live closer to them, and better access to cultural amenities has led to

[2] See https://ec.europa.eu/eurostat/documents/3859598/5925925/KS-RA-12-022-EN.PDF.

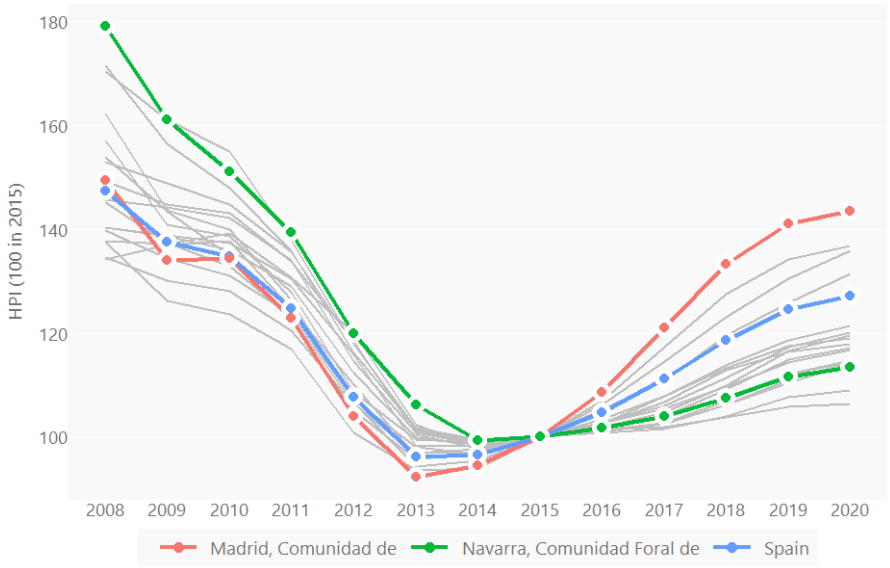
[3] The 2016 regulation (https://eur-lex.europa.eu/eli/reg/2016/792/oj) has been complemented in 2020 with a new text adding the requirement for all EU countries to produce joint and separate house price indices for new and existing dwellings (https://eur-lex.europa.eu/eli/reg_impl/2020/1148/oj).

[4] In the following, the terms quality-adjusted house price indices and house price indices (HPIs) will be used interchangeably.

[5] The corresponding indices, with breakdowns by type of dwellings, are available in the OECD database on national and regional house price indices. This database is updated at quarterly frequency. 28 OECD countries currently compile at least one house price index at subnational level, and 16 of them provide subnational indices covering all types of dwellings, thus giving a comprehensive picture of regional real-estate markets. The data are also available as part of an interactive visualisation tool, known as the OECD House Price Tracker.

gentrification and above (national) average house price growth in some of the largest cities in OECD countries. Nevertheless, the quest for larger living spaces and the development of teleworking practices following the COVID-19 pandemic may reverse this phenomenon. In the current situation, subnational house price statistics are becoming more relevant than ever to track the potential reallocation of housing demand across regions and cities within countries.

Figure 1.1. INE house price indices for Spain and 17 Spanish autonomous communities (2015 = 100)



Source: INE, OECD database on national and regional house price indices

6. In spite of their importance for economic analysis and the development of housing policies (OECD, 2021[2]), HPIs are designed to measure house price developments over time but they are silent about the underlying house price levels. Similarly, Consumer Price Indices (CPIs) allow measuring inflation (i.e. how consumer prices develop over time), but only Purchasing Power Parities (PPPs) allow comparing price levels across space.[6]

7. Statistics on house price levels are typically not available from official statistical agencies, neither at national nor subnational level. Nevertheless, contrary to HPIs they could be directly compared with the average income or the borrowing capacity of households and could therefore provide key information on the difficulties faced by households in acquiring a house. The 2019 OECD Regional Outlook (OECD, 2019[3]) emphasises that the geographical patterns of public discontent are closely related to the degree of regional inequalities, and that policies to address public discontent need to have a place-based dimension. House price level differentials across regions reflect these

[6] Note that PPPs cover all types of goods and services that are consumed, invested or exported in an economy. Therefore, specific PPPs are compiled for dwellings and other investment goods. Nevertheless, only new dwellings, and only a handful of dwelling types with very precise characteristics to allow for international price comparisons, are taken into account for the compilation of PPPs. Moreover, in line with national accounts conventions, the price of land is excluded from the value of investment. Lastly, most statistical agencies only compile PPPs at national level. For these reasons, the available PPPs do not allow comparing house prices across regions within the same country, nor taking into account the specific nature of dwellings in the housing stock of each region.

regional inequalities and statistics on this issue could contribute to the design of better regional economic policies.

8. Moreover, statistics on house price levels would also help to better understand the difficulties faced by households in moving from one region to another. Even though labour mobility has been shown to be an important stabilisation mechanism in response to national or regional demand shocks (Blanchard et al., 1992[4]), differences in housing affordability across regions can be a major barrier to labour mobility within a country (Ganong and Shoag, 2017[5]). In Europe, labour mobility is generally much lower than in the United States and has been identified as a barrier to the proper functioning of the monetary union. Even within their countries of residence, Europeans tend to move less than people in other regions of the world (Dao, Furceri and Loungani, 2014[6]). Empirical findings on domestic migration patterns in Spain suggest strong effects of relative house prices between regions of origin and destination on the migration decision, especially in the period after 2008 (Liu, 2018[7]).

9. The aim of this paper is to put forward a method to estimate regional house price levels that are representative of the underlying stock of dwellings, and which is scalable to different countries. Spain has been selected as a pilot country for this exercise because INE already provides regional HPIs which turn out to be very useful for the estimation of regional house price levels, both as benchmarks and inputs, and because we could gain access to two micro datasets for Spain. The first dataset, provided by the Spanish notaries, includes average transaction prices and the corresponding number of transactions at province and municipality levels. The second dataset includes average asking prices at district level provided by the real-estate website Idealista.[7] Both datasets include quarterly information from 2007 to 2020, a period where house prices in Spain show large variations, which further reinforces the relevance of working with Spanish data.[8]

10. The method to estimate regional house price levels advocated in this paper works in two stages. In the first stage, house price levels are estimated based on a stratification of house transaction prices and using stock weights to aggregate strata. In the second stage, a state-space model is used to improve upon the stratified estimates obtained in the first stage.

11. The main conclusions of the paper are as follows:

- For the estimation of stratified house price levels, using geographically disaggregated data helps to control for quality effects and to ensure that changes over time in house price levels reflect true price changes rather than changes in the characteristics of transacted dwellings. In the case of Spain for example, there is a gain in accuracy from moving from province-level to municipality-level data.
- Weighting strata based on the number of dwellings in the stock rather than the number of transactions makes a significant difference for regions with a large share of rural areas. Using stock weights rather than transaction weights increases the weight of such areas and reduces regional house price levels by up to 10-20% for some Spanish regions. Nevertheless, the exact Census year that is used to estimate stock weights seems to be of second-order importance, and house price evolutions are much less sensitive to the weighting scheme than house price levels.
- Differences in house price level estimates based on asking and transaction prices are region specific, they vary with the business cycle, and they are potentially very

[7] www.idealista.com/en/data/.

[8] Across all datasets, we only include data for the 17 autonomous communities of Spain and exclude the autonomous cities of Ceuta and Melilla.

large. These differences may be related to a selection bias when collecting asking prices on specific websites, a spread between asking and transaction prices for individual dwellings, or both.

- Since the mix of properties in the dwelling stock of a reasonably large geographical area is usually stable from one year to the next, the evolutions of house price levels that are representative of the stock of dwellings should correspond to pure price changes. Therefore, quality-adjusted HPIs can provide additional information to increase the reliability of house price level estimates.
- State-space models provide the adequate statistical framework to combine information from transaction prices and HPIs, and they have two distinct benefits. First, they guarantee that estimated house price levels have the same evolutions as the corresponding HPIs published by official statistical agencies. Moreover, they use the available information on house price levels at all dates without having to choose a reference period arbitrarily, thus leading to only minor revisions over the past when new data come in.
- Our results show that the decline in house prices in Spain following the global financial crisis of 2008-09 initially reduced the dispersion in house prices across Spanish regions but this dispersion has increased again after 2012. Since 2018, it exceeds the one recorded in 2008.
- In the last decade, housing affordability measured as the number of years of average regional income that are necessary to purchase a dwelling of 100 m² deteriorated substantially in the capital region of Madrid compared to all other Spanish regions. Monitoring whether and how teleworking opportunities and the demand for larger living spaces outside of city centres following the COVID-19 pandemic will affect regional housing affordability in the future will be key.

12. The rest of the article is organised as follows. The next section explains why the evolutions of representative house price levels should be consistent with those of quality-adjusted HPIs and shows that the currently available information on house price levels in Spain does not fulfil this requirement. The third section discusses the sensitivity of stratified house price levels to the granularity of the stratification and to the types of weights and prices that are used as inputs. The fourth section introduces the state-space approach to improve upon the house price levels obtained with a stratification method. The fifth section discusses the results obtained for Spain and the article concludes by discussing the key role that statistical agencies have to play to foster the development of official statistics on regional house price levels.

2. Relationship between representative house price levels and quality-adjusted house price indices

13. Overall, the mix (or the quality) of properties in the dwelling stock of a reasonably large geographical area (e.g. region or country) can be considered as stable from one year to the next. This is first because, in a given year, only a small fraction of the dwelling stock corresponds to new dwellings. In the case of Spain for example, the share of new dwellings in the stock varies from 2.3% in 2008, after a housing boom decade, to 1.9% in 2019, after a decade of much slower construction activity.[9] Moreover, service lives of dwellings tend to be long and renovation investments limit the depreciation of existing dwellings. Therefore, the evolutions of house price levels that are representative of the underlying stock of dwellings should largely correspond to pure price changes, i.e. exactly what quality-adjusted house price indices intend to measure. If this condition does not hold, it can be inferred that the estimated house price levels are not representative of the underlying stock of dwellings.

14. Stratification methods, as long as they allow controlling for quality effects, offer a simple way to compile house price levels that reflect the structure of the underlying stock. These methods consist in separating the total sample of transacted properties into a number of sub-samples (e.g. municipalities, or districts within large municipalities), also called strata, where property prices are more homogeneous than in the total sample. Once average prices have been compiled based on observed transaction prices in each elementary stratum, they can be aggregated to the upper (e.g. regional or national) level using Census weights on the available surface of dwellings in each stratum. This weighting scheme ensures that the weight of each stratum in the estimated house price level is based on its relative importance in the stock of dwellings rather than in observed transactions.

15. Defining P_m^t as the average price per m² in stratum *m* at date *t*, and Q_m^0 as the total surface of dwellings (in m²) in the underlying stock, the average house price level P_A^t in the region *A* composed of the first *M* strata is calculated as follows:

$$P_A^t = \sum_{m=1}^{M} \frac{Q_m^0}{\sum_{m=1}^{M} Q_m^0} P_m^t \qquad (1)$$

16. In practice, the weighting scheme will be kept constant for several years, based on the assumption that the relative surface of dwellings in each stratum hardly changes at annual frequency, and because this information comes from infrequently updated Censuses.[10] In this case, the evolution of the average house price level in region *A* between periods t and $t+1$ can be rewritten as a stock-weighted Laspeyres-type house price

[9] At the autonomous community level, we observe the largest share of new dwellings in the region La Rioja in 2011 with about 5%, falling to 4.4% in 2019. Similar information is available from Ministerio de Fomento for all autonomous communities and provinces. See www.mitma.gob.es/informacion-para-el-ciudadano/informacion-estadistica/vivienda-y-actuaciones-urbanas/estadisticas/stock-de-vivienda-nueva/estadisticas-sobre-stock-de-vivienda-nueva.

[10] Section 3 and Annex C discuss the impact of using the 2011 or the 2019 Census to estimate regional house price levels and evolutions in Spain. Differences are minor in all cases. More precisely, this type of price index in which quantities are inherited from an earlier period rather than updated at each date is called a Lowe index.

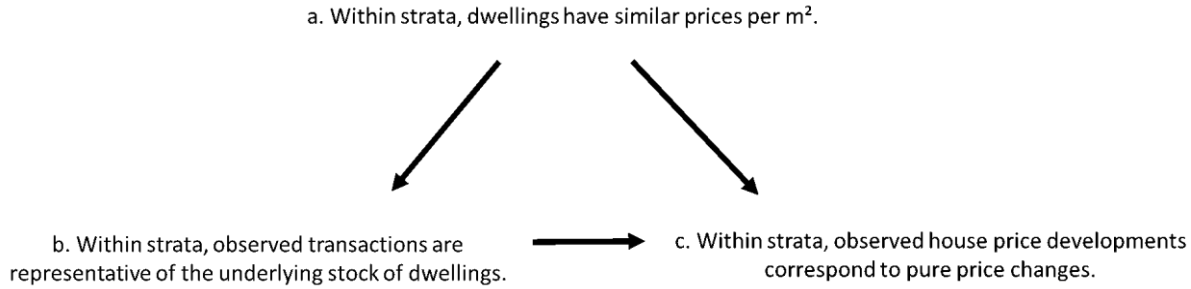
index.[11] This shows the close relationship between representative house price levels and quality-adjusted house price indices, as long as they are based on the same types of weights and prices.

$$\frac{P_A^{t+1}}{P_A^t} = \frac{\sum_{m=1}^{M} Q_m^0 P_m^{t+1}}{\sum_{m=1}^{M} Q_m^0 P_m^t} = \sum_{m=1}^{M} \left(\frac{Q_m^0 P_m^t}{\sum_{m=1}^{M} Q_m^0 P_m^t} \right) \left(\frac{P_m^{t+1}}{P_m^t} \right) \qquad (2)$$

17. One of the main difficulties when using stratification methods is to select an appropriate stratification to ensure that the evolution of house prices between different periods does not mix pure price changes with changes in the quality of the transacted dwellings in each stratum. Given the importance of location as a price-determining characteristic for dwellings, it is usually used to define strata. Other criteria such as the age of dwellings may also be used and make the composition of dwellings more homogeneous within strata. Nevertheless, the size of the sample of transacted properties in each period imposes a natural limit to the use of stratification methods.

18. Figure 2.1 gives two sufficient conditions under which ratios of observed transactions prices in consecutive periods allow capturing pure price changes within strata. It is the case, for example, when all dwellings in a given stratum and at a given date have similar prices per m², or when observed transactions are representative of the underlying stock of dwellings in all strata and at all dates. Obviously, the second condition (b) is less demanding than the first one (a).

Figure 2.1. Measuring pure price changes with stratification methods



Note: Arrows correspond to logical implications.

19. In cases where the ratio of average transaction prices does not correspond to pure price changes, stratification methods are typically combined with hedonic methods to calculate quality-adjusted house price ratios within strata.[12] While hedonic models allow assessing the price of individual dwellings in different periods, they usually require very detailed information on dwelling characteristics. At best, this information is available for transacted dwellings, but not for all dwellings in the stock. Therefore, it would be difficult to estimate house price levels that are representative of the entire stock of dwellings using hedonic models and the present paper will propose an alternative strategy to achieve this goal.

[11] More precisely, this type of price index in which quantities are inherited from an earlier period rather than updated at each date is called a Lowe index.

[12] For a detailed explanation of the most widely used hedonic methods, see Chapter 5 of the Handbook on Residential Property Price Indices see OECD et al. (2013[12]) or Hill (2011[18]).

20. In Spain, in addition to the quality-adjusted HPIs based on transaction prices provided by INE, the Ministry in charge of public works and buildings (*Ministerio de Fomento*) publishes stock-weighted house price levels per m² for each province and autonomous community in Spain, based on appraisals.[13] Nevertheless, it turns out that the evolutions of house prices given by these two sources may be very different, as Table 2.1 illustrates. For example, house prices in Andalucía, Cataluña and Madrid, the three most populated autonomous communities in Spain, increased by 4%, 18% and 29% between 2013 and 2020 according to *Ministerio de Fomento*, whereas they increased by 24%, 45% and 56% according to INE. Moreover, the two data sources can also give conflicting information on relative house price evolutions *across* regions. Figure 2.2 plots *relative* house prices in Castilla y León compared to Madrid between 2007 and 2020, according to both sources. Despite conflicting information about house price evolutions over time for Castilla y León and Madrid, the two sources imply largely similar *relative* price evolutions in the two regions.[14] For example, both sources indicate that house prices in Castilla y León have substantially declined relative to Madrid between 2012 and 2020 (by around 30%). By contrast, Figure 2.3 plots relative house prices in Cataluña and Madrid. In this case, the two sources give conflicting messages. According to *Ministerio de Fomento*, the ratio of house prices between Cataluña and Madrid grew by 13.4% between 2007 and 2011, whereas it declined by 5.7% according to INE.

21. These discrepancies can originate from multiple sources, including the use of different weights (stock weights for *Ministerio de Fomento* vs. transaction weights for INE), different types of prices (appraisals for *Ministerio de Fomento* vs. transaction prices for INE), and the fact that the quality of the dwellings tracked by *Ministerio de Fomento* may not be constant over time. In the latter case, this would mean that the house price levels released by *Ministerio de Fomento* are not representative of the underlying stock of dwellings.

22. Whatever their source, these discrepancies are confusing for users and they imply that the option of simply taking regional house price levels released by *Ministerio de Fomento* for a given year and backcasting/extrapolating them with INE's HPIs to compile time series of house price levels should not be recommended. Depending on the reference year that is used for house price levels, users may end up with very different house price levels in other years. Even relative house prices across autonomous communities (*e.g.* between Cataluña and Madrid) may be sensitive to the choice of the reference year.

23. In the following, we will put forward a method to estimate regional house price levels that are representative of the underlying stock of dwellings. We will first discuss the sensitivity of stratified house price levels to the granularity of the stratification method and the types of weights and house prices, using the HPIs released by INE as benchmarks for house price evolutions. We will then propose a practical way to fully align the stratified house price levels obtained in a first stage with the evolutions given by HPIs.

[13] The methodology followed by *Ministerio de Fomento* for the compilation of regional house price levels is available at: www.mitma.gob.es/recursos_mfom/pdf/B0E2BE62-28EF-41A8-B9D4-CCBD92A28643/144522/MetodValorVivienda.pdf. The corresponding data can be accessed at: www.fomento.gob.es/BE2/?nivel=2&orden=35000000 (*Valor tasado de vivienda libre*).

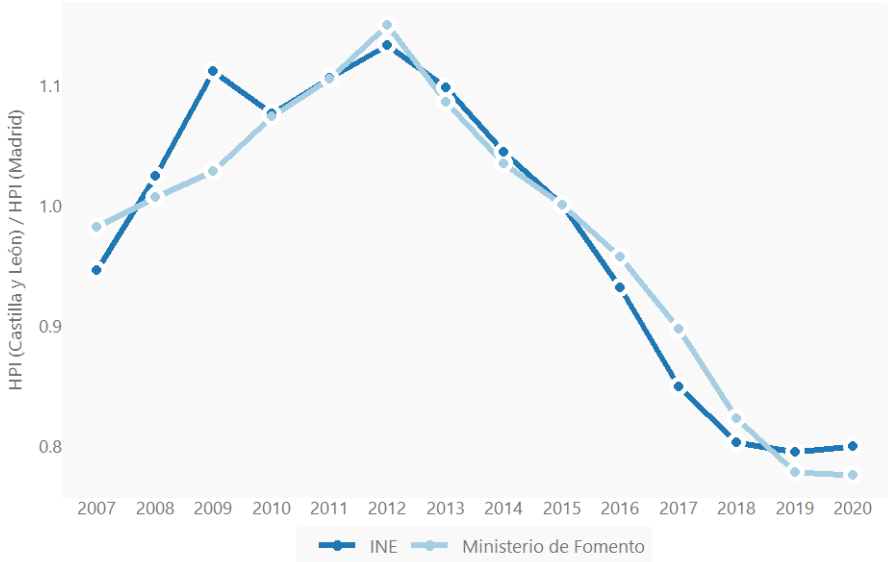
[14] Since the information on house prices given by INE is only available in index form, the information on house price levels given by *Ministerio de Fomento* is transformed into indices with 2015 as a base year. Index ratios for two regions can then be formed.

