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Probabilistic sampling strategy as a means of improving quality of price indices

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Abstract

In spite of theoretical inferiority, a large majority of statistical institutes use non-probabilistic sampling techniques in price surveys. The main disadvantage of non-probabilistic sample design is that the risk of biased results is increased. Attempting to handle this risk in the domain of service producer price indices (SPPI) of professional services, the Croatian Bureau of Statistics (CBS) developed an innovative methodology and implemented it relying on the probability proportional to size (PPS) sample design. The purpose of the paper is to evaluate the impact of the probabilistic sampling strategy on the quality of price indices as shown in the case of SPPI for professional services at the CBS. The paper outlines respective methodological upgrading of SPPI compilation at the CBS, including also the method for variance estimation. The effect of the probabilistic sampling on SPPI is analysed by comparison with traditional purposive sampling surveys. The quality of SPPI based on the probabilistic sample approach is examined by coefficients of variation and confidence intervals.

Keywords: accuracy, price index, probability sampling, weights design.

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Introduction

Service producer price indices (SPPI) are the youngest member of the family of price indices, which are one of the most known and widely used products of official statistics. Purpose of SPPI is to trace price movements that reflect the supply and demand conditions in the service markets (OECD, Eurostat, 2014).

SPPIs serve two main functions. The first is to provide an indication of price changes by producers of services, and therefore it is used as an indicator of inflationary pressure. The second is to provide a suitable deflator of nominal values of output or intermediate consumption or the compilation of production volumes in the national accounts (OECD, Eurostat, 2014). Considering the role of SPPIs in macroeconomic and business analysis and in compilation of key national aggregates the quality of these indicators are of utmost importance, in particular quality dimension “accuracy”. Thus, the data of price indices used as deflators in compilation of GDP in constant prices for service sector influence 55% of volume of GDP in Croatia (Croatian Bureau of Statistics, 2017).

Errors, which impact the accuracy of SPPI’s could occur at any stage of the production process. In this paper we will focus on the impact of sampling techniques on the accuracy of SPPIs. Data on service prices are mainly collected by sample surveys based on two stage sample procedure: first, the observation units (enterprises) and then, the services and transactions to be priced are selected into the sample. The selection of observation units and services can be done using either probabilistic methods or non-probabilistic ones. The producer has to be aware that using non-probabilistic methods introduces bias in the indices, which is very difficult to be estimated. Risk of bias is low in the case when surveyed population is highly heterogeneous in the sense that small number of large units contribute a majority of the total of certain key characteristic (e.g. turnover). If, on the other hand, surveyed population is more homogeneous, meaning that there is large number of smaller units that significantly contribute to the total value of the population characteristics and additionally these small units show different price behaviour, bias introduced by the non-probabilistic approach, can be quite significant. Nevertheless, in spite of theoretical inferiority of non-probabilistic methods, in practice mainly non-probabilistic sampling techniques are used for both, selection of observation units and services (ILO et al., 2004a; Eurostat, 2010). Croatia is one of the few European countries, which practice probabilistic sampling approach in price statistics.

Literature review indicates that sampling issues in the context of index numbers were investigated mainly for consumer price indices (Reinsdorf, Triplett, 2009; Heravi, Morgan, 2014) where sampling context is different and focused on lower level of the selection of commodities. The specific problem of SPPI bias due to prevailing practice of cut-off sampling with inclusion in sample only big firms though numerous small or even micro firms dominate and create major part of industry’s output has not attracted particular interest of researchers so far. (Such industries are known in theory of industrial organisation and market analysis as industries with low concentration (Khemani, Shapiro, 1993).

Some researchers have dealt with issues of SPPI probabilistic sampling, but not in relation to real data based on non-probabilistic surveys (Wingren, 2009; Lothian, Patak, 2007). Also, SPPI manual is not very instructive regarding sampling issues and it refers mainly to producer price index manual (OECD, Eurostat, 2014; ILO et al., 2004b).

