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The Recovery of the Input-Output Analysis in the Czech Republic

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Abstract

The input-output analysis has a long tradition in the former Czechoslovakia starting in the 1960s. These models were originally used for central planning and price re-construction during socialism. Since the 1970s, there have been three sets of tables, for Czechoslovakia, the Czech Republic and the Slovak Republic. After 1989, input-output models gained a label of socialist planning instrument and they were mostly abandoned in Eastern countries. On the contrary, sophisticated input-output models became accessible for the most researchers in the West because of common usage of personal computers. Matrix computations that took months in the past became available to everyone. Alongside with the supply of input-output tables of the EU countries, also researchers in the Central and East Europe started to use these sets of models again. In the recent time, the input-output models are widely used both on national and international level, ranging from private agencies to the OECD. Nowadays, the recovery of Leontief models and theory has been used in the Czech Republic, as well. Such models have become a standard part of the research for macroeconomic, environmental, regional and similar purposes.[2]

Keywords	***JEL code***
Input-output analysis, supply and use tables, national accounts	*C67, E20*

INTRODUCTION

The history and objectives of the input-output analysis are fascinating. The ideas that led people to the construction of the input-output model, predictions and assessment of the development of the economy, grew into different branches of economics and among them we cannot omit Leontief' input-output analysis. The history of the concept and its applications around the world from the early 1920s to the contemporary sophisticated models shows us how a relatively simple concept at the beginning can be extended and searched for by many followers.

The roots of input-output tables are usually located to the time of Francois Quesnay, a Belgian, acting in France in the 18th century and, among other things, he brought Tableau Économique. W. Leontief

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[2] The paper resulted from the invited lecture at the 22nd scientific conference *Application of Mathematics and Statistics in Economics*, held in Kutná Hora, Czech Republic, during 28.8–1.9.2018.

also followed the General Equilibrium Theory developed by L. Walras. Nowadays, it is pretty difficult to identify whose ideas were implemented at first. It is obvious that Human efforts for generalising and graphical description of the economic flows were perpetual and extended dynamic gained at the beginning of the 20th century. The link between production, consumption and wealth is an outstanding issue and input-output based tools are often used for similar analyses. The production function that stands behind the input-output model cannot be omitted, neither can other assumptions. The potential of input-output tables is extraordinary since a detailed description of the economy allows connection between many different areas of human being. Beside economics, a lot of different input-output based applications can be found in environmental area or social science.

There is probably no single author of input-output tables since Leontief presented input-output tables but similar tables were used in the Soviet Union, as well. Soviet scientists as Vladimir G. Groman, Pavel I. Popov and Lev N. Litoschenko were working on the description of the centrally planned economy and construction of the first five-years plans. Similar processes used for the systematic description of the economy were applied in Nazi Gemany, as well, see Staeglin and Fremdling, 2012. Anyway, the milestone of input-output analysis came along with the work of Wassily Leontief despite all disputations about the invention of input-output tables. However, the invention of input-output analysis can be hardly disputed. The work of W. Leontief awarded by Nobel Prize in 1973 went into history of economics. His definition of production function and fixed input constraints have been used as a basis for future more or less flexible econometric models. Among Leontief's pupils, we can find such great economists as Rober Sollow, Vernon Smith, Paul Samuelson and others. There is also a lot of literature devoted to the input-output analysis, such as Miller and Blair (2009).

1 FOUNDATIONS OF THE INPUT-OUTPUT TABLES AND ANALYSIS IN THE CZECH REPUBLIC

The roots of the input-output analysis are connected with central planning in the former Czechoslovakia in the late 1950s. The first practical estimates were realised in the 1960s when the Federal Statistical Office published symmetric the input-output tables for former Czechoslovakia. These so-called commodity-by-commodity or commodity-by-organisation structural balances were compiled every five years. It was predominantly a tool for central planning processed in high detail (hundreds of commodities) but the computational issue became one of the most relevant problems associated with the use of this tool. The demands for dimension due to planning purposes became very challenging. The planning commission intended to use input-output tables mainly for price reconstructions (Sixta, 2015) and central planning in line with the Soviet model. Separate input-output tables for the Czech Republic then used for the Czech Socialist Republic began to be compiled from the 1970s. The first set was published for 1973, see Sixta (2013). The detail of the breakdown of individual Czech and Slovak input-output tables was lower than the federal one. Initial attempts for combination of western System of National Accounts and socialist Material Product System failed, see Arvay (1992) and, later, former Czechoslovakia and other socialist countries switched to national accounts.

At the begging of the 1990s, when the previous statistical system – System of the Balances of National Economy was abandoned and the System of National Accounts began to be implemented, a big gap appeared in the use of the input-output analysis. The stigma of the planning tool that input-output tables gained from the socialist era was difficult to overcome. Moreover, the problem of the data availability was also serious. The set input-output framework was often regarded as a supplementary issue of national accounts rather than core business. To date, this is very much reflected in the priorities of statistical offices.

The Czech Statistical Office published the first set of input-output tables in 1995 for the Czech Republic for 1992. Since then the publication of supply and use tables at purchasers' prices has been started. The Czech Statistical Office had been working on the incorporation of supply and use tables into regular compilation process, but these tables were compiled seldom and later finished for 1995 and 1997.

The Czech Statistical Office carried out the first comprehensive revision of national accounts in 2004 and since then input-output tables are fully incorporated into Czech national accounts. These tables are compiled less frequently than in obligatory five year period. Currently, the Czech Statistical Office publishes supply and use tables (SUTs), symmetric product-by-products tables and symmetric industry-by-industry tables at basic prices. These tables are also available for total economy, the use of domestic output and the use of imported products. Since 2014 when the latest revision took place, new economic elements such as processing services, merchanting and re-exports have been introduced into national accounts and input-output tables, see Musil and Cihlář (2016). These latest amendments are easy to confuse scientists who are used to traditional input-output tables. Some of changes very often offer a strange view on the economy on the first sight. In many cases the efforts for statistical purity leads to very complicated statistical outcome and the figures lose their explanatory purpose.

2 WHAT IS A MODERN INPUT-OUTPUT TABLE?

Lots of experts think that the input-output table is still the same as it was in the 1930s or at least that some of the changes and updates done were relatively negligible. From the technical point of view, they are right, the table is the same, and it still has three quadrants. However, the content has changed

Figure 1 Symmetric Input-Output Table for 1973, Czech Republic, CSK mil.

Industry	Intermediate consumption (IC)				TOTAL (IC)	Personal consum-ption	Social consum-ption.	Investment + inventories	Export	Transfers with Slovakia	Losses and differences	Uses
	Agric.	Industry	Constr.	Services								
Agriculture	20 837	34 629	129	60	55 655	11 673	1 866	2 742	1 575	–1 249	1 553	73 815
Industry	17 602	302 596	28 775	23 864	372 838	121 141	24 006	36 826	73 255	4 130	–1 502	630 694
Construction	503	2 706	1 923	2 306	7 437	697	7 455	54 440	918	–70	–101	70 776
Services	2 690	39 115	6 414	9 420	57 638	8 963	1 650	1	18 037	0	–214	86 075
Total IC	41 631	379 045	37 242	35 650	493 568	142 473	34 977	94 008	93 785	2 811	–263	861 359
Depreciation	2 626	14 687	1 241	7 132	25 686							
Wages	20 058	52 079	14 066	23 427	109 630							
Other net production	4 558	30 481	9 343	14 014	58 396							
Profit	–2 013	48 590	7 097	917	54 591							
Sales tax	99	38 469	1	0	38 568							
Gross value added	25 329	184 306	31 747	45 490	286 872							
Output	66 960	563 351	68 989	81 141	780 440							
Import	6 854	67 342	1 787	4 934	80 918							
Resources	73 814	630 694	70 776	86 075	861 358							

Source: Sixta (2013)

significantly in line with the development of national accounts and development of the measurement of the product (Sixta, 2015).

The question what and how it should be measured has been discussed just from the foundation of input-output tables. Input-output tables describe production, i.e. output in national accounts methodology[3] and therefore core issue lies in the definition of production. The scope of human activities defining range of production has been still developing. From a relatively narrow set of activities in F. Quesnay table to very broad categories of output that are not traded on the market and just imputed. Some activities are easily measured such as selling goods, providing service but some of them are measured with difficulties such as imputed rentals, agriculture self-supply or outcomes of publicity available research.

It can be easily demonstrated on the case of socialist and modern input-output table. In line with the state ideology of Marxism, so called non-productive sphere providing non-market services or pseudo-market services for households were not measured. It means that about 1/3 of domestic products was not covered even though the table look like the same as used in the West, see Figure 1.

It can be mentioned that some tricky situation appeared when studying these tables. For example, telecommunication services were relatively expensive and profitable in the late 1970s and 1980s and despite that, they were regarded as non-productive if purchased by households. Such tricky issues complicated statistical picture of the economy as well as data compilation. In this particular case it means that the profit and loss statements of the telecommunication company had to be artificially divided into two parts. We could find many different examples how the measurement issues had to be put in line with the state ideology.

When we compare socialist input-output table with the modern one, we will not find significant difference on the first sight, see Figure 2.

In fact, the crucial difference lies in the definitions of indicators within the cells of the input-output table. The scope of national accounts has been constantly increasing in line with the development of the society. Currently, the definition of production is very wide and the same stands for the definition of final use. It is not useful to recall all the changes in national accounts' standard and it is important to focus on the latest one.[4] The SNA 2008 and its European modification ESA 2010 brought some important changes that affected the input-output tables on a large scale. At least the following two changes influence input-output tables significantly.

ESA 2010 and SNA 1993 brought the most notable changes connected with **wider definition of investments** (asset borderline). Gross capital formation currently comprises intellectual assets such as expenditure on research and development, software, databases etc. In practice, it means that new products appeared in the gross capital formation column for particular rows (products).

The second change is connected with different **treatment of foreign trade**. Incorporation of re-export means that the country can export products even though these products are not produced within the country. Thus, we can have zero output and non-zero exports (and imports). This change is not very logical for input-output tables' users, but it reflects the pure change of the ownership of goods. This affects only the table for totals. The tables describing the use of domestic output are not influenced. Therefore, more issues that are serious are connected with the methodical change of the recording of processing. Processing is the activity when the producer is working on the someone else´s goods. Despite that, according to SNA 1993, the goods entered into intermediate consumption and then into output. Producer was selling the goods at higher price composed from material costs and producer margin. Similarly, it was recorded in imports and exports. However, SNA 2008 requires that only producers´ margin should be recorded and exported. Therefore, a significant change in the notion of both foreign trade and output

[3] The question when input-output tables became a standard set of official national accounts is discussed in Sixta (2015).
[4] To those who are interested in the changes of national accounts, I can recommend Bos (1992) or Hronová et al. (2019).

Figure 2 Symmetric Input-Output Table for 2015, Czech Republic, CZK mil.

CZ-CPA	Label	Products CZ-CPA						TOTAL	Households	Governm +NPISH	GFCF	Inventories	Exports (F.O.B.)	Final use	Total uses
		A	B	C	D+E	F	G-U		P.3		P.51+P.53	P.52	P.6		
A	Agriculture	33 227	172	128 668	2827	917	21 555	187 366	63 644	352	3 143	7 821	57 152	132 112	319 478
B	Mining	560	2 870	104 812	64 640	7 496	6 071	186 449	3 062	0	0	2 564	48 138	53 764	240 213
C	Manufacturingl	66 778	12 629	2 076 707	61 293	149 744	435 572	2 802 723	502 796	30 790	480 424	54 272	3 018 110	4 086 392	6 889 115
D+E	Energy	4 711	3 258	92 543	104 561	6 951	74 984	287 008	162 681	2686	0	–1885	63 599	227 081	514 089
F	Construction	3 900	587	22 472	7 838	270 578	116 947	422 322	10 006	90	454 479	932	17 732	483 239	905 561
G-U	Setvices	41 339	10 666	568 676	60 305	195 206	1 619 213	2 495 405	1 106 134	870 549	238 959	–749	549 265	2 764 158	5 259 563
P.2	**Intermediates (bp)**	**150 515**	**30 182**	**2 993 878**	**301 464**	**630 892**	**2 274 342**	**6 381 273**	**1 848 323**	**904 467**	**1 177 005**	**62 955**	**3 753 996**	**7 746 746**	**14 128 019**
D.21 -D.31	Net taxes on p	4 947	402	19 849	691	7 327	84 170	117 386	276 705	5 812	44 827	0	15 474	342 818	460 204
P.2	**Intermediates (pp)**	**155 462**	**30 584**	**3 013 727**	**302 155**	**638 219**	**2 358 512**	**6 498 659**	**2 125 028**	**910 279**	**1 221 832**	**62 955**	**3 769 470**	**8 089 564**	**14 588 223**
D.1	Compensations	39 438	18 845	470 529	37 710	99 657	1 154 910	1 821 089							
D.29 -D.39	Other taxes	–28 310	–630	–2 319	2 221	740	2 151	–26 147							
K.1	CFC	22 660	8 900	202 169	68 183	35 801	631 064	968 777							
B.2n +B.3n	NOS	69 024	4 151	365 090	61 371	121 703	750 521	1 371 860							
B.1g	**GVA (bp)**	**102 812**	**31 266**	**1 035 469**	**169 485**	**257 901**	**2 538 646**	**4 135 579**							
P.1	**Output (bp)**	**258 274**	**61 850**	**4 049 196**	**471 640**	**896 120**	**4 897 158**	**10 634 238**							
P.7	**Imports (C.I.F)**	**61 204**	**178 363**	**2 839 919**	**42 449**	**9 441**	**362 405**	**3 493 781**							
P.1+P.7	**Resources**	**319 478**	**240 213**	**6 889 115**	**514 089**	**905 561**	**5 259 563**	**14 128 019**							

Source: Czech Statistical Office, own computations took place. For example, the refinery does not produce petroleum from imported oil but produces only a service for a processing fee that exports to the owner of crude oil and finished petroleum. The last tricky point connected with foreign trade is co-called merchanting. It means that goods purchased and sold abroad is recorded on the gross concept on exports side. When purchasing goods as a negative export, it is recorded as export. Hence, the export for a particular product can be negative. Of course, when selling it is recorded in exports, as well. This change is not logical and it contributes to the confusion of the input-output tables' users.

Apart from directly visible changes, some other changes significant in the matter are not visible directly. One of the most important relates to the capitalisation of expenditures on research and development. The capitalisation caused that government expenditures were reclassified from the government expenditures to gross fixed capital formation of government sector. In some cases, reclassification of non-market output to output for own final use may lead to changes in product classification depending on the instruction. For example, the output of universities investing in research and development was classified as the product of education according to SNA 1993. However, in line with SNA 2008 at least two different products are produced, education and research and development. Expenditures on education are still used within government consumption expenditures but expenditures on research and development are classified as gross fixed capital formation.

Similarly as ESA 1995, ESA 2010 comprises in the chapter Input-Output Tables also Supply and Use tables. Supply and use tables are used mainly by statisticians for computational purposes such as deflation and balancing in national accounts. Supply and use tables also serve as a basis for modern input-output tables since the input-output tables are derived from supply and use tables at basic prices by mathematical models. The readers can find standard applications and links for both supply and use tables and input-output tables in the Manual (Eurostat, 2008). The Czech Statistical Office devoted a special web page to publication and methodology.[5]

3 WHO USES INPUT-OUTPUT TABLES AND WHY?

When compiling input-output tables statistical authorities should know their users. It allows both sides to avoid misunderstanding. Currently, there is a wide range of users covering statisticians, economists and environmentalists, etc. We can construct many models for different purposes using both statistic and dynamic description of the economy, see Šafr (2016). We can also find non-monetary models such as time input-output tables, see Zbranek and Fischer (2014). We can find many of examples in the Manual or we can use different publicly available applications.

The OECD represents one of the most useful application that is available nowadays. This project is called "TiVA"[6] (Trade in Value Added). The extraordinary benefit of the TiVA database consists in the input-output approach to the value added that provides interesting qualitative information about country's economy. Among lots of interesting indicators, the share of domestic value added embodied in exports belongs to the most important, see Figure 3. It expresses how much gross value added created by domestic producers is embodied in the country's exports. The input-output model behind includes all subcomponents provided by domestic producers and excludes imported intermediates. This indicator shows both the country dependency on the imports and ability to provide high value added goods and services for foreign markets.

In many cases, simple indicators such as the share of export in GDP do not provide adequate information. In the Czech Republic where the share of exports in GDP reaches 80% in 2016, the situation is more complex. It is useful to discuss what the contribution of domestic economy and net befits are.

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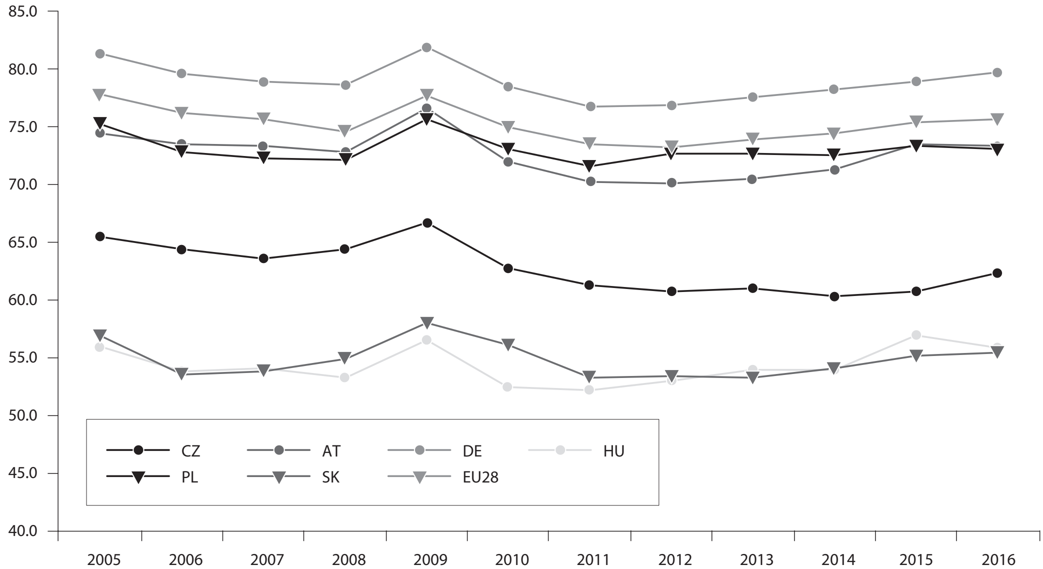
5 *<http://apl.czso.cz/pll/rocenka/rocenkaout.dod_uziti?mylang=EN>*.

6 For details see: *<http://www.oecd.org/sti/ind/measuring-trade-in-value-added.htm>*.

Figure 3 The share of domestic value added in exports, in %



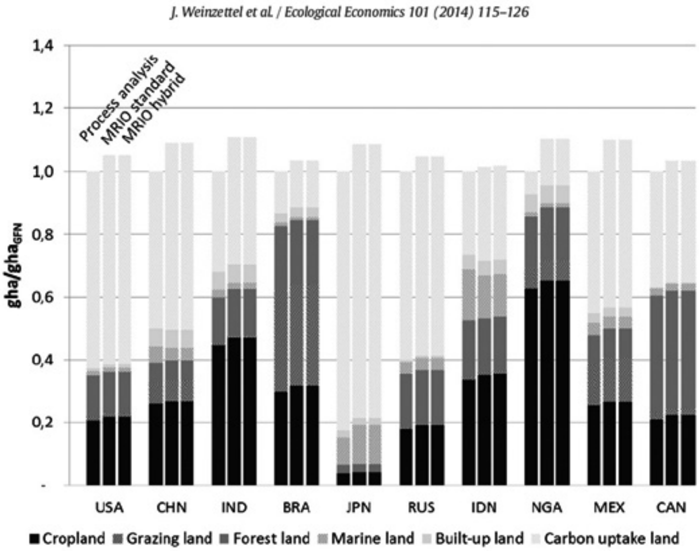
Source: Database TiVa, OECD

Data presented on the Figure 3 may help understand the issue. In 2005, the share of value added embodied in exports was 66% in the Czech Republic while the EU average was 78%. For available years (2005 to 2016), we can see slow downward trend. On the one side, the share of domestic value added in Czech exports is declining that indicates low ability to produce high-level value added goods. On the other side, the figures for the Czech Republic are influenced by the location of the country since many multinational enterprises locate their factories and distribution centres in the Centre of Europe. The exception was the year 2009 when the economy was influenced by economic crisis. Similar situation stands for Slovakia and Hungary. On the contrary, German economy reaches about 80% of value added in exports in the whole period and it shows us that the trade in value added for Germany is positive.

Beside economic studies,[7] input-output tables are very often used for environmental studies. Mostly when input-output tables can be arranged in the form of multiregional model describing simultaneously different regions and the links between them. This is very useful for environmental modelling since the effects of consumption or production can be distributed around the world. Such research is also conducted in the Czech Republic at the Charles University Environment Centre. Environment usage of input-output tables is focused on bringing the answers to the serious issues connected with the change of the climate, biodiversity, global warming etc. Figure 4 brings an example from this broad category of possible use, national requirements on bio-productive land, Weinzettel (2014). The picture shows requirements estimated by three different approaches based on enlarged input-output tables (multi-regional tables). The information presented in the chart refers to the necessary CO_2 absorption by the plants on the ground. We can find many different analyses relating to environmental research and input-output tables that fit very well for these purposes. The logic and assumption about the technology that stay behind the input-output tables is optimal for environmental studies.

[7] In many cases, input-output tables serve as a data source for other statistical computations, for example the structure of consumption of non-residents is used in computation of remittances, see Šimková and Langhamrová (2015).

Figure 4 National direct requirements on domestic bio-productive land



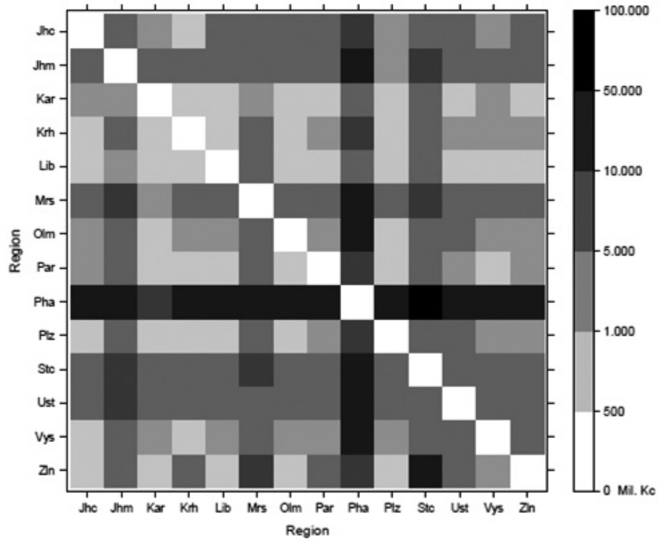
Source: Weinzettel (2014)

4 EXTENSION AND FOLLOW UP OF THE INPUT-OUTPUT ANALYSIS

Traditional usage of input-output tables is still very popular but the number of users of extended input-output tables is still rising. The focus on input-output tables is currently on extended input-output models. Among them, very popular branch is represented by regional extensions, see Leontief and Strout (1963). Regional extensions contain single regional input-output tables and interdependent multiregional tables. These tables are used for economic and environmental studies. That is why that the demand for regional input-output tables still exists despite the official supply of such data is relatively rare. Unfortunately, in the most cases this agenda is usually on the very edge of the interest of the official statistics. In some developed countries such as the United States, Finland, Spain or Australia they have sound experience with regional input-output tables. In the Czech Republic, the construction of regional input-output tables is an academic issue since the Czech Statistical Office does not compile them. Despite that, these tables exist due to the compilation by several scientists. The substantial difference between official statistical construction and scientific approach used mainly for the construction of technical confidents lies in the detail and consistency with nation accounts data.

One example of Czech regional input-output tables that are fully consistent with national symmetric input-output tables comes from the Department of Economic Statistics of the University of Economics in Prague. These regional input-output tables were compiled for 2011 and 2013 as sole regional tables for 14 regions of the Czech Republic (NUTS 3 level), see Sixta and Vltavská (2016). Later on, these tables were inter-connected by various approaches by Šafr (2018) and arranged in the form of the multiregional model. Figure 5 brings the illustration of the production flows between the regions of the Czech Republic that is a precondition for the construction of inter-regional model. This example was constructed on the basis of the Newton gravity approach. Interregional links are a subject of many input-output based studies despite general lack of data, e.g. Květoň and Šafr (2019). Similarly, the macroeconomic impact of the expenditures on specific events such as cultural events, educational events, etc. can be studied on regional level in a better way than on the total economy, see Vltavská and Fischer (2017). The issue of planning potential on the regional level is also tempting for policymakers.

Figure 5 Newton gravity approach used for estimation of production flows, CZK mil.



Note: Abbreviations of the codes are in the Annex.
Source: Šafr (2018)

Regional input-output tables are not compiled for the countries only. In fact, they are mostly constructed for the groups of regions, countries or economic blocks. We have also a good example on the European level, where Eurostat participated in the project 'Full International and Global Accounts for Research in Input-Output Analysis' (FIGARO), see Rueda-Cantuche and Rémond-Tiedrez (2016). This project was supported by the European Commission's Directorate-General 'Joint Research Centre'. The project is aimed to produce experimental EU-Inter Country Supply, Use and Input-Output Tables (EU-IC-SUIOTs) for the reference year 2010 in line with the ESA 2010 methodology, see Eurostat (2016). The project lasted 3 years and the results were published in 2018. It offers integrated sets of tables broken down by industries with linked capital and labour productivity indicators. It is a nice example of extending of rigid statistics for experimental approach. Moreover, the Eurostat plans to integrate it with environmental accounts and explore possible extensions with global business statistics.[8]

We can also identify input-output roots in Computable General Equilibrium (CGE) models that are very popular for economic modeling. The class of CGE models is very wide and due to increased computable possibilities available to nearly to anyone. There are many useful projects aimed at impacts of external shocks on economic equilibrium. The possibility of CGE models is very wide and currently in line with demographic ageing (Lisenkova et al., 2010). The Study of Lisenkova et al. is aimed at the economic impact of ageing on Scotland. The advantage of the CGE models is the possibility to incorporate decline in population, labour supply and economic activity or different migration scenarios. Similar project is also being solved for the Czech Republic at the University of Economics.[9] The key idea that social and demographic events in the society can be linked with economic statistics and with its main part

8 The data can be approached at: <*https://ec.europa.eu/eurostat/web/experimental-statistics/figaro*>.
9 The project "Economy of Successful Ageing", no. 19-03984S " is expected to be finished by December 2021. It should provide economic scenarios for population ageing of the Czech Republic by 2080.

(production) has been proved several times. I expect that multi-dimensional project combining different indicators and assumptions from wide area of human life will become more frequent.

CONCLUSION

Input-output agenda covering both input-output tables compiled by the official statistics and input-output analysis have long tradition in the Czech Republic. Usually, Czech scientist preferred product-by-product symmetric input-output tables. The popularity of input-output tables has its roots in the time of former socialist Czechoslovakia when this tool was used for central planning. Despite the fact, that the assumptions of input-output models clearly show that these models need to fit for centrally planning economies. In other words, I seriously doubt if input-output tables based planning under centrally planned economy is possible. Anyway, this usage put a bad stamp or stigma on the Input-Output Analysis in the Czech Republic and it took a long time to disappear.

