Report to the Swiss Federal Statistical Office (FSO) on two hedonic models: the residential property (house) price index (RPPI) and the rent price index (RPI)

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The evaluation took place between March and September 2020. A trip to Switzerland was planned but could not take place due to the coronavirus travel restrictions. This was especially problematic for the RPPI component of this Report which was based on confidential data that could not be analyzed remotely. This Report was based on detailed FSO documentation, meetings using Microsoft Teams with my FSO counterparts,[1] and extensive technical exchanges by email. These exchanges involved my writing, and their responding to, general strategic issues and detailed points on econometrics and property price index number measurement. On the basis of these exchanges, my FSO counterparts ran many iterations of routines using R software on the database. This method of working, while not as effective as working *in situ*, was productive and covered all pertinent issues to my professional satisfaction.

Hedonic RPPIs and RPIs are unusual for price index statisticians in that they are based on econometric/statistical regression models. The reliability of hedonic RPPIs and RPIs in turn rests on the reliability of the underlying estimated regression models, for which there are well-established diagnostic measures and charts, estimators, and much more. Throughout the contract I have written background guidance notes which, while not part of this Report, supplement the work to corroborate and provide further information on these technical issues. I am also writing a technical support paper on econometric issues in hedonic RPPI measurement which I will subsequently share with the FSO. Further, the empirical work benefits from being highly competently coded by FSO staff in the software R and all my advice has been cross-referenced to R routines.

The Report considers RPPI and RPI measurement issues for the FSO in sections I and II respectively. There are many commonalties in the issues faced by theses two indices and section II takes this into account by way of a briefer account in which there are implicit cross-references to section I. Section III has brief conclusions.

I. Residential property (house) price index (RPPI)

1. Data

A major strength of these quarterly indices is their data. The FSO team - RPI and RPPI - are to be congratulated on the extensive data sets including the ingenuity in devising some of the explanatory variables. RPPI data benefit from being based on transaction prices, an impressive coverage of transactions from the 26 largest mortgage banks in Switzerland, and an extensive listing of explanatory variables, including a novel set of micro-locational variables that usefully supplement the

[1] The FSO team comprised Corinne Becker Vermeulen, Manuel Brand (RPPI) and Vincent Rappo (RPI) with additional comments from Laetitia Fourcade (RPI).

dummy locational ones. The RPPI data set includes 83,324 (35,724 single-family-homes (sfhs)and 47,600 condominiums) observations (transactions) for 2017-2019, and over 70 price-determining explanatory variables. The regression diagnostics are most satisfactory - especially so for a housing sector in a relatively small country with diverse housing types and locational agglomerations – and are testament to the richness of the explanatory data set.

The timeliness of the data is impressive. The RPPI can currently be released about 45 days after the quarter, with *all* data received within about 21 days, validation, cleaning, and preparing for dissemination taking up the remaining time.

Shortcomings of the (loans-based) data include the omission of cash purchases and the coverage of loans data. These are considered by the FSO to be relatively minor, though a medium-term objective – not a high priority one - would be to formally attempt to identify the extent of such omissions by say recourse to land registry data.
It is recommended that details of the data and its shortcomings are published as part of a more general methodological paper on the RPPI.
It is recommended that as a medium/long-term objective attention is given to further improving the timeliness of the RPPI, timeliness being particularly important for macroeconomic policy formulation.

2. Diagnostics tests and treatment of outliers for the hedonic regression

The FSO team set up the data using R software which has excellent capabilities for handling large databases and contains routines for identifying and treating outliers, regression estimators and diagnostics, and enabling the computation of RPPIs. The FSO team have demonstrated their expertise in this area. Aside from the basic regression diagnostic statistics, regression models were examined and issues considered regarding the testing for, and treatment of, heteroscedasticity, multicollinearity, normality of residuals, omitted variable bias, and specification bias and functional form. Well-established econometric/statistical criteria have been implemented by the FSO to ascertain the reliability of the hedonic models that underlie their measures. The results were most satisfactory and lay down a set of criteria for the validation and assessment of further hedonic regression models, be they for additional stratification and/or updates in future time periods.