Table 2.1. Regional house price evolutions according to INE and Ministerio de Fomento

	2008 - 2013			2013 - 2020	
Autonomous communities	**INE**	***Ministerio de Fomento***		**INE**	***Ministerio de Fomento***
Andalucía	-27.96%	-29.98%		23.91%	4.30%
Aragón	-40.84%	-35.88%		17.73%	-2.11%
Asturias, Principado de	-30.82%	-22.42%		13.21%	-7.93%
Balears, Illes	-31.95%	-22.90%		45.22%	27.74%
Canarias	-29.92%	-28.71%		21.45%	17.75%
Cantabria	-37.94%	-23.99%		23.30%	-6.58%
Castilla - La Mancha	-32.64%	-32.73%		8.46%	-7.49%
Castilla y León	-33.85%	-25.15%		13.34%	-8.20%
Cataluña	-41.84%	-31.07%		45.11%	17.90%
Comunitat Valenciana	-33.31%	-31.60%		20.63%	5.55%
Extremadura	-25.71%	-13.77%		3.86%	-3.46%
Galicia	-28.91%	-22.05%		14.71%	-1.01%
Madrid, Comunidad de	-38.31%	-30.59%		55.70%	28.67%
Murcia, Región de	-30.02%	-34.07%		16.50%	-7.36%
Navarra, Comunidad Foral de	-40.66%	-20.16%		6.78%	0.91%
País Vasco	-36.63%	-16.40%		21.93%	-4.89%
Rioja, La	-40.31%	-26.84%		15.20%	-5.65%

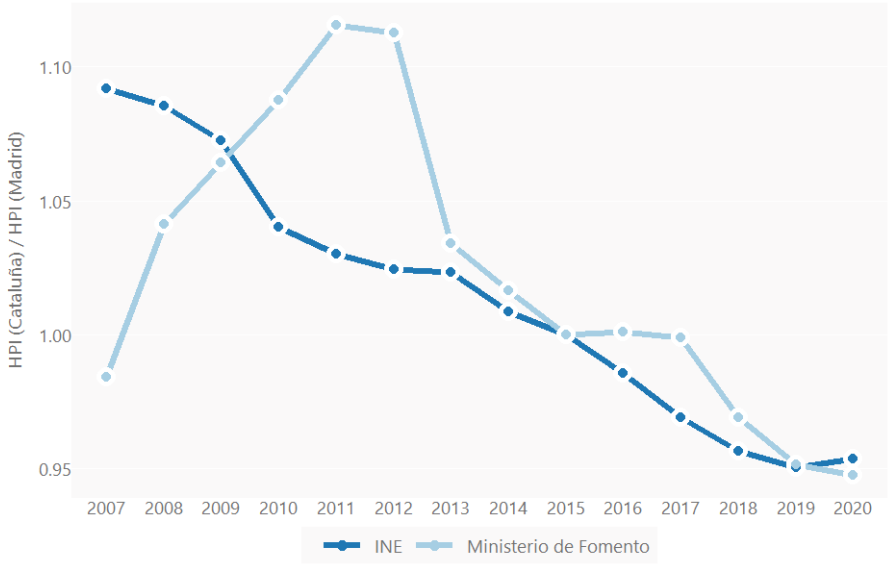
Source: INE, *Ministerio de Fomento*, authors' calculations.

Figure 2.2. Relative house prices in Castilla y León and Madrid, according to INE and Ministerio de Fomento (2015 = 1)



Note: The figure plots ratios of house price indices for Castilla y León and Madrid, according to INE and Ministerio de Fomento, taking 2015 as a base year. A decline in the index indicates that house prices grow faster (or decline at a slower pace) in Madrid than in Castilla y León.
Source: INE, *Ministerio de Fomento*, authors' calculations.

Figure 2.3. Relative house prices in Cataluña and Madrid, according to INE and Ministerio de Fomento (2015 = 1)



Note: The figure plots ratios of house price indices for Cataluña and Madrid, according to INE and Ministerio de Fomento, taking 2015 as a base year. A decline in the index indicates that house prices grow faster (or decline at a slower pace) in Madrid than in Cataluña.
Source: INE, *Ministerio de Fomento*, authors' calculations.

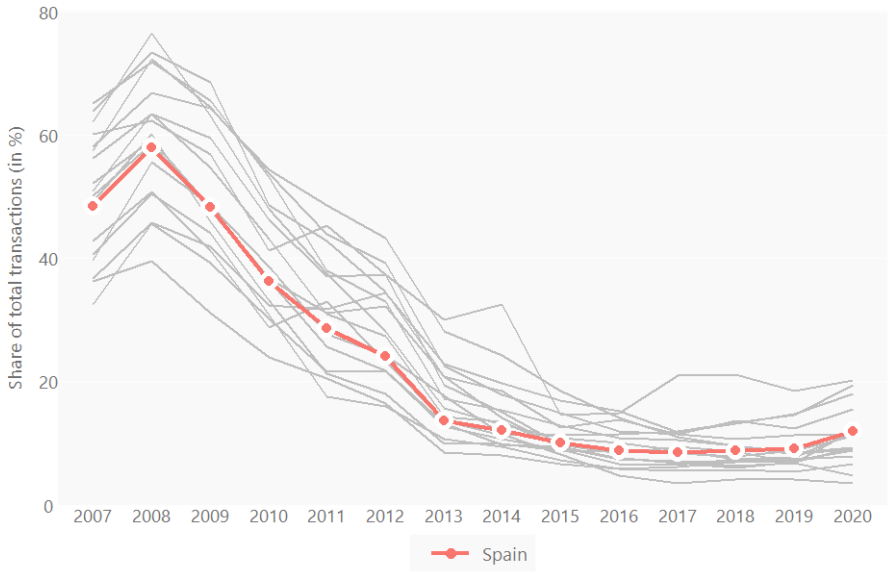
3. Sensitivity of stratified house price levels to the granularity of the stratification and to the types of weights and prices that are used as inputs

24. Given the importance of size and location as price determining characteristics for dwellings, transaction prices should at least be converted into prices per m² and broken down by geographical area for the estimation of representative house price levels according to equation (1).

25. In the case of Spain, the distinction between new and existing dwellings turns out to be very important as well, at least to estimate *transaction-weighted* HPIs. In the early 2000s, the Spanish housing market experienced a construction and house price boom that ended with the global financial crisis of 2008-09. Consequently, the share of new dwellings in housing *transactions* rapidly declined from 60% in 2008 to less than 20% after 2013 (Figure 3.1). Since new dwellings are consistently sold at a higher price per m² than existing dwellings,[15] omitting to stratify transactions into new and existing dwellings would lead to an overstatement of house price declines in the wake of the financial crisis, resulting from a mix between price and quality changes.

[15] The premium for new dwellings compared to existing dwellings is around 20-30% on average in Spain and quite stable over time, but with large variations across regions.

Figure 3.1. Share of new dwellings in total housing transactions in Spain



Note: Each grey line corresponds to an autonomous community.
Source: *Consejo General del Notariado* (CGN), authors' calculations

26. Rather than explicitly considering the breakdown into new and existing dwellings for the stratification of housing transactions, we will focus on existing dwellings in the following. Indeed, the aim of this paper is to estimate house price levels that are representative of the stock of dwellings and new dwellings only represent a marginal share of this stock (from 2.3% in 2008 to 1.9% in 2020, see above).

27. In order to assess the capacity of geographical stratification methods to control for quality effects, we will first estimate stratified house price indices and compare them with the corresponding HPIs for existing dwellings compiled by INE based on hedonic regressions.[16] The same house transaction prices from the Spanish notaries are used for the compilation of the stratified indices and of INE's hedonic indices, but two sets of stratified indices are compiled depending on whether this information is used at the province or municipality level.[17] In all cases, transaction weights are used to aggregate house price evolutions across strata.[18] Table 3.1 compares the evolution of house prices in all autonomous communities over 2008-2013 and 2013-2020, according to INE and the two sets of stratified indices. Annex B includes the corresponding charts.

[16] The methodology followed by INE for the compilation of quality-adjusted HPIs is available at: www.ine.es/en/daco/daco42/ipv/metodologia2015_en.pdf. The hedonic regressions underlying the compilation of the HPIs are based on detailed information on individual dwelling characteristics.

[17] For confidentiality reasons, price and surface information on transactions in municipalities with less than three transactions in a given year are grouped by province (see Annex A).

[18] While INE usually computes transaction weights as a weighted average over several years (the previous three years up to 2012, the previous year from 2013 to 2015, and the previous two years since 2016), we rely on previous year's transactions to compute weights. This strategy only marginally affects the results and allows compiling indices from 2008 onwards. Based on the data at our disposal, relying on the exact same methodology as INE to compute weights would only allow compiling indices from 2010 onwards.

28. As expected, in the large majority of cases the more granular geographical stratification (at municipal level) leads to house price evolutions that are either closer to those given by the more sophisticated official HPIs, or nearly as close as the stratification at province level.[19] Overall, the municipal-level stratification leads to a reasonably good fit with the official HPIs, but with differences across regions (see Table 3.1 and Annex B).[20] In the case of Andalucía and Madrid for example, the fit is very good to excellent (see Figure 3.2 and Figure 3.3), but it is less the case for other regions such as Cantabria, Castilla - La Mancha, Castilla y León and Murcia, thus pointing to the difficulty of geographical stratification to fully control for quality effects and justifying a further adjustment of the stratified house price levels obtained at this stage (see Section 4).

Table 3.1. Regional house price evolutions of existing dwellings according to INE HPIs and stratification-based estimates

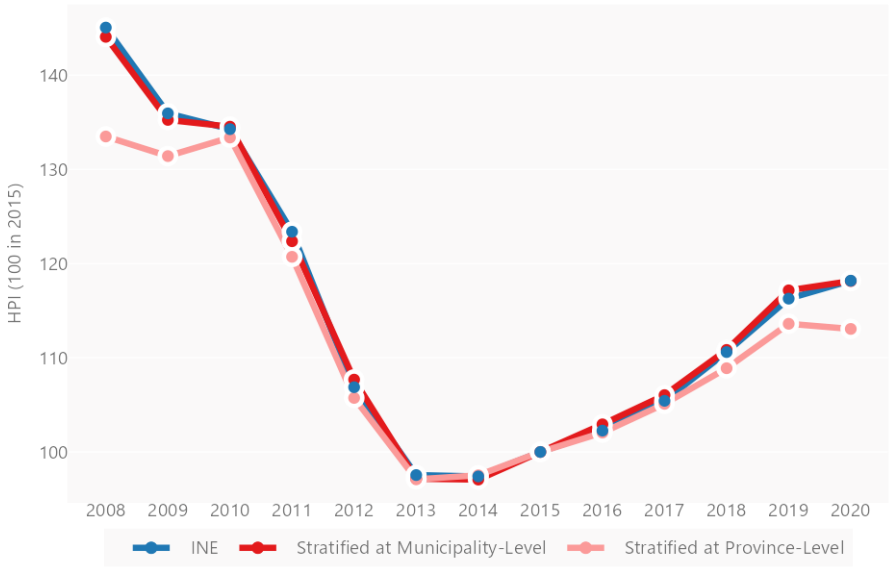
	2008 - 2013				2013 - 2020		
		OECD estimates				OECD estimates	
Autonomous communities	**INE**	**Municipality**	**Province**		**INE**	**Municipality**	**Province**
Andalucía	-32.75%	**-32.57%**	-27.27%		21.16%	**21.61%**	16.44%
Aragón	-43.93%	**-47.44%**	-37.11%		16.37%	1.25%	**1.27%**
Asturias, Principado de	-34.00%	**-29.24%**	-21.33%		10.18%	**4.62%**	2.75%
Balears, Illes	-35.62%	-27.19%	**-30.34%**		44.18%	53.70%	**43.87%**
Canarias	-32.51%	**-30.69%**	-29.44%		19.90%	42.54%	**23.61%**
Cantabria	-39.35%	**-35.07%**	-31.90%		20.47%	**1.64%**	-1.39%
Castilla - La Mancha	-35.97%	-47.69%	**-32.18%**		5.64%	**7.29%**	10.38%
Castilla y León	-39.12%	**-39.83%**	-26.57%		12.22%	-2.85%	**3.85%**
Cataluña	-42.90%	-46.99%	**-45.29%**		42.70%	**46.21%**	32.68%
Comunitat Valenciana	-36.23%	-41.04%	**-38.09%**		18.77%	25.47%	**15.06%**
Extremadura	-30.30%	**-22.77%**	-9.01%		2.43%	-9.89%	**8.06%**
Galicia	-33.48%	**-29.19%**	-22.74%		11.62%	**8.37%**	7.06%
Madrid, Comunidad de	-40.06%	-43.39%	**-42.40%**		53.39%	**50.83%**	41.17%
Murcia, Región de	-34.66%	-40.67%	**-37.48%**		14.34%	**9.09%**	6.07%
Navarra, Comunidad Foral de	-43.70%	**-38.35%**	-27.57%		2.47%	14.81%	**1.73%**
País Vasco	-40.16%	**-34.25%**	-31.84%		16.11%	**16.92%**	13.12%
Rioja, La	-40.70%	**-44.63%**	-30.55%		14.66%	**11.62%**	5.60%

Note: For each autonomous community and sub-period, the level of stratification (municipality or province) leading to the best fit with INE HPIs is indicated in bold.
Source: INE, *Consejo General del Notariado* (CGN), authors' calculations.

[19] Based on Table 3.1, only five exceptions to this statement can be reported: for Castilla - La Mancha between 2008 and 2013, and for the Balearic Islands, the Canarias, and the autonomous communities of Valencia and Navarra between 2013 and 2020.

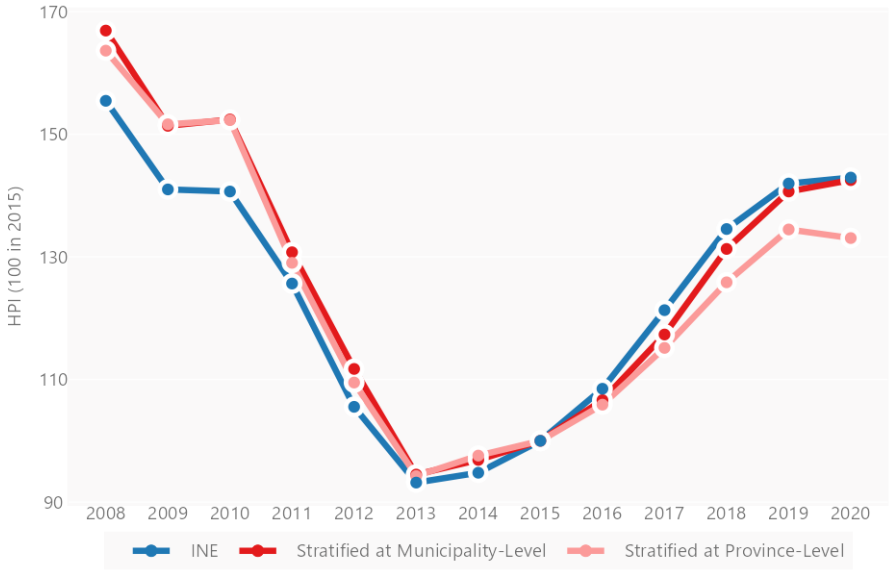
[20] Remember that we focus on existing dwellings here. If both new and existing were considered, a stratification by municipality and dwelling vintage would be necessary to roughly match the evolutions given by INE's HPIs for all dwellings.

Figure 3.2. House price developments in the autonomous community of Andalucía according to INE HPIs and stratification-based estimates (2008-2020)



Source: INE, *Consejo General del Notariado* (CGN), authors' calculations.

Figure 3.3. House price developments in the autonomous community of Madrid according to INE HPIs and stratification-based estimates (2008-2020)



Source: INE, *Consejo General del Notariado* (CGN), authors' calculations.

29. We now turn to the sensitivity analysis of house price level estimates to the choice of weights to aggregate strata. Strata can be aggregated using transaction or stock weights. While most statistical agencies use transaction weights to compile house price indices,[21] stock weights are more appealing for the estimation of house price levels if they are to be representative of the overall stock of dwellings in a given region or country.

30. For the calculation of stock weights, we use Census information on dwelling floor space instead of the surface of transacted dwellings. More precisely, we rely on the information on the number and average surface of dwellings at the section level from the Census and use it to compile the total dwelling floor space for all municipalities in Spain.

31. Two main conclusions emerge from this sensitivity analysis. First, estimated house price levels and evolutions at the autonomous community level are extremely similar when using information from the 2011 or 2019 Censuses.[22] Second, the main differences between the two weighting schemes (transaction or stock weights) are observed for estimated house price *levels* in autonomous communities with a large share of rural areas.

32. With transaction weights, (rural) areas with a low housing market activity are under-represented. For each autonomous community, Table 3.2 compares the average share of the 30% of municipalities with the lowest and highest prices per m^2 in the total dwelling stock and the total transacted surface. In most cases, municipalities with the lowest prices per m^2 receive a substantially higher weight when using stock weights rather than transaction weights. The difference is especially pronounced in regions with a large share of rural areas. In Andalucía for example, high-priced areas account for around 75% of transactions but represent only around 65% of the underlying stock in terms of surface. By contrast, in more densely populated Communities such as Cataluña and Madrid, transactions are much more representative of the underlying stock and the two weighting schemes produce weight shares that are much closer to each other than for rural areas.

Annex D compares the evolutions of indices and levels per m^2 based on stock and transaction weights to aggregate strata for the five most populated autonomous communities in Spain (Andalucía, Cataluña, Comunitat Valenciana, Galicia and Madrid). All series are compiled from average transaction prices at the municipality level. In most cases, the two weighting schemes lead to very similar house price *evolutions*. A similar pattern has been documented by Diewert ($2010_{[8]}$) regarding the evolutions of transaction and stock-weighted hedonic HPIs. By contrast, the weighting variable has a much stronger influence on the corresponding house price *levels*. Due to the stronger representation of low-priced rural areas, house price levels obtained with stock weights tend to be lower than those obtained with transaction weights. For example, in Andalucía (Figure 3.4) and Galicia, house price levels estimated with stock weights are around 10-20% lower than

[21] Relying on transaction-weighted HPIs is relevant if the objective is to deflate the output of the intermediation services provided by real-estate agencies, or for measuring price changes of owner-occupied housing (OOH) services based on a net acquisition approach. Nevertheless, relying on stock-weighted HPIs is more relevant if the objective is to estimate real changes in the stock of residential housing (Eurostat et al., 2013, Diewert et al., 2017). The fact that most statistical agencies only release transaction-weighted HPIs may be related to two main reasons: (1) the fact that these indices only require to collect information on housing transactions, and (2) the idea that the use of one set of weights or the other only has little influence on house price developments in practice (see e.g. Diewert 2010). In the present paper, we show that the same does not hold for house price levels, at least in rural regions.

[22] Annex C provides an overview of the house price evolutions obtained with the 2011 and 2019 Censuses and confirms that they are indeed very close. A similar comparison of estimated house price levels in both cases is available upon request.

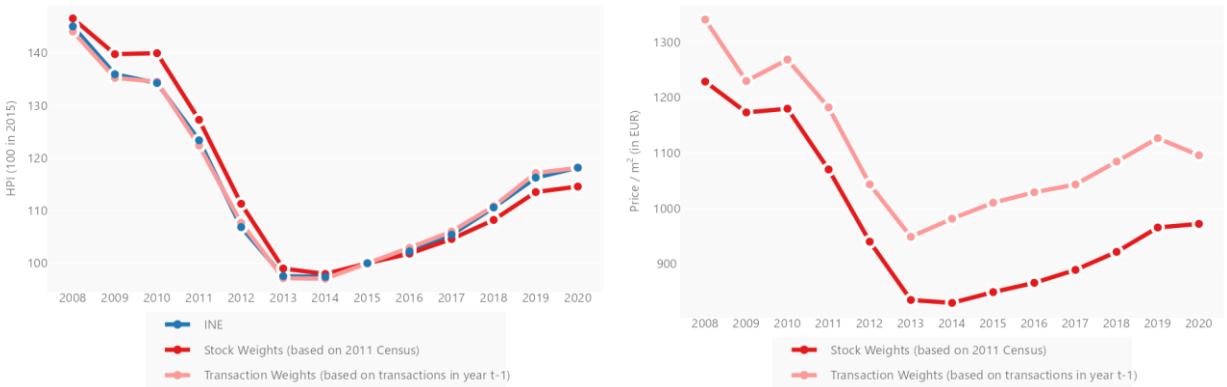
those estimated with transaction weights, whereas the two indices follow virtually the same evolutions. In line with Table 3.2, in regions like Cataluña and Madrid (Figure 3.5), using stock or transaction weights does not lead to significant differences in evolutions nor levels.