Contemporary input-output analysis has many followers covered by the International Input-Output Association.[10] Many fans are also in the Czech Republic. Input-output analysis is currently easy to use since computational possibilities are incomparable with the situation in 1960s when this idea came to Czechoslovakia as a tool for planning. Currently, we can find lots of databases of useful data suitable for different studies that are freely available on websites.

The input-output analysis has been used for many different purposes since the 1930's but the original one, description of the economy, is not the prevailing. The most common applications are connected to environmental, ecological or social applications. It underlines that input-output tables and input-output analysis and this way of thinking is far from being forgotten and it keeps its popularity onwards.

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ANNEX

Nb	NUTS3 code	Abbreviation	Region name
1	CZ010	Pha	Prague
2	CZ020	Stc	Central Bohemian
3	CZ031	Jhc	South Bohemian Region
4	CZ032	Plz	Plzeň Region
5	CZ041	Kar	Karlovy Vary Region
6	CZ042	Ust	Ústí nad Labem Region
7	CZ051	Lib	Liberec Region
8	CZ052	Krh	Hradec Králové Region
9	CZ053	Par	Pardubice Region
10	CZ061	Vys	Vysočina Region
11	CZ062	Jhm	South Moravian Region
12	CZ071	Olm	Olomouc Region
13	CZ072	Zln	Zlín Region
14	CZ080	Mrs	Moravian-Silesian Region

The Impact of the Price Index Formula on the Consumer Price Index Measurement

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Abstract

The Consumer Price Index (CPI) is a common measure of inflation. Similarly to the Harmonised Index of Consumer Prices (HICP), it is determined using the Laspeyres index, thus data on the consumption of the basket of goods do not have to be current. The Laspeyres index, using weights only from the base period, may not reflect changes in consumer preferences that occurred in the studied year. In the ideal case, the CPI should be measured by one of the so called superlative price indices, such as the Fisher, Törnqvist or Walsh index formulas. The main problem with such indices is that they need expenditure data from the current period. The aim of the article is to assess the impact of the choice of the price index formula on the CPI measurement. We verify differences among known index formulas at the lowest and some higher data aggregation levels. We use known bilateral unweighted and weighted formulas together with their chained versions.

Keywords

Inflation measurement, Consumer Price Index (CPI), price indices, elementary price indices, chain indices, formula bias, scanner data

JEL code

C43, C38, E31

INTRODUCTION

The consumer price index (CPI) measures changes in the price level of market basket of consumer goods and services purchased by households and it is a common measure of inflation. The CPI is a statistical estimate constructed using the prices of a sample of representative items whose prices are collected periodically, and it approximates changes in the costs of household consumption assuming the constant utility (COLI, *Cost of Living Index*). Similarly to the Harmonised Index of Consumer Prices (HICP), the CPI is determined using the Laspeyres index, thus data on the consumption of the basket of goods do not have to be current (White, 1999; Clements and Izan, 1987). The Laspeyres index, using weights only from the base period, may not reflect changes in consumer preferences that occurred in the studied year

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(Hałka and Leszczyńska, 2011). It leads to the conclusion that the Laspeyres index can be biased due to the commodity substitution. Many economists and statisticians treat *superlative indices* (such as the Fisher index or the Törnqvist index) as the best approximation of COLI (Von der Lippe, 2007). The difference between the Laspeyres index and the superlative index should approximate the value of the commodity substitution bias (White, 1999; Białek, 2016). The Fisher index is the most popular among superlative indices and it is called "ideal" since it satisfies most of tests derived from the axiomatic price index theory (Balk, 1995), including *time reversibility*. Nevertheless, the Fisher price index, similarly to other superlative price index formulas, makes use of current-period expenditure data, and thus its usefulness in the CPI measurement is limited. Admittedly, it is possible to approximate the Fisher index by means of indices using only consumption data from the base period (Lloyd, 1975; Moulton, 1996; Shapiro and Wilcox, 1997; Lent and Dorfman, 2009; Białek, 2017a, 2017b), nonetheless most countries in the world continue to use the Laspeyres index to measure the CPI (White, 1999).

Scanner data, i.e. transaction data that specify turnover and numbers of items sold by GTIN (a barcode, formerly known as the EAN code), provide a new opportunity of calculating price indices, since they give information about prices and quantities even at the lowest data aggregation level. The methodology for the CPI (or HICP) construction using scanner data has strongly evolved for the last year (see for instance: Ivancic et al., 2011; Krsinich, 2014; Griffioen and Ten Bosch, 2016; de Haan et al., 2016; Chessa and Griffioen, 2016; Chessa, 2017; Diewert and Fox, 2017). Probably, in the nearest future, statistical agencies will be able to use any price index formula for CPI calculations if only they use daily or weekly updated scanner data. Having scanner data sets, we may calculate superlative price indices at the lowest level of data aggregation (even lower than COICOP 5).

The aim of the article is to assess the impact of the choice of the price index formula on the CPI measurement. We verify differences among known index formulas both at the lowest and some higher data aggregation levels. We focus on known unweighted and weighted formulas together with their chained versions but we do not consider the so called multilateral methods and indices which are strictly dedicated to scanner data cases (Chessa, 2016). Our paper is organised as follows: Sections 2 and 3 discuss elementary and weighted price indices respectively, Section 4 presents the idea of chain indices, Sections 5 and 6 present results from our empirical and simulation studies, while Section 7 provides some final conclusions and remarks.

1 ELEMENTARY PRICE INDICES

A recommendation of the European Commission concerning the choice of the elementary formula at the lowest level of data aggregation can be found on website: <*http://www.ilo.org/public/english/bureau/stat/download/cpi/corrections/annex1.pdf*> and it is as follows: *"For the HICPs the ratio of geometric mean prices or the ratio of arithmetic mean prices are the two formulae which should be used within elementary aggregates. The arithmetic mean of price relatives may only be applied in exceptional cases and where it can be shown that it is comparable*". In other words, if expenditure information is not available, the European Commission recommends the Jevons (1865) price index (see also: Diewert, 2012; Levell, 2015), which can be written for the base period and the current period as follows:

$$P_J^{0,t} = \prod_{i \in G_{0,t}} \left(\frac{p_i^t}{p_i^0}\right)^{\frac{1}{N_{0,t}}}, \tag{1}$$

where p_i^τ denotes the price of the i-th product at time $\tau \in \{0,t\}$, $G_{0,t}$ denotes the set of matched products in both moments 0 and t and $N_{0,t} = card\ G_{0,t}$. On the other hand, the same recommendation takes also into consideration ("in exceptional cases") the Carli (1804) price index, which can be written as follows:

$$P_C^{0,t} = \frac{1}{N_{0,t}} \sum_{i \in G_{0,t}} \frac{p_i^t}{p_i^0}, \tag{2}$$

In the literature, we can find also some other elementary price indices. One of the oldest propositions of elementary indices is the Dutot price index, i.e.

$$P_D^{0,t} = \frac{\frac{1}{N_{0,t}} \sum_{i \in G_{0,t}} p_i^t}{\frac{1}{N_{0,t}} \sum_{i \in G_{0,t}} p_i^0}. \tag{3}$$

There are many papers that compare the above-mentioned unweighted price index numbers. Early contributions of Eichhorn and Voeller (1976), Dalen (1992) and Diewert (1995) provide studies of properties of elementary indices from an axiomatic point of view. The differences between elementary indices, in terms of changes in the price variances, have been considered for sample indices by using the Taylor approximations (see e.g.: Dalen, 1992; Diewert, 1995; Balk, 2005 for details). The earlier literature, using the actual data underlying the consumer price index, has shown that the differences at the elementary aggregate level between the Dutot, Carli and Jevons indices can be quite substantial (see Carruthers et al., 1980; Dalen, 1994; Schultz, 1995; Moulton and Smedley, 1995).

1.1 Weighted price index formulas

As it was mentioned in the *Introduction*, in practice, the Laspeyres price index is used to measure the CPI (White, 1999; Clements and Izan, 1987). The Laspeyres price index (1871) can be expressed as follows:

$$P_{La}^{0,t} = \frac{\sum_{i \in G_{0,t}} p_i^t q_i^0}{\sum_{i \in G_{0,t}} p_i^0 q_i^0}, \tag{4}$$

where q_i^τ denotes the price of the i-th product at time $\tau \in \{0,t\}$.The Paasche price index (1874) uses quantities from the current period in its body and it can be written as follows:

$$P_{Pa}^{0,t} = \frac{\sum_{i \in G_{0,t}} p_i^t q_i^t}{\sum_{i \in G_{0,t}} p_i^0 q_i^t}. \tag{5}$$

In the so called economical approach (in the price index theory), it is assumed that the real value of the COLI should belong to the interval whose lower and upper limits are determined by values of the Laspeyres and Paasche indices. The most recommended index formulas for the CPI measurement are *superlative* price indices, firstly proposed by (Diewert, 1976). In this paper, we consider the Fisher (1922), Törnqvist (1936) and Walsh (1901) superlative price index formulas which can be defined respectively:

$$P_F^{0,t} = \sqrt{P_{La}^{0,t} \cdot P_{Pa}^{0,t}}, \tag{6}$$

$$P_T^{0,t} = \prod_{i \in G_{0,t}} \left(\frac{p_i^t}{p_i^0}\right)^{\frac{s_i^0 + s_i^0}{2}}, \tag{7}$$

$$P_W^{0,t} = \frac{\sum_{i \in G_{0,t}} p_i^t \cdot \sqrt{q_i^0 q_i^t}}{\sum_{i \in G_{0,t}} p_i^0 \cdot \sqrt{q_i^0 q_i^t}} . \tag{8}$$

In the paper, we consider two additional and well-known weighted price index formulas, namely the Marshall-Edgeworth index (1887) and the Geary Khamis (GK) index (Geary, 1958; Khamis, 1972), i.e.

$$P_{ME}^{0,t} = \frac{\sum_{i \in G_{0,t}} p_i^t \cdot (\frac{q_i^0 q_i^t}{2})}{\sum_{i \in G_{0,t}} p_i^0 \cdot (\frac{q_i^0 q_i^t}{2})} , \tag{9}$$

$$P_{GK}^{0,t} = \frac{\sum_{i \in G_{0,t}} p_i^t \cdot (\frac{q_i^0 q_i^t}{q_i^0 + q_i^t})}{\sum_{i \in G_{0,t}} p_i^0 \cdot (\frac{q_i^0 q_i^t}{q_i^0 + q_i^t})} . \tag{10}$$

Formulas (9) and (10) are not superlative but they are symmetrical, i.e. they remain the same upon interchanging of quantity vectors. These formulas have good axiomatic properties (Von der Lippe, 2007). Let us note that the Marshall-Edgeworthand the Geary-Khamis price indices differ from the Walsh formula only with respect to the used type of mean of quantities.

1.2 Chain indices

In the previously presented so called "direct approach", the results of price index formula $P^{0,t}$ are not influenced by what happens to prices and quantities in the intermediate points in time. A chain index $P_{CH}^{0,t}$ is essentially a specific type of temporal aggregation (over time) and it provides a measure of the cumulated effect of successive price steps from time moment 0 to 1, from 1 to 2, …, and from $t-1$ to t. In other words, the chain index takes into account all intermediate periods (months as a rule): 1, 2, …, $t-1$ and it can be written in a general form as follows:

$$P_{CH}^{0,t} = P^{0,1} \cdot P^{1,2} \cdot \ldots \cdot P^{t-1,t} = \prod_{\tau=1}^{t-1} P^{t,t+1} . \tag{11}$$

Please note that any price index formula can play a role of the base price index P. For instance, taking the Laspeyres index as the base index, we obtain the following Laspeyres chain index:

$$P_{CH-La}^{0,t} = P_{La}^{0,1} \cdot P_{La}^{1,2} \cdot \ldots \cdot P_{La}^{t-1,t} = \prod_{\tau=1}^{t-1} P_{La}^{t,t+1} . \tag{12}$$

2 EMPIRICAL STUDY

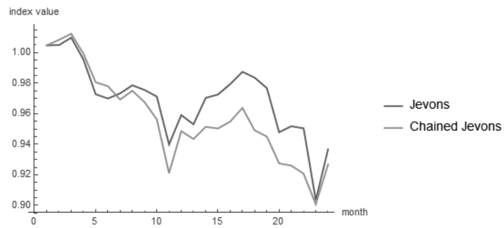
Case 1

The first data set was obtained from *allegro.pl*, which is one of the biggest e-commerce platform in Poland. We collected monthly transaction data on a homogeneous group of 33 different child safety seats. The time interval for observations was Dec. 2016–Dec. 2018 and the reference month was Dec. 2016 ($\tau = 0$).

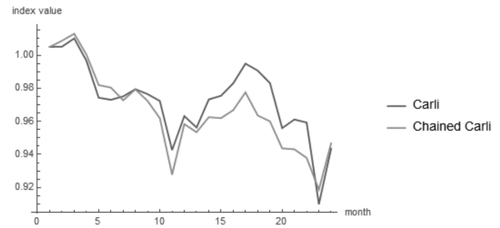
We collected data on average monthly prices of sold child safety seats, numbers of monthly transactions, numbers of items sold and corresponding expenditures. We matched observed products for each pair of subsequent months by using EAN codes and, having their descriptions, by using also some text mining methods. We ruled out from the sample poorly available products and products with relatively small expenditures to reduce the sample to the most typical and popular models of child safety seats (17 models). As a consequence, we took into consideration 17 378 transactions. As mentioned above, scanner data allow us to apply both unweighted and weighted indices for their analysis, and that is just what we did. Our results are presented in Figures 1–3 and in Table 1 which present differences between considered price indices.

Figure 1 Comparison of unweighted indices together with their chained versions (a homogeneous group: child safety seats, time interval: Dec. 2016–Dec. 2018)

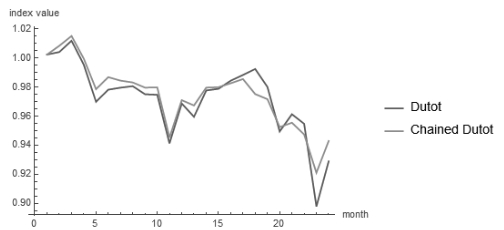
a) The Jevons index vs the Chained Jevons index



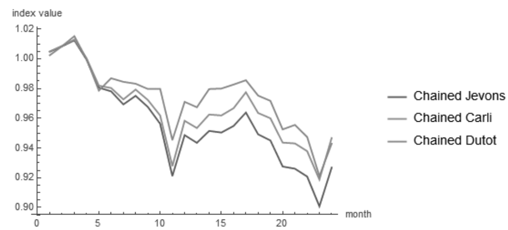
b) The Carli index vs the chained Carli index



c) The Dutot index vs the Chained Dutot index



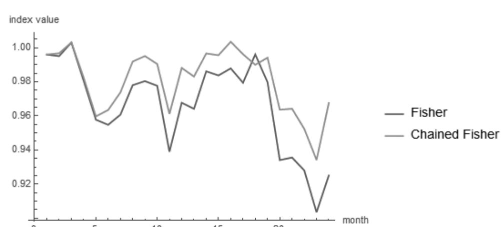
d) Comparison of chained elementary indices



Source: Own elaboration based on data from: <allegro.pl>

Figure 2 Comparison of weighted indices together with their chained versions (a homogeneous group: child safety seats, time interval: Dec. 2016–Dec. 2018)

a) The Fisher index vs the Chained Fisher index



b) Comparison of superlative indices

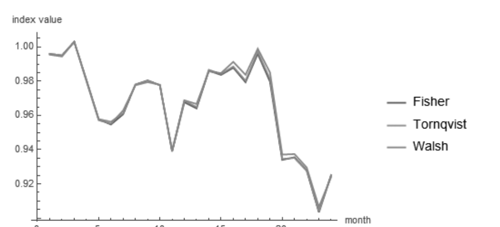
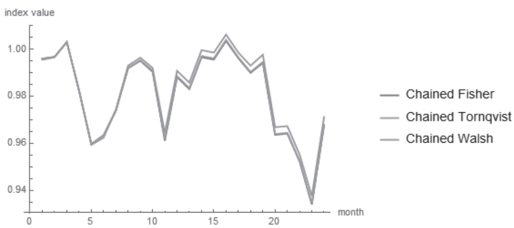
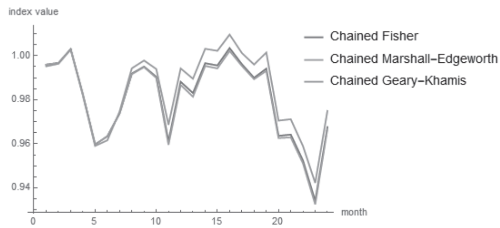


Figure 2 (continuation)

c) Comparison of chained superlative indices

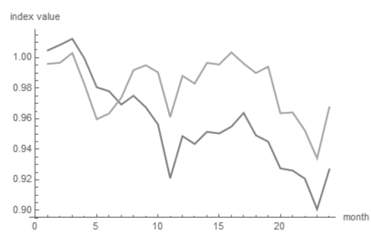


d) Comparison of chained symmetrical indices



Source: Own elaboration based on data from: <allegro.pl>

Figure 3 Comparison of chained Jevons and Fisher indices (a homogeneous group: child safety seats, time interval: Dec. 2016–Dec. 2018)



Source: Own elaboration based on data from: <allegro.pl>

Table 1 Comparison of all discussed price indices for different time intervals

Price index	**Time interval**			
	[0,6]	[0,12]	[0,18]	[0,24]
	Unweighted formulas			
Jevons	0.9700	0.9591	0.9837	0.9367
Chained Jevons	0.9781	0.9486	0.9492	0.9268
Carli	0.9730	0.9631	0.9906	0.9435
Chained Carli	0.9804	0.9583	0.9635	0.9467
Dutot	0.9783	0.9688	0.9925	0.9289
Chained Dutot	0.9869	0.9711	0.9752	0.9429
	Weighted formulas			
Fisher	0.9547	0.9677	0.9960	0.9250

Table 1 (continuation)

Price index	Time interval			
	[0,6]	[0,12]	[0,18]	[0,24]
Weighted formulas				
Chained Fisher	0.9634	0.9881	0.9899	0.9676
Törnqvist	0.9563	0.9685	0.9971	0.9252
Chained Törnqvist	0.9635	0.9885	0.9903	0.9680
Walsh	0.9552	0.9688	0.9989	0.9241
Chained Walsh	0.9624	0.9907	0.9929	0.9712
Marshall-Edgeworth	0.9539	0.9665	0.9936	0.9125
Chained ME	0.9634	0.9867	0.9893	0.9668
Geary-Khamis	0.9568	0.9708	1.0033	0.9356
Chained GK	0.9616	0.9942	0.9960	0.9749

Source: Own elaboration based on data from: <allegro.pl>

Case 2

At the beginning of the following case study, we used all discussed indices together with their chain versions for the inflation analysis in the United Kingdom and Bulgaria in the years: 2007–2017. Currently there are no differences between the CPI and the HICP (Harmonized Index of Consumer Prices) in the case of these countries. We decided to consider also the Czech Republic using the corresponding HICP data from Eurostat. We collected year-to-year data on CPI/HICP levels and weights for each group of goods from the COICOP-4 digit level of data aggregation. We calculated all the above-mentioned weighted price indices including the yearly chained Laspeyres and Fisher price indices (see Figures 4–6). Some detailed results (concerning the yearly inflation rate in considered countries measured by using different index formulas) for sample years (2011, 2014 and 2017) and additionally for the COICOP-3 digit level are presented in Tables 2–4.

Figure 4 Comparison of values of weighted price index formulas (CPI data from the United Kingdom, ECOICOP-4, 2007–2017)

Substitution bias effect

a. The reference year = 2006

b. Annual changes (year-to-year)

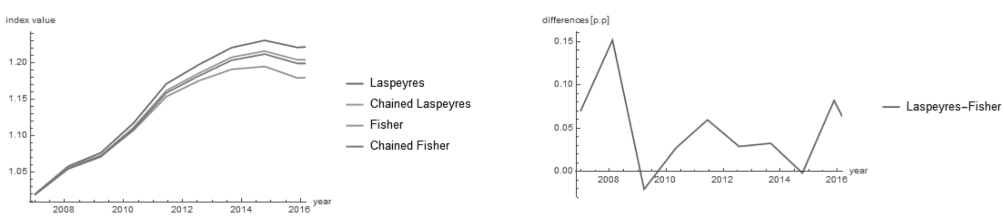
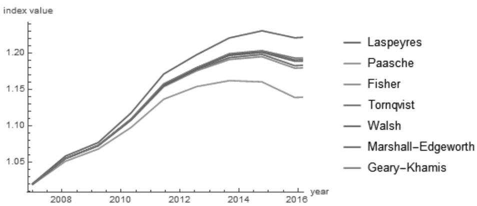


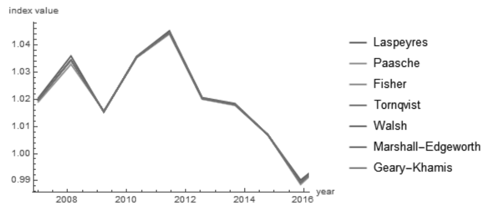
Figure 4 (continuation)

Comparison of all discussed price indices

c. The reference year = 2006



d. Annual changes (year-to-year)

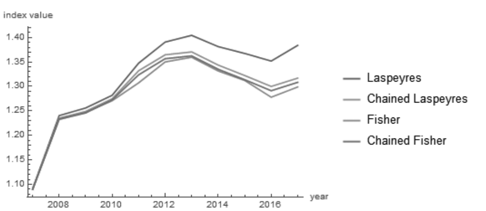


Source: Own elaboration based on data from Eurostat

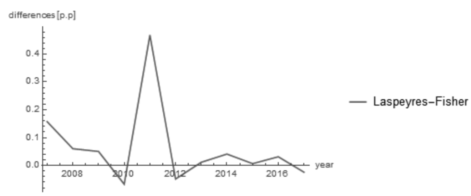
Figure 5 Comparison of values of weighted price index formulas (CPI data from Bulgaria, ECOICOP-4, 2007–2017)

Substitution bias effect

a. The reference year = 2006

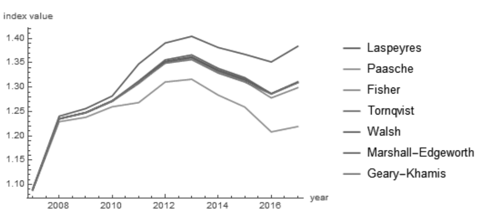


b. Annual changes (year-to-year)

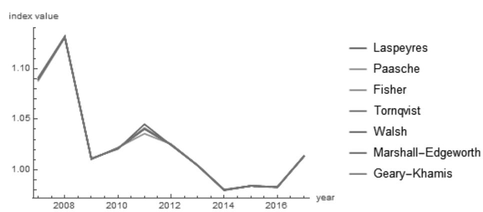


Comparison of all discussed price indices

c. The reference year = 2006



d. Annual changes (year-to-year)

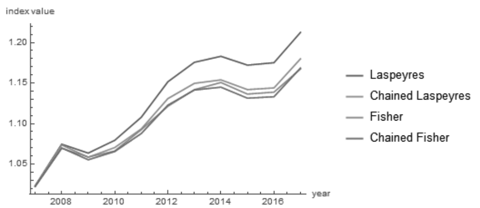


Source: Own elaboration based on data from Eurostat

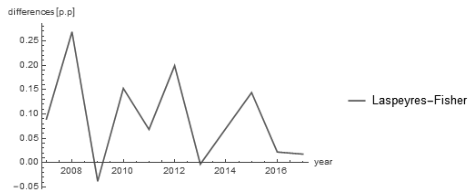
Figure 6 Comparison of values of weighted price index formulas (HICP data from the Czech Republic, ECOICOP-4, 2007–2017)

Substitution bias effect

a. The reference year = 2006

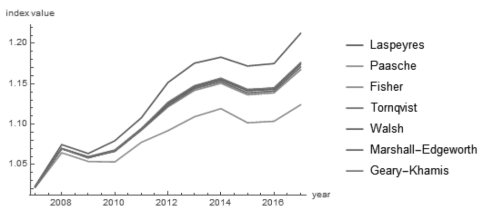


b. Annual changes (year-to-year)

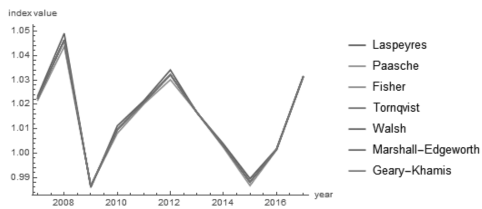


Comparison of all discussed price indices

c. The reference year = 2006



d. Annual changes (year-to-year)



Source: Own elaboration based on data from Eurostat

Table 2 Yearly inflation rate [%] measured by different index formulas in the United Kingdom (years: 2011, 2014, 2017)

Used index formula	COICOP 3			COICOP 4		
	2011	2014	2017	2011	2014	2017
Laspeyres	4.416	1.092	2.572	4.518	1.689	2.772
Paasche	4.224	1.144	2.539	4.399	1.693	2.739
Fisher	4.320	1.118	2.556	4.459	1.691	2.755
Walsh	4.323	1.126	2.556	4.461	1.696	2.756
Marshall-Edgeworth	4.322	1.118	2.556	4.460	1.691	2.754
Geary-Khamis	4.324	1.132	2.556	4.463	1.699	2.755

Source: Own elaboration based on data from Eurostat

Table 3 Yearly inflation rate [%] measured by different index formulas in Bulgaria (years: 2011, 2014, 2017)

Used index formula	COICOP 3			COICOP 4		
	2011	2014	2017	2011	2014	2017
Laspeyres	3.643	–1.730	1.111	4.502	–1.963	1.309
Paasche	3.163	–1.708	1.140	3.567	–2.046	1.357
Fisher	3.403	–1.719	1.126	4.033	–2.004	1.333
Walsh	3.421	–1.719	1.126	4.083	–2.002	1.333
Marshall-Edgeworth	3.407	–1.719	1.126	4.043	–2.005	1.333
Geary-Khamis	3.435	–1.720	1.127	4.119	–1.999	1.334

Source: Own elaboration based on data from Eurostat

Table 4 Yearly inflation rate [%] measured by different index formulas in the Czech Republic (years: 2011, 2014, 2017)

Used index formula	COICOP 3			COICOP 4		
	2011	2014	2017	2011	2014	2017
Laspeyres	2.059	0.512	2.446	2.152	0.375	3.138
Paasche	2.051	0.477	2.461	2.015	0.2333	3.102
Fisher	2.055	0.495	2.453	2.083	0.304	3.120
Walsh	2.056	0.495	2.454	2.083	0.305	3.120
Marshall-Edgeworth	2.055	0.495	2.453	2.084	0.304	3.121
Geary-Khamis	2.057	0.495	2.455	2.081	0.306	3.121

Source: Own elaboration based on data from Eurostat

CONCLUSIONS – RESULTS

Case 1 in our empirical study (see Empirical Study section) concerns the elementary aggregation. Our first results are not surprising, i.e. after using scanner data on child safety seats, we observe substantial differences between direct and chained elementary indices (see Figure 1a, 1b and 1c), in particular, the smallest differences are observed in the case of the Dutot formula (Figure 1c) and the biggest differences rise in the case of the Jevons index. The relations between chained elementary indices seem to be adequate to their known relations in the fixed basket approach, i.e. the chained Jevons index provides the smallest values (see Figure 1d). Figure 2 compares the superlative Fisher, Törnqvist and Walsh indices together with their chained versions and it considers also two well-known, symmetrical price indices, namely the Marshall-Edgeworth and the Geary-Khamis formulas. In the fixed basket approach, superlative indices approximate each other (Diewert, 1976), and in our case, they behave in the same way, i.e. there are no substantial differences between superlative indices and between their chained versions (see Figure 2b and 2c, Table 1) in our study. Similarly, the chained Marshall-Edgeworth and the chained Geary-Khamis indices do not differ strongly from the chained Fisher index in the considered case (Figure 2d).