The (univariate and multivariate) detection and treatment of outliers treatment of outliers included a univariate cleaning of extreme prices but rightly focused on multivariate outliers excluding transactions with high Cook's Distance (CD). For the 2017-2019 hedonic regressions there were only a limited number of such influential observations – 32,401 *minus* 30,594 *equals* 1,807 observations - and their deletion had no substantive effect on the coefficient estimates, though there was a substantial increase in $\bar{R}^2$, from 0.7019 to 0.8125 for sfhs. The limited number of influential observations arises from the robust model specification and richness of the explanatory data set.

Detailed background notes on diagnostic tests and the detection and treatment of outliers were prepared for the FSO in response to the RPI paper, though apply equally to the RPPI. A lengthier paper on econometric diagnostic statistics for property price indices is under preparation and an advance draft will be shared with the FSO for comments.
It is recommended that a methodological paper that contains the regression results and diagnostics be made available. This will reflect well on the transparency, rigor, and credibility of the FSO's property price indices.

3. Time period over which the hedonic regression is estimated and periodicity of updating the hedonic regression

Exploratory data analysis found that a hedonic regression estimated using only 2018 data (sample size of about 10,500 for sfhs and about 13,500 for condominiums) had very good explanatory power ($\bar{R}^2$ = 0.81 and 0.82 respectively) with signs and magnitudes of estimated coefficients according with *a priori* expectations, and both models benefiting from satisfactory diagnostics tests. However, following discussions with the FSO they expressed a preference to initially ground the RPPI on the secure, stable, base of a hedonic regression estimated over the three years 2017-2019. Estimated regression equations were found to have good properties over this extended period. There are two issues in this regard: the duration of the period over which the hedonic regression is estimated and the periodicity of the regression updates. A concern with a continuing extended period of 3-years and infrequent regression updates is that this would unduly lag and smooth the indices making them less responsive to turning points in property price bubbles, a most important deficiency for central bank's macroeconomic policy-making.

In response to this concern, the FSO plan to annually update the hedonic regression - the first annual update will use 2020 data and be chain-linked in 2021. Further, the FSO plan to investigate whether the length of the hedonic estimation period can be shortened, with it in mind that a rolling, and thus quite possible unduly smoothing, 2019-2020 model be next estimated. Preliminary analysis on 2018 data, based on an extensive diagnostic evaluation, found the use of hedonic regression estimated over a 1-year period quite feasible, providing similarly good diagnostics to those using 2017-2019 data.

The FSO have further proposed the use of 2019Q4=100, as opposed to 2017-2019=100, as an index reference period for the RPPI based on a 2017-19 hedonic regression. I have advised the FSO that although this hedonic formulation is not without meaning, irregularities in the definition of the hedonic RPPI arise from it.

It is recommended that while a 2017-2019 might be used to ground the RPPI, the FSO should quickly move to chaining the indices based on hedonic regression equations preferably estimated over a single year updated every 1 year.
It is recommended that the FSO move on their next hedonic update to a hedonic regression where the RPPI reference period=100 coincides with the period of the hedonic regression and the overlap period of the (chained) updated RPPI.
For the long term, as the database increases, empirical work should be undertaken and published on the (in)stability over time of the estimated hedonic coefficients; effect on measured RPPIs of different extended periods for the hedonic regression; and of different periodicities of updating the regression. Operational decisions as the length of the time period over which the regression is estimated and periodicity of the updates are then based on rigorous analysis of empirical evidence. The rolling and smoothing of the extended period should be a last resort employed when confronted with unduly volatile results.