Table 3.2. Share of municipalities with the 30% lowest and 30% highest prices per m², in house transactions and the underlying stock of dwellings

	Stock Weights			Transacted Surface Weights	
Autonomous communities	**Bottom 30%**	**Top 30%**		**Bottom 30%**	**Top 30%**
Andalucía	11.11%	65.68%		6.29%	76.06%
Aragón	25.05%	47.53%		10.97%	61.28%
Asturias, Principado de	7.04%	64.97%		4.75%	74.26%
Balears, Illes	13.04%	56.59%		11.47%	58.81%
Canarias	12.54%	42.09%		7.45%	53.12%
Cantabria	15.49%	56.15%		10.67%	55.17%
Castilla - La Mancha	21.84%	42.12%		9.39%	61.48%
Castilla y León	18.87%	43.26%		7.10%	64.91%
Cataluña	11.54%	60.48%		8.97%	62.02%
Comunitat Valenciana	13.33%	58.58%		7.86%	67.17%
Extremadura	11.05%	42.55%		10.01%	58.68%
Galicia	16.91%	54.41%		6.42%	67.98%
Madrid, Comunidad de	5.06%	80.42%		4.10%	78.71%
Murcia, Región de	6.95%	74.27%		5.49%	79.20%
Navarra, Comunidad Foral de	34.45%	39.19%		26.16%	43.07%
País Vasco	8.48%	54.01%		7.44%	57.93%
Rioja, La	29.01%	45.18%		17.03%	55.14%

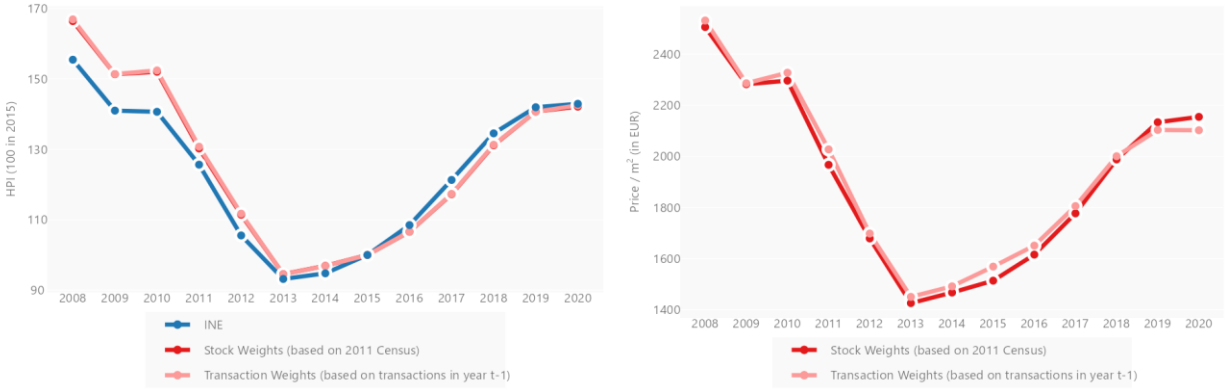
Source: INE (2011 Census), *Consejo General del Notariado* (CGN), authors' calculations. Transaction weights are averaged over 2008-2020.

Figure 3.4. Estimated house price evolutions and levels per m² in the autonomous community of Andalucía, with a stratification at municipality level, and either transaction or stock weights to aggregate strata



Source: INE (2011 Census), *Consejo General del Notariado* (CGN), authors' calculations.

Figure 3.5. Estimated house price evolutions and levels per m² in the autonomous community of Madrid, with a stratification at municipality level, and either transaction or stock weights to aggregate strata



Source: INE (2011 Census), *Consejo General del Notariado* (CGN), authors' calculations.

33. Apart from the weight variable used to aggregate strata, the type of price data can also have a substantial impact on the resulting estimated house price levels. Except in some countries, micro data on house transaction prices are confidential and therefore difficult to access for economists and researchers interested in the housing market. In this case, a possible strategy is to replace transaction prices with asking prices collected from real-estate websites. Granular information on asking prices can be retrieved with web-scraping techniques. Average prices for specific areas may also be directly available from real-estate websites.

34. When conducting analyses using asking prices, the following assumptions are often made, at least implicitly:

- The sample of advertisements collected on the web is representative of all transactions taking place in the market.
- For individual dwellings, either asking prices are close to final transaction prices, or the spread between the two is constant over time, so that relative prices across regions and house price evolutions can be meaningfully computed from asking prices. Note that if the spread is time-varying but with a synchronised evolution across regions, this will distort region-specific house price evolutions but not relative price evolutions across regions.

35. The availability of granular asking prices (from the real-estate website Idealista) and transaction prices (from the General Council of Notaries) allows us to assess the validity of these assumptions for Spain, and the risk users are taking when relying on asking instead of transaction prices to estimate regional house price levels.

36. It turns out that differences in house price level estimates based on asking and transaction prices are region specific, time-varying and potentially very large. These differences may be related to a selection bias when collecting asking prices on specific websites, a spread between asking and transaction prices for individual dwellings, or both.

37. Galesi et al. (2020[9]) have already documented the existence of a time-varying spread between asking and transaction prices for *individual* dwellings in Spain. The economic explanation for this phenomenon is as follows. When housing demand falls relative to supply, the bargaining power of buyers grows and transaction prices fall. Nevertheless, asking prices tend to incompletely reflect this dynamic for a number of

reasons. For example, advertisements on real-estate websites may be outdated, in which case asking prices reflect past market conditions, or sellers may be reluctant to accept a lower price than anticipated before the negotiation with a potential buyer starts (Genesove and Mayer, 2001[10]). As relative demand and supply for housing depend on economic conditions, the difference between asking and transaction prices varies along the business cycle.

38. For the following analysis, we estimate house price levels for all autonomous communities using stratification methods relying on transaction or asking prices. In both cases, strata correspond to municipalities[23] and the average price of dwellings in a stratum is calculated based on transactions or advertisements of both new and existing dwellings.[24] Strata are aggregated up to the autonomous community level using stock weights that are derived from the 2011 Census. While this strategy ensures that all municipalities receive the same weight in both cases, it cannot control for the fact that, within municipalities, asking prices collected from the Idealista website may not be fully representative of all transactions taking place in the market.

39. Table 3.3 shows differences between house price level estimates based on asking and transaction prices. These differences usually exceed the spreads that have been estimated by Galesi et al. (2020[9]) for individual dwellings, which may be related to the fact that the advertisements collected from the Idealista website are not always representative of all transactions taking place in the market. In 2008, house prices were at their peak. They reached their trough in 2013 and subsequently grew again until 2020. While transaction prices were slightly below asking prices in 2008, they fell much more strongly until 2013 and grew faster until 2020. Interestingly, in all but two autonomous communities, the price spread has – to date – not narrowed to the level of 2008, where it reached its lowest average value over the available sample.

40. As Figure 3.6 and Figure 3.7 show for the autonomous communities of Andalucía and Madrid, estimated house price levels can be very different depending on which data source is used. In these two regions, house price levels based on asking prices are between 5 and 45% higher than house price levels based on transaction prices. Similar discrepancies can be observed in most other regions. The two figures also show the importance of distinguishing new and existing dwellings within each municipality. Price estimates using transaction data obtained when weighting average prices for new and existing dwellings separately are substantially lower at the beginning of the sample, in relation to the lower share of new dwellings in the stock than in transactions, as previously discussed.

41. In conclusion, even though web-scraped asking prices can be considered attractive for their limited cost, unrestricted access and wide geographical coverage, relying on this

[23] The Idealista database actually provides information on asking prices at the district level, which is more granular than the municipality level. Nevertheless, we rely on a stratification at the municipality level in the following, for consistency with the CGN database on transaction prices. On average across regions, the stratification of asking prices at the municipality level leads to house price level estimates that are 0.3% higher than a stratification at the district level. Differences range from -7.2% in Aragon to +6.7% in Asturias.

[24] Since the Idealista database does not include a breakdown into new and existing dwellings, in Table 3.3 we consider all dwellings when analysing transaction prices. Only Figure 3.6 and Figure 3.7 include results when considering either all dwellings together, or distinguishing new and existing dwellings and using their respective weights in the stock, given by Ministerio de Fomento (see Footnote 10 and: www.mitma.gob.es/informacion-para-el-ciudadano/informacion-estadistica/vivienda-y-actuaciones-urbanas/estadisticas/stock-de-vivienda-nueva/estadisticas-sobre-stock-de-vivienda-nueva).

source of information to estimate regional house price levels may lead to significantly different results than when relying on transaction prices. Since these discrepancies are region-specific, they do not only affect absolute price levels, but also relative house price levels across regions.[25] Unless a reliable method can be devised to correct for the difference between asking and transaction prices, transaction prices should be preferred to assess housing affordability across regions. Admittedly, monitoring the discrepancy between asking and transaction prices may be of interest as well, e.g. to anticipate turning points in the housing market, but this is beyond the scope of this paper and we leave it as an avenue for further research.

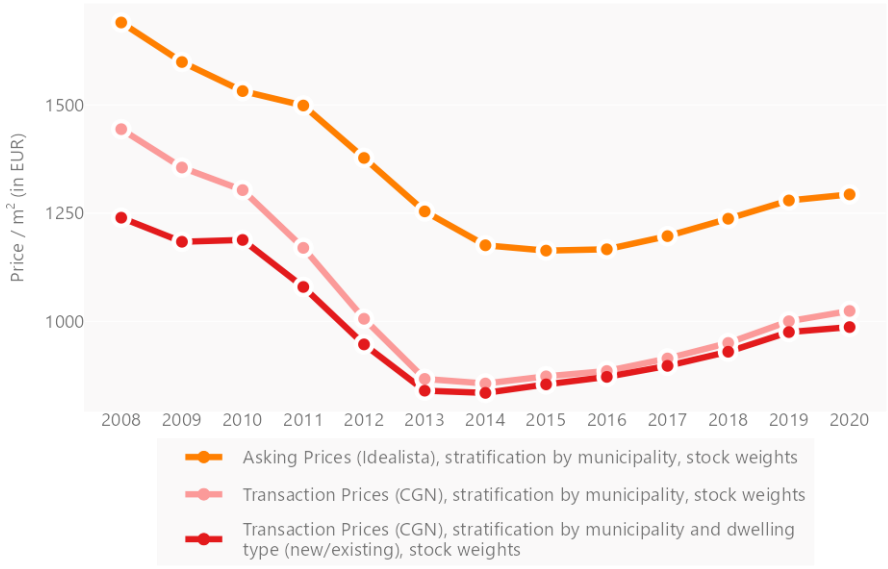
Table 3.3. Percentage difference between estimated house price levels per m² based on asking and transaction prices

Autonomous communities	2008		2013		2020
Andalucía	17.06%		44.64%		26.64%
Aragón	17.62%		47.13%		28.90%
Asturias, Principado de	7.31%		47.44%		27.84%
Balears, Illes	10.10%		39.95%		36.64%
Canarias	1.85%		29.56%		17.16%
Cantabria	-0.83%		35.66%		20.34%
Castilla - La Mancha	18.51%		56.65%		35.47%
Castilla y León	27.99%		66.53%		44.58%
Cataluña	2.41%		50.04%		17.31%
Comunitat Valenciana	1.35%		47.31%		24.17%
Extremadura	60.97%		73.04%		57.64%
Galicia	15.63%		49.45%		31.70%
Madrid, Comunidad de	3.95%		46.80%		24.20%
Murcia, Región de	-5.57%		41.53%		22.38%
Navarra, Comunidad Foral de	5.25%		23.39%		9.47%
País Vasco	5.34%		31.64%		10.65%
Rioja, La	-5.76%		45.02%		37.83%

Source: *Consejo General del Notariado* (CGN), Idealista, authors' calculations. Positive values mean that asking prices are higher than transaction prices.

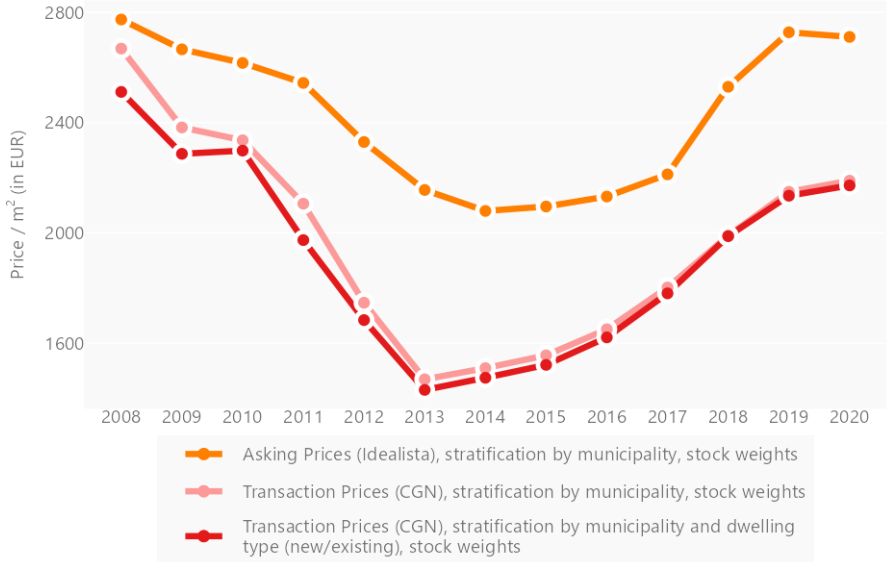
[25] For example, relative house prices between the autonomous communities of Cataluña and Madrid decreased by 9% between 2008 and 2013 according to transaction prices, whereas they decreased by 5.7% over the same period when using asking prices. This is because the spreads between asking and transaction prices evolved in different ways in these two regions (see Table 3.3).

Figure 3.6. Estimated house price levels per m² in Andalucía, based on asking or transaction prices



Source: *Consejo General del Notariado* (CGN), Idealista, authors' calculations.

Figure 3.7. Estimated house price levels per m² in Madrid, based on asking or transaction prices



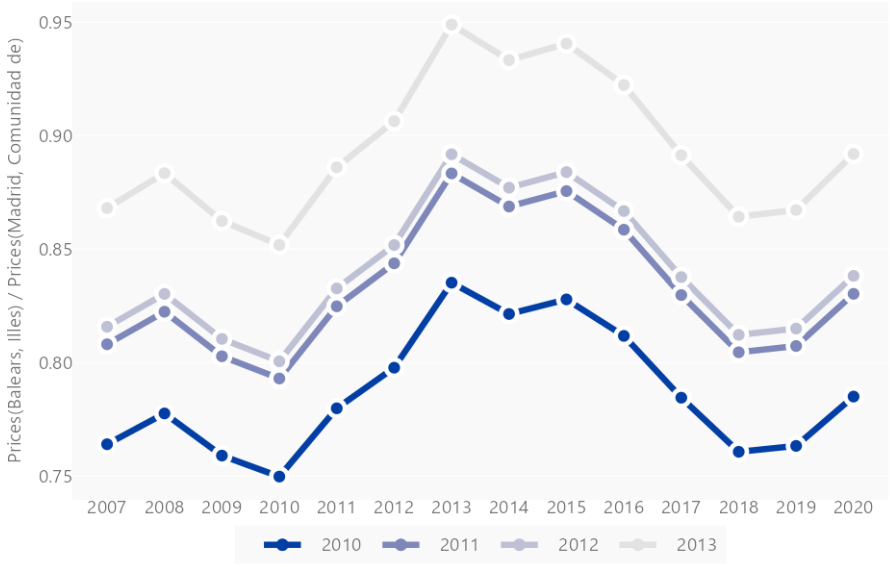
Source: *Consejo General del Notariado* (CGN), Idealista, authors' calculations.

4. Estimating house price levels that are consistent with quality-adjusted HPIs

42. A simple and intuitive way for statistical agencies to release information on house price levels based on their existing data sources and HPIs would be to calculate average transaction prices at a given point in time and backcast/extrapolate this information based on the evolutions given by the HPI for the corresponding geographical area. The Office for National Statistics (ONS) in the United Kingdom applies this method to publish average house prices at the national and regional levels. The ONS acknowledges that the prices estimated with this method are sensitive to the reference year in which prices are measured.[26] This is because the prices observed at different points in time do not correspond to the same dwellings, hence inducing possible differences in quality in addition to differences in prices. Moreover, the size of revisions when switching from one reference year to another may be different across regions, meaning that relative price levels across regions may also be revised. Since the quality of transacted dwellings typically changes over the business cycle, the size of revisions may also depend on the relative position in the business cycle of the reference years used for the calculation of house price levels.

43. We illustrate this pattern using Spanish data. Figure 4.1 plots relative prices per m^2 in the Balearic Islands relative to Madrid under different reference years. For each reference year, the house price level is backcast and extrapolated using official HPIs for existing dwellings. This example shows that even close reference years can lead to very different conclusions about absolute and relative prices across regions. While house price levels estimated with 2010 as reference year suggest that prices in the Balearic Islands were 24% lower than those in Madrid in 2008, the series obtained with 2011 as reference year suggests that the difference was only 19%, and with 2013 as reference year, the difference falls to 13%.

Figure 4.1. House price levels per m^2 in the Balearic Islands relative to Madrid, depending on the reference year



26 www.gov.uk/government/publications/about-the-uk-house-price-index/quality-and-methodology.

Source: INE, *Consejo General del Notariado* (CGN), authors' calculations.

44. We now propose an alternative method that does not rely on an arbitrary reference year to obtain house price level estimates. The core idea of this method is to treat the true house price level as an unobserved variable in a state space model. The model imposes that this variable has exactly the same evolution as the corresponding regional HPI provided by the statistical agency. Therefore, the main purpose of the model is to determine a reference house price level in each region. It also assumes that estimated house price levels obtained by stratification are noisy estimates of the true but unobserved house price levels. This approach is close in spirit to the one proposed by Rao, Rambaldi and Doran (2010[11]) to estimate PPP time series based on a few observed benchmark PPPs (here playing the same role as our noisy house price level estimates) and GDP deflators (here playing the same role as HPIs).

45. The model is composed of a measurement equation and two state equations describing the evolution of the underlying house price level and of the measurement error.

Measurement equation

$$\log P_t^A = \log \alpha_t + \epsilon_t \quad (3)$$

46. P_t^A is the house price level in region A that is estimated using the best possible stratification method. α_t is the true but unobserved house price level, and ϵ_t captures the estimation error (e.g. due to quality effects that we do not control for with a stratification method).

State equations

$$\begin{cases} \log \alpha_t = \log \alpha_{t-1} + \Delta \log(HPI_t^A) \\ \epsilon_t = \sum_{i=1}^{p} \phi_i \epsilon_{t-i} + \eta_t \end{cases} \quad (4)$$

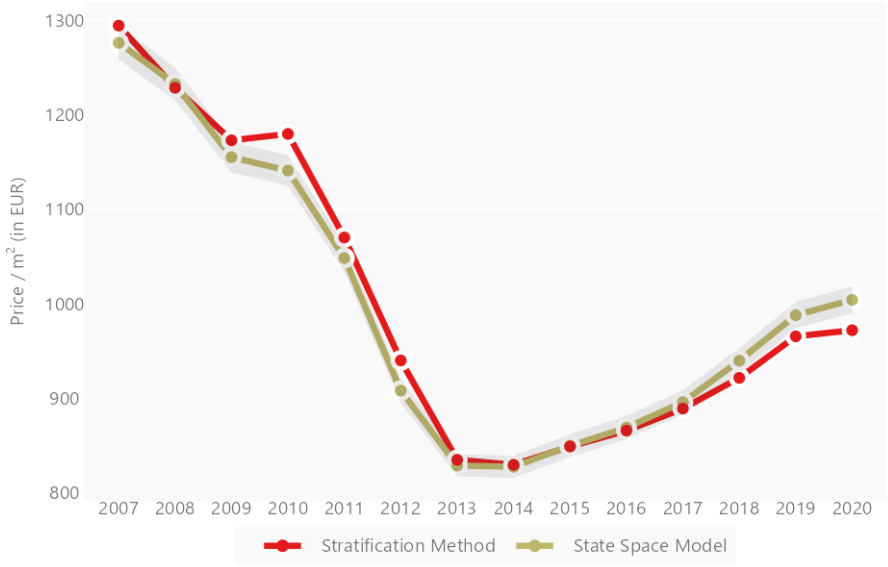
47. The choice of the relevant HPI in the first state equation deserves some discussion. Ideally, one should use a stock-weighted HPI covering all types of dwellings in the region. Since in practice most statistical agencies, including INE, compile transaction-weighted HPIs, we will rely on transaction-weighted HPIs for existing dwellings in this paper. Doing so puts a zero weight on new dwellings, which is a reasonable assumption given their marginal share in the stock of dwellings (see footnote 9) and avoids relying on the much higher share of new dwellings in transactions (see Figure 3.1). Moreover, the previous sensitivity analysis has shown that transaction-weighted HPIs usually provide a good approximation of stock-weighted HPIs for existing dwellings. Accordingly, the first-stage house price level estimates that are used in the measurement equation (P_t^A) only correspond to existing dwellings.