Nevertheless, due to the dynamic structure of the used scanner data set, the choice between the direct method and the chained one does matter (see Figure 1a). For instance, the two-yearly price dynamics in the considered group of products measured by the chained Fisher index is bigger over 4 p.p. than the analogous price change measured by the direct Fisher index (see Table 1). Case 1 of our empirical study allows us to also note that differences between the chained Jevons and the chained Fisher indices are large (see Figure 3, Table 1) and in the case of measurement of yearly price dynamics the difference may exceed 3.9 p.p. (Table 1).

In **Case 2**, we compare CPIs of three countries (the United Kingdom, Bulgaria, the Czech Republic) calculated by using several weighted price index formulas and for two levels of data aggregation (COICOP-3 and COICOP-4). Firstly let us note that the CPI substitution bias is rather small in the case of the year-to-year inflation measurement (the highest bias level is observed in Bulgaria in 2011 – see Figure 5b) and as a rule the differences between the Laspeyres and the Fisher price indices do not exceed 0.15 p.p. (see Figure 4b, 5b and 6b). Nevertheless, calculating inflation rates for longer time intervals, we observe much bigger differences between the Laspeyres and Fisher formulas (together with their chained versions), so the annual updating of weights in the CPI measurement is very important for the CPI substitution bias reduction (see Figure 4a, 5a and 6a). Although all considered weighted formulas provide quite similar values for year-to-year CPI calculations (see Figure 4d, 5d and 6d), we should be aware of the fact that even small underestimation or overestimation of the real value of inflation may be very dangerous for national economies. Table 2–4 provide some detailed information about differences between yearly inflation rates measured by different price index formulas in considered countries. For instance, the above-mentioned differences in 2011 after using the Laspayres and the Fisher formulas are 0.096 p.p. and 0.24 p.p. in the case of the United Kingdom and Bulgaria respectively (see Table 2 and Table 3). The choice between the superlative formulas and the Marshall-Edgeworth or the Geary-Khamis indices is not so important in our study as we thought it would be. Moreover, the used data aggregation level seems to strongly influence yearly inflation rate calculations (see Table 2–4). For instance, the yearly inflation rate in 2017 in the Czech Republic measured by the Laspeyres formula equals 2.446 % and 3.138% for the COICOP-3 digit and COICOP-4 digit data aggregation levels respectively.

DISCUSSION AND GENERAL REMARKS

In the traditional CPI measurement, we use elementary price indices for calculations of price dynamics at the lowest level of data aggregation and the most recommended (by Eurostat) elementary price index formula is the Jevons index. This recommendation is based on economical, statistical and axiomatic approaches in the price index theory (Levell, 2015). For instance, from the axiomatic point of view, the Jevons index satisfies desirable axioms: the time reversal test and the circular test. The same property can be observed in the case of Dutot formula, and thus, when the basket of goods is fixed in compared time moments, we do not observe differences between values of these indices and values of their chained versions. Nevertheless, it may change in the case of using scanner data, mainly due to the fact that scanner data sets have a very dynamic structure, i.e. they include many cases of new and disappearing goods, strongly seasonal goods or temporary unavailable goods. In the case when the basket of goods observed during the year is not fixed, we should not expect that the direct and chained Jevons (or Dutot) indices will have the same values. Although most countries that use scanner data in their CPI calculations still apply the chained Jevons index for this purpose, many statisticians recommend using the so called multilateral methods for scanner data sets (Chessa, 2017). Multilateral methods are not investigated in this paper, nevertheless in Case 1 we consider additionally superlative indices which play an important role in constructing some multilateral methods (such as the GEKS or CCDI). Please note that scanner data provide information about prices and also quantities, so it is possible to use weighted price index formulas in their case. Taking into consideration the dynamic structure of scanner data sets, we should prefer the chained superlative price index formulas rather than the direct ones or rather, as it is suggested in the literature, the multilateral methods should be applied (the multilateral indices do not suffer from the chain drift). To sum up please note, that the choice between the elementary formulas and weighted price indices will have a substantial impact on final results in the CPI measurement. The general remark is also the fact that not only the choice of the price index formula but also the level of data aggregation used in calculations is really important in CPI calculations. Similarly, the level of the CPI substation bias seems to be sensitive to changing the COICOP level.

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Modeling of Currency Covolatilities

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Abstract

The paper deals with dynamic modeling of currency portfolios. In contrast to univariate models of exchange rates and their returns one applies multivariate time series models of the type GARCH that are capable of capturing not only conditional heteroscedasticities (i.e. volatilities) but also conditional correlations for common movements of exchange rates (so called covolatilities). One makes use of recursive estimation algorithms suggested by authors for such models which enable to control, evaluate and manage currency investment portfolios in real time. The main task of the paper is to assess whether the recursive estimation procedures suggested by the authors are applicable for real currency portfolios. It is realized by performing an extensive numerical study for bivariate portfolios of the EU currencies and US dollar concentrating on the role of the Czech crown.

Keywords

Currency covolatilities, investment index, multivariate GARCH models, pay off ratio, recursive estimation

JEL code

C51, C58, F31

INTRODUCTION

Volatility modeling plays the key role for analysis of univariate financial time series. On the other hand, understanding of comovements of more financial time series (e.g. various financial returns) is also of great practical importance since financial volatilities can move together over time across assets and markets. The models of such covolatilities are important tools for better decision-making e.g. in portfolio selection, asset pricing, hedging and risk management (see e.g. Aielli, 2013; Clements et al., 2009; Tse and Tsui, 2002).

In practice, the covolatilities are typical for currency portfolios, and one of various alternatives of their modeling consists in the application of multivariate GARCH models. In such a case one should dispose of numerically efficient estimation procedures for these models that usually contain a higher number of parameters. The aim of the paper is to assess whether the recursive estimation procedures suggested by the authors (see Section 2 for the proposed estimation methodology) are applicable just for currency portfolios. The data used in the corresponding numerical study are relatively long time series of daily exchange rates of the selected EU currencies and US dollar over eighteen years 2001–2018. In addition, special instruments assist in evaluating the management procedures based on portfolio optimization, namely the investments indices and pay off ratios (see Section 3.4). These instruments allow to draw some interesting conclusions of the case study that can have significant practical impacts.

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The paper is organized as follows. Section 1 reviews MGARCH modeling, in particular the definitions of multivariate processes MEWMA and diagonal BEKK. Section 2 presents the main principles of suggested recursive estimation of these models. Section 3 is the key one. It contains an extensive numerical study for exchange rates of EU currencies and US dollar with the objective of currency portfolio management. The last section summarizes the main conclusions of this paper.

1 MODELING OF COVOLATILITIES

The successful concept for modeling of univariate volatility consists in conditional heteroscedasticity approach realized by GARCH models. In particular, the univariate GARCH(1,1) processes $\{r_t\}$ have the form

$$r_t = \sigma_t\varepsilon_t = \sqrt{h_t}\varepsilon_t,\ \sigma_t^2 = h_t = \omega + \alpha_1 r_{t-1}^2 + \beta_1\sigma_{t-1}^2, \tag{1}$$

where ε_t are *iid* random variables with zero mean and unit variance (strict white noise), σ_t^2 is the conditional variance of r_t representing the volatility at time t given information observed till time $t - 1$, and finally $\omega > 0$, $\alpha_1 \geq 0$, $\beta_1 \geq 0$ are parameters of the process fulfilling $\alpha_1 + \beta_1 < 1$ (the sufficient conditions of positivity and stationarity of the process). One can consider processes of higher orders GARCH(r, s) or include a nonzero conditional mean but GARCH(1,1) model according to (1) is usually sufficient in routine financial applications (mainly for returns of various financial assets).

The multivariate generalization of (1) aims to model conditional covolatilities (i.e. conditional covariance matrices) in m dimensional processes $\{r_t\}$. One can apply a model scheme analogous to (1) (ignoring a potential nonzero conditional mean vector) in the form

$$\boldsymbol{r}_t = \mathbf{H}_t^{1/2} \cdot \boldsymbol{\varepsilon}_t, \tag{2}$$

where $\boldsymbol{\varepsilon}_t$ are *iid* random vectors with zero mean and identity covariance matrix and $\mathbf{H}_t$ is an $m\times m$ positive definite Ω_{t-1}-measurable matrix with square root matrix denoted as $\mathbf{H}_t^{1/2}$ (i.e. $\mathbf{H}_t = \mathbf{H}_t^{1/2}(\mathbf{H}_t^{1/2})^\top$). It represents the covariance matrix conditioned by the information observed till time $t - 1$ (Ω_t is the smallest σ-algebra such that $\{r_s\}$ is measurable for all $s \leq t$). The additional part of multivariate GARCH model is the so-called covolatility equation for the matrices $\mathbf{H}_t$ that determines the type of the corresponding model (see Sections 1.1–1.3) and contains unknown parameters ordered in a column vector $\boldsymbol{\theta}$ (therefore, one should write $\mathbf{H}_t(\boldsymbol{\theta})$ or even $\mathbf{H}_{t\,|\,t-1}(\boldsymbol{\theta})$ correctly). All vectors without transposition signs in this text are column wise.

1.1 MEWMA Models

Multivariate exponentially weighted moving average model (MEWMA or multivariate exponentially weighted moving average) is a modeling scheme which is in the univariate case supported by the commercial risk controlling software denoted as RiskMetrics (1996). In this case the covolatility equation for the conditional covariance matrix $\mathbf{H}_t$ has the form

$$\mathbf{H}_t = (1 - \lambda)\boldsymbol{r}_t\boldsymbol{r}_t^\top + \lambda\mathbf{H}_{t-1},\ \lambda \in (0, 1), \tag{3}$$

where λ is the only parameter to be estimated (see e.g. Hendrych and Cipra, 2019) for the univariate case. It means that the method is very parsimonious in parameters (and also constraints on λ are very simple).

1.2 Diagonal BEKK Models

Diagonal BEKK(1,1) model denoted also as dBEKK(1,1) (Baba, Engle, Kraft, Kroner, see e.g. Bauwens et al., 2006) has the covolatility equation of the form

$$\mathbf{H}_t = \mathbf{C}^{\mathsf{T}}\,\mathbf{C}^{\mathsf{T}} + \mathbf{A}\boldsymbol{r}_{t-1}\,\boldsymbol{r}_{t-1}^{\mathsf{T}}\,\mathbf{A} + \mathbf{B}\mathbf{H}_{t-1}\mathbf{B}\,, \tag{4}$$

where **C** is an $m \times m$ upper diagonal matrix with positive diagonal elements and **A** and **B** are $m \times m$ diagonal matrices with positive a_{11} and b_{11} (**A**, **B** and **C** are matrices of unknown parameters restricted to uniquely identify the given model, and the positive definiteness of $\mathbf{H}_t$ is guaranteed automatically in this model by its construction, see Bauwens et al., 2006). The model (4) is also parsimonious in parameters. Further reduction of parameters can be achieved in the scalar BEKK(1,1) model (sBEKK), where **A** and **B** are a scalar times unit matrix so that MEWMA can be obtained as a special case. Particularly, in the bivariate case one has

$$\mathbf{H}_t = \begin{pmatrix} c_{11} & 0 \\ c_{12} & c_{22} \end{pmatrix}\begin{pmatrix} c_{11} & c_{12} \\ 0 & c_{22} \end{pmatrix} + \begin{pmatrix} a_{11} & 0 \\ 0 & a_{22} \end{pmatrix}\begin{pmatrix} r_{1,t-1}^2 & r_{1,t-1}r_{2,t-1} \\ r_{2,t-1}r_{1,t-1} & r_{2,t-1}^2 \end{pmatrix}\begin{pmatrix} a_{11} & 0 \\ 0 & a_{22} \end{pmatrix} + \tag{5}$$
$$+ \begin{pmatrix} b_{11} & 0 \\ 0 & b_{22} \end{pmatrix}\begin{pmatrix} \sigma_{11,t-1} & \sigma_{12,t-1} \\ \sigma_{12,t-1} & \sigma_{22,t-1} \end{pmatrix}\begin{pmatrix} b_{11} & 0 \\ 0 & b_{22} \end{pmatrix} \quad \text{with} \quad \begin{matrix} a_{11} > 0, & b_{11} > 0, \\ c_{11} > 0, & c_{22} > 0. \end{matrix}$$

1.3 Other Multivariate GARCH Models

There is a broad offer of other covolatilities models of the type MGARCH (see Bauwens et al., 2006; Silvennoinen and Teräsvirta, 2009). For instance, the constant conditional correlation GARCH(1,1) model denoted as CCC-GARCH(1,1) (see e.g. Bauwens et al., 2006) has the covolatility equation of the form

$$\mathbf{H}_t = \mathbf{D}_t\mathbf{R}\mathbf{D}_t\,, \tag{6}$$

where $\mathbf{D}_t = \mathrm{diag}\{\sqrt{h_{11,t}}, \ldots, \sqrt{h_{mm,t}}\}$ is an $m \times m$ diagonal matrix with diagonal elements equal to square roots of univariate volatilities $h_{ii,t}$ fulfilling univariate volatility equations:

$$h_{ii,t} = \omega_{ii} + \alpha_{ii} r_{i,t-1}^2 + \beta_{ii} h_{ii,t-1}, \quad i = 1, \ldots, m\,, \tag{7}$$

(ω_{ii}, α_{ii} and β_{ii} are parameters of the process fulfilling constraints $\omega_{ii} > 0$, $\alpha_{ii} \geq 0$, $\beta_{ii} \geq 0$, $\alpha_{ii} + \beta_{ii} < 1$) and $\mathbf{R} = (\rho_{ij})$ is an $m \times m$ (constant) correlation matrix (see Bauwens et al., 2006). The particular covolatilities in the matrix $\mathbf{H}_t$ can be obviously written as

$$h_{ij,t} = \rho_{ij}\sqrt{h_{ii,t}}\sqrt{h_{jj,t}}, \quad i, j = 1, \ldots, m\,, \tag{8}$$

($\rho_{ii} = 1$). A more general version of this model is the dynamic conditional correlation GARCH model (DCC-GARCH) with dynamic matrix $\mathbf{R}_t$ in (6) (see Caporin and McAleer, 2013; Engle, 2002). Another approach makes use of factor models, where the uncorrelatedness of factors can be achieved by means of various orthogonal transformations in the so-called O-GARCH (orthogonal GARCH) models.

2 RECURSIVE ESTIMATION OF MULTIVARIATE GARCH MODELS

Cipra and Hendrych (see Cipra and Hendrych, 2018; Hendrych and Cipra, 2016, 2018, 2019) developed recursive estimation for univariate GARCH models that is effective in terms of memory storage and computational complexity and can be employed e.g. in the framework of high-frequency financial time series data. The method consists in a generalization of recursive prediction error method and can be extended to the multivariate case (see Cipra, 2018) in order to construct an estimator of unknown parameters ordered in the column vector $\boldsymbol{\theta}$ by minimizing the loss function (based on the negative conditional log-likelihood criterion):

$$\min_{\theta}\sum_{t=1}^{T}[\ln|\mathbf{H}_t(\boldsymbol{\theta})|+\boldsymbol{r}_t^{\mathsf{T}}\mathbf{H}_t(\boldsymbol{\theta})^{-1}\boldsymbol{r}_t]. \tag{9}$$

The corresponding estimation procedure is described algorithmically by the system of the following recursive formulas:

$$\hat{\boldsymbol{\theta}}_t = \hat{\boldsymbol{\theta}}_{t-1} - \eta_t\mathbf{R}_t^{-1}\mathbf{F}_t'(\hat{\boldsymbol{\theta}}_{t-1})^{\mathsf{T}}, \tag{10}$$

$$\mathbf{R}_t = \mathbf{R}_{t-1} + \eta_t[\tilde{\mathbf{F}}_t''(\hat{\boldsymbol{\theta}}_{t-1}) - \mathbf{R}_{t-1}], \tag{11}$$

$$\eta_t = \frac{1}{1+\xi_t/\eta_{t-1}} \text{ for } \textit{forgetting factor } \xi_t = \tilde{\xi}_t \cdot \xi_{t-1} + (1-\tilde{\xi}),\ \xi_0 = 1,\ \tilde{\xi} \in (0,1), \tag{12}$$

where:

$$F_t(\boldsymbol{\theta}) = \ln|\mathbf{H}_t(\boldsymbol{\theta})|+\boldsymbol{r}_t^{\mathsf{T}}\mathbf{H}_t(\boldsymbol{\theta})^{-1}\boldsymbol{r}_t, \tag{13}$$

$\mathbf{F}_t'(\boldsymbol{\theta})$ is the gradient of $F_t'(\boldsymbol{\theta})$, $\mathbf{F}_t''(\boldsymbol{\theta})$ is the Hessian matrix of $F_t(\boldsymbol{\theta})$ and $\tilde{\mathbf{F}}_t''(\boldsymbol{\theta})$ is the approximation of the Hessian matrix $\mathbf{F}_t''(\boldsymbol{\theta})$ such that

$$\mathbf{E}\left(\mathbf{F}_t''(\boldsymbol{\theta}) - \tilde{\mathbf{F}}_t''(\boldsymbol{\theta})|\Omega_{t-1}\right) = \mathbf{0}, \tag{14}$$

(this approximation simplifies the calculation of the corresponding Hessian matrix for particular model types). The application of forgetting factor ξ_t is typical in literature on the identification of dynamic systems since it improves the convergence properties including the statistical consistency of corresponding recursive estimators of the type (10)–(11).

For instance, let θ_k be an individual component of vector $\boldsymbol{\theta}$ of unknown parameters of diagonal BEKK(1,1) (see (4)). Then the corresponding recursive algorithm (10)–(12) for the estimation of this parameter should be supplemented by the following relations:

$$\left(\mathbf{F}_t'(\hat{\boldsymbol{\theta}}_{t-1})\right)_k = \frac{\partial F_t(\hat{\boldsymbol{\theta}}_{t-1})}{\partial\theta_k} = \left[\operatorname{tr}\left(\mathbf{H}_t^{-1}(\hat{\boldsymbol{\theta}}_{t-1})\frac{\partial\mathbf{H}_t(\hat{\boldsymbol{\theta}}_{t-1})}{\partial\theta_k}\right) - \boldsymbol{r}_t^{\mathsf{T}}\mathbf{H}_t^{-1}(\hat{\boldsymbol{\theta}}_{t-1})\frac{\partial\mathbf{H}_t(\hat{\boldsymbol{\theta}}_{t-1})}{\partial\theta_k}\mathbf{H}_t^{-1}(\hat{\boldsymbol{\theta}}_{t-1})\boldsymbol{r}_t\right], \tag{15}$$

$$\left(\mathbf{F}_t''(\hat{\boldsymbol{\theta}}_{t-1})\right)_{kl} = \frac{\partial^2 F_t(\hat{\boldsymbol{\theta}}_{t-1})}{\partial\theta_k\partial\theta_l} \approx \operatorname{tr}\left(\mathbf{H}_t^{-1}(\hat{\boldsymbol{\theta}}_{t-1})\frac{\partial\mathbf{H}_t(\hat{\boldsymbol{\theta}}_{t-1})}{\partial\theta_k}\mathbf{H}_t^{-1}(\hat{\boldsymbol{\theta}}_{t-1})\frac{\partial\mathbf{H}_t(\hat{\boldsymbol{\theta}}_{t-1})}{\partial\theta_l}\right), \tag{16}$$

$$\mathbf{H}_{t+1}(\hat{\boldsymbol{\theta}}_t) = \hat{\mathbf{C}}_t\hat{\mathbf{C}}_t^{\mathsf{T}} + \hat{\mathbf{A}}_t\boldsymbol{r}_t\boldsymbol{r}_t^{\mathsf{T}}\hat{\mathbf{A}}_t + \hat{\mathbf{B}}_t\mathbf{H}_t(\hat{\boldsymbol{\theta}}_{t-1})\hat{\mathbf{B}}_t. \tag{17}$$

In particular, in the bivariate model (5) with $\boldsymbol{\theta} = (c_{11}, c_{12}, c_{22}, a_{11}, a_{22}, b_{11}, b_{22})^{\mathsf{T}}$ the following recursive calculation of matrix differentials is possible

$$\frac{\partial \mathbf{H}_{t+1}(\hat{\boldsymbol{\theta}}_t)}{\partial c_{11}} = \begin{pmatrix} 2\hat{c}_{11t} & \hat{c}_{12t} \\ \hat{c}_{12t} & 0 \end{pmatrix} + \begin{pmatrix} \hat{b}_{11t} & 0 \\ 0 & \hat{b}_{22t} \end{pmatrix} \frac{\partial \mathbf{H}_t(\hat{\boldsymbol{\theta}}_{t-1})}{\partial c_{11}} \begin{pmatrix} \hat{b}_{11t} & 0 \\ 0 & \hat{b}_{22t} \end{pmatrix}, \tag{18}$$

$$\frac{\partial \mathbf{H}_{t+1}(\hat{\boldsymbol{\theta}}_t)}{\partial c_{12}} = \begin{pmatrix} 0 & \hat{c}_{11t} \\ \hat{c}_{11t} & 2\hat{c}_{22t} \end{pmatrix} + \begin{pmatrix} \hat{b}_{11t} & 0 \\ 0 & \hat{b}_{22t} \end{pmatrix} \frac{\partial \mathbf{H}_t(\hat{\boldsymbol{\theta}}_{t-1})}{\partial c_{12}} \begin{pmatrix} \hat{b}_{11t} & 0 \\ 0 & \hat{b}_{22t} \end{pmatrix}, \tag{19}$$

$$\frac{\partial \mathbf{H}_{t+1}(\hat{\boldsymbol{\theta}}_t)}{\partial c_{22}} = \begin{pmatrix} 0 & 0 \\ 0 & 2\hat{c}_{22t} \end{pmatrix} + \begin{pmatrix} \hat{b}_{11t} & 0 \\ 0 & \hat{b}_{22t} \end{pmatrix} \frac{\partial \mathbf{H}_t(\hat{\boldsymbol{\theta}}_{t-1})}{\partial c_{22}} \begin{pmatrix} \hat{b}_{11t} & 0 \\ 0 & \hat{b}_{22t} \end{pmatrix}, \tag{20}$$

$$\frac{\partial \mathbf{H}_{t+1}(\hat{\boldsymbol{\theta}}_t)}{\partial a_{11}} = \begin{pmatrix} 2\hat{a}_{11t} r_{1t}^2 & \hat{a}_{22t} r_{1t} r_{2t} \\ \hat{a}_{22t} r_{1t} r_{2t} & 0 \end{pmatrix} + \begin{pmatrix} \hat{b}_{11t} & 0 \\ 0 & \hat{b}_{22t} \end{pmatrix} \frac{\partial \mathbf{H}_t(\hat{\boldsymbol{\theta}}_{t-1})}{\partial a_{11}} \begin{pmatrix} \hat{b}_{11t} & 0 \\ 0 & \hat{b}_{22t} \end{pmatrix}, \tag{21}$$

$$\frac{\partial \mathbf{H}_{t+1}(\hat{\boldsymbol{\theta}}_t)}{\partial a_{22}} = \begin{pmatrix} 0 & \hat{a}_{11t} r_{1t} r_{2t} \\ \hat{a}_{11t} r_{1t} r_{2t} & 2\hat{a}_{22t} r_{2t}^2 \end{pmatrix} + \begin{pmatrix} \hat{b}_{11t} & 0 \\ 0 & \hat{b}_{22t} \end{pmatrix} \frac{\partial \mathbf{H}_t(\hat{\boldsymbol{\theta}}_{t-1})}{\partial a_{22}} \begin{pmatrix} \hat{b}_{11t} & 0 \\ 0 & \hat{b}_{22t} \end{pmatrix}, \tag{22}$$

$$\frac{\partial \mathbf{H}_{t+1}(\hat{\boldsymbol{\theta}}_t)}{\partial b_{11}} = \begin{pmatrix} 2\hat{b}_{11t} h_{11t}(\hat{\boldsymbol{\theta}}_t) & \hat{b}_{22t} h_{12t}(\hat{\boldsymbol{\theta}}_t) \\ \hat{b}_{22t} h_{12t}(\hat{\boldsymbol{\theta}}_t) & 0 \end{pmatrix} + \begin{pmatrix} \hat{b}_{11t} & 0 \\ 0 & \hat{b}_{22t} \end{pmatrix} \frac{\partial \mathbf{H}_t(\hat{\boldsymbol{\theta}}_{t-1})}{\partial b_{11}} \begin{pmatrix} \hat{b}_{11t} & 0 \\ 0 & \hat{b}_{22t} \end{pmatrix}, \tag{23}$$

$$\frac{\partial \mathbf{H}_{t+1}(\hat{\boldsymbol{\theta}}_t)}{\partial b_{22}} = \begin{pmatrix} 0 & \hat{b}_{11t} h_{12t}(\hat{\boldsymbol{\theta}}_t) \\ \hat{b}_{11t} h_{12t}(\hat{\boldsymbol{\theta}}_t) & 2\hat{b}_{22t} h_{22t}(\hat{\boldsymbol{\theta}}_t) \end{pmatrix} + \begin{pmatrix} \hat{b}_{11t} & 0 \\ 0 & \hat{b}_{22t} \end{pmatrix} \frac{\partial \mathbf{H}_t(\hat{\boldsymbol{\theta}}_{t-1})}{\partial b_{22}} \begin{pmatrix} \hat{b}_{11t} & 0 \\ 0 & \hat{b}_{22t} \end{pmatrix}. \tag{24}$$

The MEWMA model (see (3)) is a special case and simplifies the algorithm for the recursive estimation of the only parameter λ

$$\hat{\lambda}_t = \hat{\lambda}_{t-1} - \eta_t R_t^{-1} \left[\mathrm{tr}\left(\mathbf{H}_t^{-1}(\hat{\lambda}_{t-1}) \frac{\partial \mathbf{H}_t(\hat{\lambda}_{t-1})}{\partial \lambda} \right) - \boldsymbol{r}_t^{\mathsf{T}} \mathbf{H}_t^{-1}(\hat{\lambda}_{t-1}) \frac{\partial \mathbf{H}_t(\hat{\lambda}_{t-1})}{\partial \lambda} \mathbf{H}_t^{-1}(\hat{\lambda}_{t-1}) \boldsymbol{r}_t \right], \tag{25}$$

$$R_t = R_{t-1} + \eta_t \left[\mathrm{tr}\left(\mathbf{H}_t^{-1}(\hat{\lambda}_{t-1}) \frac{\partial \mathbf{H}_t(\hat{\lambda}_{t-1})}{\partial \lambda} \right) \mathbf{H}_t^{-1}(\hat{\lambda}_{t-1}) \frac{\partial \mathbf{H}_t(\hat{\lambda}_{t-1})}{\partial \lambda} - R_{t-1} \right], \tag{26}$$

$$\mathbf{H}_{t+1}(\hat{\lambda}_t) = (1 - \hat{\lambda}_t) \boldsymbol{r}_t \boldsymbol{r}_t^{\mathsf{T}} + \hat{\lambda}_t \mathbf{H}_t(\hat{\lambda}_{t-1}), \tag{27}$$

$$\frac{\partial \mathbf{H}_{t+1}(\hat{\lambda}_t)}{\partial \lambda} = -\boldsymbol{r}_t \boldsymbol{r}_t^{\mathsf{T}} + \mathbf{H}_t(\hat{\lambda}_{t-1}) + \hat{\lambda}_t \frac{\partial \mathbf{H}_t(\hat{\lambda}_{t-1})}{\partial \lambda} \tag{28}$$

(note the recursive calculation of the matrix differentials in (18)–(24) or in (28)).