4. Hedonic estimation/compilation approach

The FSO has decided to use the hedonic imputation approach. I checked the R routines and an illustrative example on a spreadsheet for its implementation and advised accordingly. The hedonic imputation approach benefits from, and is supported by, its equivalence to the characteristics/repricing approach.[2] That these two hedonic approaches with different intuitions yield the same results, when appropriately measured, further validates either of their use. The hedonic imputation approach is much less restrictive than the time dummy hedonic approach,[3] more appropriate for real-time measurement, and better grounded in index number theory. It further can have weights for the price change at the level of individual properties readily incorporated, unlike the time dummy approach. A hedonic imputation index formulation for stratum *l* compares the geometric mean of property *i* transaction prices in the current period *t* (in the numerator), with the geomean of the same period *t* properties but each priced using a period 0 hedonic regression (in the denominator), $\hat{p}^0_{i|z_i^t}$.

$$(1) \ldots\ldots\ldots\ldots RPPI_l = \frac{\left(\prod_{i\in N^t} p_i^t\right)^{\frac{1}{N^t}}}{\left(\prod_{i\in N^t} \hat{p}^0_{i|z_i^t}\right)^{\frac{1}{N^t}}}$$

The national RPPI is a weighted, w_l, sum of the strata $RPPI_l$:

$$(2) \ldots\ldots\ldots\ldots RPPI_N = \sum_l w_l RPPI_l$$

However, equation (1) was not implemented. Equation (1) requires that the period 0 index reference period is the same as the period over which the hedonic regression is estimated which is not true, at least for the initial link of the index on which the FSO RPPI is grounded. With period *b* designating the 2017-19 period of the regression, period 0, the index reference period=2019Q4=100, and period *t*, the current period, say 2020Q1 as the initial current period of the RPPI, for which 2019Q4=100:

$$(3) \ldots\ldots\ldots\ldots RPPI_l = \frac{\left(\prod_{i\in N^t} p_i^t\right)^{\frac{1}{N^t}}}{\left(\prod_{i\in N^0} p_i^0\right)^{\frac{1}{N^0}}} \div \frac{\left(\prod_{i\in N^t} \hat{p}^b_{i|z_i^t}\right)^{\frac{1}{N^t}}}{\left(\prod_{i\in N^0} \hat{p}^b_{i|z_i^0}\right)^{\frac{1}{N^0}}}$$

A more detailed mathematical exposition is provided in Annex 1.

A background note on the advantages of the approach, especially against a rolling time dummy approach, was prepared for the FSO.
It is recommended that the hedonic imputation approach be adopted in the form of a geometric mean of prices and a semi-logarithmic hedonic functional form to make it equivalent to a repricing/characteristics approach.
A move to the reference period of the hedonic regression (as the overlap) in future chained links is also recommended.

[2] Subject to the use, for a semi-logarithmic functional form for the hedonic regression, a geometric mean of prices for the hedonic imputation approach and arithmetic mean for the characteristics when using a characteristics/repricing approach.
[3] The time dummy method is used by 5 out of the 18 EU countries employing hedonic approaches – the remaining countries using variants of the characteristics/repricing and imputation approaches, that have equivalences to each other (Hill et al., 2018). Germany and the UK use the hedonic imputation approach.

5. Stratification and interaction effects

Stratification is "highly recommended" by international guidelines: "...use of a common model [running one big hedonic regression instead of stratified sub-samples] is very unrealistic." Eurostat *et al. Handbook* (2013, pp. 535-540, p. 5.39). Stratification (i) does not constrain estimated coefficients for the explanatory variables to be the same across strata – though this could be relaxed with interaction effects; (ii) provides an analytically meaningful breakdown of components whose weighted sum of property price changes equals the national index; and (iii) most importantly, a meaningful (preferably stock) weighting can be ascribed to each component, $RPPI_l$ in equation (2), rather than being dictated by the relative (between strata) influence of observations in a common regression.