48. The estimation error ϵ_t in the second state equation is modelled as an autocorrelated *AR(p)* process because unobserved quality effects are likely to be persistent over time. The corresponding autocorrelation coefficients, as well as the variance of the Gaussian process η_t, can be estimated by maximum likelihood. Based on these parameter estimates, the underlying house price level α_t and the corresponding confidence interval can finally be estimated with a Kalman smoother. We test the performance of different lag lengths p and choose the specification that performs best for each region separately. For a detailed account of the criteria applied for model selection and statistical diagnostic tests for each regional model, we refer to Annex A.

49. Figure 4.2 and Figure 4.3 compare the previous stratification-based estimates using municipalities as strata and stock weights to aggregate strata with the estimates provided

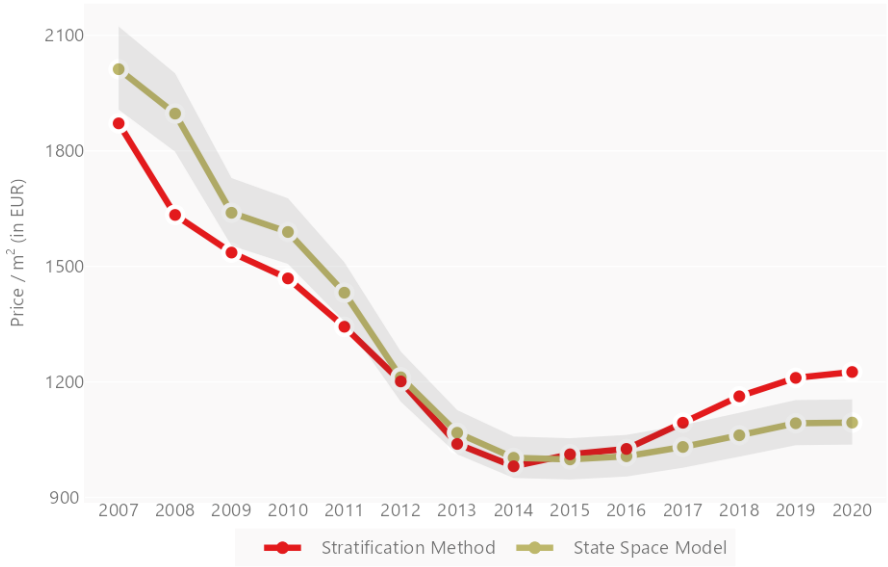
by the state-space models for Andalucía and Navarra. Since geographical stratification already allows replicating the HPI evolutions very accurately for Andalucía (see Figure 3.2), the estimates provided by the two methods are very close to each other and the confidence interval around the state-space model estimate is very narrow. By contrast, Navarra is a region for which stratification substantially underestimates the decrease in prices in the years following the global financial crisis of 2008-09. In this case, correcting for the measurement error is much more important than for Andalucía. The first-stage (stratification-based) estimate is well below (roughly 15% below) the house price level estimated by the state-space model at the beginning of the sample. The gap then becomes very narrow around 2012-2016 and widens again from 2017 onwards.

Figure 4.2. Estimated house price levels in Andalucía provided by the stratification at the municipality level and by the state-space model



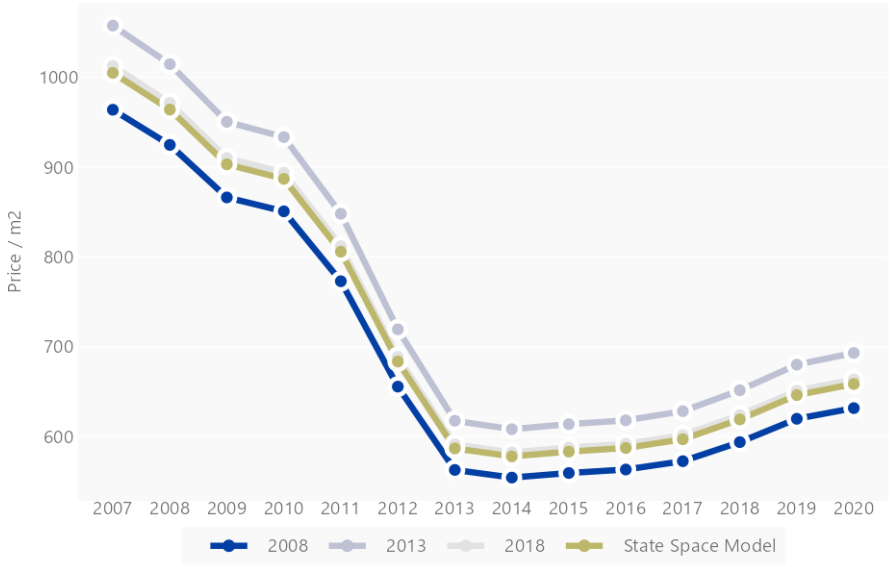
Note: The shaded areas correspond to the 95% confidence intervals around the state-space model estimates.
Source: INE, *Consejo General del Notariado* (CGN), authors' calculations.

Figure 4.3. Estimated house price levels in Navarra provided by the stratification at the municipality level and by the state-space model



Note: The shaded areas correspond to the 95% confidence intervals around the state-space model estimates.
Source: INE, *Consejo General del Notariado* (CGN), authors' calculations.

Figure 4.4. Estimated house price level for Castilla y León: State-space model and extrapolated prices with three different reference years



Source: INE, *Consejo General del Notariado* (CGN), authors' calculations.

50. In addition to fully aligning house price levels with the evolutions given by the corresponding HPIs, the second benefit of the state-space model is to take advantage of the stratification-based estimates for all years rather than only for an arbitrary reference year. Intuitively, the model provides a weighted average of extrapolated house price levels obtained for all possible reference years. This is what Figure 4.4 shows for the autonomous community of Castilla y León. The state-space model estimates lie within estimates obtained with single reference years.[27]

51. Assuming that the estimation of model parameters and the Kalman smoother recursions already rely on a sizeable sample, additional data points will not lead to substantial revisions of estimated house price levels over the past. This is in contrast with what happens when estimated house price levels are based on a single reference year. Table 4.1 compares average annual revisions of estimated house price levels in two cases: with the state-space model, and when these estimates rely on a single reference year that is updated every year (backcasting/extrapolation method). The comparison is made over 2008-2013, a period where quality effects have been shown to play a large role. The revisions obtained with the state-space model are (with one exception) one or two orders of magnitude smaller than those obtained with the backcasting/extrapolation method.

[27] In the case of Spain, it turns out that the results of the regional state-space models are very close to geometric averages of extrapolated time series based on HPI evolutions and all possible reference years, with all time series receiving equal weight. It is only for Comunitat Valenciana (3.3%), Extremadura (3.1%), Cantabria (2%), Asturias (1.2%) and Balearic Islands (1.1%) that the difference is larger than 1%. The difference is also constant over time in all cases.

Table 4.1. Average (root mean squared) revision in price level estimates over the sample due to a reference year update (backcasting/extrapolation method) or the addition of an additional year of data (state-space model) over 2008-2013

Autonomous communities	Backcasting/Extrapolation Method		State-Space Model
Andalucía	1.815%		0.030%
Aragón	3.167%		0.390%
Asturias, Principado de	4.051%		0.294%
Balears, Illes	1.925%		0.191%
Canarias	1.420%		0.198%
Cantabria	1.539%		0.236%
Castilla - La Mancha	1.614%		0.033%
Castilla y León	2.693%		0.124%
Cataluña	2.213%		0.047%
Comunitat Valenciana	2.514%		1.286%
Extremadura	3.086%		0.081%
Galicia	3.055%		0.214%
Madrid, Comunidad de	2.155%		0.055%
Murcia, Región de	1.979%		0.007%
Navarra, Comunidad Foral de	3.839%		0.077%
País Vasco	2.510%		0.147%
Rioja, La	5.923%		0.018%

Note: For all regions, 2008-2013 data are first discarded and house price levels are estimated over 2014-2020. The experiment then runs backwards in time in order to capture the effect of adding the post-financial crisis data to the sample. This is the time where the most significant price and quality changes take place, hence leading to the largest potential revisions. When 2013 data are added to the sample, the reference year for the backcasting/extrapolation method is updated from 2014 to 2013 and average (root mean squared) percentage revisions in house price levels over 2014-2020 are calculated. Similarly for the state-space model, the model parameters are re-estimated and the Kalman smoother is re-run with 2013 data added to the sample. The process is then iterated by progressively adding data for the years 2012 to 2008 to the sample. Table 5 reports average revisions across all steps.
Note that a re-estimation of the state-space model after a data update results in uniform shifts of the estimated price levels across all time periods compared to the estimates without the additional data. Hence relative (%) revisions using the state-space model are of the same size if one considers house price level estimates for the latest available date or the entire past.
The experiment only had to be adjusted for the Canarias because the estimation of the state-space model parameters at least needs data over 2012-2020 to converge. In this case, average revisions are calculated by progressively adding data for the years 2011 to 2008 to the sample.
Source: authors' calculations.

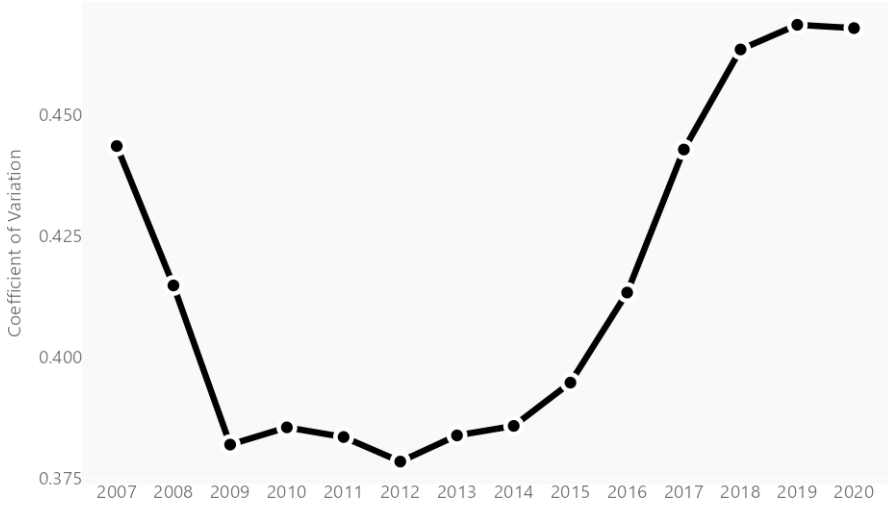
5. Analysis of the results

52. We now turn to the analysis of regional house price levels in Spain, building on the results provided by the regional state-space models. We start by assessing the degree of heterogeneity in regional house price levels and its development over time, before assessing housing affordability across Spanish regions.

53. In most Spanish regions, house prices peaked in 2008, reached their trough in 2013 and then started to increase again, but usually without reaching their 2008 peak. Nevertheless, not all regions were hit equally hard by the decline in house prices after 2008. The recovery of the housing market after 2013 was also heterogeneous across regions. These patterns can be documented using the quality-adjusted HPIs compiled by INE (see Figure 1.1).

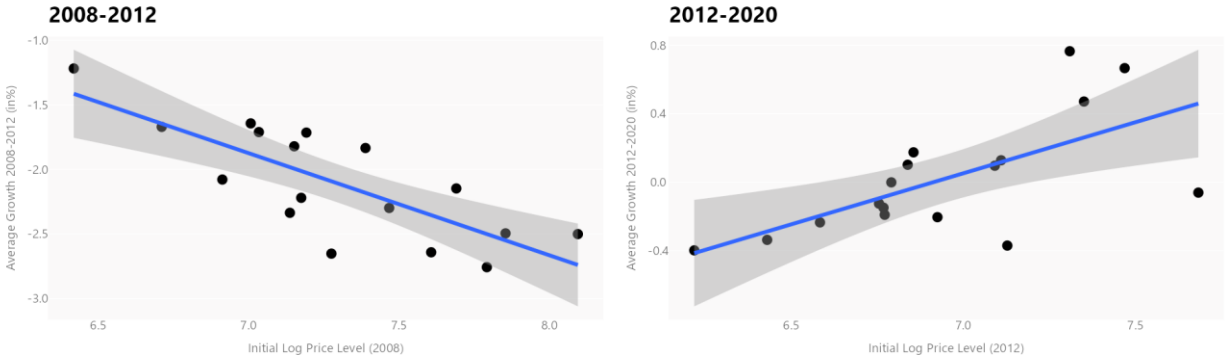
54. In addition, regional house price levels can help understand whether regional housing markets in Spain became more similar or diverged in the wake of the global financial crisis. Figure 5.1 shows the evolution of the coefficient of variation[28] of regional house price levels in Spain between 2008 and 2020. The decline in house prices following the financial crisis initially reduced the dispersion in house prices across regions, but this dispersion started to increase again after 2012, exceeding after 2016 the dispersion that was recorded in 2008.

Figure 5.1. Coefficient of variation of house price levels per m² across Spanish regions, 2008-2020



Source: authors' calculations.

Figure 5.2. Relationship between the initial house price level and the subsequent house price growth across Spanish regions, 2008-2012 and 2012-2020



Note: The blue lines are linear regression lines and the shaded areas are the corresponding 95% confidence intervals.
Source: authors' calculations.

[28] For each year, the coefficient of variation is calculated as the ratio of the standard deviation to the mean of regional house price levels per m².

55. The decline in the heterogeneity of regional house price levels between 2008 and 2012 suggests that regions with higher price levels in 2008 saw stronger price declines than those with lower initial price levels. By combining information on house price levels and evolutions, we can further illustrate this convergence process between 2008 and 2012, and the subsequent divergence process between 2012 and 2020. Figure 5.2 shows how regional house price growth over these two sub-periods is related to regional house price levels in 2008 and 2012, respectively. The left panel confirms that there is a negative relation between a region's price level in 2008 and its average house price growth between 2008 and 2012. By contrast, the right panel shows a positive relation between a region's price level in 2012 and its average house price growth between 2012 and 2020, thus pointing to a divergence process at work.

56. Another advantage of house price levels over house price indices is that they can be directly related to regional household income statistics, thus allowing to assess housing affordability and potential barriers to labour mobility.[29]

57. We assess housing affordability by calculating the number of years of average regional household income that are necessary to purchase a dwelling of 100 m² in each region.[30]

58. Figure 5.3 shows the evolution of this indicator across Spanish regions between 2008 and 2020. Two main conclusions can be drawn from this chart. First, housing affordability improved in most regions in the years following the financial crisis, and either stabilised or started to deteriorate again (e.g. in Madrid) after 2013. Nevertheless, dwellings are slightly more affordable in 2020 than in 2008 in all Spanish regions. The second conclusion is related to the heterogeneity in housing affordability across Spanish regions. For example, it took under 3 years of average household income in 2008 to purchase a 100m^2 dwelling in Extremadura, compared to more than 8 years in País Vasco, and a similar heterogeneity can be observed in all years. In other words, regional differences in household income do not fully compensate for differences in house prices.[31]

59. In Figure 5.4, we zoom in on the recovery period to assess how housing affordability in the rest of the country developed relative to the capital region of Madrid. The general pattern is clear. Relative to Madrid, housing affordability has improved in all regions between 2013 and 2020. In most regions, relative housing affordability compared to Madrid improved by 20 to 30%, but Cataluña stands out with an improvement of less than 10%. These numbers show how expensive housing has become for residents in the region of Madrid relative to the rest of the country. However, the deterioration in housing affordability in Madrid seems to have come to a halt in 2018. It remains to be seen whether

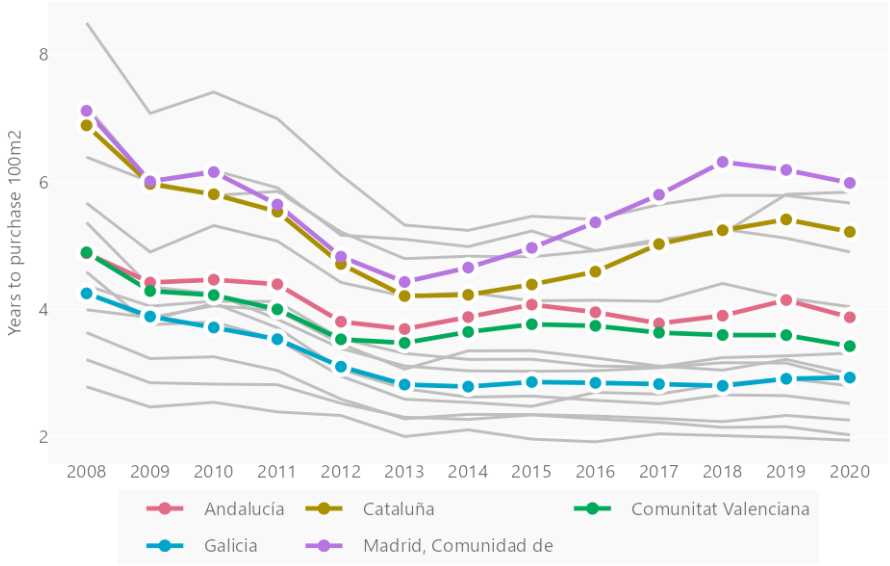
[29] Other definitions of housing affordability could be used. For example, Gan and Hill (2009[13]) distinguish between purchasing affordability, defined as the ability to borrow enough funds to purchase a dwelling, repayment affordability, defined as the ability to repay the mortgage, and income affordability. Here, we use the concept of income affordability.

[30] Regional income statistics are sourced from INE's Living Conditions Survey. The sample runs from 2008 to 2020.

[31] Alternatively, and Figure 5.4 could be done based on average regional income per person (also available from INE's Living Conditions Survey) instead of average regional income per household. When relying on income per person, the number of years to purchase a dwelling of 100m² is scaled up by region-specific factors comprised between 2 and 3. Nevertheless, the region of Madrid still stands out as the region with the largest increase in the number of years to purchase a dwelling since the mid-2010s, and the ranking of house price levels between the five most populated regions in Spain (Madrid, Cataluña, Andalucía, Comunitat Valenciana, and Galicia) remains unchanged.

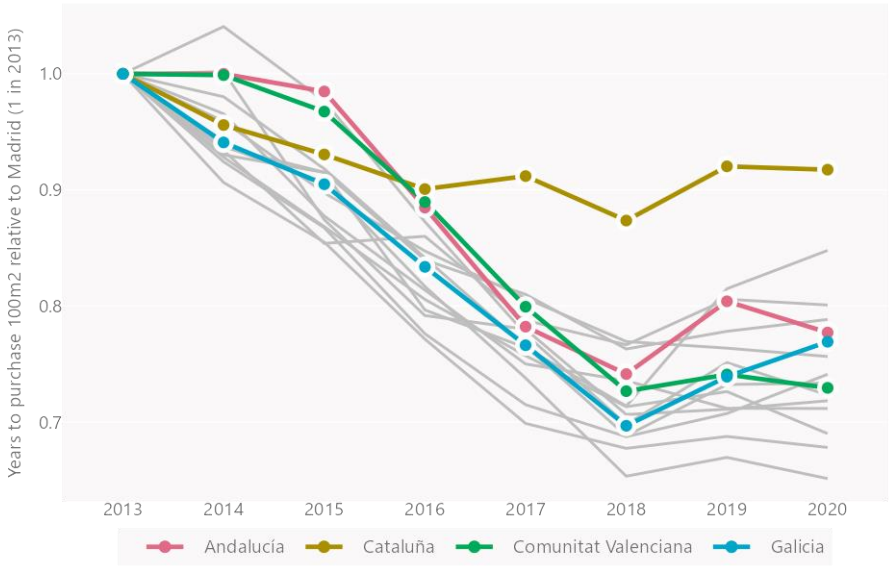
teleworking opportunities and the demand for larger living spaces outside of city centres following the COVID-19 pandemic will affect regional housing affordability.