The purpose of the paper is to evaluate the impact of probabilistic sampling strategy on quality of price indices. Our research hypothesis is that in service industries characterised by low concentration, inclusion of small units by random sample could improve accuracy of SPPI. This hypothesis was examined for SPPI for two professional service industries in Croatia ("Architectural and Engineering Activities and related Technical Consultancy" and "Advertising").

The paper is structured into six sections. After this introductory section, methodological framework of compilation of SPPI at CBS is given, describing shortly basic procedure of SPPI compilation at CBS and discussing general rationale for non-probabilistic sampling. In the next section specific reasons for inclusion of probabilistic sampling for SPPI are illustrated by two professional service industries. Then methodological upgrading of SPPI compilation induced by probabilistic sampling is defined. Central section presents results of statistical analysis of effects of probabilistic sampling on SPPI for the two professional service industries. In the concluding section, the main research findings are summarised.

Methodological framework of compilation of SPPI at CBS

In the period from 2008 - 2016, SPPI for 21 service industries were developed and implemented into regular production at CBS, for five of them with inclusion of probabilistic approach.

For each service industry specific methodology has been developed considering its characteristics of output, of market with price mechanism and data availability, but respecting general methodological guidelines (OECD, Eurostat, 2014), the EU regulations on short-term statistics (European Parliament, 1998, 2005) and common conceptual framework of SPPI production developed at CBS (Croatian Bureau of Statistics, 2015). Essential feature of SPPI methodology at CBS is annual update of weights, which is theoretically superior solution compared to fixed weights (ILO et al., 2004b, Eurostat, 2012).

Backbone of the common conceptual framework of methodology is the basic procedure for SPPI compilation as defined by system of index formulas in several stages.

Step 1: Compilation of ratio (individual price index for a service (u) of service group (g) for enterprise (h) in particular quarter (q) of year (y).

$$Ip_{ugh}^{q,y/4,y-1} = \frac{\mathrm{p}^{q,y}}{\mathrm{p}^{4,y-1}} \quad (1)$$

The last quarter of previous year *(4,y-1)* is recommended base period for price indices in the case of annual update of weights (Eurostat, 2012).

Step 2: Calculation of a simple (unweighted) price index for services within the same service group at enterprise level using Jevons formula (unweighted geometric average). This index relates to an elementary aggregate (e.g. group service in an enterprise). Use of Jevons formula at the level of elementary aggregate is supported by index numbers theory (ILO et al., 2004b, 2004a).

$$Ip_{gh} = \sqrt[n_{gh}]{Ip_{gh1} \cdot Ip_{gh2} \cdots Ip_{ghn}} \quad (2)$$

Step 3. Calculation of price index for service groups using price indices of service groups by enterprises (as elementary aggregates) and weight them by share of turnover of this group in enterprise turnover for this activity. Weighted arithmetic average is used as a compilation formula, which approximates Laspeyres index (OECD, Eurostat, 2014):

$$p_g^{q,y/4,y-1} = \frac{\sum_{h=1}^{H} Ip_{gh}^{q,y/4,y-1} W_{gh}}{\sum_{h=1}^{H} W_{gh}} \quad (3)$$

Step 4 Calculation of price index for the activity as a whole using price indices of service groups and corresponding weights calculated as a sum of turnover for group services by enterprises:

$$Ip'^{y/4,y-1} = \frac{\sum_{g=1}^{G} Ip_g^{q,y/4,y-1} W_g}{\sum_{g=1}^{G} W_g} \tag{4}$$

Symbols used: $h = 1,2,\dots,H$ (number of enterprises producing service within group g); $g = 1,2,\dots,G$ (number of group of services g in activity SPPI); n_{gh} = number of services for group g in enterprise h; q, y = current quarter q of year y; $q-1, y$ = previous quarter of year y; $4, y-1$= 4th quarter of previous year (base period); W_{gh} = weight at period $y-1$ for group g in selected price of reporting unit h based on turnover (basic weights); W_g = weight at period $y-1$ for group g; p_{ugh} = price of product u of group g in selected price of reporting unit h.