Theoretical properties of the suggested recursive estimation algorithm coincide with the conventional non-recursive case (as *t* goes to infinity), where the corresponding negative conditional log-likelihood criterion is minimized. Namely, convergence and asymptotic distributional properties are identical for a sufficiently large number of observations. Refer to Ljung and Söderström (1983) for the theoretical background of the prediction error method. Simulation experiments based on these recursive formulas deliver promising results not published here. In Section 3 this approach is used in a case study for real currency data. Extensive simulations performed by the authors including theoretical aspects of recursive estimation formulas suggested by the authors for MGARCH models (and used numerically in this case study for currencies) will be published later.

3 CASE STUDY

The main objective of this contribution is to verify applicability of recursively estimated multivariate GARCH models for modeling covolatilities among currencies. Such models are capable of capturing conditional correlations in the context of various multivariate data but their efficiency should be compared. Moreover, due to recursive estimation the given approach is appropriate for financial data recorded with higher frequencies (at least daily) which is just the case of currency data. On the other hand, the conclusions of the case study presented in this section may be important from the practical point of view since one discusses the dynamic interconnection of the Czech crown with other currencies. Particularly, the estimated mutual covolatilities of corresponding currencies are indicators of the mutual currency risk that plays an important role in various regulatory systems in banking and insurance and for constructing statistical prognosis in economy (see Bollerslev, 1990).

3.1 Description of Data

More explicitly, the presented case study analyzes bivariate conditional correlation (or covariance) matrices between the log-returns of daily currency rate Czech crown/EUR against other seven currencies */EUR in EU28 and also against US dollar/EUR (see Table 1). Note that the Bulgarian lev (BGN) is omitted since it is strongly fixed to euro so that the corresponding returns in this analysis would be permanently zero. The time range of the study is Jan 2001–Dec 2018 according to ECB (refer to <http://sdw.ecb.europa.eu/browse.do?node= 9691296>), i.e. one deals with eight bivariate processes $\{\boldsymbol{r}_t\}$ of length $T = 4\,605$ observations. Each of them has the same first component, namely the log-returns of daily currency rate Czech crown/EUR (see Table 1). The log-returns are used typically when the yield of financial assets is analyzed and compared, e.g. in our case:

$$r_t^{USD/EUR} = \ln\left(\frac{(USD/EUR)_t}{(USD/EUR)_{t-1}}\right). \tag{29}$$

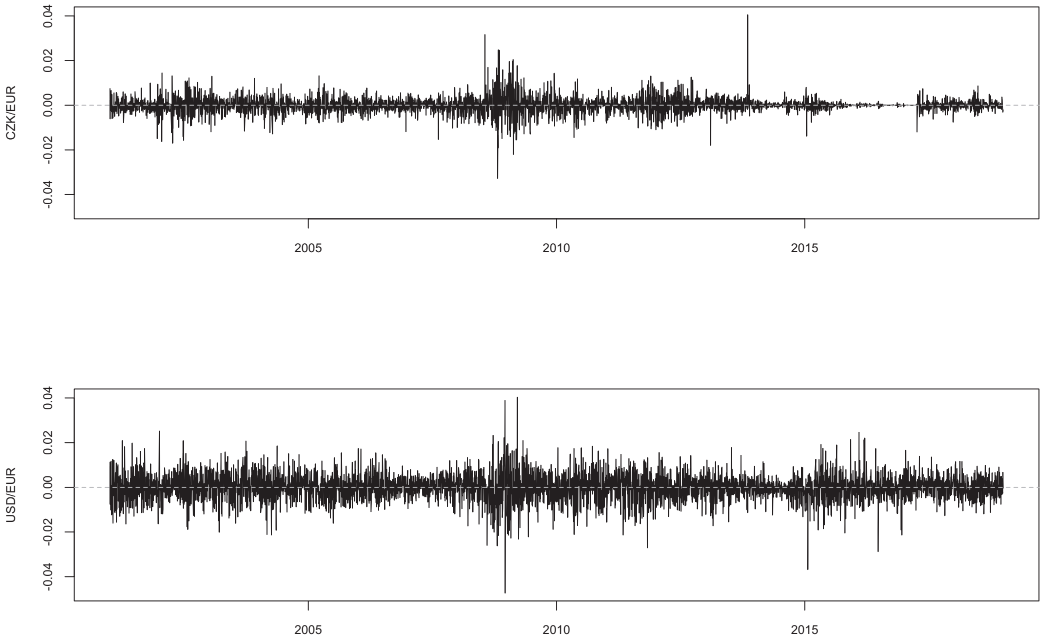
For instance, Figure 1 displays graphically log-returns of daily currency rate CZK/EUR and USD/EUR in period Jan 2001–Dec 2018.

Table 1 Currencies used in case study and components of processes $\boldsymbol{r}_t = (r_{1,t}, r_{2,t})^T$

Currency	Abbreviation	$r_{1,t}$	$r_{2,t}$
Croatian kuna	HRK	$r_t^{CZK/EUR}$	$r_t^{HRK/EUR}$
Danish krone	DKK	$r_t^{CZK/EUR}$	$r_t^{DKK/EUR}$
Hungarian forint	HUF	$r_t^{CZK/EUR}$	$r_t^{HUF/EUR}$
Polish zloty	PLN	$r_t^{CZK/EUR}$	$r_t^{PLN/EUR}$
Romanian leu	RON	$r_t^{CZK/EUR}$	$r_t^{RON/EUR}$
Swedish krona	SEK	$r_t^{CZK/EUR}$	$r_t^{SEK/EUR}$
UK pound sterling	GBP	$r_t^{CZK/EUR}$	$r_t^{GBP/EUR}$
US dollar	USD	$r_t^{CZK/EUR}$	$r_t^{USD/EUR}$

Source: Own construction

Figure 1 Log-returns of daily exchange rates CZK/EUR and USD/EUR in period JAN 2001–DEC 2018



Source: ECB <http://sdw.ecb.europa.eu/browse.do?node=9691296>

3.2 Model Estimation

For each of eight pairs of log-returns of daily currency rates $\boldsymbol{r}_t = (r_{1,t}\, , r_{2,t})^\top$ (see Table 1) one has estimated two types of the bivariate GARCH models:

- MEWMA model (see Section 1.1),
- dBEKK(1,1) model (see Section 1.2)

(such a choice is intentional since one of the objectives of our study is to compare performance of simple model schemes represented just by the model MEWMA and more complex models with larger number of parameters represented in this study by the model dBEKK(1,1)).

More precisely, we have made use of the recursive estimation algorithms of the type (15)–(24) respecting various technicalities involved when applying this procedures for real data, namely the initialization of the recursive calculations and the choice of forgetting factor in (12) (e.g. one can use a constant forgetting factor $\xi_t = 0.99$ or an increasing forgetting factor $\xi_t = 0.99\ \xi_{t-1} + 0.01$, etc., see e.g. Hendrych and Cipra, 2019). Moreover, some constraints on parameters (mainly their positivity or non-negativity) must be fulfilled to guarantee the positive definiteness of covolatility matrix $\mathbf{H}_t$.

3.3 Verification tests

The particular models are verified by means of the bivariate Ljung-Box test (see Cipra, 2013, p. 348; Ljung and Box, 1978; Lütkepohl, 2005, p. 171). The test is applied in two versions: the first version (see the test statistics Q(MEWMA) and Q(dBEKK) in Table 2) based on estimated bivariate residuals verifying the serial uncorrelatedness and the second version (see test statistics $Q2$(MEWMA) and $Q2$(dBEKK) in Table 2) based on squares of estimated bivariate residuals verifying the elimination of heteroscedasticity. The maximum delays of corresponding statistics Q is chosen as 8 ~ ln(4 605) (i.e. the natural logarithm of time series lengths as it is usually recommended).

Table 2 presents p-values for both versions of this test. In both cases, the better results are obtained for MEWMA model (the residual uncorrelatedness is rejected on the level of significance 5% only in one case for Q(MEWMA) and in no case for $Q2$(MEWMA)). The substantially worse results for Q(dBEKK) and $Q2$(dBEKK) consist mainly in the fact that estimation of models with higher number of parameters is a more complex problem in the volatile environment of currency exchange rates (it is also confirmed by other empirical results for currencies which are not reported in this paper).

Table 2 Multivariate Ljung-Box tests (columns $Q(\cdot)$ and $Q2(\cdot)$ contain p-values)

Exchange rate 1	Exchange rate 2	Q(MEWMA)	Q2(MEWMA)	Q(dBEKK)	Q2(dBEKK)
CZK/EUR	DKK/EUR	0.36637	0.21492	0.00554	0.49086
CZK/EUR	GBP/EUR	0.00825	0.57121	0.65633	0.00000
CZK/EUR	HRK/EUR	0.36117	1.00000	0.00049	0.00111
CZK/EUR	HUF/EUR	0.22317	0.95423	0.60785	0.45449
CZK/EUR	PLN/EUR	0.16215	0.08995	0.05619	0.03928
CZK/EUR	RON/EUR	0.22871	0.76751	0.00921	0.04658
CZK/EUR	SEK/EUR	0.54316	0.37302	0.00145	0.59162
CZK/EUR	USD/EUR	0.49079	0.99968	0.47606	0.55483
Number of non-rejections of the null		7	8	4	4

Source: Own construction

There are other tests that could be applied in our study. In particular, Laurent et al. (2012) addressed the issue of the selection of MGARCH models in terms of variance matrix of forecasting accuracy with a particular focus on relatively large-scale problems. They considered 10 assets from the New York Stock Exchange and compared various models based on 1-, 5- and 20-day-ahead conditional variance forecasts over a period of 10 years using the so-called model confidence sets (MCS) and the superior predictive ability (SPA) tests.

3.4 Outputs

Figure 2 presents conditional correlations among daily log returns of exchange rates CZK/EUR and */EUR for seven currencies from Table 1 recursively estimated by means of models MEWMA and dBEKK(1,1) in period Jan 2001–Dec 2018. One can see that the used model approach injects an important dynamic aspect to the analysis of mutual behavior of currencies (sometimes with very intensive covolatilities). Some exchange rates show significant correlation links to the Czech crown. In particular, one can notice the relatively high positive correlations between the Czech crown/EUR against the Hungarian forint/EUR or the Polish zloty/EUR. On the contrary, the Czech crown/EUR is nearly neutral against the Croatian kuna/EUR or the Danish krone/EUR (if we ignore the presence of noise). There is another interesting aspect, namely the correlation results obtained by means of various models can differ significantly.

For instance, the conditional correlations by the MEWMA seem to be in some periods more volatile than by the dBEKK(1,1) (refer to the Czech crown/EUR against the Hungarian forint/EUR since 2015) or can even show some trends (consult the increasing trend of Czech crown/EUR against the UK pound sterling/EUR in the period 2013–2016).

Further results in Figure 3 correspond to another objective of our study, namely to evaluate the applicability of MGARCH models in the portfolio optimization context. A similar approach to the currency portfolio investment has been suggested by Franke and Klein (1999) for optimal currency portfolio management using neural networks. One considers eight currency portfolios $\boldsymbol{r}_t = (r_{1,t}, r_{2,t})^\top$ from Table 1 that are optimized each trading date. More explicitly, one recalculates weights for minimum variance portfolios recursively in time applying one-step-ahead predictions of conditional covolatilities $\mathbf{H}_t = \mathbf{H}_{t|t-1}$ obtained by the corresponding models MGARCH recursively estimated for time t using information known till time $t-1$, see Section 2 (gains like interests and losses like transaction costs caused by managing the portfolio are neglected). In other words, one reevaluates each trading date the portfolio weights $\mathbf{w}_t = (w_t, 1 - w_t)^\top$ when minimizing the portfolio risk measured by the portfolio variance (or by its standard deviation), i.e. one solves optimization problems:

$$\min \mathbf{w}_t^\top \mathbf{H}_t \mathbf{w}_t \qquad \text{subject to } \mathbf{w}_t^\top \mathbf{1} = 1,\ \mathbf{w}_t \geq 0 \tag{30}$$

Figure 2 Conditional correlations between daily log returns of exchange rates CZK/EUR and */EUR for eight currencies from Table 1 recursively estimated by means of models MEWMA and dBEKK(1,1) in period JAN 2001–DEC 2018

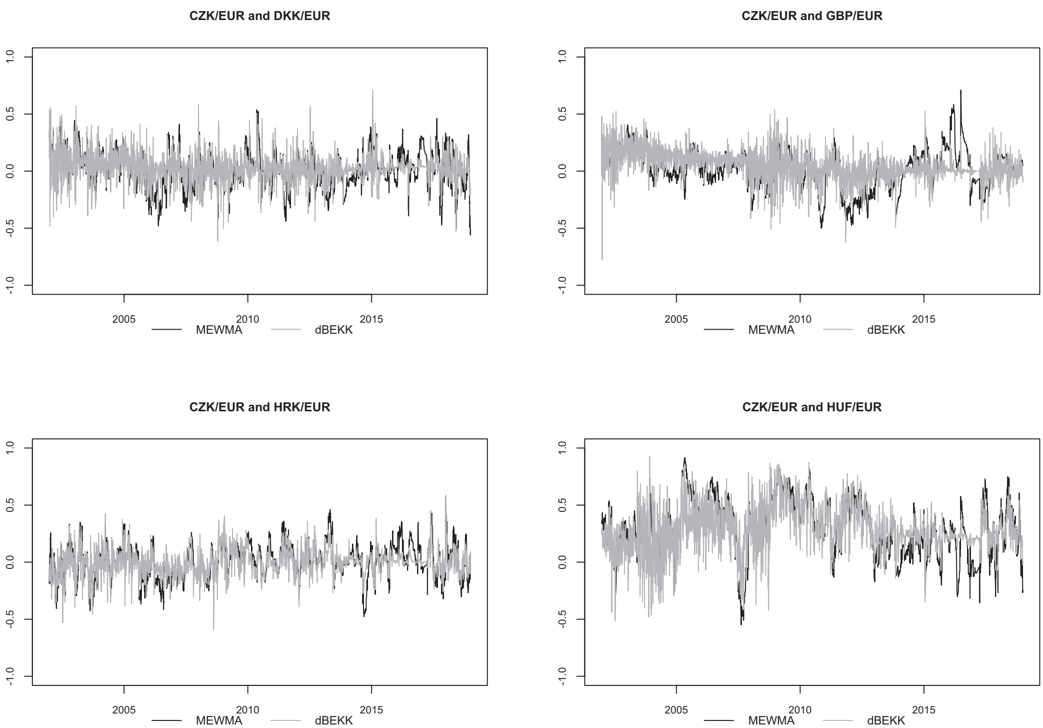
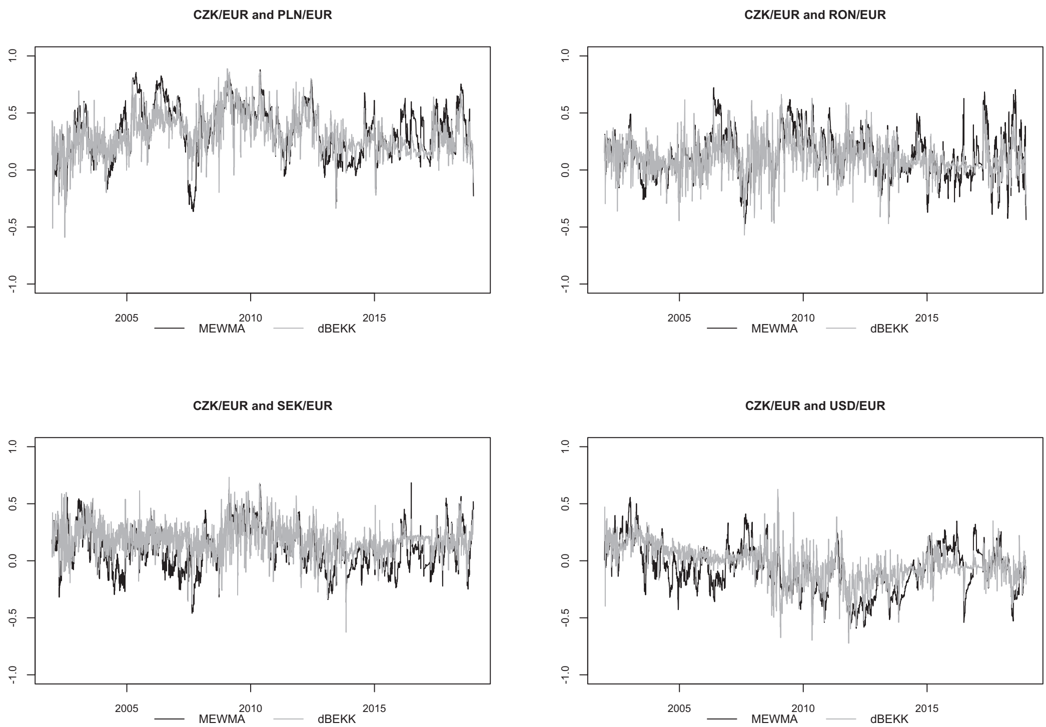


Figure 2 (continuation)



Source: Own construction

for unit vectors **1**. The minimization of portfolio risk is a reasonable criterion for daily management of currency portfolios since the average daily yield is usually near to zero. One could also permit the short sales operations, when the non negativity constraints for weights in (30) are canceled which allows an explicit solution of (30) in the form

$$\mathbf{w}_t = \frac{\mathbf{H}_t^{-1}\mathbf{1}}{\mathbf{1}^{\mathrm{T}}\mathbf{H}_t^{-1}\mathbf{1}}. \tag{31}$$

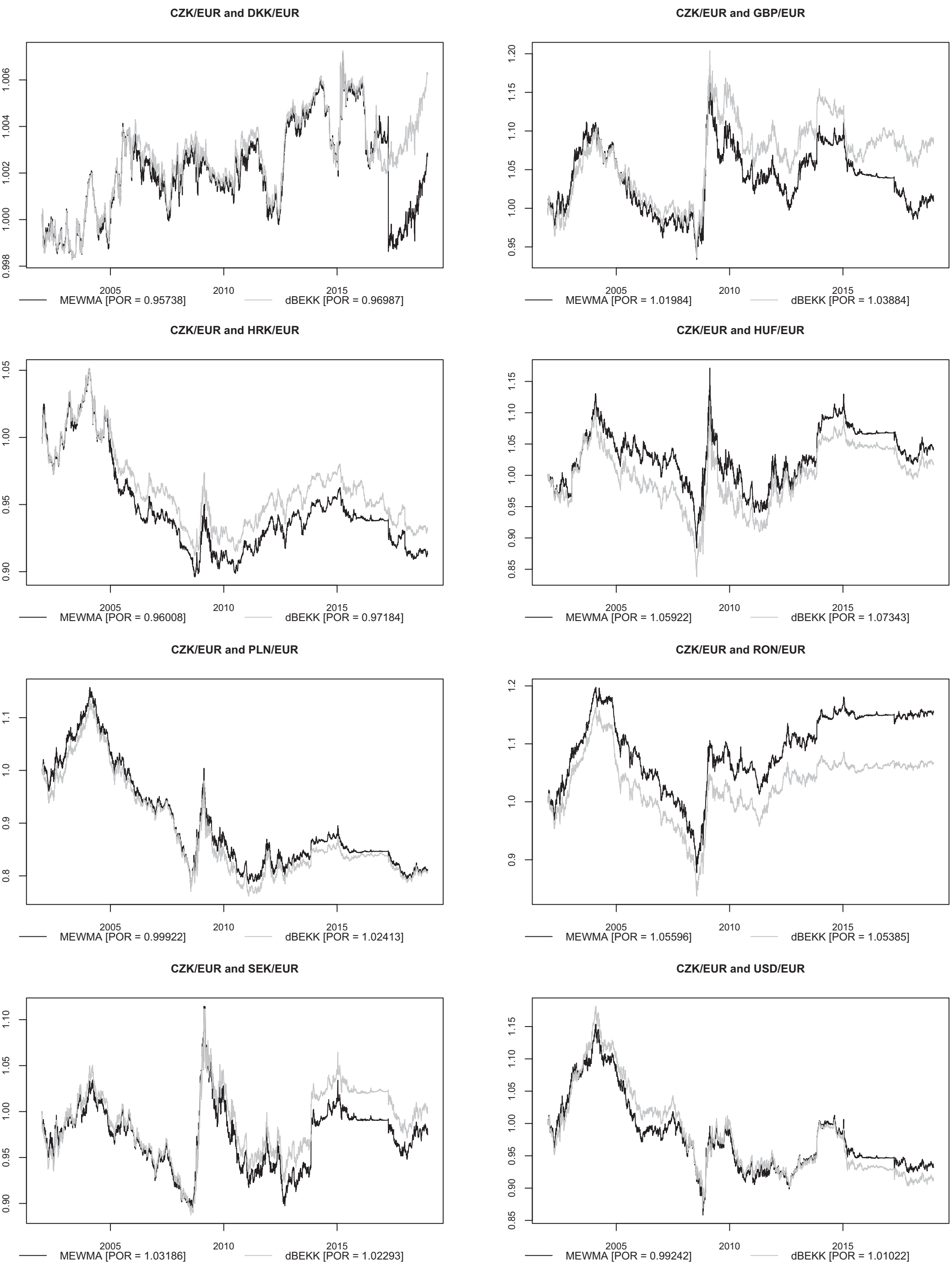
The described management procedure has two numerical outputs:

Firstly, one follows the development of an initial investment in amount of 1 EUR for each portfolio. Figure 3 shows for each pair of currencies from Table 1 the plot of investment indices $\{I_t\}$ defined in time t recursively as

$$I_t = I_{t-1}\{w_t \exp(r_{1,t}) + (1 - w_t)\exp(r_{2,t})\},\ t = 2, 3, ..., T \tag{32}$$

with I_1 = 1 EUR. In other words, I_t represents the value (in EUR) at time t of particular portfolio composed of CZK and corresponding currency from Table 1 with initial investment capital

Figure 3 Investment indices for eight exchange rates from Table 1 recursively estimated by means of models MEWMA and dBEKK(1,1) in period JAN 2001–DEC 2018



Source: Own construction

of 1 EUR when the optimal weights are always constructed one-step-ahead in MEWMA or dBEKK(1,1) model by solving the optimization task (30) repeatedly.

We can see that the investment strategy based on MEWMA model guarantees better investment results than dBEKK(1,1) model (with exception of the portfolio investing to CZK and DKK and the portfolio investing to CZK and GBP where both models give nearly identical results). In particular, the best investment results in terms of the investment index were obtained by investing the initial capital to CZK and GBP followed by investing to CZK and USD.

Secondly, for each plot in Figure 3 one calculates so-called pay off ratio *POR* (see Franke and Klein, 1999):

$$POR = \frac{\frac{1}{T_+}\sum_{t=2}^{T}\{w_t[\exp(r_{1,t})-1]+(1-w_t)[\exp(r_{2,t})-1]\}^+}{\frac{1}{T_-}\sum_{t=2}^{T}\{w_t[\exp(r_{1,t})-1]+(1-w_t)[\exp(r_{2,t})-1]\}^-}, \qquad (33)$$

where $a^+ = \max(a, 0)$ is the positive part of a, $a^- = \max(-a, 0)$ is the negative part of a, T_+ is the number of nonzero summands in the numerator of (33) and T_- is the number of nonzero summands in the denominator of (33). The optimal portfolio weights w_t and $1 - w_t$ are again constructed one-step-ahead using MEWMA or dBEKK(1,1) model similarly as in (32), i.e. by solving the optimization task (30) repeatedly. Obviously, if $POR > 1$ (or $POR < 1$) then the mean of positive returns in the given investment portfolio is larger (or smaller) than the mean of negative returns, respectively.

For our investment portfolios the pay off ratios are slightly above the equilibrium unit value (with exception of the portfolio investing to CZK and DKK which is anomalous also from the point of view of investment indices, see above). This result is not surprising due to positive correlations between components of particular investment portfolios (see above) so that it is difficult to enforce more significant daily diversification effects.

CONCLUSION

The realized case study confirmed that the application of multivariate GARCH models is an approach that can be useful when one models and controls on line portfolios of assets with a higher frequency of records and potential conditional correlations among components changing in time. The typical examples are currency portfolios examined in our case study. The study found various dynamical links among some currencies and outlined potential applications in portfolio management.

The study showed that simpler models with lower number of parameters should be preferred in practice. Particularly, in our case the models MEWMA seem to be much better than more sophisticated models dBEKK both in the sense of statistical tests and in the sense investment results based on the corresponding model approach.

Future research can extend the dimension of models or even include portfolios with a high number of components which is the case of stock indices.

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Comparative Analysis of Results of Assessing the Central Federal District's Regions' Economic Development by Using Linear and Non-Linear Models

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Abstract

This paper provides a comparative analysis of results of estimating specific efficacy that characterizes the amount of gross regional product depending on expenditure on technological innovations, the fixed capital and the average annual number of persons employed. This approach includes comparison of actual data with normative values calculated for three types of models: linear, logarithmic, and power multiplicative. The particular performance indicator is determined as a relation between actual and normative values for the Russian Federation's Central District's regions. The investigation's information base was statistical data on the regions of the RF CFD for 2007–2016. The issues under discussion are differences in results of evaluation obtained in using the first, second and third type models.

Keywords	**JEL code**
Indicators, gross domestic product by region, modeling	*C10, P25, R11, R15*

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INTRODUCTION

The economy of the region is characterized by a number of indicators, one of which is the regions' gross domestic product (GDP).

However, the comparative analysis of the regions' GDP in terms of absolute values is not quite correct since each subject, its condition and functioning are determined by a number of specific factors and distinctive features. Consequently, it is necessary to use such indicators that would be immune to measuring and standardization while taking into account the specific properties of the objects (regions) under study. Such indicators can be formed using an econometric approach that enables construction of the models on whose basis it is possible to establish a link between the results of functioning of a complex system (an individual region in this case) and the factors of its condition and impact.