Figure 5.3. Years of average regional household income necessary to purchase a dwelling of 100 m²



Note: The highlighted regions are the five most populated regions in Spain.
Source: INE (Living Conditions Survey), authors' calculations.

Figure 5.4. Years of average regional household income necessary to purchase a dwelling of 100 m² in each region relative to the autonomous community of Madrid (2013 = 1)



Note: The highlighted regions are the four most populated regions in Spain excluding Madrid.
Source: INE (Living Conditions Survey), authors' calculations.

6. Conclusion

60. This article has discussed the relevance of regional statistics on house price levels to assess housing affordability and potential barriers to labour mobility. Following the publication of international guidelines in this area in 2013, official statistical agencies now regularly compile quality-adjusted house price indices (HPIs) at national level and an increasing number of them have started to compile similar indices at regional level. Nevertheless, they do not provide national or regional statistics on house price levels.

61. In the absence of official statistics on house price levels, other government agencies or private data providers may fill this gap but, without coordination, the resulting statistics are unlikely to be consistent with the HPIs produced by official statistical agencies using different methods and data sources. These agencies have a key role to play to ensure coordination in this area.[32]

62. This article has put forward a method to compile regional house price levels that are representative of the underlying stock of dwellings, consistent with the evolutions given by quality-adjusted house price indices, and based on the information on house price levels that is available at all dates rather than in a single reference year. Hopefully, this will contribute to the development of such statistics at the international level because the proposed method is scalable to different countries.

63. For the compilation of regional house price levels in Spain, this article has relied on the same transaction prices that are used by INE for the compilation of HPIs and which also appear as a natural choice for assessing housing affordability. In countries where appraisals are used for the compilation of HPIs, they should probably be used for the compilation of house price levels as well. Nevertheless, even though web-scraped asking prices can be considered attractive for their limited cost, unrestricted access and wide geographical coverage, this article has shown that relying on this source of information to estimate regional house price levels may lead to significantly different results than when relying on transaction prices. Therefore, we think that priority should be given to the estimation of house price levels based on transaction prices (or appraisals if they are used to compile HPIs). Admittedly, asking prices may provide additional important insights on housing market developments. For example, changes in the gap between asking and transaction prices may signal turning points in housing markets, but we leave this as an avenue for further research.

[32] Note that the coexistence of conflicting statistics on house price developments is a situation that typically happened before official statistical agencies started to produce quality-adjusted HPIs themselves, or to coordinate the work of other relevant government agencies in this area. In the United Kingdom for example, inconsistencies between the HPIs previously published by the Office for National Statistics (ONS), the UK Land Registry, and the Land and Property Services Northern Ireland (LPSNI) led to the 2010 National Statistician's Review of House Price Statistics and the development and publication of a single official HPI from 2015 onwards.

References

Blanchard, O. et al. (1992), "Regional Evolutions", *Brookings Papers on Economic Activity*, Vol. 1992/1, p. 1, http://dx.doi.org/10.2307/2534556. [4]

Dao, M., D. Furceri and P. Loungani (2014), "Regional Labor Market Adjustments in the United States and Europe", *IMF Working Papers*, Vol. 14/26, p. 1, http://dx.doi.org/10.5089/9781475598476.001. [6]

Diewert, W. (2010), "Alternative approaches to measuring house price inflation", *Discussion Paper 10-10, Department of Economics, The University of British Columbia, Vancouver, Canada, V6T 1Z1, 2010*. [8]

Diewert, W. (2009), "The Paris OECD-IMF workshop on real estate price indexes: conclusions and future directions", *Price and productivity measurement*, Vol. 1, pp. 87-116. [15]

Diewert, W., J. Haan and R. Hendriks (2014), "Hedonic Regressions and the Decomposition of a House Price Index into Land and Structure Components", *Econometric Reviews*, Vol. 34/1-2, pp. 106-126, http://dx.doi.org/10.1080/07474938.2014.944791. [14]

Diewert, W., N. Huang and K. Burnett-Isaacs (n.d.), "Alternative Approaches to Measuring Resale Housing Price Indexes", *Discussion Paper 17-05, Vancouver School of Economics*. [16]

Durbin, J. and S. Koopman (2012), *Time Series Analysis by State Space Methods*, Oxford University Press, http://dx.doi.org/10.1093/acprof:oso/9780199641178.001.0001. [17]

Galesi, A. et al. (2020), *Regional Housing Market Conditions in Spain*, University of Maastricht, http://dx.doi.org/10.26481/umagsb.2020029. [9]

Ganong, P. and D. Shoag (2017), "Why has regional income convergence in the U.S. declined?", *Journal of Urban Economics*, Vol. 102, pp. 76-90, http://dx.doi.org/10.1016/j.jue.2017.07.002. [5]

Gan, Q. and R. Hill (2009), "Measuring housing affordability: Looking beyond the median", *Journal of Housing Economics*, Vol. 18/2, pp. 115-125, http://dx.doi.org/10.1016/j.jhe.2009.04.003. [13]

Genesove, D. and C. Mayer (2001), "Loss Aversion and Seller Behavior: Evidence from the Housing Market", *The Quarterly Journal of Economics*, Vol. 116/4, pp. 1233-1260, http://dx.doi.org/10.1162/003355301753265561. [10]

Glaeser, E. (2020), "Urbanization and Its Discontents", *Eastern Economic Journal*, Vol. 46/2, pp. 191-218, http://dx.doi.org/10.1057/s41302-020-00167-3. [1]

Hill, R. (2011), "Hedonic Price Indexes for Housing", *OECD Statistics Working Papers*, No. 2011/1, OECD Publishing, Paris, https://dx.doi.org/10.1787/5kghzxpt6g6f-en. [18]

Liu, L. (2018), "Regional Labor Mobility in Spain", *IMF Working Papers*, Vol. 18/282, p. 1, http://dx.doi.org/10.5089/9781484387764.001. [7]

OECD (2021), *Brick by Brick: Building Better Housing Policies*, OECD Publishing, Paris, https://dx.doi.org/10.1787/b453b043-en. [2]

OECD (2019), *OECD Regional Outlook 2019: Leveraging Megatrends for Cities and Rural Areas*, OECD Publishing, Paris, https://dx.doi.org/10.1787/9789264312838-en. [3]

OECD et al. (2013), *Handbook on Residential Property Price Indices*, Eurostat, Luxembourg, https://dx.doi.org/10.1787/9789264197183-en. [12]

Rao, D., A. Rambaldi and H. Doran (2010), "Extrapolation of purchasing power parities using multiple benchmarks and auxiliary information: a new approach", *Review of Income and Wealth*, Vol. 56, pp. S59-S98, http://dx.doi.org/10.1111/j.1475-4991.2010.00386.x. [11]

Annex A. Data and methods

Data Sources

Consejo General del Notariado (CGN)

- Geometric averages of transaction prices by municipality. Within municipalities, average transaction prices are available for new and existing dwelling together and separately. New dwellings are defined as dwellings that have never been transacted before the recorded transaction.
- Average floor space broken down by municipality and dwelling type (new or existing) within municipalities
- Total number of transactions broken down by municipality and dwelling type
- All municipality and dwelling type pairs (e.g. existing dwellings in a given municipality) with less than three transactions in a given period are grouped together at the province level.
- Quarterly frequency, 2007Q1-2020Q4

Idealista

- Average asking prices by district, not broken down by dwelling type
- Number of advertisements per district
- Monthly frequency, 2006M1-2020M9

Instituto Nacional de Estadística (INE)

- Quality-adjusted HPIs for all autonomous communities, for new and existing dwellings separately and grouped together, quarterly frequency, 2007Q1-2021Q1
- Census data on total floor space of all dwellings at Census section level, 2001, 2011 and 2019 vintages

Ministerio de Fomento

- Regional house price levels, quarterly frequency, 1995Q1-2021Q1[33]
- Share of new dwellings in the total stock of dwellings, by Autonomous community

[33] The methodology followed by Ministerio de Fomento for the compilation of regional house price levels is available at: www.mitma.gob.es/recursos_mfom/pdf/B0E2BE62-28EF-41A8-B9D4-CCBD92A28643/144522/MetodValorVivienda.pdf. The corresponding data can be accessed at: www.fomento.gob.es/BE2/?nivel=2&orden=35000000 (Valor tasado de vivienda libre).

Imputation of missing data on housing transactions

At the most granular level, missing observations are very common in the database on transaction prices that is used for this research. For example, small municipalities may not record transactions every quarter and there may be quarters without any transaction. The confidentiality threshold of at least three transactions per observational unit (e.g. existing dwellings in a given municipality) at each date further increases the amount of missing observations at the municipality level. The fact that the corresponding transactions are grouped together at the upper (i.e. province) level preserves some of the information but we do not know whether observations at the lower level are missing because there were no transactions at this level or because the number of transactions was below the confidentiality threshold. In other words, we do not know which municipalities have been grouped together at the province level.

A missing observation in the 4th quarter of a given year is especially problematic because 4th quarters are used as reference periods for the compilation of house price indices. Therefore, missing data in a 4th quarter prevents using data for the corresponding observational unit in all quarters of the following year even if there is data for these quarters.

In order to minimise the impact of missing observations without systematically imputing missing observations that have already been grouped together at the upper level, in practice we only impute missing data if they pertain to a 4th quarter of a given year. These 4th quarter imputations are only used for the calculation of house price indices in the following year.

For each observational unit, missing transaction prices in a 4th quarter are imputed by linear interpolation between the closest dates for which data are available. For the compilation of transaction-weighted house price indices, the transacted surface of dwellings is also imputed based linear interpolations.

Calculation of transaction and stock weights

For the compilation of transaction-weighted house price indices, weights are constructed based on the previous year's transacted surface of dwellings. When municipalities are grouped together at the province level for confidentiality reasons, the corresponding surface of transacted dwellings is observed.

For the compilation of stock weights, we rely on the information on the number and average surface of dwellings at the section level from the Census and use it to compile the total dwelling floor space for all municipalities in Spain. When municipalities are grouped together at the province level for confidentiality reasons, the corresponding floor space in the stock of dwellings is calculated as the difference between the floor space at province level and the floor space of observed municipalities. The Census does not include breakdowns by dwelling age, but *Ministerio de Fomento* provides additional information on the share of new dwellings in the stock of dwellings of each autonomous community in Spain. In order to calculate stock weights that are relevant for existing dwellings, the information from the Census is combined with the one from *Ministerio de Fomento*, assuming that the share of new dwellings is the same in all municipalities of a given autonomous community. In practice, removing new dwellings only leads to marginal adjustments as compared to stock weights that would only be based on the Census.

Additional information on the state-space models

We estimate region-specific state-space models for all Spanish regions (autonomous communities). For region *A*, the measurement and state equations are as follows:

Measurement equation

$$\log P_t^A = \log \alpha_t + \epsilon_t$$

P_t^A is the house price level in region *A* that is estimated using the best possible stratification method. α_t is the true but unobserved house price level that we want to estimate, and ϵ_t captures the estimation error (e.g. due to quality effects that we do not control for with a stratification method).

State equations

$$\begin{cases} \log \alpha_t = \log \alpha_{t-1} + \Delta \log(HPI_t^A) \\ \epsilon_t = \sum_{i=1}^{p} \phi_i \epsilon_{t-i} + \eta_t \end{cases}$$

The first state equation imposes that the true but unobserved house price level for region *A* has exactly the same evolution as the quality-adjusted house price index for this region. The second state equation specifies the dynamics of the discrepancy between the stratified house price level ($\log P_t^A$) and the unobserved house price level (α_t). In the paper, this discrepancy (or measurement error) is assumed to follow an *AR(p)* process. η_t is a centred Gaussian process with variance σ_η^2.

In the simple case where the measurement error is an *AR(1)*, and using the same notations as Durbin and Koopman (2012), the model can be written in matrix form as follows:

Measurement equation

$$\log P_t^A = \underbrace{(1 \quad 1)}_{Z} \begin{pmatrix} \log \alpha_t \\ \epsilon_t \end{pmatrix}$$

State equations

$$\begin{pmatrix} \log \alpha_{t+1} \\ \epsilon_{t+1} \end{pmatrix} = \underbrace{\begin{pmatrix} 1 & 0 \\ 0 & \phi_1 \end{pmatrix}}_{T} \begin{pmatrix} \log \alpha_t \\ \epsilon_t \end{pmatrix} + \begin{pmatrix} \Delta \log(HPI_{t+1}^A) \\ 0 \end{pmatrix} + \underbrace{\begin{pmatrix} 0 \\ 1 \end{pmatrix}}_{R} \eta_{t+1}$$

The only measurement error in the model (ϵ_t) is included in the state vector. Hence, using Durbin and Koopman's (2012) notations, we can set H equal to 0 in the measurement equation (not reported above).

The only minor specificity of this model is that the first state equation includes an exogenous variable and no stochastic driving process (hence $R(1) = 0$). Compared to the standard textbook model (Chapter 4 in Durbin and Koopman 2012), the presence of the exogenous variable only implies a small change in the Kalman equation to update the expectation of the state vector, as follows:

$$a_{t+1} = T a_t + \underbrace{X_{t+1}}_{\substack{\text{Exogenous variable} \\ \begin{pmatrix} \Delta \log(\text{HPI}_{t+1}^{\text{A}}) \\ 0 \end{pmatrix} \text{ in our case}}} + K_t v_t$$

Due to the specification of the first state equation, we rely on a diffuse initialisation of the Kalman filter and smoother.

In practice, we use the STATA command *sspace* [34] to estimate the two hyperparameters of the model (ϕ_1 and σ_η) by maximum likelihood and to run the Kalman filter and smoother.

Model selection and specification checks for the regional state-space models

As stated above, the state-space model parameters are estimated by maximum likelihood, using quarterly time series of stratified house price levels and HPIs. Each model is estimated with up to three autocorrelation parameters. The best autocorrelation structure is selected based on statistical diagnostic tests on the standardised residuals of the measurement equation (Durbin and Koopman, 2012), information criteria (AIC, BIC) and likelihood ratio tests to assess whether estimated autocorrelation parameters are significantly different from zero. The corresponding results are presented in Table A.1 and Figure A.2.

For 12 regions out of 17, information criteria are in agreement with each other and with likelihood ratio tests, and the statistical tests on the standardised residuals confirm the validity of the chosen specification. Information criteria and tests on standardised residuals give conflicting results for Andalucía, Castilla – La Mancha, Castilla y León, Galicia and La Rioja. The respective specification is selected for Andalucía, Castilla – La Mancha and Castilla y León because diagnostic tests on standardised residuals favour one specification over the other. The *AR(1)* specification is selected for Galicia because standardised residuals are normally distributed. Since diagnostic tests on standardised residuals favour the *AR(2)* specification over the *AR(1)* specification in the case of La Rioja, the former was selected. In practice, Figure A.1 shows that the different possible specifications for these three regions only lead to marginal differences in estimated house price levels.

[34] See www.stata.com/manuals/tssspace.pdf.

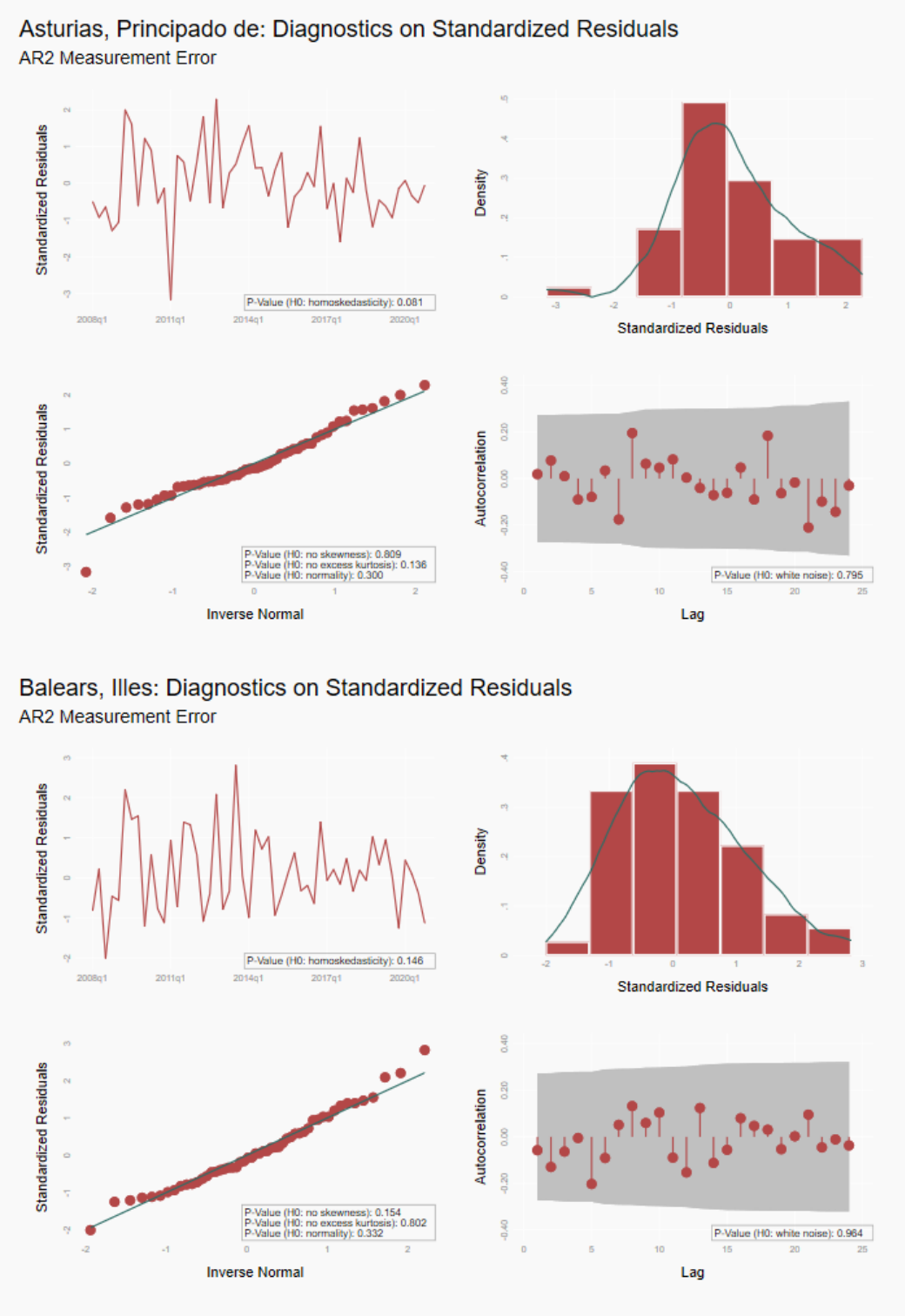
Figure A.1. Estimated house price levels with different autocorrelation structures of the state-space models for Andalucía, Galicia and Madrid

Table A.1. Model selection criteria and likelihood ratio tests for different autocorrelation structures of the regional state-space models

	AR(1)			AR(2)			AR(3)			Likelihood Ratio Tests (p-values)		
Autonomous communities	**Likelihood**	**AIC**	**BIC**	**Likelihood**	**AIC**	**BIC**	**Likelihood**	**AIC**	**BIC**	**$\phi 2 = 0$**	**$\phi 2 = \phi 3 = 0$**	**$\phi 3 = 0$**
Andalucía	136.59	-269.17	-265.23	140.83	**-275.66**	**-269.75**	NA	NA	NA	0.004	NA	NA
Aragón	97.83	**-191.67**	**-187.73**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Asturias, Principado de	105.68	-207.37	-203.43	109.71	**-213.42**	**-207.51**	109.83	-211.66	-203.78	0.005	0.016	0.626
Balears, Illes	NA	NA	NA	117.61	**-229.22**	**-223.31**	NA	NA	NA	NA	NA	NA
Canarias	122.08	**-240.17**	**-236.23**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cantabria	89.89	-175.79	-171.85	95.78	**-185.56**	**-179.65**	NA	NA	NA	0.001	NA	NA
Castilla - La Mancha	117.49	-230.99	-227.05	119.95	**-233.90**	**-227.99**	NA	NA	NA	0.027	NA	NA
Castilla y León	103.31	-202.62	-198.67	108.37	**-210.74**	**-204.83**	NA	NA	NA	0.001	NA	NA
Cataluña	131.66	-259.32	-255.38	133.77	**-261.55**	**-255.64**	NA	NA	NA	0.040	NA	NA
Comunitat Valenciana	141.29	**-278.58**	**-274.67**	141.30	-276.61	-270.75	NA	NA	NA	0.865	NA	NA
Extremadura	95.71	-187.41	-183.47	97.74	-189.48	-183.57	100.13	**-192.27**	**-184.39**	0.044	0.012	0.029
Galicia	109.86	-215.72	**-211.78**	111.69	**-217.37**	-211.46	112.11	-216.23	-208.35	0.056	0.105	0.355
Madrid, Comunidad de	122.42	-240.85	-236.91	126.08	**-246.17**	**-240.26**	NA	NA	NA	0.007	NA	NA
Murcia, Región de	113.89	**-223.78**	**-219.84**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Navarra, Comunidad Foral de	75.01	**-146.03**	**-142.09**	NA	NA	NA	NA	NA	NA	NA	NA	NA
País Vasco	102.81	**-201.62**	**-197.68**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Rioja, La	75.44	-146.87	**-142.93**	76.79	**-147.58**	-141.67	77.00	-145.99	-138.11	0.100	0.210	0.522