This system of formula is based on traditional economic approach of index calculation (Allen, 1975; Diewert, Nakamura, 1993), which implies that price movement of the sampled units (or services) is representative for the price movement of the population. Price movement, expressed as indices, must be weighted by economic meaning of units (or services) measured by output variable, usually by turnover. Following the rationale of traditional approach, frequent mode in compilation of price indices in general and also for SPPI is to include into sample some units (usually the biggest ones) relying on some non-probabilistic criteria of selection.

Such an approach is justified when the surveyed units cover dominant share of market in terms of turnover and it is likely that prices of uncovered units, (i.e. units that have probability 0 to be included in the sample), do not behave substantially different.

At CBS, both conditions were examined for each service industry by market analysis prior to development of SPPI methodology. In the next section we summarise main findings for service industries "Architectural and Engineering Activities and related Technical Consultancy" and "Advertising". Full market analysis was carried out at CBS in 2014 within project Technical Assistance of Business Statistics and Upgrading of Data Collection System 1.2.1 (Croatian Bureau of Statistics, 2014). These two service industries were selected as the cases for analysis of impact of probabilistic sample design on SPPI because they were the first where the probabilistic approach was used and have the longest SPPI time series, from 2015 onwards.

Key market characteristics of analysed service industries

Architectural and Engineering Activities and related Technical Consultancy (ARCH/ENG) is coded by international standard classification of activities NACE Rev.2 and by Croatian National Classification of Activities (NKD) as activity group M 71.1. It consists of two activities classes: M 71.11 Architectural activities and M 71.12 Engineering activities and related technical consultancy.

In Table 1, the key features of the market of selected service industries in Croatia are presented by distribution of enterprises and turnover by size (persons employed) for classes M 71.11 and M 71.12 in Croatia. The distribution is presented for year 2016.

Architectural services are provided mostly by rather small enterprises with less than 10 employees. In engineering services some large enterprises operate, but small enterprises dominate. Activity class M 71.12 Engineering activities and related technical consultancy is more important than M 71.11 Architectural activities as the majority of enterprises (76.3%) and of turnover (89.9%) of M 71.1 were classified into class M 71.12 in 2016.

Advertising industry is defined as activity group M 73.1 in NACE Rev.2 and includes two classes: M 73.11 Advertising and M 73.12 Media Representation.

Table 1 Distribution of enterprises and turnover by size of enterprises for M 71.11 and M 71.12 in Croatia

Persons employed	71.11 Architectural activities			71.12 Engineering activities and related technical consultancy		
	Enterprises		Turnover %	Enterprises		Turnover %
	Number	%		Number	%	
0-4	1,162	89.5	59.9	3,330	79.8	28.9
5-9	108	8.3	23.8	549	12.2	22.9
10-19	24	1.9	11.3	199	4.8	17.2
20-49	4	0.3	5.0	72	1.7	15.7
50-99	-	-	-	15	0.4	8.3
100-249	-	-	-	5	0.1	4.1
250 and more	-	-	-	2	0.1	2.9
Total	1,298	100.0	100.0	4,172	100.0	100.0

Source: Statistical Business Register, 2016.

These two classes deal with quite different services. The first activity class consists of services making or preparation of advertising and includes all the creative work around creating a commercial. The second class is setting up or presenting a commercial: advertising can be set up or presented in various media such as magazines, newspapers, radio, television, online, large tables and leaflets.

Table 2 Distribution of enterprises and turnover by size of enterprises for M 73.11 and M 73.12 in Croatia

Persons employed	73.11 Advertising			73.12 Media Representation		
	Enterprises		Turnover %	Enterprises		Turnover %
	Number	%		Number	%	
0-4	1,379	88.0	24.1	145	84.8	21.3
5-9	102	6.5	16.2	18	10.5	5.9
10-19	52	3.3	19.6	4	2.3	17.7
20-49	27	1.7	30.1	3	1.8	44.3
50-99	4	0.3	5.2	1	0.6	10.8
100-249	1	0.1	2.4	-	-	-
250 and more	1	0.1	2.4	-	-	-
Total	1,566	100.0	100.0	171	100.0	100.0

Source: Statistical Business Register, 2016.

This activity is highly scattered i.e. there are very few medium and large units, and a significant number of small units that generate most of turnover. Comparing two classes, class 73.11 and class 73.12, the first one is more important because it covers 79% of turnover and 90% of employees.