The latter of those determine the impact of the control agencies used for obtaining the desired result. The choice of model specifications for describing the object of research is generally subjective. However, this subjectivity rests on a number of criteria, including the previous investigation results for similar objects, the essential nature of factors, included in the model, its adequacy and accuracy, the applicability, etc. On the one hand, the variety of models and tools for analyzing complex systems gives the researcher an array of options, while on the other it creates a problem of substantiating the choice of relevant approaches to evaluating its condition and operability. This is what determines the relevance of the investigation being carried out. The object of research is the Central Federal District (CFD) of the Russian Federation (RF). The subject of research is the influence of condition and impact factors on the regions' GDP.

The aim of the investigation is to conduct a comparative analysis of results of evaluating the regions' economy with the aid of the method being developed and using linear and non-linear models.

1 SURVEY AND LITERATURE REVIEW

The investigations related to evaluation of the state and functioning of complex systems, including regions, are based on three approaches.

The first of them presupposes the use of generally accepted indicators of evaluating the state and functioning of complex systems. These indicators are shown in various statistical databases.[7] Thus it becomes possible to observe the general dynamics and the current state of the objects of investigation and forecast the behavior of trend models.

The second approach is based on building mathematical models that connect the results of the system's functioning with operability factors. In most cases they represent an extension of classical models of an economic balance and economic growth and that of cyclic models.

The economic balance models are associated with works of such researchers as Keynes (1936) who proposed the "cost – production" model and Leontief (1925) who developed the intersectional balance model. Those models were further developed by the optimum resource distribution models (Kantorovich, 1939), a model of general economic equilibrium (Neumann, 1945, 1946), asymmetric information market models (Akerlof et al., 2001) and others.

The economic growth models are dealt with in the works of Harrod (1939), Solow (1956), Domar (1946) and others.

At the basis of cyclic models are the works of Kondratiev and Oparin (1928), Schumpeter (1935), Freeman (1979), Kleinkneht (1987) and others.

Modern mathematical models for describing an economy or part thereof can be divided into two classes that include models which are a system of equations consisting of derivative functions with

[7] Federal State Statistics Service of the Russian Federation (ROSSTAT) [online]. <*http://www.gks.ru*>. Eurostat [online]. <*http://www. ec.europa.eu/eurostat/data/database*>.

a different set of restrictions and a system of differential equations describing changes in the economy's main indicators in compliance with its condition.

At their basis are the well known function classes of Cobb et Douglas (1928), Solow (1956), Leontief (1941), production function with constant elasticity of substitution (CES-function), multifactor production function with constant elasticity of substitution of Mihalevsky (CESM-function) and others. For more details see Kleyner (2016). The problem of substantiating their choice for describing the objects and subjects remains open to date.

The World-3 model (Meadows et al., 1972) that describes not only economic but also social trends at the global level can be referred to the second class.

The third approach is associated with the econometric modeling, in which case the functional type of model and the composition of its factors are determined using correlation and regression analysis. In many cases, the analysis of state and functioning of the object under study, including a region's economy and its components, involves linear models (Dreyer and Schmid, 2017; Sayaria et al., 2018) since they are the simplest; quadratic models (Charfeddineand and Mrabet, 2017); logarithm models (Lin and Benjamin, 2018); translog model from the Cobb–Douglas production function (Zhenhua and Guangsheng, 2016); and power multiplicative models, including those with allowance for an innovative component (Makarov et al., 2016). Over 800 works were published in 2018 on building econometric models for different objects of investigation,[8] which in some way or other use the above mentioned models.

The models built serve as a basis for developing forecasts and evaluating the level of development of objects (regions) under study. Used for this purpose are particular and general (integral) evaluation indicators. The procedures of building integral evaluation indicators are quite diverse. Worth noting, among them, are the procedures of calculating mean characteristics by using weight coefficients (Tretyakova and Osipova, 2016); formation of an indicator as the chief component (Aivazian, 2003); size reduction by multiple dimension scaling (Tolstova, 2006); data envelopment analysis (Charnes et al., 1978) and others.

The proposed investigation is based on previous works of the authors involved in building models for evaluating the region's level of development (Zhukov et al., 2016a, 2016b; Zhukov, 2018a, 2018b), which include formation of particular and general evaluation indicators with the use of the econometric approach. This article focuses on analysis of models used for evaluating a region's economy, including its particular efficiency indicators.

2 DATA AND METHODS

The methodology of evaluating a regions' economy, used in this work, presupposes calculating particular efficiency indicators determined as a ratio between actual and normative results of functioning of objects under study.

The particular performance indicator can be calculated using the formula:

$$\xi_{k,i}(t) = \frac{y_{k,i}{}^{0}(t)}{y_{k,i}{}^{)0}(t)}, \tag{1}$$

where $y_{k,i}{}^{0}(t)$, $y_{k,i}{}^{)0}(t)$ – normalized actual and normative values of indicator, k – region index, i – indicator index.

Normalization is carried out using the formulas:

$$y_{k,i}{}^{0}(t) = \frac{y_{k,i}{}^{*} - \min\,\{y_{k,i}{}^{*}, y_{k,i}{}^{)*}\}}{\max\,\{y_{k,i}{}^{*}, y_{k,i}{}^{)*}\} - \min\,\{y_{k,i}{}^{*}, y_{k,i}{}^{)*}\}}\,, \tag{2}$$

8 The data are obtained based on the relevant request to the international scientometric database [online]. [cit. 8.11.2018]. <*http:// www.sciencedirect.com*>.

$$y_{k,i}^{)0}(t) = \frac{y_{k,i}^{)*} - \min\{y_{k,i}^{*}, y_{k,i}^{)*}\}}{\max\{y_{k,i}^{*}, y_{k,i}^{)*}\} - \min\{y_{k,i}^{*}, y_{k,i}^{)*}\}}, \tag{3}$$

here $y_{k,i}^{*}$, $y_{k,i}^{)*}$ – standardized actual and normative values determined using the formulas:

$$y_{k,i}^{*}(t) = \frac{y_{k,i} - M(y_i(t))}{\sigma(y_i(t))}, \tag{4}$$

$$y_{k,i}^{)*}(t) = \frac{y_{k,i}^{)} - M(y_i^{)}(t))}{\sigma(y_i^{)}(t))}, \tag{5}$$

where $M(y_i(t))$, $M(y_i^{)}(t))$, $\sigma(y_i(t))$, $\sigma(y_i^{)}(t))$ – respectively, mean and standard deviation.

The special feature of this approach is that the indicators, thus formed, enables to avoid the problems of comparing the objects of investigation in using different units of measurement and data change ranges. Under such circumstances the indicator allows for a simple interpretation. If its value is larger than a one, the functioning of the system can be considered satisfactory.

The normative value is a regressive model connecting the system's functioning results with the factors of its state and an impact on it.

We shall use a linear, logarithmic and power multiplication form of the model:

$$y_{k,i}^{)*} = \sum_{j=1}^{n} C_{i,j} \cdot x_j^{*} + \sum_{s=1}^{s} D_{i,s} \cdot z_s^{*}, \tag{6}$$

$$\ln(y_i^{)*}) = \sum_{j=1}^{n} C_{i,j} \cdot \ln(x_j^{*}) + \sum_{s=1}^{s} D_{i,s} \cdot \ln(z_s^{*}), \tag{7}$$

$$y_i^{)*} = \prod_{j=1}^{n} x_j^{*C_{i,j}} \cdot \prod_{s=1}^{s} z_s^{*D_{i,j}}, \tag{8}$$

where n is the number of state factors, s is the number of impact factors, $C_{i,j}$, $D_{i,s}$, are corresponding weight coefficients between i productive (result of functioning of system) and j and s standardized factors of x_j^{*} state and z_s^{*} impact. State factors are a set of essential properties the system possesses at a given moment in time. Impact factors are a set of controlled properties leading to changes in the system's functioning results. The subjects of management can change impact factors. Substitution of actual values x_j^{*} and z_s^{*} in (1) for k region can produce an individual norm. The models described by Formulas (7) and (8) are identical.

Chosen as objects of investigation were regions of the Russian Federation's Central District (17 regions less Moscow).

The 2007–2016 reports of the Russian Federation's State Statistics Service (ROSSTAT) became an information basis of the investigation.[9]

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[7] Federal State Statistics Service of the Russian Federation (ROSSTAT) [online]. [cit. 20.11.2018]. *<http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/ru/statistics/publications/catalog/doc_113862350615>*.

Chosen as an efficiency indicator was the particular assessment indicator characterizing the regions' GDP. Also involved in the process were the state and impact factors.

The least square method (backward selection) was used to select included variables. The absolute indicator, presented in terms of value, was adjusted according to purchasing power parity (PPP) in US dollars for comparing with the international level (see Table 1).

Table 1 Ruble exchange rate at purchasing power parity (PPP) in US dollars

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Rub/USD	13.98	14.34	14.02	15.82	17.35	18.46	20.48	21.26	23.98	23.70

Source: ROSSTAT, own construction

3 RESULTS AND DISCUSSION

Model specification was presented by the following formulas:

$$y_{10.1/lin}^{)*} = \underset{(0.044)}{0.602} \cdot x_{1,1}^{*} + \underset{(0.042)}{0.337} \cdot x_{1,2}^{*} + \underset{(0.014)}{0.076} \cdot z_{22.17}^{*}, \ (R^2 = 0.986, \ v = 166), \tag{9}$$

$$y_{10.1/log}^{)*} = \underset{(0.049)}{0.565} \cdot \ln(x_{1,1}^{*}) + \underset{(0.054)}{0.347} \cdot \ln(x_{1,2}^{*}) + \underset{(0.030)}{0.097} \cdot \ln(z_{22.17}^{*}), \ (R^2 = 0.932, \ v = 166), \tag{10}$$

$$y_{10.1/mul}^{)*} = x_{1,1}^{*0.565} \cdot x_{1,2}^{*0.347} \cdot z_{22.17}^{*0.097}, \ (R^2 = 0.984, \ v = 166), \tag{11}$$
$$(0.049) \quad (0.054) \quad (0.030)$$

where $y_{10\ 1/lin}^{)*}$, $y_{10.1/log}^{)*}$, $y_{10\ 1/mul}^{)*}$ are the model linear, logarithm and multiplicative GDP by region in terms of PPP in US dollars, respectively, $x_{1,1}^{*}$ is the fixed capital, $x_{1,2}^{*}$ is the average annual number of persons employed, $z_{22.17}^{*}$ is the expenditure on technological innovation, () are standard errors, R^2 is determination coefficient, v are degrees of freedom.

For these models, the determination coefficient is statistically significant at 1% level. F-test was used for assessment. For assessing the model coefficients t-test was used. All coefficients are statistically significant at 5% level. The highest coefficient of determination is characteristic for the entire linear model.

Table 2 Results of tests to verify the models' adequacy

Model/test	t	TP	DW	R/S	SRC
Linear	1.58E-04	122	1.929	6.531	1.060, 1.432, 1.245
Logarithm	1.66E-03	120	1.944	5.323	0.553, 0.019, 0.683
Multiplicative	2.89E-01	128	1.752	7.326	0.553, 0.019, 0.683
Table values	1.974	101	$d_L = 1.61$ $d_U = 1.73$	$R/S_L = 5.112$ $R/S_U = 8.560$	1.974
Result	adequate	adequate	adequate	adequate	adequate

Note: Valid at 5% level.
Source: Author's calculations

Five (5) tests with residuals were carried out for checking the model quality:

- the correspondence of the equality 0 of the mean (Student statistic (t-test));
- random character (the test on turning points (TP-test));
- presence (absence) of autocorrelation (the Durbin–Watson statistic (DW-test));
- correspondence of normal probability distribution (R/S –criterion (R/S-test));
- checking for heteroscedasticity (Spearman rank correlation (SRC-test)).

Results of the tests are shown in Table 2. Table 1 shows that all models are adequate. For interval evaluation of model values the following formula was used:

$$\hat{y}_{10.1} = \hat{y}_{10.1} \pm t_{1-\alpha,v=n-p-1} \cdot s_y \cdot (1 + [XZ]_0^{\,T} \cdot ([XZ]^T \cdot [XZ])^{-1} \cdot [XZ]_0)^{1/2}, \tag{12}$$

where s_y is standard error, $\hat{y}_i$ is calculated value by Formulas (9) to (11), $t_{\alpha,n-p-1}$ is the coefficient characterizing the confidence level (determined by the Student distribution table), α is value (at 5% level), n is the number of observations, p is the number of model parameters; $[XZ]$ is matrix of state and impact factors, $[XZ]_0$ is vector of specified values.

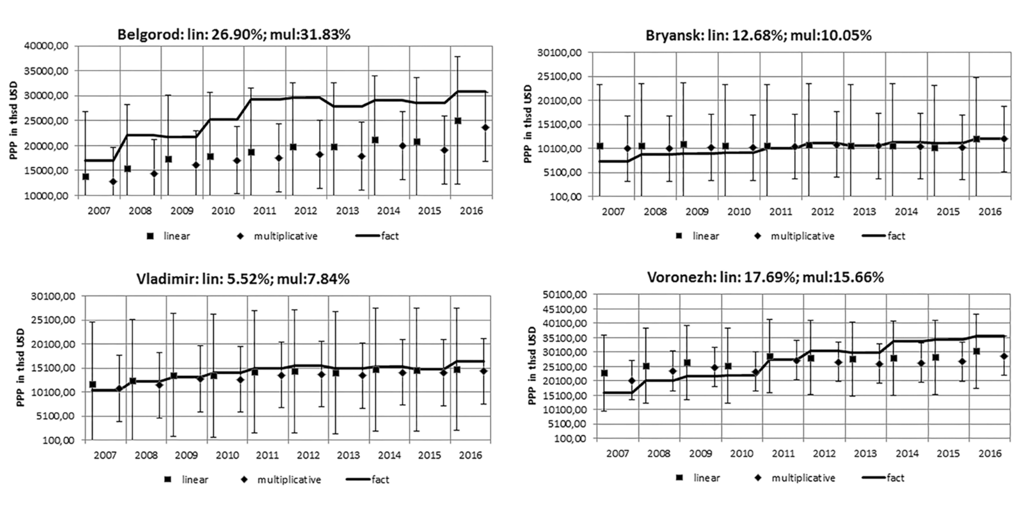
Dynamics of relevant indicators is shown in Figures 1 through 4.

Given that in transition to absolute values the models (7) and (8) are identical to ($\hat{y}_{10\ 1/mul}^{\ *} = \exp(\hat{y}_{10.1/log}^{\ *})$), only linear and multiplicative models are supplied in these Figures. Digits in the title (lin and mul) characterize the average relative error:

$$E_{rel} = \sum_{i=1}^{n} \left| \frac{y_i - \hat{y}_i}{y_i} \right| \cdot 100\%. \tag{13}$$

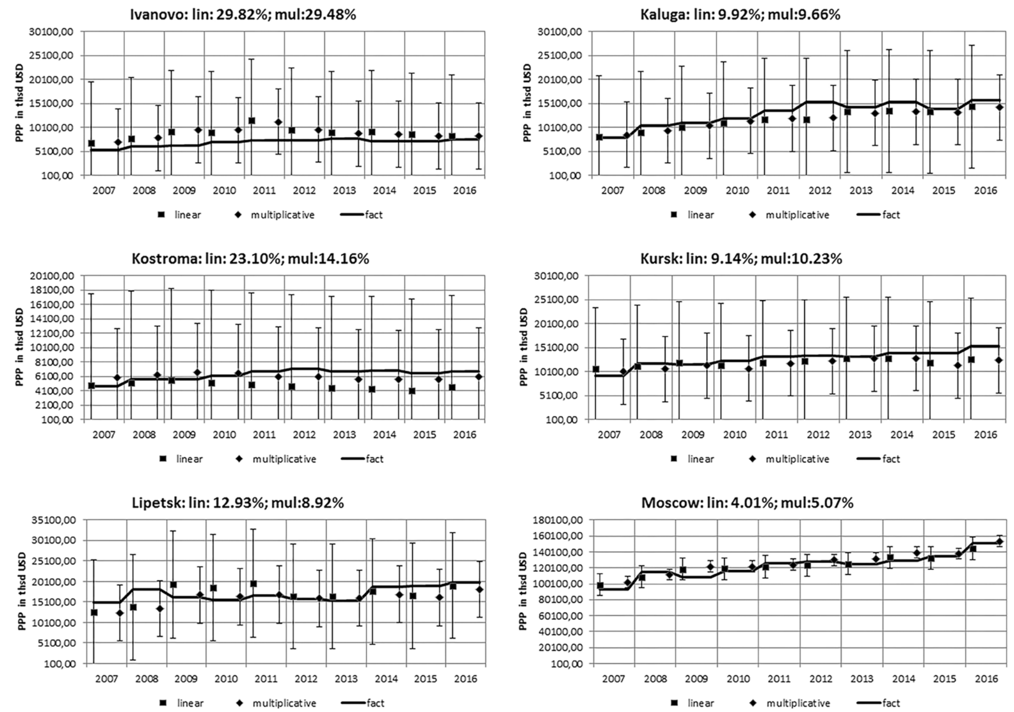
Figures 1 through 4 show that for some regions, for instance, Belgorod, Bryansk, Vladimir, Voronezh, Kursk, Lipetsk, Tver, Tula and Yaroslavl, the values calculated using the linear model are higher than

Figure 1 Dynamics of actual and calculated values of GDP by regions (Belgorod to Voronezh regions)



Note: Linear, multiplicative are calculated values by linear and multiplicative models, respectively, fact is actual (empirical) data, lin and mul values are average relative error.
Source: Author's calculations

Figure 2 Dynamics of actual and calculated values of the GDP by regions (Ivanovo to Moscow regions)



Note: Linear, multiplicative are calculated values by linear and multiplicative models, respectively, fact is actual (empirical) data, lin and mul values are average relative error.
Source: Author's calculations

those calculated using the multiplicative model. For Kostroma, Moscow and Orel regions the values calculated using the linear model are lower than values, calculated using the multiplicative model. For Ivanovo, Kaluga, Ryazan, Smolensk and Tambov regions this difference varies between positive and negative.

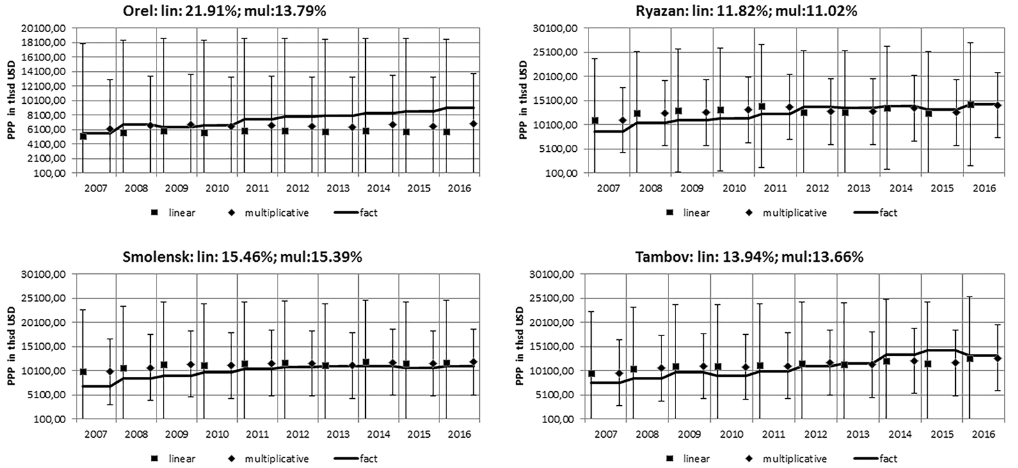
It means that at this stage the issue of choosing a model for forming the normative remains open.

For regions of the Central Federal District the particular assessment indicator is calculated using Formula (1). The results are shown in Figures 5 through 6.

Figures 5 and 6 show that the quantitative assessment of different models produces different results. However, the linear model gives an upper estimate of the particular assessment indicators for Orel region, the logarithm model gives upper estimate for Smolensk and Tver regions, while the multiplicative model gives an upper estimate for Belgorod region only. The estimates vary for remaining regions. The dynamics of these values is similar for linear, logarithm, and multiplicative models. To determine the causes that impact these results, it is necessary to additionally study the curvatures obtained in building particular assessment indicators.

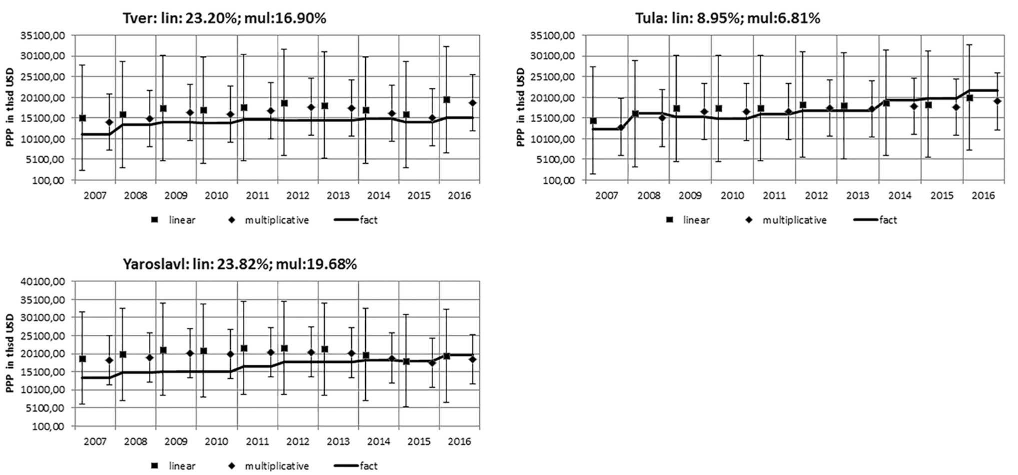
For this purpose, the isoquants are built while fixing one of the variables, for example, the expense on technological innovation ($z_{22.17}^{*}$), presenting them in three versions: absolute units of measurement, standardized and a normalized version.

Figure 3 Dynamics of actual and calculated values of GDP by regions (Orel to Tambov regions)



Note: Linear, multiplicative are calculated values by linear and multiplicative models, respectively, fact is actual (empirical) data, lin and mul values are average relative error.
Source: Author's calculations

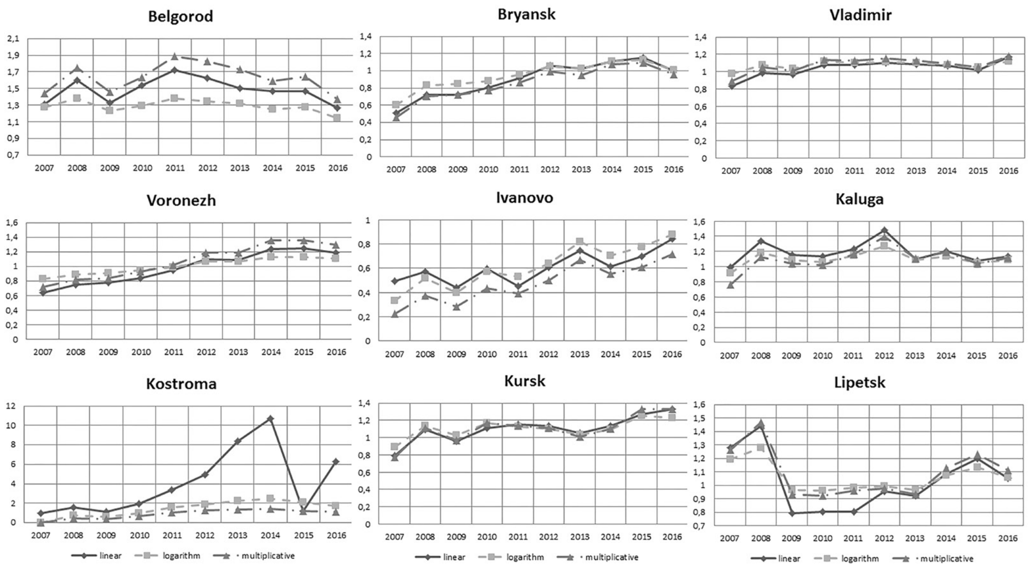
Figure 4 Dynamics of actual and calculated values of GDP by regions (Tver to Tula and Yaroslavl regions)



Note: Linear, multiplicative are calculated values by linear and multiplicative models, respectively, fact is actual (empirical) data, lin and mul values are average relative error.
Source: Author's calculations

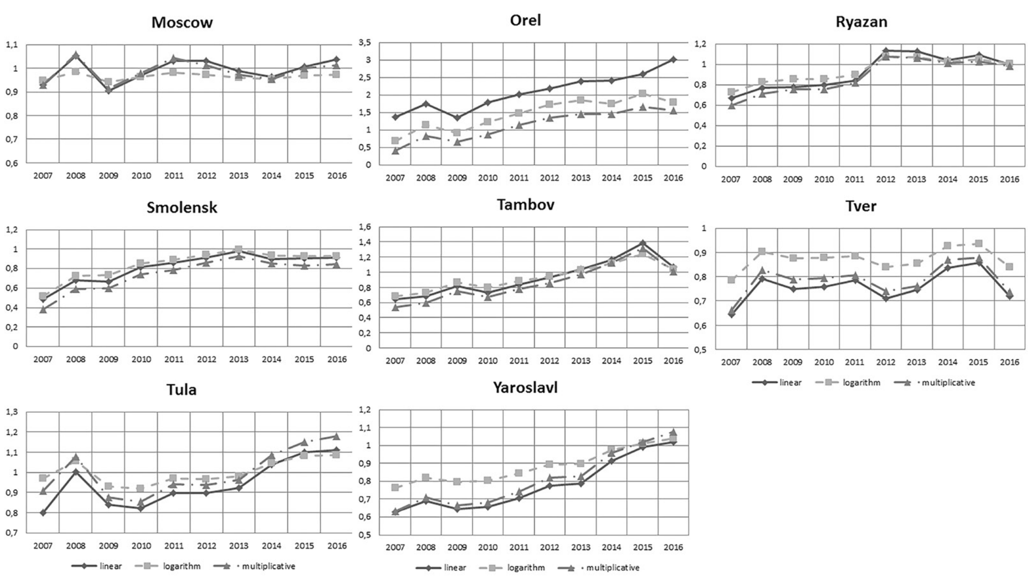
The results obtained in absolute units of measurement for various GDP values by regions in US$ ($20, $50 and $80 million) are shown in Figure 7. The fixed expense on technological innovation is $11.9 million, which corresponds to a standardized value equal to a one.