My work benefited from having access to the results from separate (stratified) hedonic regression models, for 2017-2019 and 2018 alone, for single family houses (sfh) and condominiums (condos). At first sight, I emphasized the need for further stratification by locational variables, *cantons* where sample sizes were sufficiently large, or groups thereof, or by Major Statistical Regions (MSR), in addition to property type. In extensive discussions, the FSO argued that a more pertinent stratification for the Swiss context would be by five community groups – in order to have sufficient transactions – of community_types (1=urban community of a large agglomeration (large cities), 2=urban community of a medium-sized agglomeration (medium cities), 3=urban community of a small or outside of an agglomeration, 4=intermediate community, 5=rural community). This would provide further insights into the analysis of differential price changes than currently available from other RPPI providers. These might further be separated for individual large cities, such as Geneva, Zurich and Basel, sample sizes and regression diagnostics permitting. I have not had sight of such individual results, but this appears to be most sensible.

Within each stratum, meaningful interaction effects should be tested and included as necessary. Particular focus should be on interaction terms for *cantons*. Without such terms the implicit assumption is that the coefficients on other explanatory variables are the same for each canton. However, there are *a prio*ri reasons to expect the coefficients on say *volumeofbuilding* for the RPPI to differ across *cantons*. It should be borne in mind that the denominator in equation (1) is made up of the predicted (log) prices in period 0 of properties (their characteristics) transacted in period *t*. An individual property in a particular community should not have its out-of-sample price predicted by a coefficient that applies to the broad community of properties, say major cities. The inclusion of relevant interaction effects will tailor the prediction to the specific canton. Even then, there is much location-specific variability within a canton, which merits the development of finer locational variables.

On a technical note: the standard *t*-tests of statistical significance for the coefficients on interaction terms are, however misleading and their interpretation requires the regression to be estimated with a straightforward technique of "centering" the variable. A background note on the inclusion of interaction effects, the interpretation of the coefficients (and need for centering), and (joint) tests of statistical significance was prepared for the FSO.
It is recommended that subject to adequate sample sizes, the initial stratification should be by the five community *clusters for each of sfh and condos. Where sample sizes are too small, cantons/communities should be grouped.*
*It is recommended that the FSO include meaningful interaction effects- with a focus on canton*s *- within the stratification to be adopted using appropriate tests and centering as outlined above.*

It is recommended that for (very) longer-term data development the FSO works towards a finer locational classification within cantons, though this may be highly problematic owing to current confidentiality constraints on the data.

6. On weighting

Weights for aggregating strata RPPIs, as in equation (2) should, for financial stability and macroeconomic policy, be relative **stock values** as opposed to **transaction values**. The value of the national level of loans to households for residential property purchases is secured on the value of the stock of the housing. If the price of property falls dramatically in a recession, the negative equity is not limited to new transactions, but to the value of the whole housing stock. Further, a concern of macroeconomic policy is the wealth effect, felt by all owners, during a price bubble as all owners (irrationally) form (unrealistic) expectations from transaction price increases. It is not just those who transact properties in a bubble who borrow and spend more, and then have problems with negative equity when the bubble bursts. It is recognized that the FSO will only have transaction value weights available for the launch of the RPPI. The forthcoming population Census should be helpful in determining stock value weights, preferably aligned with a perpetual inventory approach to update the weights on a more frequent (than 10-yearly) basis.

Weighting **at the level of the individual property** can readily be incorporated into the indices without need for further information. The price change of a house in, for example, Geneva should get more weight than the price change of a commensurate cheaper house. Silver (2018, equations (23) and (24) and section E) provides the detail with equation (1) requiring a simple adjustment in its commensurate line of code in R.
It is recommended that the FSO should establish a work program to derive stock values as weights for the RPPI, transaction value weights for the RPI, and implement weighting at the individual property level for both indices.