From the data, presented in Table 2, it can be clearly seen that the distributions in the respective activities are far from being dominated by the small number of large units. For instance, if we would want to cover 75% of the total turnover in the activity group M 71.1, we would have to take approx. 20% of the units in the frame and if we would aim to cover 75% of the total number of employees, we would have to take even approx. 40% of the units. Hence, these figures indicate that the "scattered" population of small units is not negligible and that the usage of the probabilistic sample, aiming at covering that part of the population, is a reasonable choice in this case.

Implication of probabilistic sampling for SPPI compilation

The sample frame for ARCH/ENG and ADV consists of enterprises from Croatian Statistical Business Register with the main activity M 71.1 or M 73.1. A small part of the population that has a negligible share of key variables' values was additionally excluded from the frames and consequently from the sampling procedure.

Due to the significance of the small enterprises in these activities, sample design is set-up as combination of probability sampling for small enterprises and census (take-all approach) for large enterprises. The class of large enterprises was selected by taking the units that have more than 20 employees or generate more than 50 million kuna of turnover.

Random sample of small units was selected by using the usual design in the case of business surveys: the stratified one-stage sampling. The stratum of small enterprises was hence additionally stratified according to the NACE class (4-digit code) and the random sample was selected by using systematic probability proportional to size (PPS) sampling. Number of employed persons was used for implicit stratification. Turnover was used as a size variable in PPS approach.

In this way, for activity ARCH/ENG 189 units were selected in the sample of pilot survey for 2014, 104 of them with certainty, and for ADV 107 units were selected, 38 of them with certainty.

Selection of units into SPPI surveys by using probability sample demanded appropriate amendment of SPPI index compilation in terms of defining the weights. There are two types of weights in SPPI compilation: basic weights and modified weights.

Basic weights are weights based on turnover data from every reporting unit. Data on turnover are fulfilled in the questionnaire form in the first quarter of the year and are related to the turnover of previous year. Final index for the activity could be calculated using only these basic weights (see: formula (3) and (4) of basic procedure).

Modified weights are used when random sample approach is used for the selection of the observed units. These weights are obtained by combining basic weights and the random sample grossing-up factors calculated by strata. Grossing up factor for a stratum was calculated through the following steps:

- Sample design weights calculation. Sample design weights are determined as the inverse value of the inclusion probability. Since the PPS sampling was used (with turnover as size variable), design weights were determined as the relative share of turnover for certain unit inside the stratum, multiplied by the number of selected units in stratum.
- Non-response adjustment. Non-response adjustment coefficient is calculated by taking the ratio of sampled units to sum of responded and out-of-scope units in each stratum.
- Calibration. With the calibration procedure weights are corrected in such way that for the chosen auxiliary variables the weighted sums for the responded units equal to the known population values. In our case turnover was chosen as the auxiliary variable. Because of the large number of out-of-scope units, the "frame turnover total" had to be adjusted to take into account this fact.

Compared to basic weights, modified weights increase relative importance of smaller, randomly selected units (inversely proportional to turnover) and of all units in strata with higher non-response and higher share of misclassified units.

If we would strictly consider the price index as the complex statistical estimator, we would face very demanding task for standard error estimation (Wingren, 2009). To make this procedure more feasible in the regular statistical production, the "classical analytical variance estimation approach" (Wolter, 1985) was slightly adopted to fit the specific needs. We accepted two "simplification assumptions". Firstly, we assumed that the data were collected by using the cluster sample approach and that the enterprises, selected at the first stage, reported all the service groups at the second stage. Secondly, we assumed that individual price index for a service or service group was a direct observed value. By such approach, we considered estimated index as the estimation of the (weighted) mean of price indices, what made the variance estimation quite straightforward task.

Estimated index on the level of the service group and on the level of the whole activity is calculated simply as the weighted average of individual price indices for service groups and the mean is taken as the estimator in the procedure of standard error estimation.