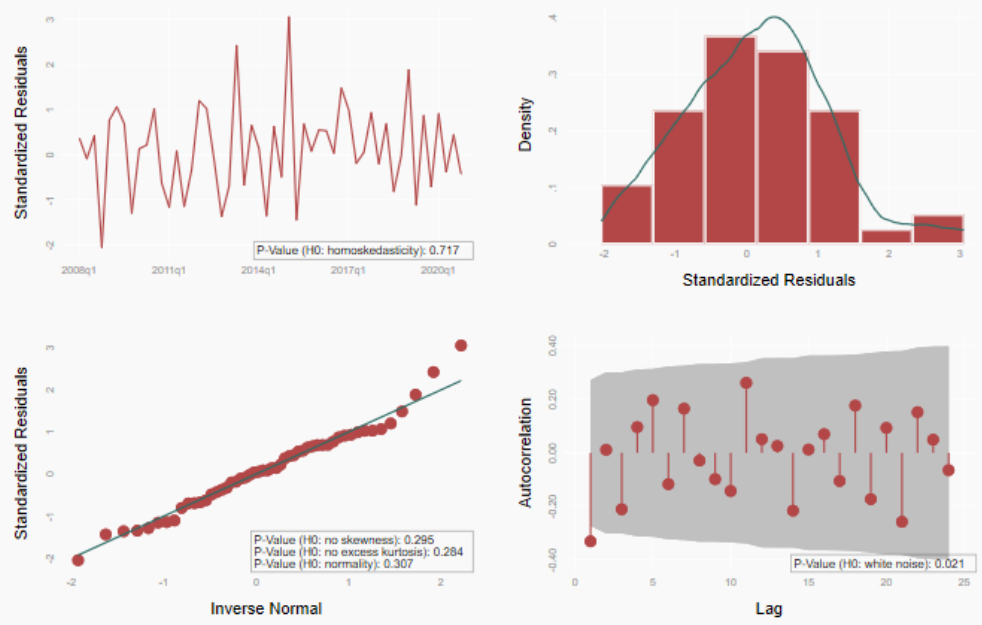
Note: The specification minimising AIC/BIC for a given autonomous community is marked in bold. Note that the model minimising AIC/BIC may not be the preferred specification if it the standardised residuals do not satisfy the assumptions that the model imposes. If a model does not converge, the corresponding cell contains *NA*.

Figure A.2. Statistical diagnostics tests on the standardised residuals of each regional state-space model (preferred specification)


Asturias, Principado de: Diagnostics on Standardized Residuals
AR2 Measurement Error
Standardized Residuals
P-Value (H0: homoskedasticity): 0.081
2008q1
2011q1
2014q1
2017q1
2020q1
Density
Standardized Residuals
Standardized Residuals
P-Value (H0: no skewness): 0.809
P-Value (H0: no excess kurtosis): 0.136
P-Value (H0: normality): 0.300
Inverse Normal
Autocorrelation
P-Value (H0: white noise): 0.795
Lag
Balears, Illes: Diagnostics on Standardized Residuals
AR2 Measurement Error
Standardized Residuals
P-Value (H0: homoskedasticity): 0.146
2008q1
2011q1
2014q1
2017q1
2020q1
Density
Standardized Residuals
Standardized Residuals
P-Value (H0: no skewness): 0.154
P-Value (H0: no excess kurtosis): 0.802
P-Value (H0: normality): 0.332
Inverse Normal
Autocorrelation
P-Value (H0: white noise): 0.964
Lag

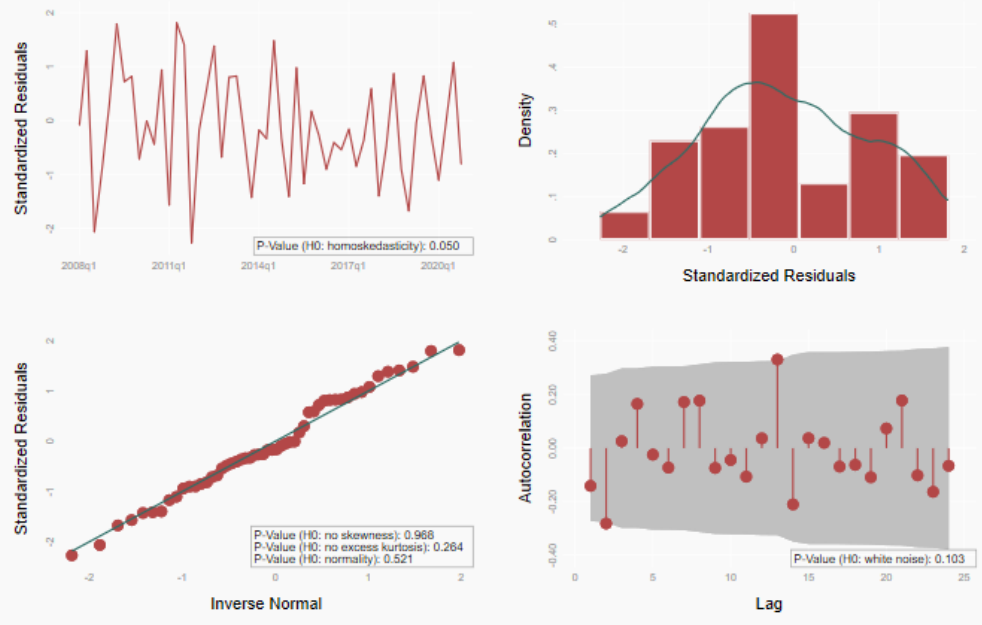
Canarias: Diagnostics on Standardized Residuals

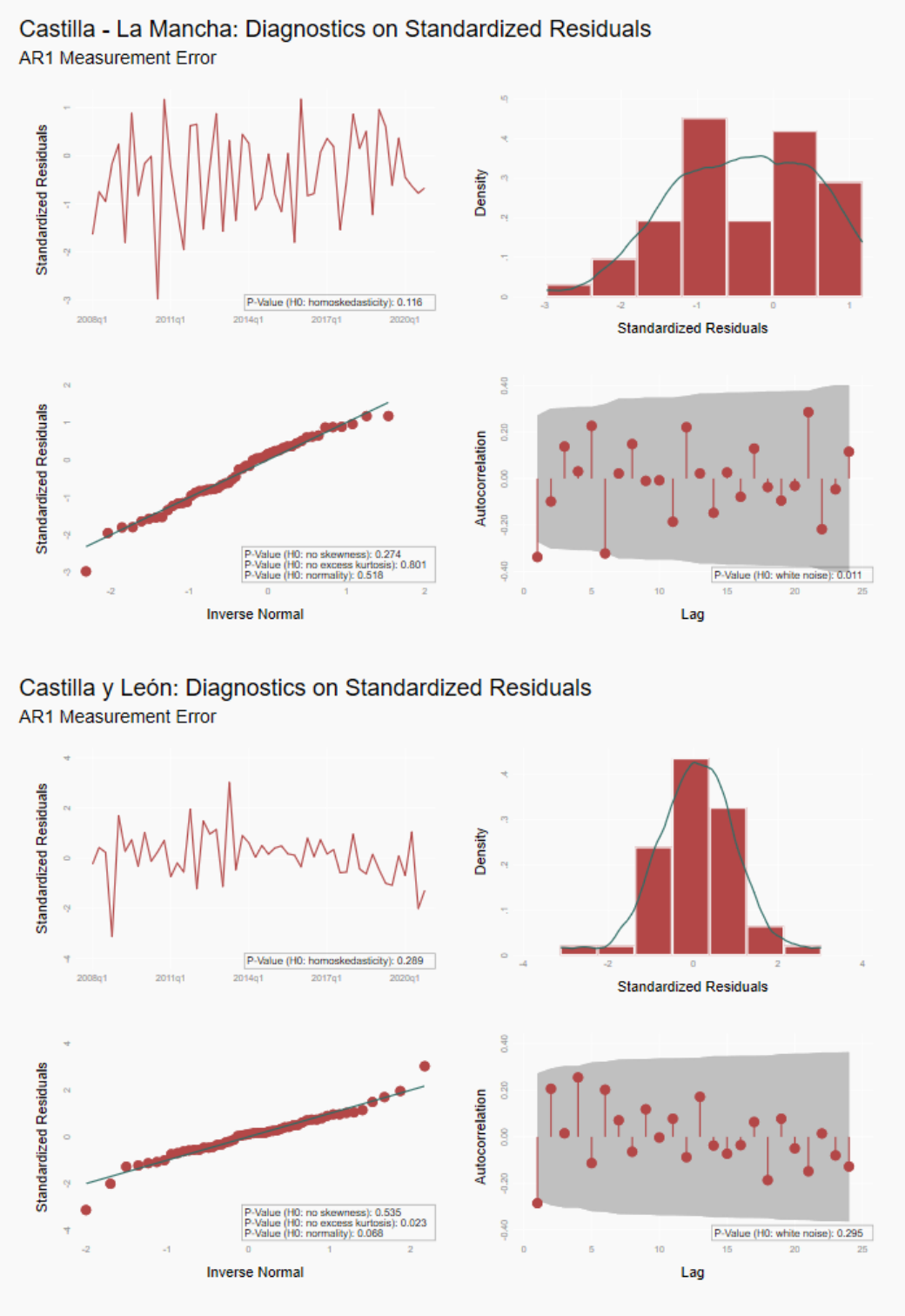
AR1 Measurement Error



Cantabria: Diagnostics on Standardized Residuals

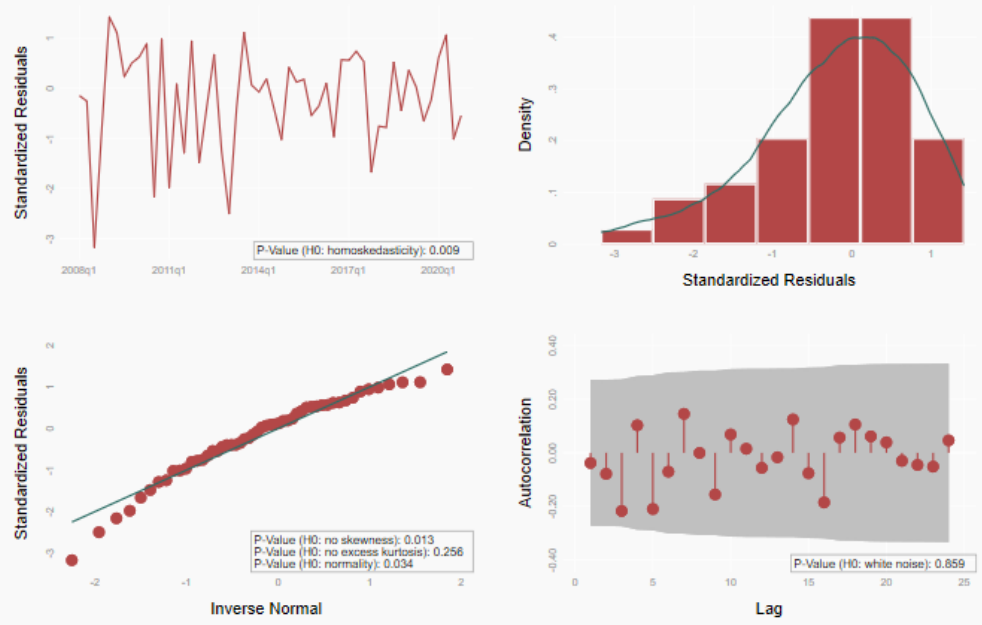
AR2 Measurement Error




Castilla - La Mancha: Diagnostics on Standardized Residuals
AR1 Measurement Error
Standardized Residuals
P-Value (H0: homoskedasticity): 0.116
2008q1
2011q1
2014q1
2017q1
2020q1
Density
Standardized Residuals
Standardized Residuals
P-Value (H0: no skewness): 0.274
P-Value (H0: no excess kurtosis): 0.801
P-Value (H0: normality): 0.518
Inverse Normal
Autocorrelation
P-Value (H0: white noise): 0.011
Lag
Castilla y León: Diagnostics on Standardized Residuals
AR1 Measurement Error
Standardized Residuals
P-Value (H0: homoskedasticity): 0.289
2008q1
2011q1
2014q1
2017q1
2020q1
Density
Standardized Residuals
Standardized Residuals
P-Value (H0: no skewness): 0.535
P-Value (H0: no excess kurtosis): 0.023
P-Value (H0: normality): 0.068
Inverse Normal
Autocorrelation
P-Value (H0: white noise): 0.295
Lag

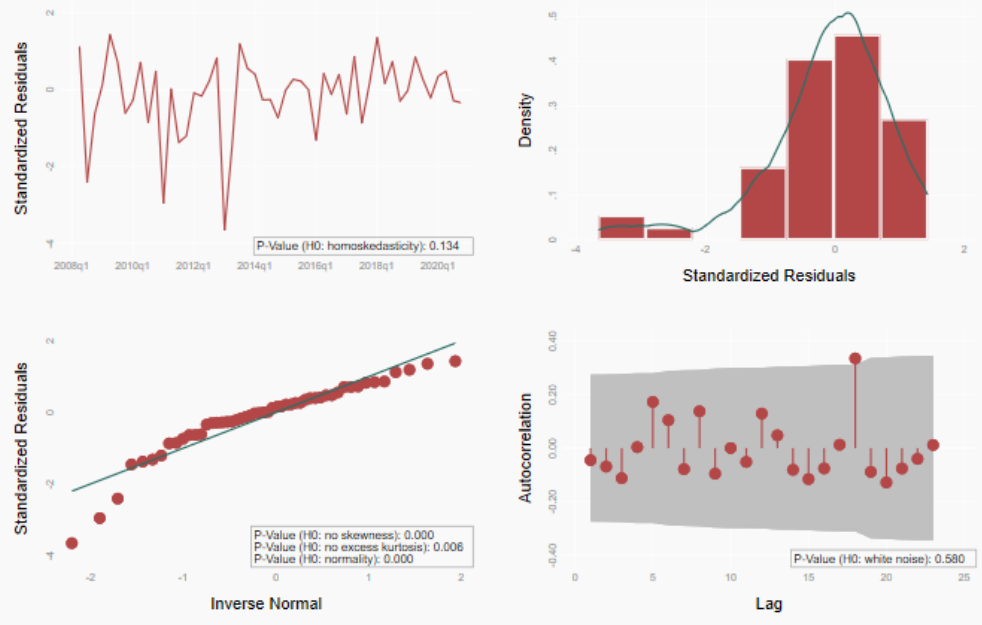
Cataluña: Diagnostics on Standardized Residuals

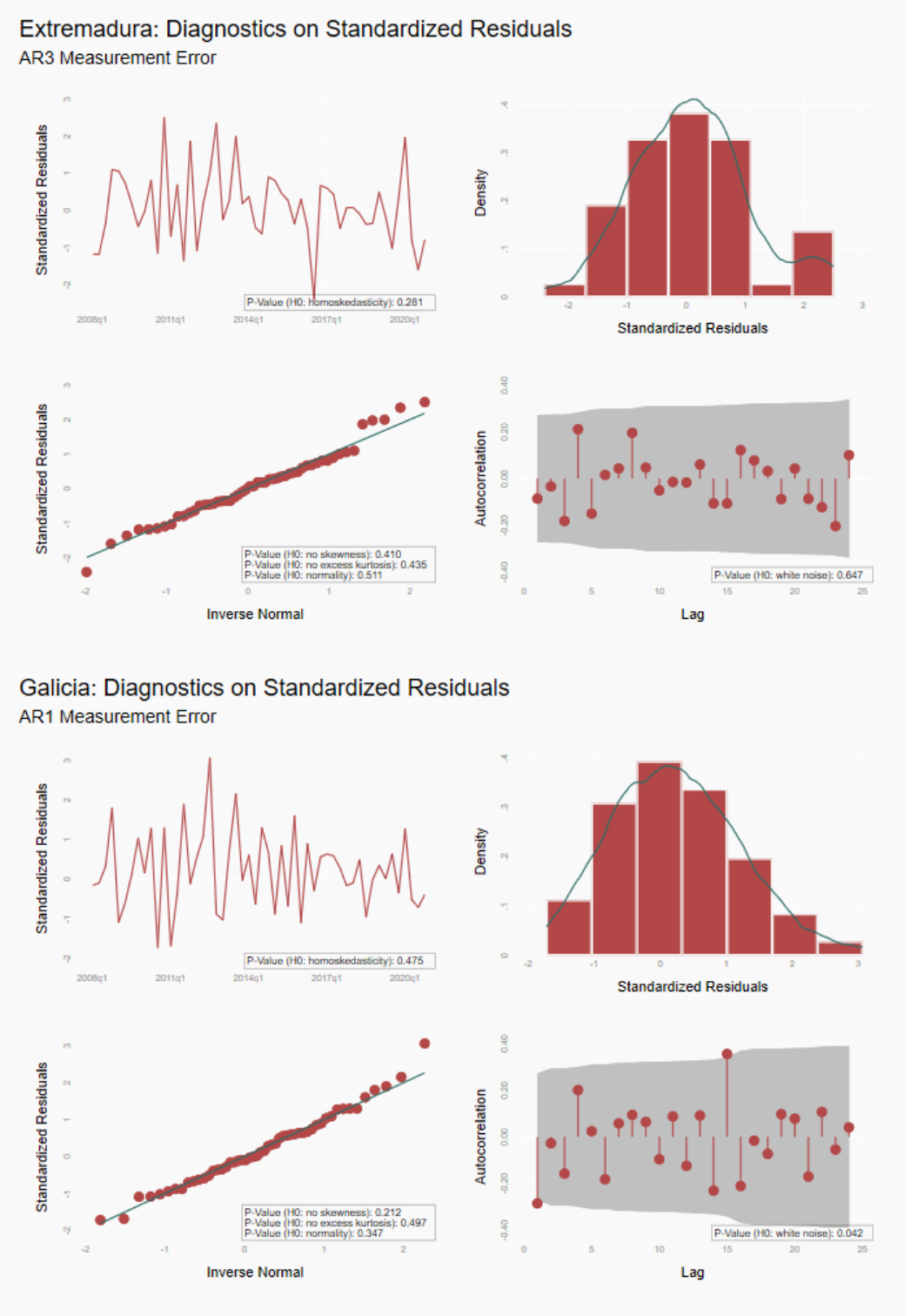
AR2 Measurement Error



Comunitat Valenciana: Diagnostics on Standardized Residuals

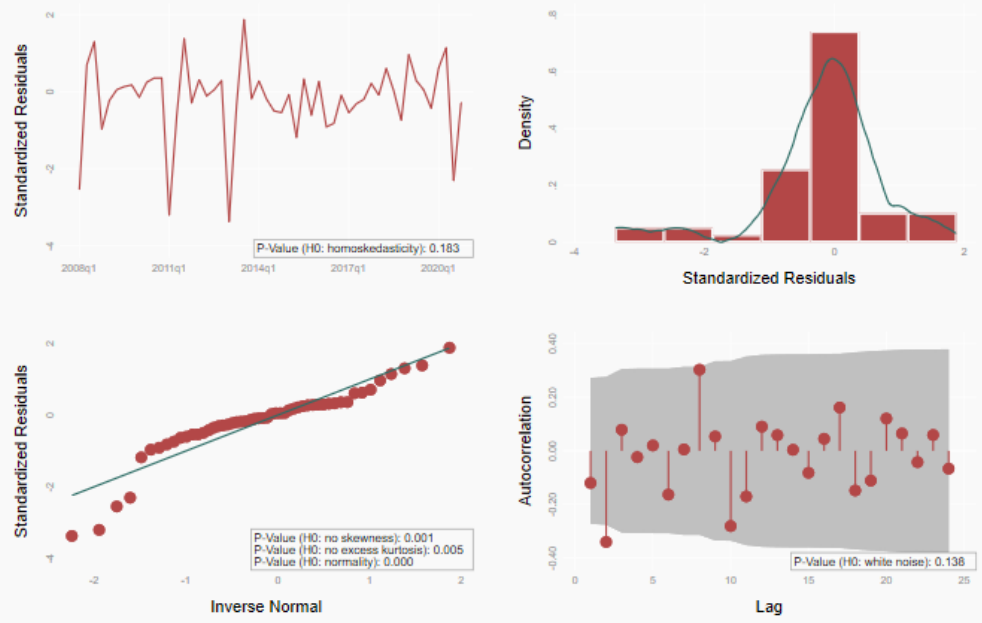
AR1 Measurement Error




Extremadura: Diagnostics on Standardized Residuals
AR3 Measurement Error
Standardized Residuals
P-Value (H0: homoskedasticity): 0.281
2008q1
2011q1
2014q1
2017q1
2020q1
Density
Standardized Residuals
Standardized Residuals
P-Value (H0: no skewness): 0.410
P-Value (H0: no excess kurtosis): 0.435
P-Value (H0: normality): 0.511
Inverse Normal
Autocorrelation
P-Value (H0: white noise): 0.647
Lag
Galicia: Diagnostics on Standardized Residuals
AR1 Measurement Error
Standardized Residuals
P-Value (H0: homoskedasticity): 0.475
2008q1
2011q1
2014q1
2017q1
2020q1
Density
Standardized Residuals
Standardized Residuals
P-Value (H0: no skewness): 0.212
P-Value (H0: no excess kurtosis): 0.497
P-Value (H0: normality): 0.347
Inverse Normal
Autocorrelation
P-Value (H0: white noise): 0.042
Lag