7. More detailed points on the inclusion of variables and specification of the hedonic regression

including/excluding tax burden: the inclusion of the *taxburden* explanatory variable was discussed at length, it being arguably open to criticism since it is not a quality characteristic of the property. Further, changes in *taxburden* may affect house prices which would be wrongly partialed out in the regression. The case by the FSO was that for the Swiss context, *taxburden* was a proxy variable, in a cross-sectional regression, for the quality of the location and while it did not have a marked effect on $\bar{R}^2$, it would be useful for making out-of-sample predictions for property transactions, a key component of the hedonic imputation approach. Further, *taxburden*, as broadly categorised, was argued to change only slightly over time for a location.
It is recommended that taxburden be included in the regression model if it has been found to have a substantive effect on measured RPPIs, say for using a 2018 regression for quarterly 2019 indices. A methodological document should footnote the rationale for its inclusion.

semi-log vs mixed model: the FSO specifies its hedonic model taking logarithms of the left-hand-side (LHS) and a mixed RHS – some explanatory variables having log transformations, some not. This follows Wooldridge (2103) and while quite defensible, is a departure from the usually employed semi-logarithmic functional form that benefits from more consistent interpretation of estimated coefficients, being widely employed by other NSIs, and rooted in RPPI measurement theory. The use of a semi-logarithmic functional form allows for an equivalence between the hedonic imputation and

hedonic characteristics/repricing formulations giving, in turn, more credence to these methods – see Silver (2018, page 43). A background note on the subject was prepared for the FSO.
It is recommended that a semi-logarithmic functional form be used.

presentation of results: while charts of the indices by strata and at the national level should be presented to reflect long-term trends, quarter-on(preceding)quarter QonQ(-1) figures should also be presented, later supplemented by QonQ(-4) data. Excel tables of figures should be included to facilitate ease of use by users. *Stargazer* in R should be used for the presentation of hedonic results, especially when comparing models.

II. Rent Price Index (RPI)

While the methodological comments provided above related to the RPPI, similar issues arose for the RPI. The outline below while based on the more detailed comments for the RPPI, where relevant, is also tailored to the RPI context and supplement them for RPI-specific issues.

1. On data

The dataset after cleaning, amounted to 70,000 recorded rental prices for dwellings (observations) over 29 quarters (December 2010 to February 2018), on average about 2,400 observations per quarter and a rich set of explanatory variables. The data were well set up in R.

Of note, 11,500 dwellings are surveyed on average each quarter - 333,500 observation over the period - implying about 80 percent of the dwellings are removed from the sample. This removal of observations is attributed to the same dwellings, at fixed rental prices and characteristics, being included in the database several times - at most over a 2 year period, as the sample is rotated. The exclusion was justified by the FSO in order not to give a higher weight to duplicated observations and better reflect the heterogeneity of the observations. The exclusion of duplicated observations in a regression has been shown in the literature to affect both the estimated coefficients and the standard errors. An appropriate econometric procedure would be to include the duplicate observations but treat the data as (unbalanced) panel data and use say an fixed effect estimator. The heterogeneity of the observation in their entirety would be reflected in the hedonic modelling – they are valid valuations factored into the rental price for the whole period. Leaving them out would be to lose valuable information. However, an estimated hedonic regression over such a long period is in any event not recommended for real-time RPI measurement.

A more appropriate procedure would be to cut back the periods over which the sample is taken for the hedonic regression to one that provides a sufficient sample size and stability – at least a year perhaps on a similar basis to the CPI updated weights - and use all data. The analysis can be repeated without the duplicates to identify the effects on the measured RPI, as can the use of panel data techniques.
It is recommended that details of the data and their merits and shortcomings are published in a methodological paper on the RPI.
It is recommended that the hedonic regression be estimated over a shorter period than the current 29 quarters, say 4-8 quarters to much improve the responsiveness and minimize the lag in measuring changes in rental prices. As will be noted above, this will also minimize the extent of duplicated observations. Duplicated observations should be included, though the hedonic regression can be estimated without the duplicated observations and RPIs calculated to establish the extent to which the issue of duplicated observations matters.