When discussing accuracy of price indices, we have to keep in mind that in the theory of the inferential statistics standard measure of the error of statistical results (mean square error) is composed of two components: standard error and bias. In the situation when we are considering the non-probability versus probability sampling approach, we are typically dealing with the trade-off between the bias and sampling error. In the continuation we will present some results of this trade-off in the case of the SPPI indices, introduced and described in previous sections. We have to stress out that the analysis focuses only on empirical results, the theoretical framework of this problem is not considered since it is beyond the scope of this paper.

Results

As we pointed out in previous sections, random sample of "small units" was introduced to reduce the bias, caused by the fact that one part of the population has 0 probability of being included into sample in the sampling approach, which is currently the prevailing practice (e.g. cut-off sampling) when the selection method for the SPPI calculation is in question. On the other hand, with the introduction of probability sampling, each index has a certain standard error, but this error can (contrary to the bias) be (unbiasedly) estimated from the survey data itself. The relationship between sampling error and bias could be roughly studied by comparison of SPPIs compiled with probabilistic and non-probabilistic approach. Therefore, we calculated two versions of quarterly chain indices (comparison base is previous quarter) for ARCH/ENG and for ADV for period 2015-2017. For the first version (probabilistic approach) we took all sampled units (probabilistic sampled and take-all units) and used modified weights (PS/MW). For the second version (traditional approach) we took only take-all units and used the basic weights (TA/BW).

Both versions of SPPI indices are presented in Table 3 and in two graphs (Figure 1 for ARCH/ENG, Figure 2 for ADV).

SPPI precision was studied by standard errors and respective coefficients of variation. Both indicators were calculated for the probabilistic SPPIs - PS/MW (which includes also the random sample of "small units") by the procedure, described in section 4 and by using two different schemes of sample rates. By the version 1 we used the "original sample rates" (by strata), hence the sample rates as they were introduced by sampling. With this implementation, sample rates for take-all units are 1 and consequently these units don't contribute to standard error, although the data of these units were "normally" taken into account when calculating indices. By the version 2 we used the recalculated sample rates, taking only the responding and out of scope units as sampled units. With this implementation, also the take-all part of the data contributes to the standard error, if we don't get the response from all these units.

The estimated coefficients of variation for chain indices are presented in Table 4.

Table 3 Impact of sampling approach on SPPI indices, Architectural and Engineering Activities; Advertising, quarterly chain indices, Croatia

Current period of chain index	Architectural and Engineering Activities		Advertising	
	probabilistic	traditional	probabilistic	traditional
	PS/MW	TA/BW	PS/MW	TA/BW
Q1 2015	97.13	98.71	99.30	99.85
Q2 2015	100.17	97.78	104.75	106.46
Q3 2015	100.20	102.71	99.04	98.04
Q4 2015	101.76	101.89	105.23	107.39
Q1 2016	100.38	100.16	97.21	98.03
Q2 2016	101.26	98.91	99.96	100.89
Q3 2016	100.84	101.01	98.41	98.89
Q4 2016	99.77	103.33	101.42	102.24
Q1 2017	98.87	98.68	98.56	98.10
Q2 2017	99.48	98.76	101.73	102.54
Q3 2017	100.74	101.25	99.82	99.35
Q4 2017	99.30	99.85	100.18	101.40

Source: authors' calculations based on CBS, 2015, 2017.

Table 4 Coefficients of variation by two different schemes of sample rates

Current period of chain index	Architectural and Engineering Activities		Advertising	
	Coefficients of variation		Coefficients of variation	
	Version 1	Version 2	Version 1	Version 2
Q1 2015	2.9%	2.8%	1.2%	1.1%
Q2 2015	1.9%	1.7%	1.2%	0.8%
Q3 2015	1.9%	1.6%	2.1%	1.8%
Q4 2015	3.1%	2.8%	1.5%	1.2%
Q1 2016	0.8%	0.2%	1.6%	1.6%
Q2 2016	0.8%	0.3%	1.5%	1.5%
Q3 2016	0.8%	0.2%	1.0%	0.9%
Q4 2016	1.3%	0.3%	1.2%	1.1%
Q1 2017	1.4%	1.1%	2.7%	2.6%
Q2 2017	0.8%	0.6%	1.4%	1.3%
Q3 2017	0.9%	0.6%	1.3%	1.1%
Q4 2017	1.0%	0.6%	0.5%	0.5%

Source: authors' calculations based on CBS, 2015, 2017.