Figure 5 Dynamics of particular performance indicator for regions (Belgorod to Lipetsk regions)



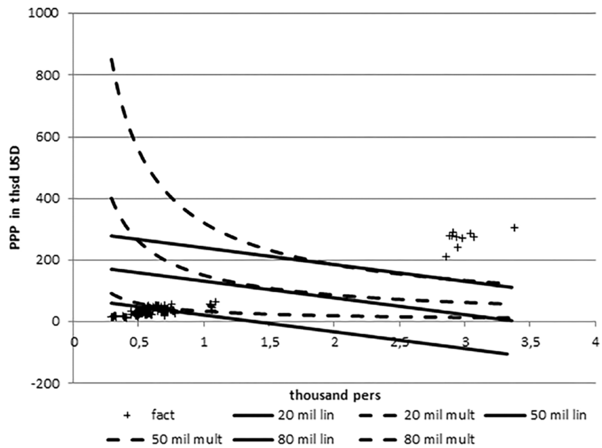
Source: Author's calculations

Figure 6 Dynamics of particular performance indicator for regions (Moscow to Yaroslavl regions)



Source: Author's calculations

Figure 7 Regions' GDP isoquants in terms of PPP in US dollars



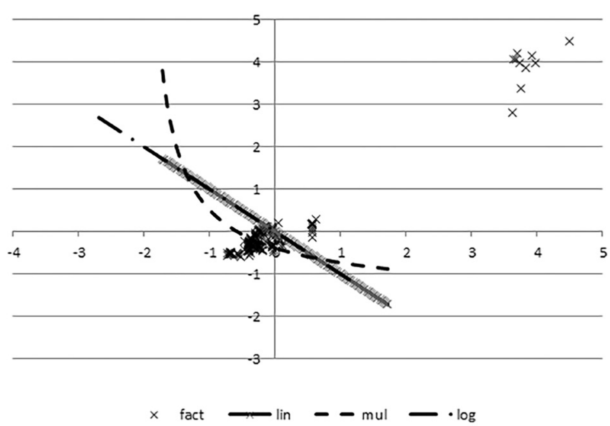
Note: Mil lin, mil mul are isoquants which are calculated by linear and multiplicative models for $20, $50 and $80 million regions' GDP respectively; fact is actual (empirical) data, x-axis is an average annual number of persons employed (thousands persons), y-axis is the fixed capital (PPP in thousand US dollars).
Source: Author's calculations

Figure 7 shows only linear and multiplicative models since in converting the logarithmic model to absolute values, the logarithmic and multiplicative model forms coincide.

In increasing the expenditure on technological innovation to the maximum actual value, equal to $5.6 million, the level lines for the linear and multiplicative models did not overlap.

If the data are presented in a standardized format, by using Formulas (4) and (5), then the change of GDP absolute values by regions and the expense on technological innovations of the values inclination and shift for linear and multiplicative models will not be observed (Figure 8).

Figure 8 Standardized regions' GDP isoquants



Note: Lin, mul, log are calculated values by linear and multiplicative models, respectively; fact is actual (empirical) data, x-axis is the standardized average annual number of persons employed, y-axis is the standardized fixed capital.
Source: Author's calculations

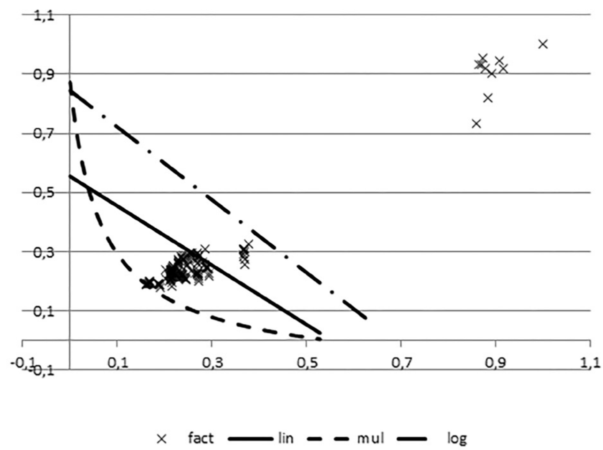
Figure 8 shows that values calculated using the logarithmic model lie on the linear model but are shifted to the left in relation to the linear model. This is explained by the fact that the initial data were processed for logarithms. Also, it can be seen that at one and the same set value of the regions' GDP and the expenditure on technological innovations, the norms calculated using linear and logarithmic models allow for larger values of $x_{1,1}^*$ and $x_{1,2}^*$ in an area formed by overlapping of relevant isoquants. In this case the area contains most of the empirical data for the CFD regions.

Following normalization according to Formulas (2) and (3) the logarithmic level line came out above others. This is easily seen in Figure 9. The change in the regions' GDP and expenditure on technological innovations does not change the level lines formed by the set values of $x_{1,2}^0$ and $x_{1,2}^0$.

To convert the variables $x_{1,1}^*$ and $x_{1,2}^*$ to a normalized format ($x_{1,1}^0$ and $x_{1,2}^0$), formulas similar to Formulas (2) and (3) were used.

Figure 9 shows that the logarithmic model allows for higher values of $x_{1,1}^0$ and $x_{1,2}^0$, while the multiplicative one does for lower values of $x_{1,1}^0$ and $x_{1,2}^0$. It means that in forming the norms, at all other conditions being equal, the logarithmic model will yield the lowest norms for assessing the regions' GDP, the linear model will produce mean values, while the multiplicative model will yield the highest or the most rigorous (strictest) norms.

Figure 9 Normalized regions' GDP isoquants



Note: Lin, mul, log are calculated values by linear and multiplicative models, respectively; fact is actual (empirical) data, x-axis is the normalized average annual number of persons employed, y-axis is the normalized fixed capital at full accounting value at the end of the year.
Source: Author's calculations

It is known that the norms are established by control agencies. Therefore, at the current stage the choice of a model can be determined depending on the importance of developing the regions' economy compared to social development and securing their ecological safety, that are the agencies' priority functions. Among other things, these priorities must be tied up with the concept of sustainable development.

Another aspect that can be a basis for choosing the described models is the qualitative nature of influence exerted by capital, labor, and innovations. It is obvious that the production included in the regions' GDP, needs both labor and production assets, while the use of innovations heightens the production efficiency and determines competitiveness in the modern rapidly developing world. It is expressly the existence of these three components that are the essence of the generalized form of the Cobb-Douglas function presented by Formula (8) for 3 variables. The logarithmic model, as Figures 7 to 9 show, allows for formation of lower norms for the regions, which may decrease the competitiveness level. The linear model, while giving a mean evaluation of the norm, allows the production process without the use of either labor or capital or innovations, which at the current level of development is not possible on the regions' scale.

Consequently, the choice of the model can be determined using three mutually supportive criteria: 1) model quality and adequacy; 2) controls' priorities (the higher the normative, the more important is the indicator under study and the higher the competitiveness); and 3) qualitative (semantic) content of the model.

Table 3 assesses the models chosen for investigation.

Table 3 Results of the estimation of models by criteria

Model/Criteria	Quality and adequacy	Priority	Substantive content
Linear	+++	++	–
Logarithm	+	+	–
Multiplicative	++	+++	+

Source: Own construction

Table 3 shows that all models are good quality and adequate. In this case, the most qualitative is the linear model and in the simplest case it is possible to do with a linear model in the formation of the normative for of GDP by region. However, in order to satisfy all criteria (taking into account the substantive content of the models and the importance of GRP for the regional economy) it is necessary to use the multiplicative model. The multiplicative model significantly all requirements; it is qualitative and adequate and has the highest priority. Therefore, the authors the authors used this model to form particular performance indicator.

The results of assessing the GDP by region; the multiplicative model is presented in Table 4.

Table 4 Particular performance indicator

Region/Year	2012	2013	2014	2015	2016
Belgorod	1.822	1.733	1.593	1.642	1.375
Bryansk	0.993	0.953	1.072	1.091	0.956
Vladimir	1.150	1.129	1.097	1.053	1.182
Voronezh	1.191	1.186	1.357	1.356	1.297
Ivanovo	0.499	0.668	0.553	0.609	0.716
Kaluga	1.399	1.104	1.192	1.040	1.119
Kostroma	1.259	1.326	1.445	1.195	1.132
Kursk	1.109	1.013	1.105	1.329	1.330
Lipetsk	0.974	0.930	1.126	1.232	1.110

Table 4 (continuation)

Region/Year	2012	2013	2014	2015	2016
Moscow	1.012	0.972	0.953	1.001	1.011
Orel	1.360	1.454	1.452	1.670	1.564
Ryazan	1.074	1.065	1.010	1.028	0.981
Smolensk	0.86	0.924	0.852	0.833	0.846
Tambov	0.856	0.974	1.127	1.317	1.010
Tver	0.739	0.761	0.869	0.88	0.737
Tula	0.938	0.964	1.086	1.152	1.179
Yaroslavl	0.818	0.828	0.957	1.020	1.078

Source: Author's calculations

In 2016, most of the particular performance indicators exceeding a one, excepting Bryansk, Ivanovo, Ryazan, Smolensk, and Tver regions. For these regions, the GDP does not reach the norm, and this is a negative result. For the rest of the regions, their functioning can be considered satisfactory. However, compared to 2015, in most of the regions the indicator values dropped. In order to analyze the phenomena that affected the result, it is essential to study the extent and intensity of using the labor and capital as well as innovations, which calls for a more detailed study at the level of a concrete region.

CONCLUSION

This article deals with a comparative analysis of results of appraising Russia's Central Regions' GDP depending on their chosen model based on the author's approach, by means of which it is possible to formulate normal standards for each, taking into consideration its specifics. This makes it different from other approaches used for formulating complex systems' functioning results evaluation indicators.

In order to create normative standards the following models were chosen: linear, logarithmic, and multiplicative, which included factors characterizing labor, capital and innovations.

For substantiating the choice of the model, checks were conducted for the models' quality and adequacy. All the models proved to be adequate and of proper quality.

Following calculation of the particular performance indicator it turned out that the use of different models brings about different results. This called for the study on the isoquant's shape determined by the chosen models. The analysis showed that the highest value of evaluation indicators results from the logarithmic model, middle from the linear model and the lowest (more rigorous requirement for the regions' GDP) from the multiplicative model. At this stage the choice of the model can be determined taking into account the priorities of development of a particular region.

The next stage was evaluation of the models' semantic purport.

Thus, the developed three-level algorithm of substantiating the choice of a model for establishing the norms made it possible to adopt the multiplicative model as a basis.

The investigation results can be used for determining the causes of reduction in the regions' expected GDP values as well as for taking well-grounded managerial decisions.

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Estimating Criminal Populations from Administrative Registers

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Abstract

This study proposes a methodology for estimating the hidden criminal population working in markets of drug trafficking, prostitution exploitation and smuggling in Italy during the period 2006–2014. These estimates represent the first step of a wide procedure that has the final objective of measuring the economic flows of illegal transactions in national accounts. We exploit administrative registers coming from the Ministry of Justice, and consider these registers as lists of potential criminals. Unique codes for denounced criminals are not available, limiting so far its exploitation at micro level. This drawback has been overcome in this work by proposing an adjustment of the Zelterman estimator that accounts for the potential linkage errors caused by the lack of exact unique identifiers in the dataset. We obtain yearly estimates of the population size of criminals including also the unknown population, for the crimes of drug trafficking, prostitution exploitation and smuggling during the period 2006–2014.[4]

Keywords	***JEL code***
Illegal economy, population size estimation, Capture-recapture, Zelterman estimator, linkage errors	*C13, E26, P41, K42*

INTRODUCTION

This study seeks to estimate the hidden criminal population working in the drug markets, prostitution and smuggling of cigarettes in Italy during the period 2006–2014. This research aims to assess the size of illegal markets considered a substantial part of the illegal economy and more widely fits the field of measuring the flow of illegal proceeds to adjust GDP. According to European regulation, national accounts aggregates have to include illegal activities covering exhaustively the economic transactions which occur in the economic system. A complete coverage of economic transactions is an important aspect of the quality of national accounts.

The inclusion of illegal activities (in particular, the production and marketing of drugs, alcohol and tobacco smuggling, and prostitution) in national accounts estimates is a decision that has been taken

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[4] This paper is based on contribution at the *European Conference on Quality in Official Statistics (Q2018)* in Krakow, June 2018, Poland.

at the European level[5] and implemented by Member States following Eurostat recommendations in terms of methodological approach, quality and reliability of data sources, identification and solution of double counting.

Illegal activities for their nature are difficult to measure as people involved have obvious reasons to hide these activities. As a consequence, data sources and statistical techniques for measuring illegal economic activities are generally not homogenous and standardized.

Italy is considered one of the key countries in Europe for drug trafficking that has long since reached a transnational dimension both because of the geographic position in the Mediterranean Sea and presence of criminal organizations. The big size of this market does not concern production but only import. In Italy, prostitution is legal while it is a criminal offense to organize and exploit prostitutes. Italy adopts an approach towards prostitution of the neo-abolitionist type: outdoor prostitution is neither prohibited nor regulated, while the indoor kind is forbidden only in brothels. In essence, it is not a crime to offer paid sexual services or buy sexual services for a fee. Activities typically associated with prostitution, such as exploitation, recruitment and abetting are instead punished by law. Smuggling activities identify the violation of tax provisions relating to the manufacture, trade and consumption of products subject to the payment of a manufacturing or consumption tax. Smuggling activity goes often along with the counterfeit of cigarettes; the counterfeit of cigarettes is the production of not authentic tobacco products using a trademark without the authorization of the owner. Italy is mainly a territory of final distribution of illegal cigarettes than of transit.

Actually, the Italian National Institute of Statistics (ISTAT) estimate applies both a demand-side and supply-side approaches. Estimating the value added and other aggregates on demand indicators means to use information regarding the final users of the illegal goods or services and their consumption behaviour. In other cases, supply indicators are used, estimating the value of production from information on the production units involved or the goods seized by authorities.

Illegal market of drugs of trafficking is estimates by demand side, prostitution and smuggling of cigarettes by supply side. Trying to provide a complete coverage of the size of the above illegal markets, we calculate the hidden population of illegal authors for each of these crimes. Hidden criminal populations have been estimated since a long time with capture-recapture methods. Rossmo and Routledge (1990) estimate the size of criminal populations of migrating fugitives and street prostitutes with Capture-recapture analysis. Collins and Wilson (1990) estimate the size of the criminal population of automobile thief in Australia applying the Zelterman method. Van Der Heijden et al. (2003a) estimate the size of criminal population of drunk drivers and persons who illegally possess firearms using a truncated Poisson regression model and building the dependent variable with capture-recapture method from the Dutch police records. In order to estimate the risk of being arrested as a drug dealer and a consumer, Bouchard and Tremblay (2005) employ a capture-recapture method to determine the size of these two hidden populations in Quebec (Canada). Mascioli and Rossi (2008) estimate the drug consumers employing a capture-recapture method. Rossi (2013) estimates the hidden population of drug dealers and consumers employing different method in order to measure the market size from demand and supply side.[6] The results of this study are not so far from ours. The paper describes an approach aimed to improve the accuracy and reliability of the labour input estimates for illegal activities using an administrative database of the Ministry of Justice, available for the period 2006–2014. The source refers, in particular, to the alleged crimes for which judicial authority started a criminal proceeding and which have been enrolled in the registrations of the Public Prosecutor's

[5] The new ESA 2010 regulation states that national accounts data should be subject to assessment according to the quality criteria set out in Article 12(1) of Regulation (EC) No. 223/2009 of the European Parliament and of the Council of 11 March 2009 on European statistics. One of the criteria established by Eurostat for national accounts estimates is the accuracy and reliability of the estimates annually provided according the ESA 2010 transmission programme.

[6] See also Rey, G. M. et al. (2011).

offices. It is possible to consider the above source as a potential register of the known criminals: in this source it is possible to observe an individual more than once, if he/she is accused of committing more than one offence. However, it is unknown the number of individuals not observed by the justice system even if active in the illegal markets, so units that actually belong to the target population. The list from the Public Prosecutor's offices is therefore incomplete, as it allows us to count only a part of the interest population. This is the key question of this study. To solve this point, we assume that the counts from the Public Prosecutor's offices come from a zero-truncated Poisson distribution and a capture-recapture method with the Zelterman estimator is applied to estimate the number of criminals not observed by the judicial system. In addition, in our context, a complication occurs due to the lack of personal identifiers in the registers, caused by privacy motivations: indeed, only soft identifiers as gender, date and place of birth of the suspected criminals are available to us. In this case, it is possible that the linkage, carried out to retrace and count how many times the same individual appears in the Public Prosecutor's office lists, can be compromised. Intuitively, one can expect that some false matches (that is, false positive) may occur just because some people happen to have the same birth date, gender and place of birth. The reliability of matches is then examined by considering the occurrence of matches purely by chance. This work proposes indeed an adjustment to the Zelterman estimator in order to take into account the linkage errors. Moreover, the generalized estimator allows including covariates in the estimation of the hidden population size. The proposed estimator can be applied in different situations in which the linkage results are subject to uncertainty. For instance, in this case we only assume false links due to the fortuity of sharing the same soft identifiers; however, the same methodology can be applied in the presence of linkage errors due to inaccuracies in the matching variables.

The methodology resolves two limitations related to the nature of the source: firstly the identification of the number of the known persons involved in crimes through the correction of the criminals overlapping; secondly the identification of the proper estimator for grossing up the correct number of criminals to calculate the hidden population of illegal workers in illegal markets of drug, prostitution and smuggling to give a whole dimension to the phenomenon, identifying both the potential known and unknown criminals.

It is worth noting that our analysis deals with an administrative list of denounced crimes, referring suspected subjects in drug trafficking, prostitution exploitation and smuggling, with the aim of estimating the unknown size of people involved in the abovementioned crimes. Our estimates of the hidden criminal population working in markets of drug, prostitution and smuggling in Italy during the period 2006–2014 are coherent with the information coming from other sources.

The paper is structured as follows: in section two we describe the data, in section three we propose the methodology employed in the estimation; in section four we show the results and finally in section five we provide some concluding remarks.

1 THE DATA

This study uses annually official data provided to Istat by the Ministry of Justice regarding the alleged crimes for which the judicial authority started a criminal proceeding and which have been enrolled in the registers of the Public Prosecutor's offices. Crimes that are registered in the criminal registers of the Public Prosecutor's offices represent the first step of official knowledge about the proceeding. These data are provided to Istat without unique identifier for suspected criminals, only soft identifier as date, place of birth and gender are available. Based on this information, the crime perpetrators are identified and followed in a specific time span. In this way, the administrative source can be considered as a list of potential criminals with the count (i.e. the frequency) that they appear in the Prosecutor's offices registers. In the list we can observe individuals who are charged 1, 2, 3, ... k times, however, we cannot observe units not recorded in the Justice system. Statistically, these data can be considered as coming from a count distribution truncated at zero. The administrative register also provides some characteristics of the denounced subjects and the crime acts, like age at the moment of the crime, nationality, the association with other subjects and other crimes done. This information can be exploited to explain heterogeneity in the individual behaviours.

On the other hand, the lack of unique identifiers and the risk of false links due to the use of soft identifiers in linkage procedure have to be solved. The labour force survey (LFS) has been used as additional data source where complete identifiers are available. The information refers to legal workers under the hypothesis that false match rates are similar to those of illegal workers. The false match rate has been estimated considering the occurrence of coincidence on the birth date, gender and place of birth due to chance on distinct individuals in the LFS.

Aggregating for personal data, kinds of crime and the year of the proceedings, we observe counts for the three considered crimes as in Table 1.

Table 1 Observed counts for the three crimes of interest by the year of the proceedings

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014
Drugs	35 486	38 114	40 537	41 114	37 573	37 034	34 100	36 584	34 964
Prostitution	2 784	2 929	3 193	3 030	3 109	2 955	2 831	2 717	2 740
Smuggling	1 883	2 102	2 543	3 386	2 349	2 261	2 802	2 924	3 349

Source: Our elaboration on the registers of the Public Prosecutor's offices data

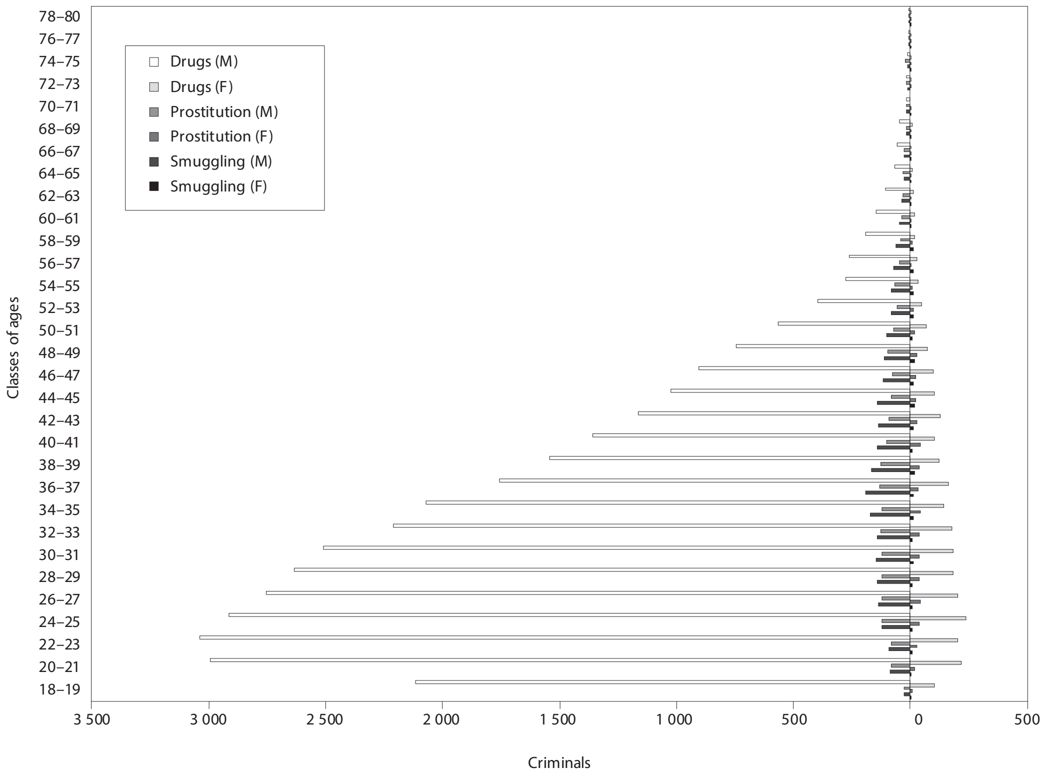
Table 1 shows the yearly number of denunciations for each type of crime and how the number of denunciations changes in time and among types of crime. It is clear that the yearly counts are quite similar for the considered crimes. For this reason, in the rest of the paper, sometimes we just show the results of a single reference year, the 2013. In addition, we decided to show the results of the crime of drug trafficking because it records the highest number of crimes and the methodology for adjusting the linkage error is more effective.

Figure 1 describes the three pyramids of age and gender of the observed populations in 2013, collapsed in just one figure in order to make evident the comparison between the different crimes. The figure shows primarily that the denunciations of drug related crimes committed by men are far greater than the denunciations made for other crimes. Prostitution and smuggling related crimes data also show that almost all the crimes are attributable to men. As we expected, the 20–40 age group is the one with the highest number of denunciations for all the three type of crimes, but in drug trafficking it is more evident than in others.

In this study the considered covariates are gender (G), age (A), nationality (N), other crimes (OC), association (As). We considered these covariates because they can help in better explaining the heterogeneity of the parameter. The covariate "age" goes to 18, the year of the majority age in Italy (that is also the age from which one can go to prison), until 80, the year that we considered possible to carry out a job. The covariate "gender" indicates the sex of the suspected criminals. The covariate "nationality" indicates if the subject is Italian or foreigner. The covariate "other crimes" indicates if the author has also one or more pending denunciation for other crimes. The covariate "association" indicates if the offender has committed the crime in association with other people.

Table 2 reports the covariates for drug crimes in 2013: as already shown by the pyramids in Figure 1, males are far more than females, most subjects are concentrated in the age group under the age of 50. Italians are only twice than foreigners. Moreover, most of the units do not have denunciations about

Figure 1 Pyramids of age and gender of illegal populations in 2013



Source: Our elaboration on the registers of the Public Prosecutor's offices data

Table 2 Counts for covariates for drug crimes in 2013

Covariate	Counts
Female	2 732
Male	33 852
≤ 30 years	18 952
30–50 years	15 555
> 50 years	2 077
Italians	23 917
Foreigners	12 667
Not-involved in other crimes	28 397
Involved in other crimes	8 187
Act alone	19 525
Act in association with other people	17 059

Source: Our elaboration on the registers of the Public Prosecutor's offices data other types of crimes, even if the denunciations for other crimes are not few. The counts are finally almost divided in half between those who acted alone and those who acted in association with other people. We have this situation because many of the subjects denounced for drug related crimes are drug dealers who are predominantly young, many of whom are foreigners but also Italians, affiliated to national organizations that manage drug trafficking.

2 METHODOLOGY

2.1 The Zelterman estimator

As shown in the previous section, the administrative register from the Justice Ministry can be viewed as a list of individuals from the population of criminals, where we are able to count how many times each individual is registered, even if with some uncertainty due to the risk of false links. However, some population members are not observed at all, so the list can be incomplete and show only part of the population. In this framework, several methods have been studied for estimating the population size, where the question is mainly how many individuals are missed by the register. Shortly, the register counts are considered to come from a zero-truncated Poisson distribution: according to a standard formulation, consider a population of size N and a count variable Y taking values in the set of integers {0, 1, 2, 3, ...}. In this study Y represents the number of criminal proceedings a person has been enrolled in the registration on the Public Prosecutor's offices in the reference time. Denote with $\{f_0, f_1, f_2, ...\}$ the frequency with which a 0, 1, 2, 3, ... occurs in this population.

Since a unit is observed only if Public Prosecutor's offices start a criminal proceedings against him/her, the subject will only be observed if there has been a positive number of proceedings with the justice institution, whilst y = 0 will not be observed in the list. Hence the list reflects a count variable truncated at zero that we denote by Y_+. Accordingly, the list has observed frequencies $\{f_1, f_2, ...\}$ but the frequency f0 of zeros in the population is unknown. The size of the list is not N but nobs, where $N = n_{obs} + f_0$ is the unknown size of the population.

The distributions of the untruncated and truncated counts are connected via:

$$P(Y_+ = j) = P(Y = j) / (1 - P(Y = 0)),$$

for $j = 1, 2, 3, ...$ For example, if Y follows a Poisson distribution with parameter λ so that:

$$P(Y = j) = Po(j \setminus \lambda) = exp(-\lambda) \lambda^j / j!, \tag{1}$$

for $j = 0, 1, 2, 3, ...$ then the associated distribution of Y_+ is given by:

$$P(Y_+ = j) = Po_+(j|\lambda) = \frac{\exp(-\lambda)}{1 - \exp(-\lambda)} \lambda^j / j!, \tag{2}$$

with $j = 1, 2, 3, ...$

Given that all units of the population have the same probability $P_i(Y > 0) = P(Y > 0) = 1 - P(Y = 0)$ of being included in the list, the population size N can be estimated by means of the Horvitz-Thompson estimator:

$$\hat{N} = \sum_{i=1}^{n_{obs}} \frac{1}{1 - P(Y = 0)} = \frac{n_{obs}}{1 - \exp(-\lambda)}. \tag{3}$$

This approach requires that λ is known and if it is not, it needs to be estimated. Clearly, λ can be estimated with maximum likelihood under the assumption of a homogeneous truncated Poisson distribution. In alternative, some different estimators have been proposed in Van Der Heijden et al (2003a, b) and Bohning et al. (2009). For instance, the Zelterman estimator proposed in Zelterman (1988) only uses the first two counts so it is less sensitive to model violations than the estimator that assumes homogeneous Poisson distribution for the entire range of frequencies f_j. Indeed, Zelterman (1988) argued the Poisson assumption might not be valid over the entire range of possible values for Y but it might be valid for small ranges of Y such as from j to $j + 1$. The original formulation of the Zelterman estimator is based on a property of the Poisson distributions, which also works for zero-truncated Poisson distributions:

$$Po\ (j + 1|\lambda) = Po\ (j|\lambda) = \lambda\ /\ (j + 1).$$

So, Zelterman (1988) suggested λ can be estimated as:

$$\hat{\lambda}_j = \frac{(j+1)f_j + 1}{f_j}\ . \tag{4}$$

Zelterman (1988) also argued to use the frequencies f_j closest to the target prediction f_0, that is f_1 and f_2, this leads to the estimator $\lambda_Z = (2f_2 / f_1$, obtained by (4) for $j = 1$.