The sample design is outside of the terms of reference of the Report, though the holding constant of the 1/8:7/8 sample rotation merits mention.

2. On methods

The overall methodology is to be the same as the RPPI – a hedonic imputation approach. The equivalence of the results for hedonic imputation and repricing/characteristics approaches when appropriate aggregators and hedonic functional forms are used (Hill *et al*. (2018) and Silver (2018)), argues for either of these formulas. Issues concerning the use of equation (1) for the hedonic imputation index, as against equation (3) for an initial grounding, follow the comments in section I.4 above and Annex 1. There does not appear to be a case for grounding the initial regression over a 3-year period , as was deemed necessary for the RPPI. More generally, a hedonic regression might be estimated for a single year, and then updated every one or two years. For the purposes of an RPI there is not the need for a tight, regularly-updated period for the hedonic regression since its purpose is not to monitor price bubbles and turning points in a timely fashion for macroeconomic policy-makers. Yet it has to provide an up-to-date rental price movement that resonates with consumer's experience to maintain the credibility of the CPI.

The duration of the period over which the hedonic regression is estimated and the periodicity of updating the regression and chain-linking the RPI should be investigated using the database to justify such decisions on an empirical basis. A hedonic regression could be estimated using the first year's data – about 9,600 observations and, using the extensive data set, hedonic regressions updated (i) annually (over 4 successive quarters), (ii) every two years and (iii) every 5 years and the resulting quarterly RPIs, chain-linked. It may be that such estimates based on smaller datasets for the hedonic regression, especially when stratified, prove unreliable, in which case hedonic regression could be estimated over say two years of data (8 quarters). Routines for estimating such hedonic regressions in RPIs require but a handful of lines in R. Then, not only would we be replicating the use of hedonic models as would be applied in real-time usage, but also have an empirical basis for evaluating the time period to serve as the basis for the hedonic regressions as well as the frequency with which the regressions should be updated.

It is recommended that a hedonic imputation approach be adopted based on a hedonic regression estimated in a reference period of 4-quarters. This would be akin to, and coincide with, the annual updating of CPI weights. This periodicity of updating may be amended if it was found that improved hedonic estimates were derived over a longer period, though updating should preferably, at least every 3 years. The periodicity of the updates and the duration of the period over which the hedonic regression is updated should be considered using empirical data set to establish the extent to which regular updates and extended durations matter for RPI measurement.

It is recommended that the hedonic regression take a semi-logarithmic functional form to better facilitate consistence in the interpretation of the coefficients of the explanatory variables and provide, with appropriate aggregators, an equivalence between the hedonic imputation and repricing/characteristics approaches, which gives more credence to their use.

It is recommended that the index reference period, which equals 100, be the same as the period over which the hedonic regression is estimated.

3. On stratification and weights

The hedonic regression for the RPI should be estimated, and RPIs calculated, for individual strata by community, or other stratifying factors found to have a sufficient sample size (and therefrom, sizable weights), distinctive regression coefficients, and likely distinctive rental price trends. Weights for aggregating strata RPIs, should for CPI purposes, be the relative values of rental transactions. The aggregation weights should follow the normal principles of post-stratification weighting: to aim for an estimate of the relative population (household consumption expenditure on rents) as opposed to sample weights. Where sample sizes are sufficient, interaction effects for cantons within stratum should be included, where found to have a significant effect – using joint tests and centered coefficient estimates, as for the RPPI. Interaction effects should also be included where there are *a priori* grounds for them to be deemed relevant, for example to expect *Netlivingarea* for the RPPI to differ across *cantons*.