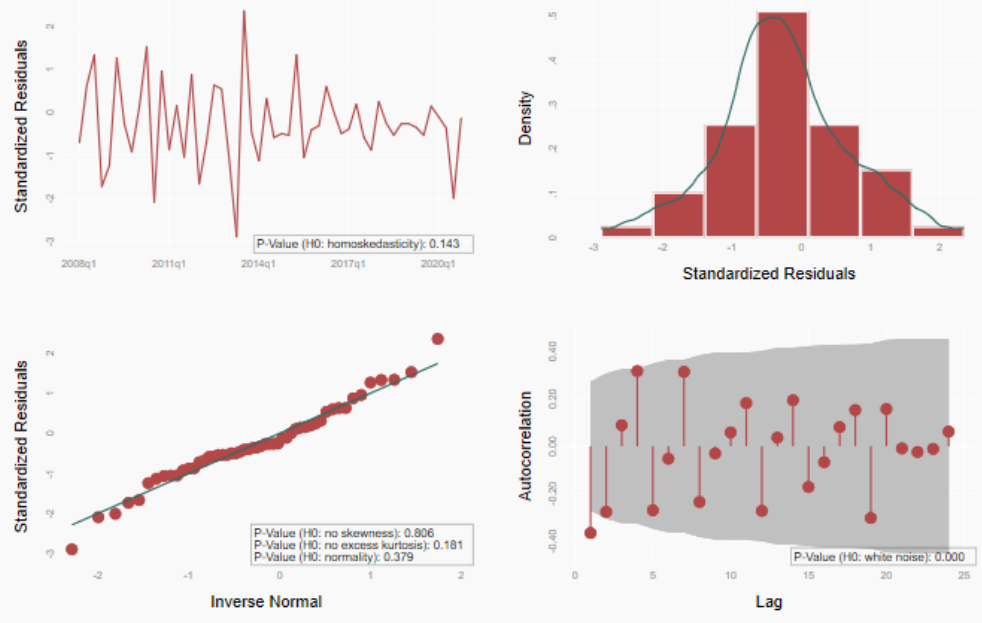
Madrid, Comunidad de: Diagnostics on Standardized Residuals

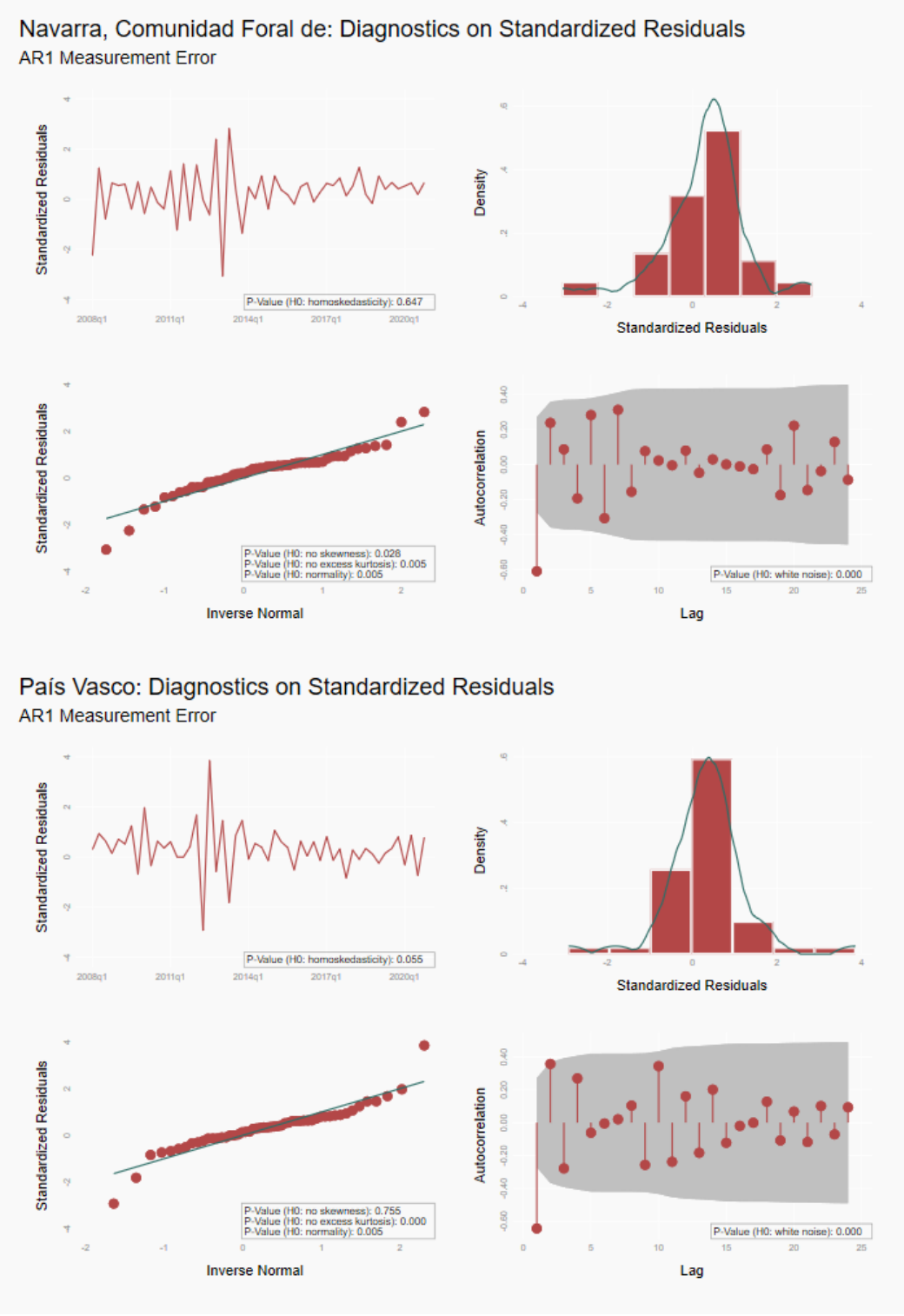
AR2 Measurement Error

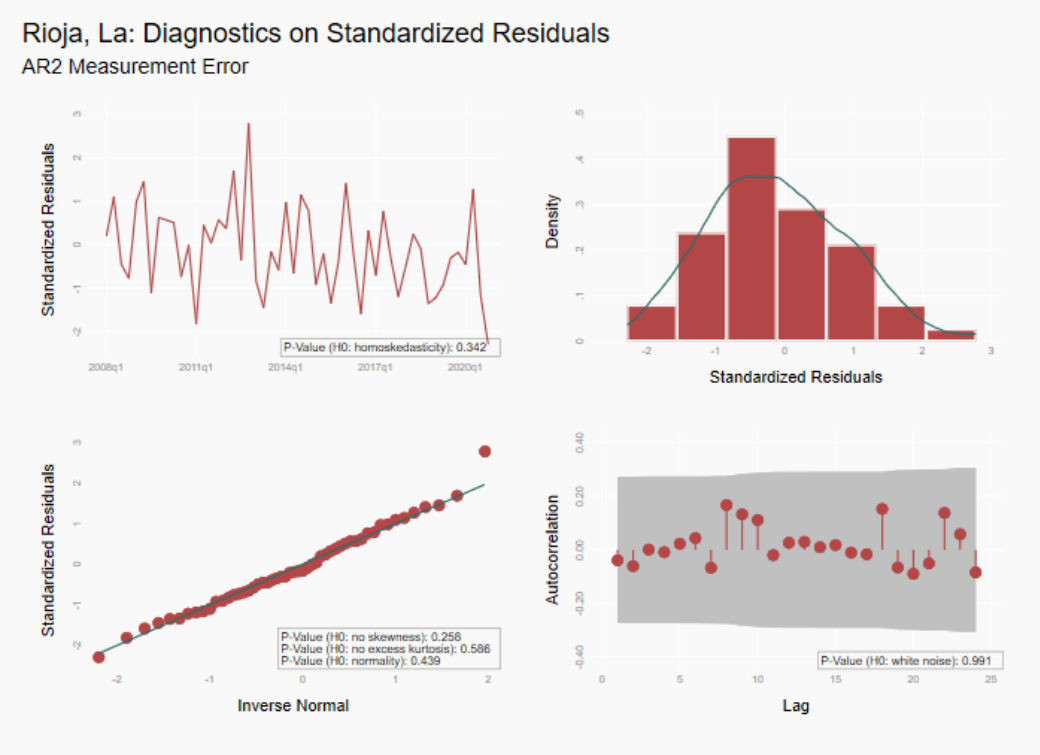


Murcia, Región de: Diagnostics on Standardized Residuals

AR1 Measurement Error

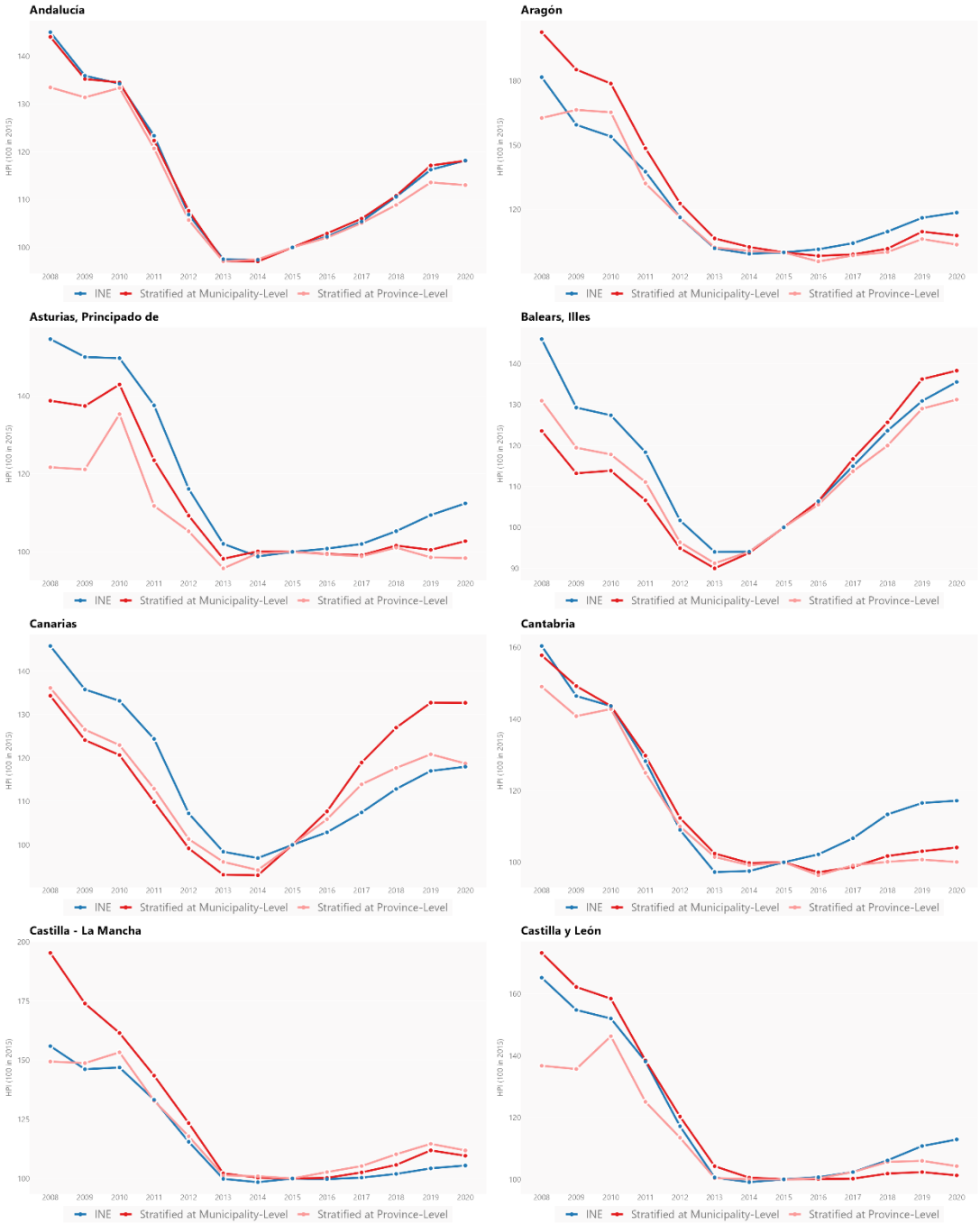



Navarra, Comunidad Foral de: Diagnostics on Standardized Residuals
AR1 Measurement Error
Standardized Residuals
P-Value (H0: homoskedasticity): 0.647
2008q1
2011q1
2014q1
2017q1
2020q1
Density
Standardized Residuals
Standardized Residuals
P-Value (H0: no skewness): 0.028
P-Value (H0: no excess kurtosis): 0.005
P-Value (H0: normality): 0.005
Inverse Normal
Autocorrelation
P-Value (H0: white noise): 0.000
Lag
País Vasco: Diagnostics on Standardized Residuals
AR1 Measurement Error
Standardized Residuals
P-Value (H0: homoskedasticity): 0.055
2008q1
2011q1
2014q1
2017q1
2020q1
Density
Standardized Residuals
Standardized Residuals
P-Value (H0: no skewness): 0.755
P-Value (H0: no excess kurtosis): 0.000
P-Value (H0: normality): 0.005
Inverse Normal
Autocorrelation
P-Value (H0: white noise): 0.000
Lag

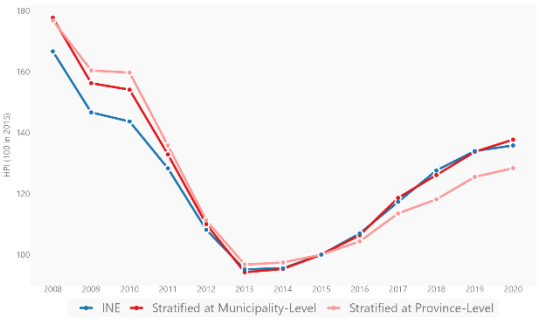

Rioja, La: Diagnostics on Standardized Residuals
AR2 Measurement Error
Standardized Residuals
P-Value (H0: homoskedasticity): 0.342
2008q1
2011q1
2014q1
2017q1
2020q1
Density
Standardized Residuals
Standardized Residuals
P-Value (H0: no skewness): 0.258
P-Value (H0: no excess kurtosis): 0.586
P-Value (H0: normality): 0.439
Inverse Normal
Autocorrelation
P-Value (H0: white noise): 0.991
Lag

Annex B. Stratification at municipality and province levels

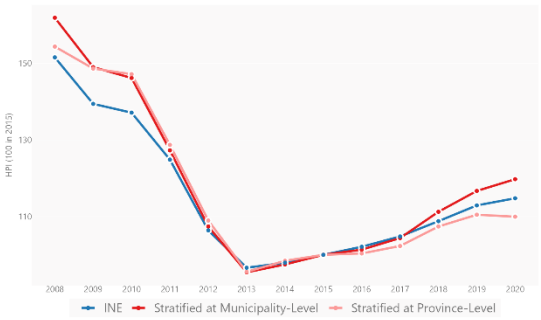
Figure B.1. Comparison of regional house price developments for existing dwellings in Spain, according to INE HPIs and stratification methods at municipality and province levels