We calculated lower and upper limit of 90% confidence interval for the regular SPPI chain indices (PS/MW), by using version 1 of standard errors and taking z-score of 1.645. Although we consider version 2 as more correct procedure for standard error estimation, we opted here for version 1. The reason is that we want to present only impact of sampling procedure, ignoring the impact of the phenomenon of non-response, which would occur and should be dealt with in both sampling scenarios. We plotted the time series of chain indices with confidence intervals together with the time series of take-all indices. The graphs for both activity groups are presented in Figure 1 and Figure 2.

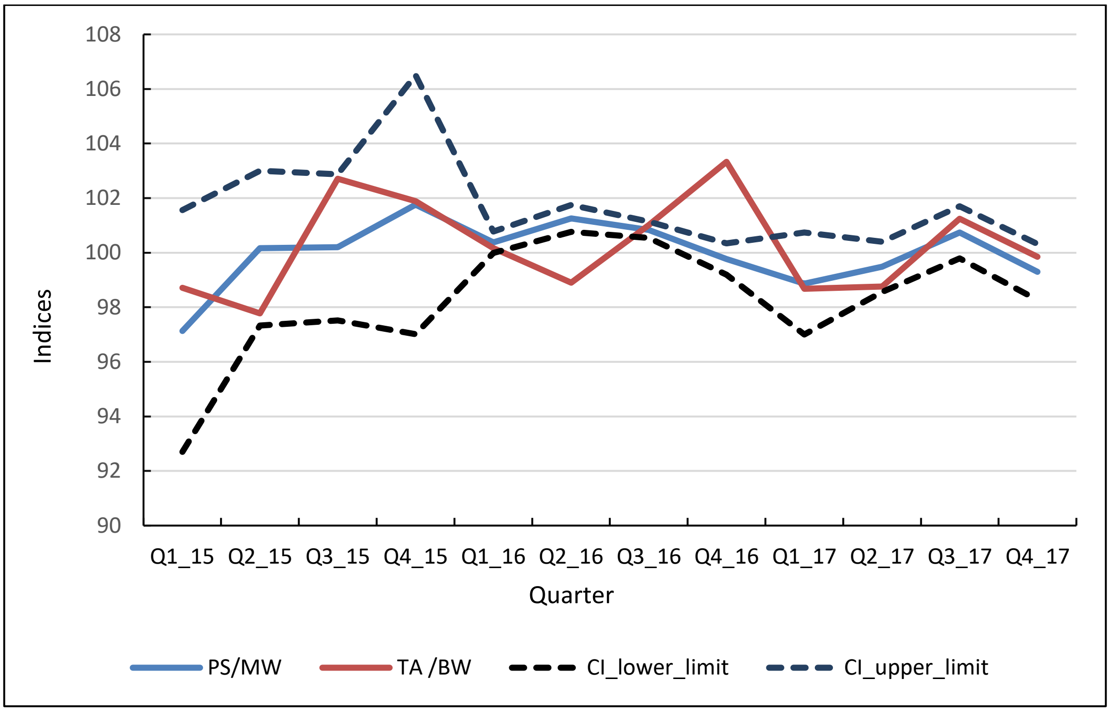

Figure 1 Quarterly series of two SPPI chain indices with CI limits for activity M 71.1-Architectural and engineering activities

Source: authors' calculations based on CBS, 2015, 2017.

In the case of ARCH/ENG, traditional 'take all' (TA/BW) SPPI fluctuates notably from quarter to quarter, indicating large volatility of the estimates. On the other hand, probabilistic SPPI (PS/MW) exhibit smoother price changes, indicating larger stability of the estimates.