4. On regression diagnostics

A full set of regression diagnostics should accompany the analysis. A draft Note on the RPI sent to the FSO on April 22, 2020 provided details of the diagnostic tests and their implementation in R. A more detailed paper is being prepared. Initial results for the RPI were that the hedonic models were much less satisfactory in terms of diagnostic tests, than the models for the RPPI. While these results related to a constrained model over 29 quarters, preliminary results for a shorter period – the details of which I have not seen at the time of preparing this Report - found similar such problems. However, now that the data have been set up, hedonic models with a higher data frequency can be fully estimated and evaluated. The preliminary work with shorter durations of the estimation period also found that the estimated coefficients of many variables are not statistically significant, comparing unfavourably with the regression undertaken over the extensive 2010-2018 period. Instability of estimated coefficients over time may of course just reflect the changing reality of the hedonic model for rental prices and justify the need to not constrain the estimated coefficients over a long period. A full analysis, as proposed above, of the effect on regression diagnostics and also the ensuing RPIs is required.

It is recommended that a full set of regression diagnostics accompany the regression results. The (previously sent) Notes on regression diagnostics and draft paper that will accompany this Report clearly show how issues including multicollinearity, heteroscedasticity, normality of residuals do not badly impact on hedonic RPPI and RPI measurement if handled properly.

Further, there is a very real sense in which RPIs are provided by many countries with a minimal, if any, adjustment for quality changes. The extensive explanatory data set demonstrates a major innovation in this area.

It is recommended that a continuing development of data is a longer term objective. This should include the following variables that have proved useful in similar hedonic regression analyses: the communal area - its size and use (gym, meeting/party rooms, swimming pool, and so forth), and extent of concierge services such as a 24/7 front desk. Also, important will be a finer division of the locational cantons.

5. On Cook's Distance and other matters

The FSO's initial reaction to adverse BP and White tests for heteroscedasticity and related plots was to exclude over 4,200 observations[4] that have high Cook's distances. Given the impact of heteroscedastic errors can be mitigated by the use of an alternative robust estimator, as utilized by the FSO team, *it is recommended that this large-scale deletion would benefit from being revisited.*

On tax burden *(ledig_vok_vmk_dopmk_100_150_200_mean)*: similar considerations apply as to those noted for the RPPI.

III. Conclusions

I am impressed with the data and the hedonic model for the **RPPI** and the rigor with which the modelling is handled. The RPPI estimated and compiled by the FSO should be amongst the exemplars for European countries.

While the FSO is committing to a 3-year period for the estimation of its hedonic regression to firmly ground it, it is recommended that the estimation period be reduced to a 2-year or (preferably) single year period with the periodicity of updates to a chain-linked index taking place on a similar basis. This is to ensure the RPP is responsive to changes in property prices in a timely manner, something essential for macro-economic policy purposes. The use of a hedonic imputation approach is warranted – especially so if a semi-logarithmic hedonic specification is used - as would be the extension of weighted stratification and use of weights at the level of the individual property. As time goes by, a longer database will be become available to retrospectively empirically test the effects of different methodologies on the estimation and compilation of the RPPI to better ground practice as to which changes matter – are empirically justified.

It is well recognized that there are inherent difficulties in properly measuring an **RPI** for a CPI. A major problem is that substantial improvements to the property and (rental) price changes take place at the end of a contract, prices being sticky within the contract period. Further, country practice is to have the sample of property rents often rotated with new properties (of a different quality) replacing existing ones, to diminish non-response. This replacement is difficult to handle and the FSO is using a hedonic methodology to cater for such changes. This is amongst the best practice for CPI RPIs.

RPPIs and RPIs are in a continuing state of improvement as access to, and developments in, data become available and new techniques are developed. These new developments may in part arise from the results of empirical studies by the FSO on their data that evaluate the effects of new methodologies, such as a change in the period over which the hedonic regression is estimated and periodicity of updating, the regression. I can certify that the work undertaken by the FSO provides a sound and excellent basis for both the current measurement of RPPIs and RPI for Switzerland and their continuing development.

[4] 68, 409 degrees of freedom plus 93 explanatory variables for the excluded model compared with 72,663 df plus 93 explanatory variables: 72,663-68,409=4,254: nearly 6 percent of the sample,\.