This estimator is unaffected by changes in the data for counts larger than 2, this contributes largely to its robustness; this solution seems particularly proper in this application because of the observed count distribution, with debatable high level frequencies, up to f_{70}, as shown for instance in Table 3.

Table 3 Frequencies of captures for drug crimes in 2013

	Counts		Counts
f_1	29 755	...	...
f_2	4 108	f_{41}	1
f_3	1 070	f_{42}	1
f_4	542	f_{43}	1
f_5	275	f_{44}	1
f_6	209	f_{45}	2
f_7	115	f_{51}	1
f_8	107	f_{59}	1
f_9	76	f_{65}	1

Source: Our elaboration on the registers of the Public Prosecutor's offices data

The presence of counts of high order, up to 70, is confirmed also for the other years. The other crimes present frequencies quite lower than drugs, e. g. the highest frequency for prostitution is around 10 and the highest frequency for smuggling is around 30. This may be due to either the fact that having carried out multiple crimes the judiciary has opened more proceedings for individual crimes or a defect of the dataset. However, in this case, the use of a robust estimator like the Zelterman seems to be recommendable to reduce the sensitivity of the results with respect to the changes in the data for counts larger than 2.

The resulting estimator for the population size is $\hat{N}_Z$:

$$\hat{N}_Z = \frac{n_{obs}}{1 - \exp(-\lambda_Z)} = \frac{n_{obs}}{1 - \exp(-2 f_2 / f_1)} \quad . \tag{5}$$

2.2 The Zelterman estimator with covariates

The Zelterman estimator can be extended so to take into account covariates to explain the observed heterogeneity as in Bohning et al. (2009). Indeed, in most applications, the assumption of homogeneous λ is not realistic while the register contains, together with the counts Y, also some information about the individual characteristics.

The covariates can be incorporated into the modeling process, by:

$$\lambda_i = 2\, exp(\boldsymbol{\beta}^T \boldsymbol{x}_i),$$

where $\boldsymbol{x}_i$ is the vector with covariate values including a constant, and $\boldsymbol{\beta}$ is the corresponding parameter vector.

Accordingly, a generalized Zelterman estimator can be derived for the population size N:

$$\hat{N}_{Z_G} = \sum_{i=1}^{n_{obs}} \frac{1}{1 - \exp(-\hat{\lambda}_i)} = \sum_{i=1}^{n_{obs}} \frac{1}{1 - \exp(-2 \exp(\boldsymbol{\beta}^T \boldsymbol{x}_i))} \quad . \tag{6}$$

In this application, the available covariates refer to both socio-demographic characteristics of the potential criminals (that is, gender, age, nationality) and features of the criminal activities (that is, the subject acts in association with other people, the subject is involved in other kinds of crimes during the reference period). A model selection can be applied so to select the proper covariates according to the principle of parsimony, identifying, if necessary, different models for each kind of crime.

This generalized formulation of the Zelterman estimator can be seen as a maximum likelihood estimator (MLE): indeed, as demonstrated in Bohning et al. (2009), a Poisson distribution with parameter λ constrained to values $Y = 1$ and $Y = 2$ yields a binomial distribution with parameter:

$$p = (\lambda / 2) / (1 + \lambda / 2) = \lambda / (2 + \lambda). \tag{7}$$

So the associated likelihood L for the event $Y = 2$ with parameter $p = \lambda / (2 + \lambda)$ is:

$$L = \prod_{i=1}^{f_1+f_2} (1-p)^{y_i-1} p^{y_i} = (1-p)^{f_1} p^{f_2} \, . \tag{8}$$

The binomial likelihood is maximized for $\hat{p} = f_2 / (f_1 + f_2)$, that is $\hat{\lambda} = \frac{2\hat{p}}{1-\hat{p}} = 2f_2 / f_1$. A great advantage of considering the Zelterman estimator as a MLE is related to the availability of its variance in a closed form.

2.3 Zelterman estimators in the presence of linkage errors

Sometimes, the identification of the units in the register/list can be affected by errors, for several reasons: typos or missing values in the identifiers, lack of complete information for privacy preserving. The errors in the unit identification can be of two types: false negative, i.e. missing link of records which actually belong to the same unit, and false positive, i.e. false link of records which actually belong to different unit. In many applications of record linkage, that is the set of methods and techniques aiming at identifying the same unit even if differently represented in data sources, it is often easy to reduce the false links, e.g. by using restrictive acceptance criteria. However, this often increases the number of missing links. In many studies of animal populations, based on the recognition of individual animals from natural markings (e.g. natural tags, photographs, DNA fingerprints), as well as in epidemiology studies, the probability of false links is often negligible, due to the caution in linkage procedures and one should only consider the risk of missing true links. In this study, we assume that linkage errors are not generated by inaccuracy in the matching variables, as usual in the literature on record linkage, but they are the results of the unavailability of complete strong identifiers that generates random matches of partial soft identifiers. So, in this application, the risk of missing true links can be assumed as negligible, while we have to take into account the false positives. In fact, data on proceedings from the Public Prosecutor's Offices are available at Istat without the codes for personal identification, i.e. without names and surnames, but only with soft identifiers like the date and place of birth and gender of person involved in the proceedings. In this case, one can suspect that the efficacy of retracing the counts for each individual can be compromised by the lack of either name or a common person identifier. Intuitively, we can expect that some false matches (that is, false positive) may occur just because some people happen to have the same birth date, gender and place of birth. The reliability of matches can be examined by considering the occurrence of match purely by chance due to the occurrences of birth dates, places and gender.

The Zelterman estimator, both the simple one and in the presence of covariates, can be adjusted to avoid bias related to the potential false linkage errors caused by the lack of strong identifiers. In fact, due to false linkage errors, the observed counts f_j^* can be inflated or deflated compared to the true values f_j. One can assume that the relationship between the observed counts and the true one can be explained by the false linkage errors and in this way it is possible to further adjust the Zelterman estimator.

Assuming false match rate α affects count f_2 in this way:

$$f_2 = (1 - \alpha)\, f_2^*,$$

i.e., only part of the observed f_2^* are true f_2, namely the part for which we do not expect linkage errors.

Consequently, we have:

$$f_1 = f_1^* + 2\alpha f_2^*,$$

$$n_{obs} = n_{obs}^* + \alpha f_2^*,$$

where f_j represents the true value and f_j^* is the observed one, for $j = 1, 2$.

The linkage errors can be considered in the likelihood:

$$log\ L = \sum_{i=1}^{f_1^*+f_2^*} y_i\,(1 - \alpha)\log(p) + (1 - y_i + 2\alpha y_i)\log(1 - p)$$

and the Zelterman estimator adjusted for linkage errors becomes:

$$\hat{N}^L_{Z_G} = \frac{n^L_{obs}}{1 - \exp(-\lambda^L)} = \frac{n^L_{obs}}{1 - \exp(-2\exp(\boldsymbol{\beta}^T \boldsymbol{x}))},$$

where n_{obs}^L and λ^L are, respectively, the linkage-adjusted observed counts and the linkage-adjusted Poisson parameter.

3 RESULTS

In order to estimate the population size of criminals including also the unknown population, for each year and crime, we started from aggregated data in Table 1 seen in the descriptive analysis of the data. Table 4 shows the different models for drug related crimes.

The covariates that most affect the dependent variable is "Association" but also "Gender" and "Other crimes". Because as evidenced in the Table 4 the Akaike test (AIC) in the model with solely the covariate "Association" is the lowest and very low is also the AIC for the model with the three covariate "Association", "Gender" and "Other crimes". This is an expected result because, as we have seen before, the crimes related to drugs are committed more by men. The model results that they have done other types of crime and that they have made them in association to other people: this strengthens the thesis that the drug related crimes are the typical crimes committed within national organizations that deal with other crimes also. Our results suggest that the estimated criminal population involved in the market of drug for 2013 is around 181 460.

Table 4 Models for drugs related crimes in 2013

Model	AIC	tt^2 Test	N	C.I.
G + A + N + OC + As	24 017	Accept remove A	183 064	175 734–190 394
G + N + OC + As	24 015	Accept remove N	183 061	175 732–190 390
G + OC + As	24 013	Reject remove none	183 057	175 728–190 386
G + OC	24 941	Reject remove OC	154 025	149 318–158 732
G	25 026	Reject remove G	151 782	147 263–156 301
OC	24 941	Reject remove OC	153 937	149 239–158 635
As	24 009	Reject remove As	181 460	174 264–188 656
Null	25 029		151 625	147 122–156 128

Note: G is gender, A is age, N is nationality, OC is organized crime, As is association with other criminals.
Source: Our elaboration on the registers of the Public Prosecutor's offices data

As stated in section 2.3 we assume that linkage errors, in particular false linkage, may affect the observed counts and we model the relationship between observed counts and true ones via the linkage errors. Moreover, as introduced in section 2, we evaluate the linkage errors on a set of data related to people involved in legal activities, i.e. the labour force sample survey (LFS) carried out by ISTAT in 2014. Personal identifiers are known for these data, as well as demographic attributes used to recognize the individuals in the administrative register. Comparing the results of linkage performed via the person identifiers with the results from the linkage based on soft attributes we assess the probability of being linked by chance in the register. As expected, the frequency of matches purely by chance increases when increasing the size of the considered records. A random sample from the LFS of the same size of suspected criminal population for each class of investigated crimes has been drawn so to measure the frequency of matches by chance of the soft identifiers in similar conditions. The linkage errors appear negligible for population size similar to those involved in prostitutions and smuggling. On the contrary, with numbers like the crimes related to drugs, it results that the frequency of matches by chance is about 1.4%. Moreover, it is almost doubled for Foreigners compared to Italians (2.72% and 1.28% respectively). These quantities have been used to adjust the estimates of the criminal population size for drugs related crimes, according to the methodology illustrated in section 3.3. For instance, Table 5 reports the adjusted and naive estimates for crimes related to drugs in 2013 for some models considered in the previous paragraph. As expected, the adjusted estimates are only slightly higher than the naive estimates, as the linkage error is still small. It can be observed that the adjusted estimates are in the confidence intervals of the naive estimates and vice-versa. For example comparing the population before and after adjusting for linkage errors of the model with solely the covariate "Association" we can see that the difference is only of 3 049 criminals.

Table 5 Comparison of linkage error adjusted estimates for drugs related crimes in 2013

Model	Ignoring linkage errors		Adjusting linkage errors	
	N	C.I.	N	C.I.
G + N + OC + As	183 061	175 732–190 390	187 518	176 992–198 044
G + OC + As	183 057	175 728–190 386	186 124	178 628–193 620
G + OC	154 025	149 318–158 732	156 687	151 868–161 506
As	181 460	174 264–188 656	184 509	177 148–191 870
Null	151 625	147 122–156 128	154 253	149 642–158 864

Note: G is gender, A is age, N is nationality, OC is organized crime, As is association with other criminals and Null is the null hypothesis.
Source: Our elaboration on the registers of the Public Prosecutor's offices data

The availability of covariates is exploited in order to obtain estimates for subpopulation of interest. For instance, knowing the different linkage errors affecting subpopulation of Italians and Foreigners, we use this covariate to properly adjust the estimates, as shown in Table 6.

Table 6 Comparison of linkage error adjusted estimates for drugs related crimes for sub-populations

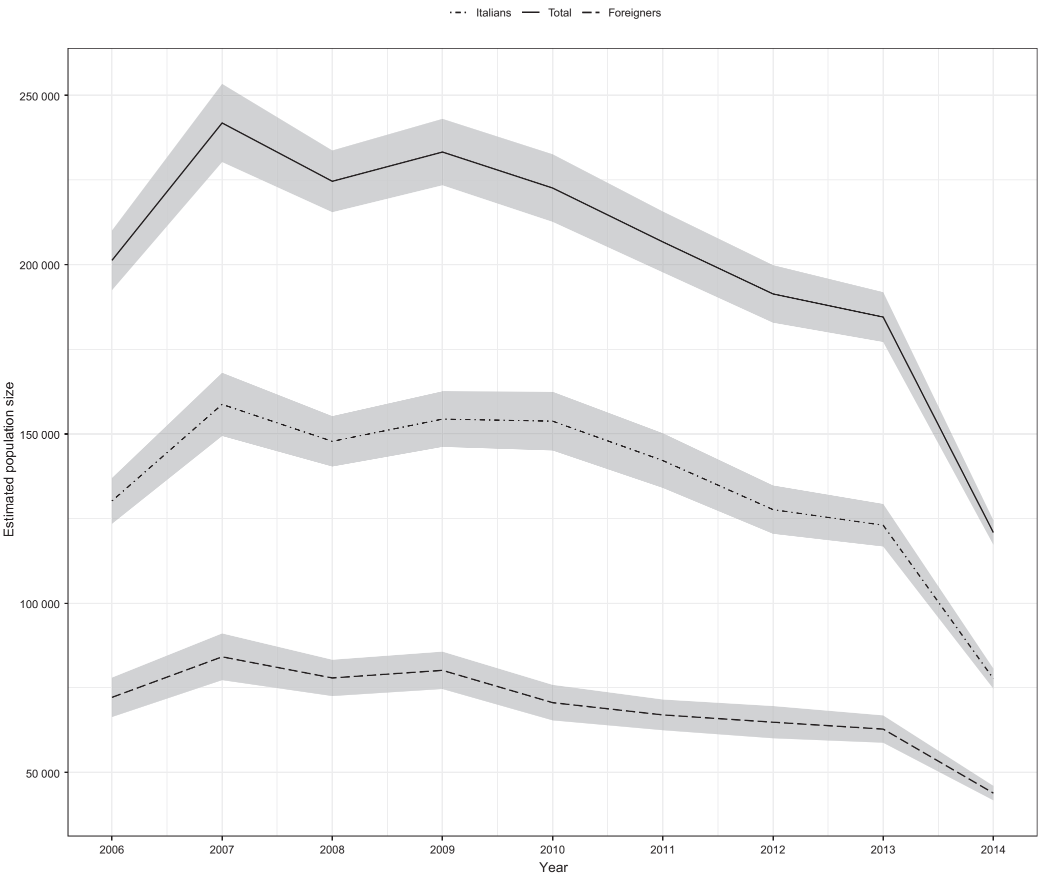
Model	Nationality	Adjusting linkage errors	
		N	C.I.
As	Italians	123 032	116 740–129 324
	Foreigners	62 813	58 779–66 847

Source: Our elaboration on the registers of the Public Prosecutor's offices data

In Figure 2, the population size for drugs is estimated for all the considered period. The confidence intervals of the estimates are also represented. Moreover, since different linkage errors affect Foreigners and Italians, the two subpopulations are adjusted separately, thanks to the available covariance on Nationality.

Finally, Figure 3 shows the population size estimates for all the considered crimes, i.e. drug, prostitution and smuggling.

Figure 2 Estimates for drugs related crimes between 2006 and 2014, for subpopulations



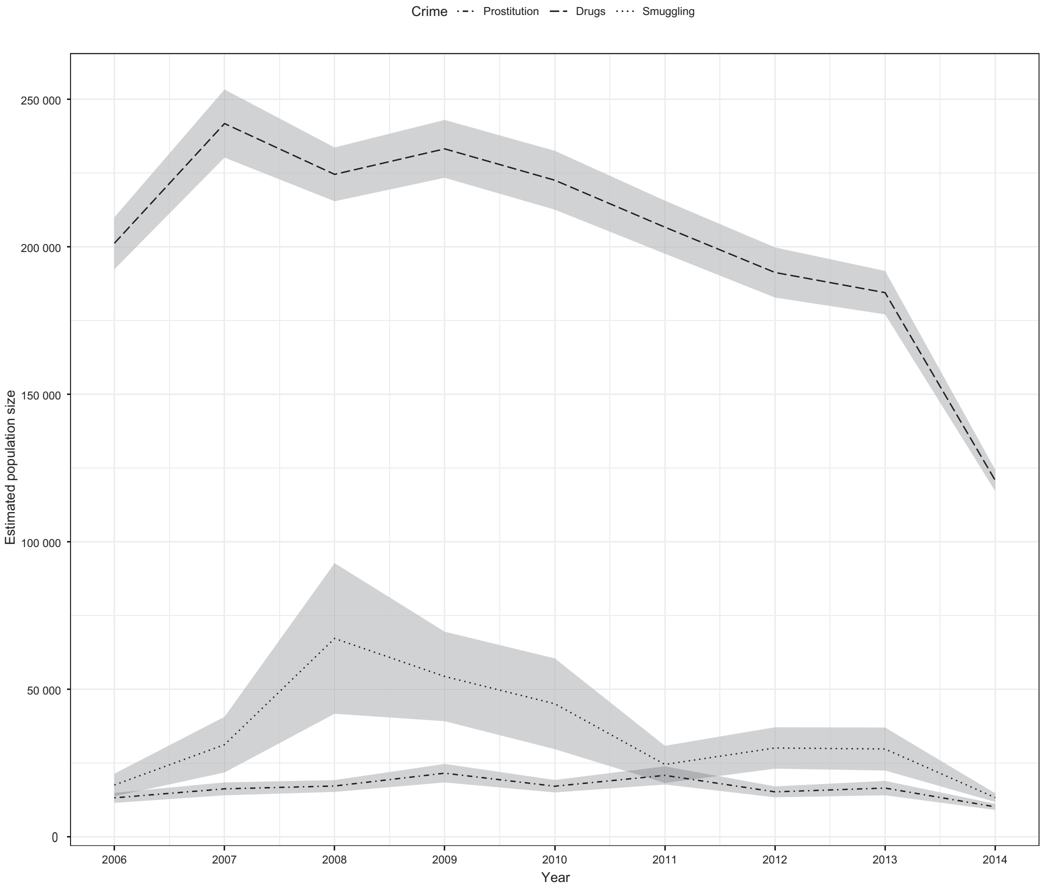
Source: Our elaboration on the registers of the Public Prosecutor's offices data

CONCLUDING REMARKS

The literature on estimating illegal populations with the Zelterman estimator already exists and can be enriched. The innovation added by this work to the literature is the calculation of the illegal population with the Zelterman estimator adjusted for the linkage error, due to the lack of exact identifiers in the dataset.

This study provides an estimate of the population of illegal persons who perform crimes related to drugs, prostitution and smuggling. The analysis observes a set of alleged crimes for which judicial authority started a criminal proceeding and which have been enrolled in the registrations of the Public Prosecutor's offices from 2006–2014. This set is intended as a potential register of the known criminals. To calculate the unknown part of criminals we use the Zelterman estimator. Moreover, due to the absence of an exact identifier for the subjects

Figure 3 Estimates for drug, prostitution and smuggling between 2006 and 2014



Source: Our elaboration on the registers of the Public Prosecutor's offices data

in the data, the Zelterman estimator needs an adjustment for the linkage error. The comparison with other data related to regular workers suggests considering the risk of linkage errors only with the numbers for the drug related crimes. The extension of the Zelterman estimator to the presence of linkage errors can be considered an innovation useful even in other applications subject to the uncertainty in the unit identification. The results of our analysis, as well as providing a number for the illegal population, show that what most affects the increase in the illegal population is the work within a criminal association, having denunciations about other crimes and gender.

Considering the difficulties of this kind of analysis due to the particular field of estimation, the impact that the theme can have on the society, and the inaccuracy of sources in general, our analysis on administrative data seems enough accurate, managing potential errors due to lack of strong identifiers. It could be the first step aiming at providing accurate estimates of the illegal market population in Italy. Further analyses will be dedicated to calculate other populations of illegal actors such as those who commit corruption or who perform other illegal activities considering characteristics specific of the crimes.

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Determining Factors of Volunteer Work Participation in Japan

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With the growing awareness of the sustainability concept, society's interest towards the consideration for the wider community and the environment has developed. Local Agenda 21 has supported the voluntary process of local community consultation with the aim to create local policies and programs that work towards achieving sustainable development. This has stimulated the need for community participation through local volunteer participants. This paper will apply prefecture level panel data for Japan to examine the determining factors of volunteer work participation. The main results show that prefectures with higher children and senior citizen population and prefectures with higher usage of the internet and media are more active in the overall participation of volunteer work. On the other hand, prefectures with stronger urbanization are less likely to participate in volunteer work.

Keywords	***JEL code***
Volunteer work, linear regression panel model, senior citizen, urbanization, Japan	*I31, J10, Z13*

INTRODUCTION

With the growing awareness of the sustainability concept, society's interest towards the consideration for the wider community and the environment has developed. Local Agenda 21 has supported the voluntary process of local community consultation with the aim to create local policies and programs that work towards achieving sustainable development. This has stimulated the need for community participation through local volunteer participants. There is also a growing need for volunteers to supplement the local governments' limitations to support current diverse lifestyles (Tanaka, 2011). Volunteer participation is also known to enhance the well-being and sense of accomplishment of the volunteers and provide valuable experience. Experience that bridges individuals with the community is a key competency recommended by the OECD, which volunteer work can provide (Saito, 2010). It is also recognised as a valuable active learning method that helps educate necessary skills for sustainable living. In Japan, there is increasing interest in volunteer work since the frequent natural disasters such as the Great Hanshin Earthquake in 1995 and the Great East Japan Earthquake in 2011. The need for volunteer work is also being recognised to address the increasing aging population in Japan which is dependent on the support of others (Mitani, 2016).

1 REVIEW OF LITERATURE

Concerning past studies on the determinants of volunteer work, Schram and Dunsing (1981) focus on married women's volunteer participation and the determining factors such as their age, education

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and marital satisfaction. Carlin (2001) also studies volunteer work by married women and examines economic variables such as income and number of children. Vaillancourt (1994) examines determinants such as age, education and occupation for volunteer work in Canada and Freeman (1997) and Taniguchi (2006) analyse the impact income level, employment and gender have on the participation of volunteer work in the United States. Burns et al. (2008) also examine gender but focus on young adults. Schady (2001) examines how volunteer work supports the development of social capital in the rural areas of Peru. Cappellari and Turati (2004) observe how extrinsic motivation reduces the volunteer participation in social services and political organizations. Concerning studies on Japan, Yamauchi (1997), Osaka University Center for Nonprofit Research and Information (2005), Nakano (2005) all find that urbanization has a negative impact on volunteer participation. Okuyama (2009) studies the factors of rural regions but was unable to achieve statistically significant results. Tsukamoto et al. (2012) examine whether the network of human relationships in the community affect volunteer participation. Fukushige (1999) finds that higher share of social citizens and youths have a positive impact on volunteer participation in Japan and Okuyama (2009), Moriyama (2007) and Ono (2006) identify that gender impacts participation. Furthermore, Atoda and Fukushige (2000) find that educational attainment in Tokyo, Oita and Nagano has a positive impact on volunteer participation and Ma (2014) also finds a positive impact with educational attainment on elderly volunteer participants. Atoda and Fukushige (2000) identify that wage has a negative impact on volunteer participation in Tokyo. Moriyama (2007) and Ono (2006) also confirm that wage has an impact on volunteer participation. However, none of the previous studies on Japan consider the impact that the availability of information may have on volunteer participation and is not included in the independent variables as a determining factor. It is reasonable to consider that the accessibility to information from the internet, with the penetration of internet for individuals as high as 80.9% in 2017 in Japan (Ministry of Internal Affairs and Communications, 2018), will affect the interest in volunteer work. Studies on volunteer participation in Japan, that examine the different fields of volunteer work are also limited. There is the study by Tsukamoto et al. (2012), which is limited to Fukui prefecture and the study by Okuyama (2009), which focuses on the fields of volunteer community cleaning, recycling, and patrolling.

Learning from the work by Segal and Weisbrod (2002) that identifies the difference in the nature of various volunteer work and the need to analyse the different fields of volunteer work, this paper not only studies overall volunteer work in Japan but analyses the fields of volunteer related to community development, elderly care and the environment. The reason it focuses on the field of community development is that according to the Ministry of Internal Affairs and Communications (2011), it is the most active field of volunteer work with the largest number of volunteer participation and is also an important area for Japan to improve its landscape and regional development. Furthermore, community development supports the Sustainable Development Goals (SDGs) of 'sustainable cities and communities' adopted by the United Nations. Concerning that Japan has the greatest aging population amongst all the developing countries, addressing the aging society is a critical challenge for the present and future (Cabinet Office, 2018). In order to address the aging population in Japan, where there is increasing population that is dependent on the support of others, the need for volunteer work is great (Mitani, 2016), which has led to the adoption of this field. Since the Brundtland Commission where sustainable development has become a global key concept, it has become necessary for Japan to address environmental concerns. The SDGs include the conservation and sustainable use of the oceans, seas and marine resources where volunteers are relied upon to monitor and clean marine litter (Hastings and Potts, 2013). Considering that Japan is surrounded by the sea on all sides, the impact of marine litter on its coasts and islands are great (Takano, 2013). Hence, tackling marine litter is considered a priority action item for Japan and there is growing need for volunteers (Ministry of Foreign Affairs of Japan, 2016). SDGs also calls for the protection, restoration and promotion of sustainable use of terrestrial ecosystems and climate action. However, afforestation and greening require active involvement from the community which requires volunteers (Ueno et al., 2012). Thus, this paper will focus on the volunteer fields of community development, elderly care and environmental work and examine whether information is a determining factor. Furthermore, it will cover other variables such as population density, income level, educational attainment, share of population of females, social citizens and children to examine their impact. In order to supplement past research, this paper will apply prefecture level data for Japan for the recent fiscal years of 2001, 2006 and 2011 to a panel data analysis to examine the determinants of volunteer work participation.

2 DATA AND METHODS

This section aims to explain the data and methods used in this article.

2.1 Volunteer Work Participation

Volunteer work in this study includes the fields of health/medical care, elderly/disabled/child care, sports/culture/art, community development, environment, safety, disaster prevention, international cooperation, and others. The total volunteer participation rate (*Vol*) is achieved by dividing the total number of volunteer participants over the age of 10 for each prefecture by the populations of over 10 years of age for each prefecture, multiplied by 100. This study further examines three fields of volunteer work. The first is environmental volunteer work which includes soap making from wasted oil; cleaning of beaches; observation and conservation of birds; desert greening; and environmental education. The environmental volunteer participation rate (*EnvVol*) is achieved in the same way by dividing the number of participants over the age of 10 for each prefecture with the populations of over 10 years of age for each prefecture, multiplied by 100. The second field covered is community development volunteer work which includes road-side gardening; urban and rural exchange; developing bicycle parks near train stations; cleaning of roads and parks; and proactive regional and community revitalisation work. The community development volunteer participation rate (*CommVol*) is obtained with the same method as the previous two volunteer participation rates. The final field reviewed is elderly care volunteer work which includes the exchange between senior citizens and children; recreational activities for senior citizens; mental care to improve well-being; communication with senior citizens who live alone; provide companionship to walk or talk; food/care services for senior citizens who are bedridden or live alone; and nursing services. The elderly care volunteer participation rate (*SnrVol*) is obtained with the same method as the other volunteer participation rates.