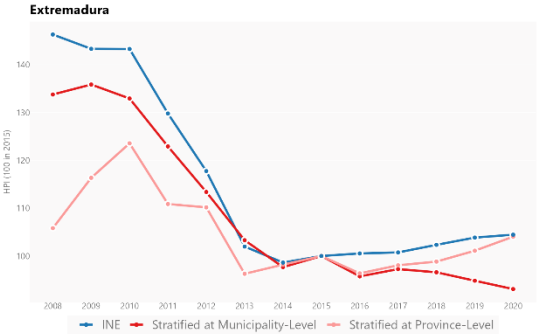
Cataluña



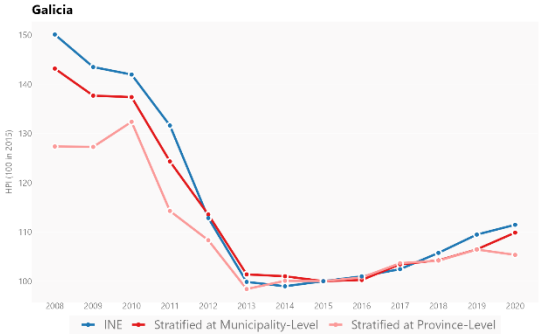
Comunitat Valenciana



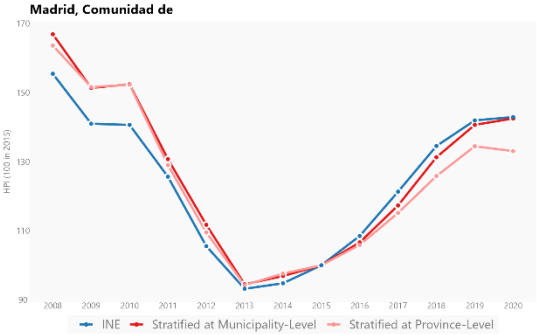
Extremadura



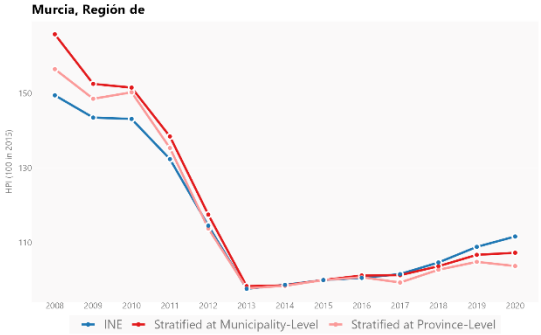
Galicia



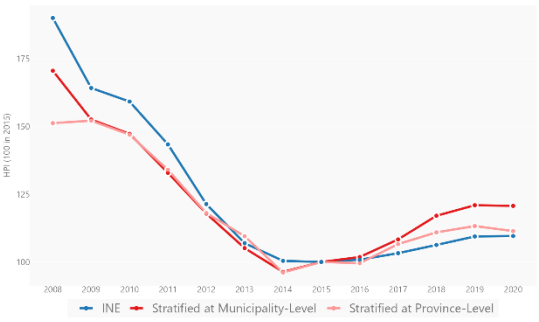
Madrid, Comunidad de



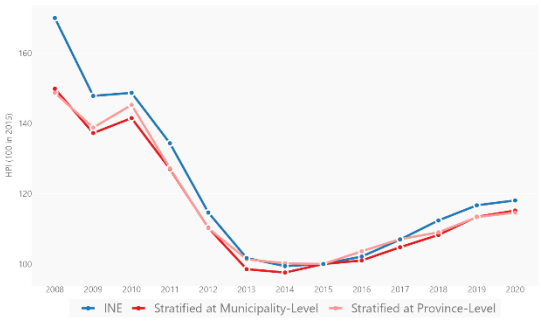
Murcia, Región de



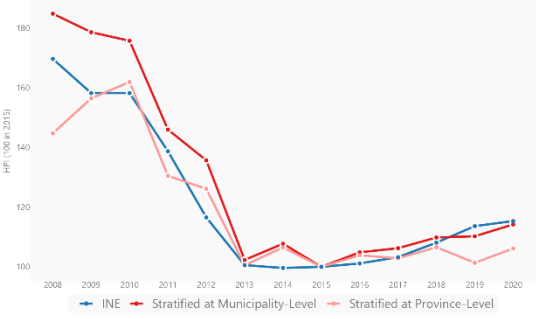
Navarra, Comunidad Foral de



País Vasco



Rioja, La



Annex C. Impact of census vintage

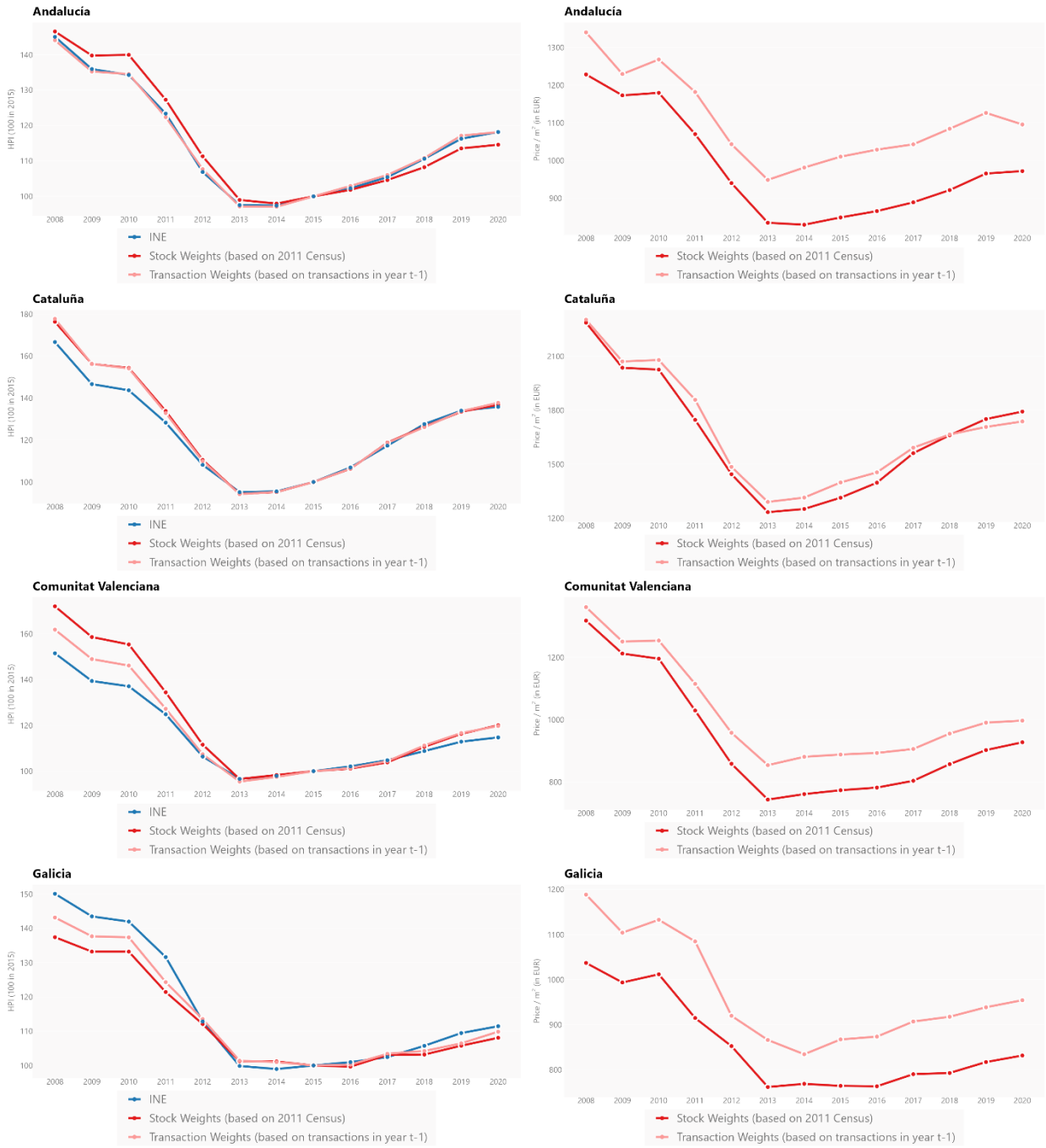
Table C.1. Impact of census vintage on stock-weighted house price indices

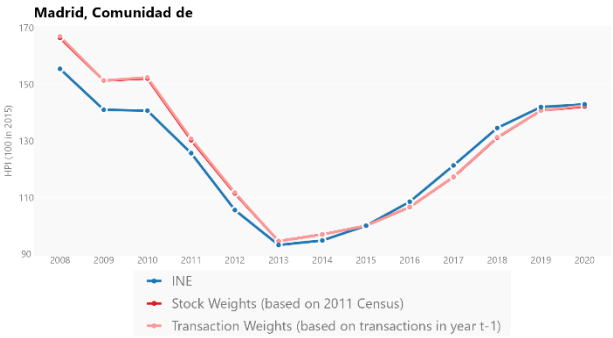
This table compares estimates of house price growth over 2008-2013 and 2013-2020 obtained from a stratification at the municipality level and using stock weights from the 2011 and 2019 Censuses to aggregate strata.

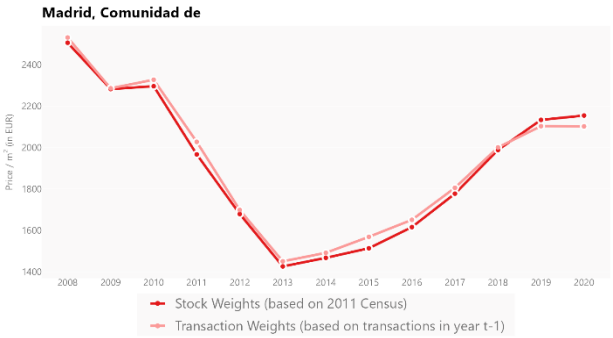
	2008 - 2013			2013 - 2020	
Autonomous communities	**2011 Census**	**2019 Census**		**2011 Census**	**2019 Census**
Andalucía	-32.45%	-32.30%		15.75%	15.38%
Aragón	-45.16%	-44.65%		3.29%	2.74%
Asturias, Principado de	-27.89%	-28.26%		1.85%	2.06%
Balears, Illes	-27.39%	-27.21%		51.96%	49.26%
Canarias	-32.70%	-32.83%		36.27%	35.63%
Cantabria	-33.74%	-33.10%		-1.54%	-2.29%
Castilla - La Mancha	-41.64%	-41.07%		3.41%	2.61%
Castilla y León	-34.19%	-33.60%		-0.20%	-0.84%
Cataluña	-46.52%	-46.63%		45.11%	43.82%
Comunitat Valenciana	-43.87%	-43.72%		24.34%	24.16%
Extremadura	-21.31%	-21.16%		-3.98%	-4.26%
Galicia	-26.32%	-25.94%		6.73%	6.51%
Madrid, Comunidad de	-43.19%	-43.14%		50.34%	50.33%
Murcia, Región de	-39.95%	-39.96%		9.42%	9.39%
Navarra, Comunidad Foral de	-39.82%	-39.62%		14.21%	13.82%
País Vasco	-32.74%	-32.84%		15.60%	15.86%
Rioja, La	-41.34%	-40.90%		6.52%	5.69%

Annex D. House price evolutions and levels using transaction or stock weights

Figure D.1. Comparison of regional house price evolutions (left column) and levels (right column)

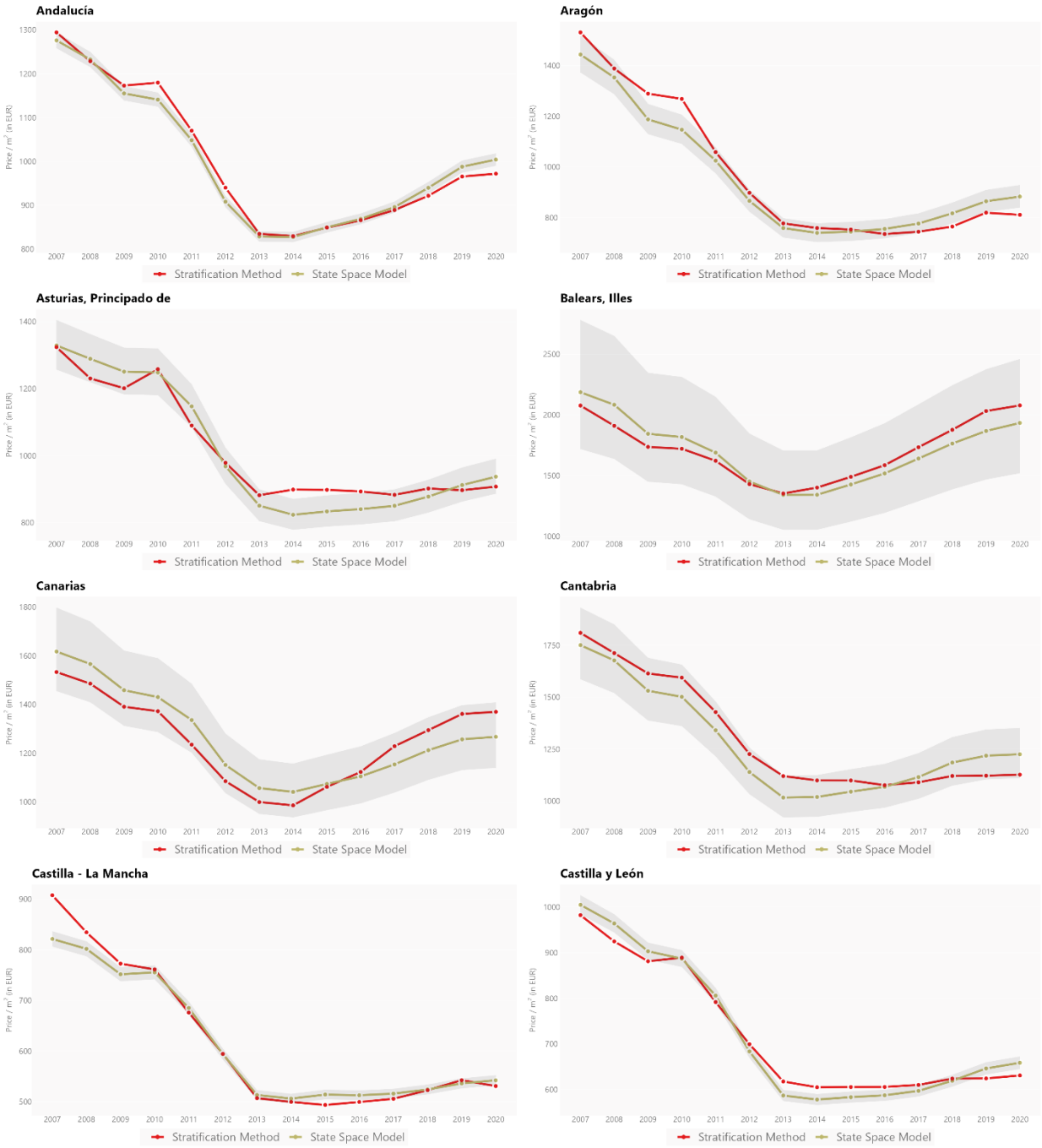



Madrid, Comunidad de
HPI (100 in 2015)
170
150
130
110
90
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
INE
Stock Weights (based on 2011 Census)
Transaction Weights (based on transactions in year t-1)

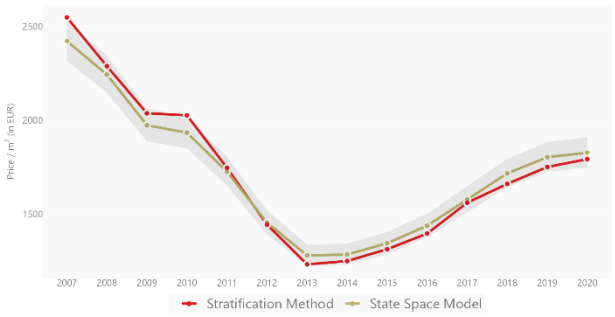

Madrid, Comunidad de
Price / m² (in EUR)
2400
2200
2000
1800
1600
1400
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Stock Weights (based on 2011 Census)
Transaction Weights (based on transactions in year t-1)

Annex E. Regional house prices according to stratification and state-space methods

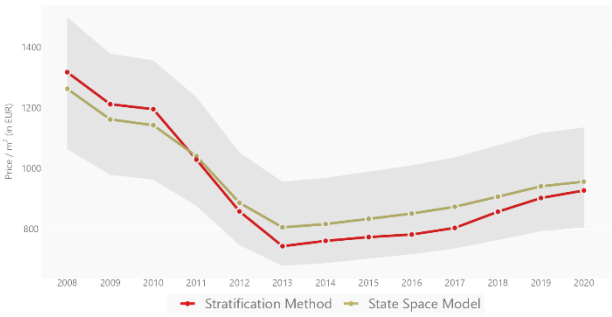
Figure E.1. Comparison of regional house prices per m² in Spain according to stratification methods and state-space models



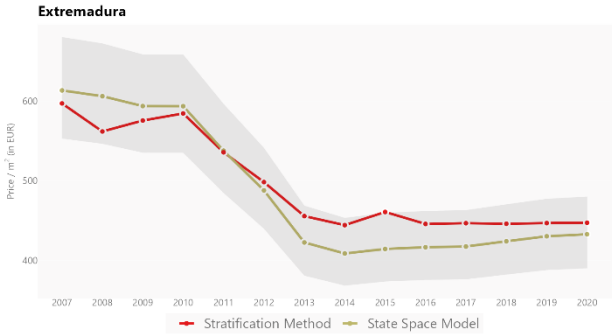
Cataluña



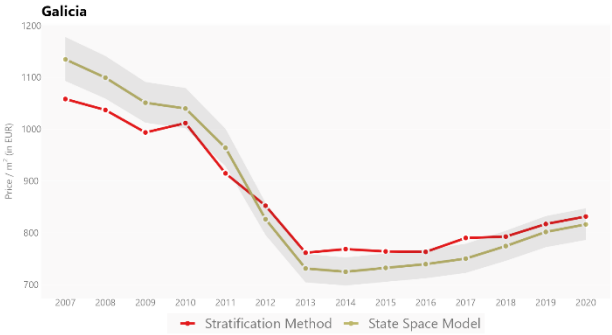
Comunitat Valenciana



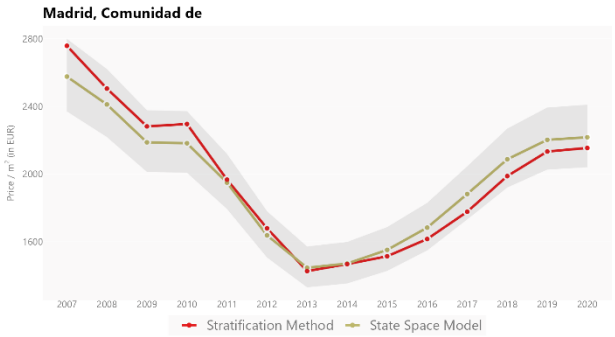
Extremadura



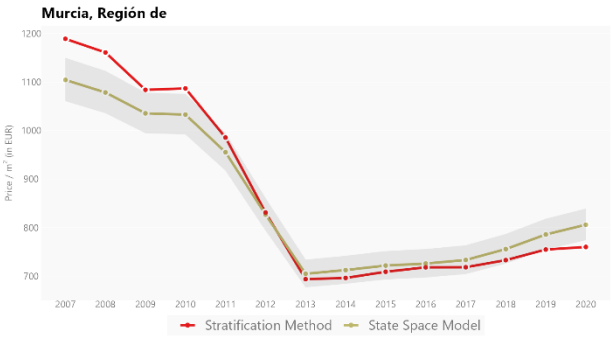
Galicia



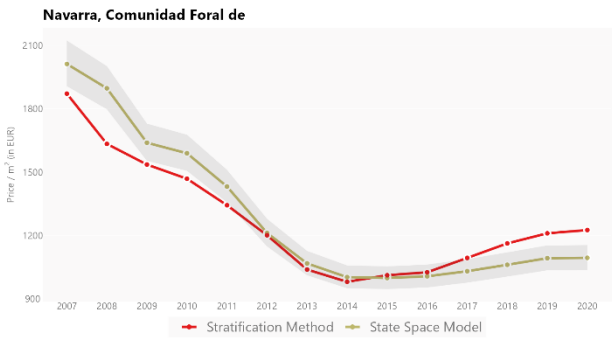
Madrid, Comunidad de



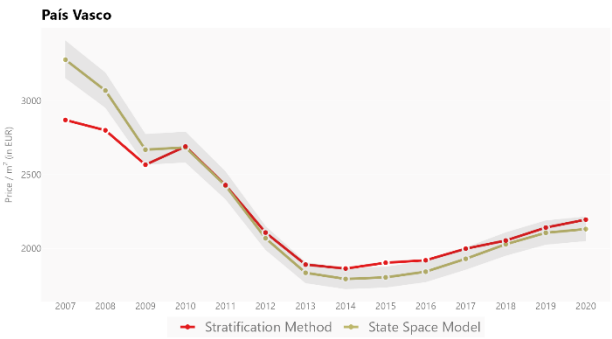
Murcia, Región de



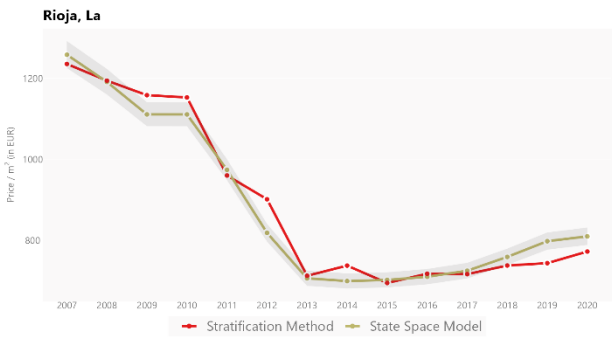
Navarra, Comunidad Foral de



País Vasco



Rioja, La



Annex F. Geographical coverage

Table F.1. Geographical coverage

	Municipalities					Districts [2]		
Autonomous communities	**Total (Census 2011)**	**CGN – Individual Entries[1]**	**CGN – Combined Entries [1]**	**Idealista**		**Total (Census 2011)**	**CGN**	**Idealista**
Andalucía	771	382	389	769		844	0	196
Aragón	731	63	668	662		72	0	27
Asturias, Principado de	78	42	36	78		68	0	26
Balears, Illes	67	48	18	67		123	0	54
Canarias	88	63	25	88		116	0	74
Cantabria	102	46	56	101		40	0	21
Castilla - La Mancha	919	162	757	847		296	0	43
Castilla y León	2248	148	2100	1979		166	0	80
Cataluña	947	326	621	939		413	0	210
Comunitat Valenciana	542	245	297	540		317	0	152
Extremadura	385	76	309	372		215	0	22
Galicia	315	126	188	314		452	0	72
Madrid, Comunidad de	179	107	72	179		87	0	79
Murcia, Región de	45	39	6	45		33	0	17
Navarra, Comunidad Foral de	272	44	228	265		95	0	12
País Vasco	251	98	153	251		140	0	57
Rioja, La	174	24	150	160		29	0	6
Spain	**8114**	**2039**	**6073**	**7656**		**3506**	**0**	**1148**

Note: [1] Columns 2 and 3 measure the average number of municipalities across time that we observe individually (column 2) and that are grouped together at the province level due to confidentiality rules. The sum of columns 2 and 3 and the value in column 1 may slightly differ due to rounding.
[2] These columns only count districts in municipalities that consist of more than one district.