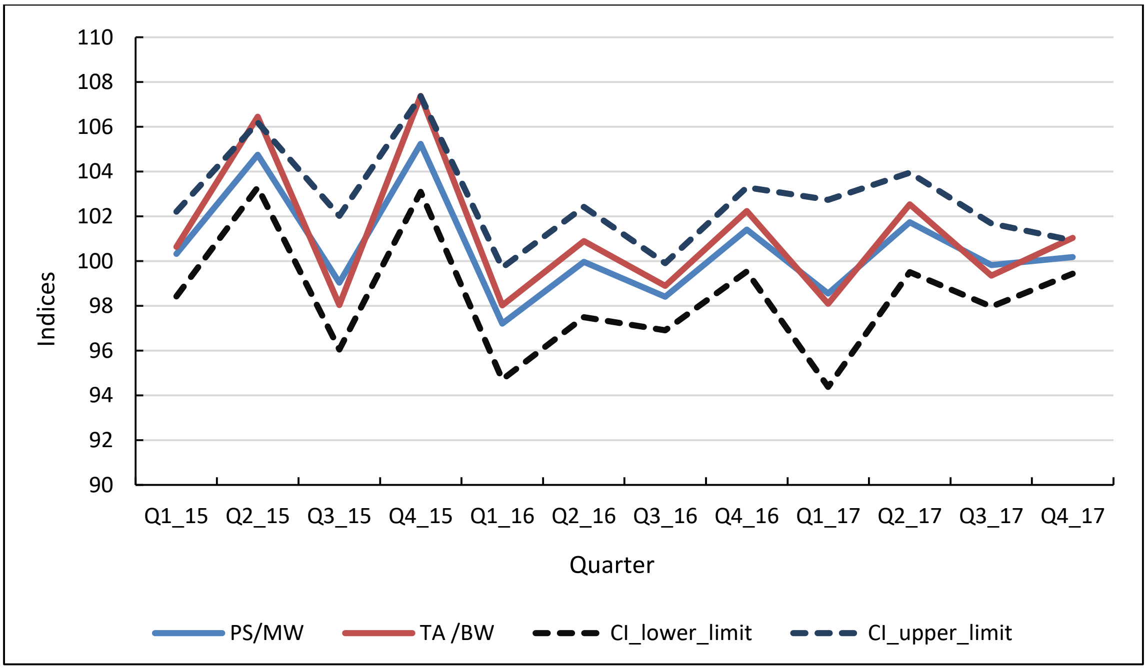

Figure 2 Quarterly series of two SPPI chain indices with CI limits for activity M 73.1 – Advertising activities

Source: authors' calculations based on CBS, 2015, 2017.

In ADV, both SPPI show very similar price movement, but practically in all periods PS/MW is below TA/BW, indicating that there could be slight overestimation due to the omission of the sub-population of small enterprises.

Conclusion

In the paper we present the usage and consequences of the usage of the probabilistic sampling approach in the case of service producer price indices at the Croatian Bureau of Statistics. In the first part of the paper we described the main methodological aspects of the indices calculation procedure, focused especially on those, induced by the random sampling approach. The second part of the paper is dedicated to the analysis of the impact of the sampling selection method on statistical results. The analysis gives some tentative conclusions that are summarised below.

The impact of introduction of the random sampling is much more evident at the level of chain indices in the case of activity 71.1 (ARCH/ENG). We see two main reasons for that. The first reason is the fact that the population is more "scattered" in the case of activity 71.1, meaning that "small units" have larger impact in this activity. The second reason is larger variability of prices in this activity, meaning that the observed phenomenon is more sensitive on the method, used for selection of observed units.

Contrary to ARCH/ENG, inclusion of small units by random sample does not re-shape price movement in ADV, but it signals the upward bias of take all approach indices for the whole period. On the other hand, index series of both industries, obtained on the basis of the random sample approach shows lower volatility than the series obtained on the basis of the "take-all approach".

The take-all indices fall out of the confidence interval of the random sample indices in the cases, when there is a slightly more pronounce oscillation of the prices. This indicates that the significant bias of the take-all sample could occur in the case when we face the more dynamic price movement.

These findings show that in industries with low concentration the ignorance of service prices of small units could distort price indices notably. We have to stress out that the analysis focuses only on empirical results of two service industries. Generalisation of the results would require extension of empirical research on other industries and longer time series and verification of findings by index numbers theory.

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