References

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Annex 1: quarter-on-quarter hedonic imputation indexes with differing periods for the hedonic estimation and index reference=100.0

A quarter-on-quarter ratio of the RPPIs for say t on t-1 meaningfully yields:

$$(3a) RPPI_l^{t-1 \to t} = \left[\frac{\left(\prod_{i \in N^t} p_i^t\right)^{\frac{1}{N^t}}}{\left(\prod_{i \in N^0} p_i^0\right)^{\frac{1}{N^0}}} \div \frac{\left(\prod_{i \in N^t} \hat{p}_{i|z_i^t}^b\right)^{\frac{1}{N^t}}}{\left(\prod_{i \in N^0} \hat{p}_{i|z_i^0}^b\right)^{\frac{1}{N^0}}} \right]$$

$$\div \left[\frac{\left(\prod_{i \in N^{t-1}} p_i^{t-1}\right)^{\frac{1}{N^{t-1}}}}{\left(\prod_{i \in N^0} p_i^0\right)^{\frac{1}{N^0}}} \div \frac{\left(\prod_{i \in N^{t-1}} \hat{p}_{i|z_i^{t-1}}^b\right)^{\frac{1}{N^{t-1}}}}{\left(\prod_{i \in N^0} \hat{p}_{i|z_i^0}^b\right)^{\frac{1}{N^0}}} \right]$$

$$= \left[\frac{\left(\prod_{i \in N^t} p_i^t\right)^{\frac{1}{N^t}}}{\left(\prod_{i \in N^{t-1}} p_i^{t-1}\right)^{\frac{1}{N^{t-1}}}} \div \frac{\left(\prod_{i \in N^t} \hat{p}_{i|z_i^t}^b\right)^{\frac{1}{N^t}}}{\left(\prod_{i \in N^{t-1}} \hat{p}_{i|z_i^{t-1}}^b\right)^{\frac{1}{N^{t-1}}}} \right]$$

This follows the well-known result that a ratio of two Lowe indexes is a Lowe index.

The second term is a meaningful quality-mix adjustment because the characteristics change, but does not have a clear equivalence to equation (1) which would require period b (2017-19)=100:

$$(4) \ldots\ldots\ldots\ldots RPPI_l = \frac{\left(\prod_{i \in N^t} p_i^t\right)^{\frac{1}{N^t}}}{\left(\prod_{i \in N^b} p_i^b\right)^{\frac{1}{N^b}}} \div \frac{\left(\prod_{i \in N^t} \hat{p}_{i|z_i^t}^b\right)^{\frac{1}{N^t}}}{\left(\prod_{i \in N^b} \hat{p}_{i|z_i^b}^b\right)^{\frac{1}{N^b}}} = \frac{\left(\prod_{i \in N^t} p_i^t\right)^{\frac{1}{N^t}}}{\left(\prod_{i \in N^t} \hat{p}_{i|z_i^t}^b\right)^{\frac{1}{N^t}}}$$

Note $\left(\prod_{i \in N^b} p_i^b\right)^{\frac{1}{N^b}}$ in the denominator of the first term is simply the geomean of prices in period b. [This is calculated in R by taking the exponent of the arithmetic mean of the log of prices.] $\left(\prod_{i \in N^b} \hat{p}_{i|z_i^b}^b\right)^{\frac{1}{N^b}}$ in the denominator of the 2nd term is the geomean of the **fitted** prices from the regression. A fortunate feature of OLS is that the mean (in this case of the logs) of the actual prices is equal to the mean of the fitted values, $\left(\prod_{i \in N^b} p_i^b\right)^{\frac{1}{N^b}} = \left(\prod_{i \in N^b} \hat{p}_{i|z_i^b}^b\right)^{\frac{1}{N^b}}$. So on division, they cancel leaving us with the right-hand-side of equation (4).

A similar simpler formulation to equation (3a) drops out when comparing quarter t with t-1.