2.2 Demographic Variables

It has been identified that demographic variables impact human behaviours (Kotler and Keller, 2010). Thus, it will be beneficial to adopt demographic variables as factors which may affect volunteer participation. This article focuses on the difference of gender as a demographic variable since the inherent or acquired influence from gender often impacts behaviour and preference (Kotler and Keller, 2010) and there are numerous past studies on the impact from the differences in gender (e.g. Kurisu and Bortoleto, 2011; Rendon, 2003). Accordingly, this article uses the share of female population (*Fem*) as one of the demographic variables to investigate whether the share of female population by prefecture impacts volunteer participation. This may allow us to observe whether there is a preference by women to participate in volunteer work. The Fem is achieved by dividing the number of female population in each prefecture by the total population of that prefecture multiplied by 100. The second demographic factor observed in this article is the share of children population (*Chd*). Since the behaviours and preferences of children will help shape future society, it will be important to understand how they relate to volunteer work. The analysis aims to understand the children population's preference towards volunteer activities. Here, the children population is defined as population younger than 15 years of age. The *Chd* is the volume of children population for each prefecture divided by the total population of that prefecture multiplied by 100. The third demographic variable examined is the share of senior citizens population (*Snr*), which is an important demographic to observe for Japan with the challenges brought by the fast aging population. Therefore, this research examines whether prefectures with a larger share of senior citizens have an impact on the participation of volunteer work. As in the previous demographic studies, it will aim to understand the preference by senior citizens towards volunteer work. The senior citizens population is defined as the population of 65 years of age and over. The *Snr* is achieved by dividing the volume of senior citizens population for each prefecture by the total population of each prefecture multiplied by 100. The educational attainment for each prefecture will be reviewed as the fourth demographic variable that affects volunteer participation. Higher educational attainment may influence a stronger interest in social issues such as the environment and community service, which may encourage the participation of volunteer activities. Volunteer participation may also be part of the educational curriculum. The expected impact of educational attainment in this case would be positive. The high school enrollment rate for each prefecture is applied as the indicator for educational attainment (*Ed*).

2.3 Information

The variable that is used to assess the information accessibility is the share of media active users (*Media*), defining active as the volume of users 10 years of age and over, who viewed, listened or read the television/ radio /newspaper/magazine for over 15 minutes per day. We can expect that larger number of active users will result in increased opportunity to access information including information on volunteer opportunities. Hence, an increase in participation of volunteer work could be anticipated which would result in a positive sign. The *Media* is obtained by dividing the number of television, radio, newspaper and magazine active users in each prefecture by the total population 10 years of age and over of that prefecture, multiplied by 100. The other variable used for information accessibility is the share of active internet users (*Inet*). Like the media active users, this is believed to impact the information accessibility, but with the information flowing both ways. This is likely to increase the level of communication and have a large influence over human behaviour. With an increase in active internet users, we can assume that the opportunity to access information on volunteer work would increase and encourage participation. This would result in a positive coefficient. The share of active internet users is the number of users of 10 years of age and over that have used the internet over 15 minutes a day for over a year for each prefecture divided by the total population of 10 years of age and over of that prefecture, multiplied by 100.

2.4 Population density

Volunteer participation may be affected by urbanization which will be represented by the independent variable, population density (*PD*). Higher *PD* has been considered to weaken community participation and bonding, resulting in lower volunteer participation. It is considered that higher *PD* increases the demand and supply of goods and services where time can be spent consuming, reducing the time available to participate in volunteer work. High *PD* could also mean that it is physically easier for networks to develop to support volunteer work. In this way, the results of the impact *PD* may have on volunteer participation could be both positive and negative. The variable used to represent *PD* is the total population of each prefecture divided by inhabitable land area of that prefecture.

2.5 Income

Higher income per capita could mean higher opportunity cost to spend time at volunteer work and as a result reduce volunteer participation. On the other hand, as suggested by the Environmental Kuznets Curve, the increase in income places a stronger demand on the quality of the environment and amenities and as a result, stronger regulations are introduced (Grossman and Krueger, 1995; Grossman, 1995; Panayotou, 1993), which may stimulate active volunteer work. Considering these points, the result of the impact income per capita has on volunteer participation may be positive or negative. Real gross income per capita for each prefecture (*RPIpc*) is used as the indicator.

The panel data applied for the variables are Japan prefecture level data for all 47 prefectures for the fiscal years of 2001, 2006 and 2011. Statistical descriptions for the data are provided in the Appendix 1. The data source for the dependent variables and the independent variables are provided in the Appendix 2.

The basic model on the determining factors impacting volunteer participation is as follows:

$$Vol_{it}\ (or\ CommVol_{it}\ or\ SnrVol_{it}\ or\ EnvVol_{it}) = Fem_{it} + Chd_{it} + Snr_{it} + Ed_{it} + Media_{it}\ (+Inet_{it}) + PD_{it}\ (+RPIpc_{it}) + D_t + \delta_i + e_{it}, \quad (1)$$

where: i is prefecture, t refers to fiscal year, δ_i indicates the individual effects of each prefecture, e_{it} denotes the error term. The analysis has taken into consideration and addressed the possibility of heteroscedasticity. Dependent variables and independent variables are translated into the form of natural logarithms. This model includes year dummy D_t in order to control the time specific effects. STATA is used for the analysis of Formula (1). When applying the linear panel regression to Formula (1), the fixed effects model and random effects model were applied to examine the differences by prefecture. The prefecture differences were allowed as intercept values in the fixed effects model. In other words, by including the dummy for each prefecture, prefecture individual effects are taken into consideration. However, there is the possibility of a reduction in the degree of freedom. The random effects model does not capture prefecture individual effects with dummy variables since it represents a lack of knowledge of the true model. Instead, the disturbance term is employed to capture the prefecture individual effects. Compared to the fixed effects model, in the random effects model, the degree of freedom is limited to the one variance for the prefecture individual effects. Hence, the reduction in the degree of freedom is limited and there is less risk of impacting the precision of the estimation of the parameter. The random effects model obtains consistent and efficient estimators by assuming that the regressors and the prefecture individual effects are uncorrelated. If this assumption does not apply, the estimators will be inconsistent. On the other hand, with a fixed effects model, the estimators from the model will be consistent and efficient under the assumption that the regressors and the prefecture individual effects are correlated. Hence, the Hausman test was conducted to examine the null hypothesis (the regressors and the prefecture individual effects are uncorrelated) against the alternative hypothesis (the regressors and the prefecture individual effects are correlated) to determine whether it could be rejected. The following Table 1 to Table 4 which cover the results of the Hausman test find that in most of the models, the random effects models are preferred over the fixed effects models.

Next, an examination is conducted to confirm whether the random effects model will be preferred over the pooled ordinarily least square (OLS) method in Formula (1). The Breusch and Pagan Lagrangian multiplier test (B-P LM test) is conducted to determine whether the variance of the prefecture individual effects is zero. If the null hypothesis is rejected, then the disturbance term covers the prefecture individual effects. Hence, the random effects Generalized Least Squares method is preferred. The results of the B-P LM test, find that the random effects model is preferred over the pooled OLS model. Taking these results into consideration along with the coefficients of the random effects model being similar in most cases with the coefficients of the fixed effects model and it would be easier to compare, this article will limit the explanation to the random effects model.

The explanation concerning the model based on the Formula (1) is provided below. First, a positive correlation between *RPIpc* and *PD* could be considered. In other words, a prefecture with a large *PD* is likely to have greater supply and consumption, hence a greater *RPIpc* can be expected. Furthermore, since it is expected that prefectures with a greater *RPIpc* will have a richer supply of goods and services, further encouraging the population to grow and as a result, a larger *PD*. Therefore, there is the possibility of multicollinearity if these independent variables are included in the model at the same time. Accordingly, other than the model adopting these variables at the same time, models where one of the variables is excluded are examined. Concerning the *Media* and the *Inet*, there is the possibility of a negative correlation between the two. That is, to viewing or reading the former may reduce the time spent on the internet and the opposite may also apply. Therefore, there is again the possibility of multicollinearity if these independent variables are included in the model at the same time and so the same precautions are taken.

This article will first examine Case 1 that adopts *PD* and only the *Media* as the factor for information accessibility. Case 2 adopts *PD*, but the *Inet* is employed as the factor concerning information. Case 3 adopts *PD* and both the *Media* and the *Inet* as the factors concerning information. Cases 4 to 6 all adopt *RPIpc* and repeats the employment of information factors as in the Cases 1 through 3. Cases 7 through 9 examine both *PD* and *RPIpc* and again repeats the adoption of the factors concerning information in the same order as in the previous cases.

3 RESULTS

First the main results concerning overall volunteer participation are provided.

Table 1 Determinants of Volunteer Participation – Overall

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Fem	–0.0609	–0.427	–0.911	0.0765	–1.240	–1.729*	–0.0939	–0.604	–1.101
	(0.928)	(0.869)	(0.948)	(1.073)	(0.933)	(0.946)	(1.030)	(0.882)	(0.933)
Chd	0.663***	1.055***	1.084***	0.632**	1.035***	1.087***	0.660***	1.023***	1.059***
	(0.227)	(0.277)	(0.272)	(0.268)	(0.317)	(0.302)	(0.237)	(0.290)	(0.287)
Snr	0.262**	0.814***	0.897***	0.442***	1.064***	1.121***	0.263**	0.815***	0.905***
	(0.116)	(0.200)	(0.194)	(0.112)	(0.187)	(0.182)	(0.115)	(0.193)	(0.185)
Ed	0.395***	0.132	0.137	0.238**	0.0464	0.0811	0.398***	0.152	0.155
	(0.121)	(0.135)	(0.138)	(0.118)	(0.141)	(0.143)	(0.120)	(0.141)	(0.144)
Media	0.353		0.704**	0.517**		0.973***	0.354		0.707**
	(0.251)		(0.312)	(0.244)		(0.291)	(0.253)		(0.309)
Inet		0.687***	0.682***		0.569***	0.593***		0.680***	0.678***
		(0.192)	(0.176)		(0.176)	(0.158)		(0.190)	(0.174)
PD	–0.110***	–0.106***	–0.0862**				–0.110***	–0.104***	–0.0840**
	(0.0320)	(0.0350)	(0.0357)				(0.0322)	(0.0353)	(0.0360)
RPIpc				–0.0839	–0.164	–0.127	–0.0105	–0.0518	–0.0502
				(0.123)	(0.122)	(0.120)	(0.114)	(0.131)	(0.128)

Table 1 (continuation)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Constant	2.189	3.337***	0.121	2.255	3.927***	–0.687	2.160	3.178***	–0.0455
	(1.373)	(0.881)	(1.626)	(1.422)	(0.906)	(1.745)	(1.442)	(0.907)	(1.682)
B-P LM test	78.95	20.96	21.77	77.01	21.07	23.83	77.41	20.77	21.54
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hausman test	22.47	7.88	9.85	14.04	16.03	11.38	28.37	10.71	11.84
	0.0041	0.3432	0.2757	0.0807	0.0249	0.181	0.0008	0.2185	0.2225
Observations	141	94	94	141	94	94	141	94	94
R-squared (overall)	0.5164	0.6586	0.6513	0.4398	0.5987	0.6064	0.5157	0.6557	0.6495

Note: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.
Source: Own construction

From Table 1, concerning the *Chd*, which is one of demographic variables, the estimated coefficients are positive and significant in all the models. This indicates that prefectures with a higher share of children under the age of 15, participate more actively in overall volunteer work. Children either have a stronger preference for volunteer work and/or it may be part of their school curriculum. Results from the study by Fukushige (1999) on the impact of youths on volunteer participation in Japan were also positive. Next, the estimated coefficients for the *Snr* are also positive and significant in all the models. Again, this implies that volunteer work overall is more active in prefectures with a higher *Snr*. This could be interpreted as senior citizens having a stronger preference towards volunteer participation overall and/or has free time to participate in volunteer activities. The results achieved are consistent with previous studies on the impact of senior citizens volunteer participation in Japan (see e.g. Fukushige, 1999; Nakano, 2005; Tsukamoto et al., 2012) and in the United States (see e.g. Segal and Weisbrod, 2002; Taniguchi, 2006). Results for *Fem* indicate negative estimated coefficients in all except one model and is found to be negative and statistically significant in Model (6). This suggests that prefectures with a higher *Fem* are more passive in participating in volunteer work. However, it should be noted that the results are insignificant in most of the models.

The results for *PD* which represents the independent variable for urbanisation are negative and significant estimated coefficients in all models. This indicates that prefectures with stronger urbanization may be less active in volunteer participation, due to weaker community involvement and/or allocating more time in pursuit of other consumption activities since a more diverse range of goods and services are available. These results are consistent with the studies on Japan by Osaka University Center for Nonprofit Research and Information (2005) and Nakano (2005) which indicate that urbanization has a negative impact on volunteer participation. With respect to the independent variables on information, the coefficients are positive in all the models. Especially the results concerning the *Inet* show positive and significant estimated coefficients in all the models. This may be due to prefectures with a higher penetration of internet users having more access to information concerning volunteer work, leading to a higher participation rate of volunteer activities. The results for the *Media* show positive coefficients and significant in the sign and test for acceptance in Models (3), (6) and (9). This shows that not only the internet, but television, radio and newspaper contribute to promoting the participation of volunteer work and they are in a complementary relationship. As for the estimated coefficients of *RPIpc*, the results are negative in all the models and insignificant. Concerning the *Ed*, it finds positive estimated coefficients in all the models and significant in Models (1), (4) and (7), although insignificant results for the test for acceptation.

Table 2 Determinants of Volunteer Participation – Community Development

	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Fem	0.849	1.657	0.951	1.944	–0.488	–1.395	1.428	0.618	–0.0433
	(1.483)	(1.494)	(1.621)	(1.486)	(1.716)	(1.621)	(1.556)	(1.552)	(1.607)
Chd	1.327***	1.845***	1.900***	1.311**	1.635***	1.797***	1.391***	1.705***	1.777***
	(0.449)	(0.483)	(0.474)	(0.527)	(0.585)	(0.540)	(0.436)	(0.479)	(0.472)
Snr	0.248	0.930**	1.059***	0.609**	1.474***	1.625***	0.220	0.974***	1.108***
	(0.272)	(0.361)	(0.354)	(0.252)	(0.315)	(0.300)	(0.264)	(0.350)	(0.339)
Ed	0.573***	0.361	0.366	0.127	0.194	0.246	0.523**	0.449*	0.449*
	(0.222)	(0.234)	(0.240)	(0.231)	(0.265)	(0.270)	(0.231)	(0.242)	(0.248)
Media	0.931***		0.892*	1.263***		1.488***	0.920***		0.879*
	(0.325)		(0.491)	(0.345)		(0.511)	(0.326)		(0.479)
Inet		1.048***	1.049***		0.754***	0.801***		1.039***	1.041***
		(0.283)	(0.263)		(0.275)	(0.244)		(0.276)	(0.256)
PD	–0.250***	–0.266***	–0.240***				–0.258***	–0.256***	–0.230***
	(0.0497)	(0.0616)	(0.0629)				(0.0503)	(0.0615)	(0.0620)
RPIpc				0.0272	–0.545**	–0.453**	0.176	–0.269	–0.253
				(0.247)	(0.240)	(0.222)	(0.185)	(0.165)	(0.158)
Constant	0.469	3.767**	–0.328	1.383	4.707***	–2.272	0.954	2.907*	–1.068
	(2.472)	(1.510)	(2.630)	(2.422)	(1.651)	(2.935)	(2.501)	(1.500)	(2.641)
B-P LM test	74.12	24.96	25.1	76.11	25.67	28.22	74.18	25.18	25.48
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hausman test	14.2	8.71	10.01	36.68	28.48	13.77	12.44	12.49	12.84
	0.0768	0.2743	0.264	0.000	0.0002	0.0879	0.1894	0.1306	0.1702
Observations	141	94	94	141	94	94	141	94	94
R-squared (overall)	0.6393	0.7138	0.7103	0.522	0.5994	0.6243	0.6381	0.7121	0.7108

Note: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.
Source: Own construction

As explained earlier, according to Segal and Weisbrod (2002), since the nature of volunteer work varies depending on the field, it will be necessary to examine the determining factors for each field. The main results for volunteer work in the field of community development will be first reviewed. From Table 2, concerning the *Chd* which is one of the demographic variables, it finds positive and significant estimated coefficients in all models. This shows that, like the case of *Vol*, the prefecture with the high *Chd* is more active in community development volunteer work. This implies that children have a strong preference towards community development volunteer activities or/and participates in community development volunteer activities as part of their school work. Next, with regards to the estimated coefficients for *Snr*, the results are positive in all the models and significant in the sign and in the test for acceptance in Models (11), (12), (17) and (18). This indicates that there is higher *CommVol* in prefectures with a higher *Snr* and suggests that senior citizens have a stronger preference towards community development volunteer activities such as cleaning of roads and parks and community services and/or has more free time to participate in community development volunteer work. These results are consistent with the study of senior citizens' volunteer participation by Tsukamoto (2012) on Japan. Concerning the independent variables for information accessibility, the results confirm positive and statistically significant estimated coefficients in all the models. As well as the results of *Vol*, the results for *CommVol* are significant and positive for both the *Media* and the *Inet*. This may be due to the wide coverage of local activities covered by the extensive regional and local media in Japan. On the other hand, concerning *PD* which represents the independent variable of urbanisation, the results find negative and significant estimated coefficients in all the models which is consistent with the results of *Vol*. This indicates that the prefecture which higher urbanization may be more passive in volunteer participation, due to weaker community involvement and/or allocating more time in pursuit of other consumption activities. With regards to the *Ed*, the results are positive estimated coefficients in all the models and statistically significant in Models (16), (17) and (18) for both the sign and the model specification test. Models (16), (17) and (18), suggest a higher preference towards community development in prefectures with a higher *Ed* and/or larger number of opportunities for volunteers in the community development work as part of their education. The study by Okuyama (2009) did not achieve statistically significant results on their study of educational attainment in volunteer participation in community cleaning in Japan. The coefficients for *RPIpc* are insignificant for all the models where the model specifications were accepted. This is consistent with the study by Okuyama (2009) on income and volunteer participation in community cleaning in Japan, which did not achieve statistically significant results. Finally, concerning the *Fem*, it shows positive estimated coefficients for the majority of the models but all of them are statistically insignificant. The study on women's volunteer participation by Okuyama (2009) to clean the community were also unable to achieve statistically significant results.

Next, we will describe the main results concerning participation of elderly care volunteer work, a major concern for the aging society of Japan.

Table 3 Determinants of Volunteer Participation – Elderly Care

	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)
Fem	0.0487	−0.206	−0.156	−0.319	−1.174	−1.228	0.119	−0.727	−0.686
	(1.451)	(1.270)	(1.301)	(1.672)	(1.331)	(1.378)	(1.693)	(1.336)	(1.389)
Chd	0.721**	1.438***	1.438***	0.747**	1.412***	1.408***	0.729**	1.360***	1.361***
	(0.292)	(0.317)	(0.320)	(0.313)	(0.338)	(0.338)	(0.315)	(0.335)	(0.337)

Table 3 (continuation)

	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Snr	0.611***	1.454***	1.444***	0.845***	1.643***	1.647***	0.605***	1.481***	1.473***
	(0.219)	(0.282)	(0.288)	(0.196)	(0.250)	(0.253)	(0.225)	(0.278)	(0.285)
Ed	0.194	–0.216	–0.213	0.0398	–0.228	–0.227	0.188	–0.168	–0.167
	(0.154)	(0.209)	(0.212)	(0.140)	(0.216)	(0.218)	(0.154)	(0.226)	(0.228)
Media	–0.272		–0.0965	–0.0453		0.142	–0.273		–0.0673
	(0.473)		(0.505)	(0.479)		(0.508)	(0.477)		(0.506)
Inet		1.069***	1.064***		1.042***	1.054***		1.069***	1.065***
		(0.348)	(0.354)		(0.337)	(0.345)		(0.342)	(0.349)
PD	–0.0895**	–0.0527	–0.0549				–0.0905**	–0.0471	–0.0487
	(0.0376)	(0.0380)	(0.0393)				(0.0369)	(0.0388)	(0.0401)
RPIpc				–0.0544	–0.187	–0.186	0.0191	–0.143	–0.142
				(0.172)	(0.206)	(0.209)	(0.187)	(0.220)	(0.223)
Constant	4.331*	3.125***	3.575	3.979	3.007***	2.310	4.390*	2.668**	2.986
	(2.392)	(0.987)	(2.491)	(2.602)	(1.025)	(2.760)	(2.569)	(1.120)	(2.648)
B-P LM test	48.96	4.93	4.89	48.81	5.18	5.18	48.87	4.92	4.9
	0.0000	0.0132	0.0135	0.0000	0.0114	0.0114	0.0000	0.0133	0.0134
Hausman test	7.93	10.24	10.00	9.46	10.41	10.11	8.11	12.26	11.98
	0.44	0.1755	0.2649	0.3053	0.1664	0.2575	0.5233	0.14	0.2147
Observations	141	94	94	141	94	94	141	94	94
R-squared (overall)	0.5827	0.6004	0.6008	0.5693	0.5949	0.5951	0.5827	0.6017	0.6019

Note: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.
Source: Own construction

From Table 3, with respect to the *Chd*, the estimated coefficients are positive and significant in all the models. This indicates that the prefecture with a higher *Chd* participate more actively in volunteer work involving elderly care, which is consistent with the results for Vol and *CommVol*. Children are showing a wide interest in volunteer work including supporting senior citizen. Intergenerational activities such as this is being encouraged since there is value to children in their development and for social citizens for their well-being (Murayama, 2009; Sugatani, 2014). Next, the results of the estimated coefficients for *Snr* are also positive and significant in all the models. Again, this implies that volunteer work for elderly care are more active in prefectures with a higher *Snr*. This could be interpreted as senior citizens having a stronger preference towards participating in elderly care volunteer work and/or has more free time to participate in the volunteer activities. The study by Tsukamoto et al. (2012) also indicates positive impact of senior citizens volunteer participation on elderly care volunteer work. With respect to the independent variables on information, the estimated coefficients are positive and significant in all the models for the *Inet*. However, they are not statistically significant for the *Media*. This suggests that it will be more effective to promote volunteer participation of elderly care through the internet. On the other hand, with regards to *PD* which represents the independent variable of urbanisation, shows negative estimated coefficients in all the models and significant for the sign and model specification in Models (19) and (25). This indicates that the prefecture with higher urbanization may be more passive in volunteer participation of elderly care, which is consistent with the results of *Vol* and *CommVol*. However, considering the social challenges of the increasing elderly urban residents living alone, this result highlights the need to address this challenge. As for the *Fem*, the results for all the models excluding Models (19) and (25) are negative estimated coefficients but not statistically significant. Concerning the *Ed* and *RPIpc*, the results are insignificant in all the models.

At last, we will review the main results concerning the participation of environmental volunteer work.

Table 4 Determinants of Volunteer Participation – Environmental Work

	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)
Fem	–2.050	–2.387	–3.054	–0.989	–3.043	–3.801*	–1.036	–2.157	–2.785
	(1.859)	(1.674)	(1.860)	(2.229)	(2.103)	(2.073)	(2.106)	(1.812)	(1.915)
Chd	0.715	1.308**	1.371**	0.800	1.312**	1.438**	0.841*	1.329**	1.402***
	(0.453)	(0.530)	(0.536)	(0.491)	(0.598)	(0.590)	(0.437)	(0.531)	(0.540)
Snr	0.424	1.081***	1.214***	0.685**	1.470***	1.594***	0.382	1.062***	1.196***
	(0.278)	(0.377)	(0.389)	(0.274)	(0.391)	(0.388)	(0.282)	(0.385)	(0.390)
Ed	0.366*	0.00768	0.0113	0.0261	–0.202	–0.161	0.279	–0.00767	–0.00912
	(0.199)	(0.206)	(0.211)	(0.182)	(0.217)	(0.223)	(0.197)	(0.212)	(0.218)
Media	0.787*		0.836	1.045**		1.281**	0.764*		0.844
	(0.424)		(0.550)	(0.440)		(0.578)	(0.428)		(0.557)
Inet		1.110***	1.112***		0.912***	0.957***		1.105***	1.110***
		(0.317)	(0.301)		(0.331)	(0.304)		(0.319)	(0.303)
PD	–0.149***	–0.187***	–0.161***				–0.163***	–0.189***	–0.164***
	(0.0478)	(0.0563)	(0.0573)				(0.0443)	(0.0565)	(0.0566)
RPIpc				0.197	–0.150	–0.0795	0.312*	0.0551	0.0688
				(0.213)	(0.188)	(0.177)	(0.186)	(0.189)	(0.180)
Constant	–2.143	0.536	–3.266	–1.290	2.078	–3.949	–1.244	0.711	–3.089
	(2.376)	(1.735)	(3.161)	(2.579)	(1.974)	(3.340)	(2.544)	(1.812)	(3.152)

Table 4 (continuation)

	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)
B-P LM test	72.25	27.13	27.73	71.89	26.46	28.57	69.61	25.97	26.44
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hausman test	20.44	7.27	6.96	12.25	14.41	8.84	23.34	10.78	9.94
	0.0088	0.4011	0.4333	0.1403	0.0444	0.3563	0.0055	0.2145	0.3556
Observations	141	94	94	141	94	94	141	94	94
R-squared (overall)	0.692	0.6081	0.6078	0.6487	0.5228	0.5461	0.7016	0.611	0.6111

Note: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.
Source: Own construction

The results from Table 4, concerning the *Chd*, are positive estimated coefficients in all the models and statically significant for the sign and significant in the model specification tests for Models (29), (30), (33), (35) and (36). This indicates that prefectures with a higher *Chd*, participate actively in environmental volunteer work which is consistent with the other fields of volunteer work which were studied. The results for the *Snr* are similar to those of the *Chd*. That is, the estimated coefficients are positive in all the models and statically significant for the signs and model specification tests in Models (29), (30), (31), (33), (35) and (36). This represents that environmental volunteer participation as well as the participation in the other fields studied is more active in prefectures with a higher *Snr*. These results were consistent with the results by Okuyama (2009) on the volunteer participation by senior citizens in recycling activities in Japan and by Tsukamoto et al. (2012) on Fukui in Japan. Concerning the other demographic variable, *Fem*, the estimated coefficients are negative in all the models and significant in Models (33). Okuyama (2009) achieved opposite results with positive impact by the participation of women in the field of recycling volunteer participation in Japan. Next, with respect to the independent variables on information, the estimated coefficients are positive in all the models. In particular, the results are significant in all the models concerning the *Inet*, which suggests that the internet is a useful tool to promote environmental volunteer participation as well as the other fields reviewed and for overall volunteer participation. As for the *Media*, the result in Models (31) and (33) are significant for the sign and model specification, which implies that mass media promotion will be effective in encouraging environmental volunteer participation. With respect to *PD* which is a variable of urbanization, the estimated coefficients are negative and significant in all the models which are consistent with the previous results on other fields of volunteer work. Concerning the *Ed* and *RPIpc*, the estimated coefficients show insignificant results in all of the models which are accepted through the model specification tests.

Finally, since we treat both dependent variables and independent variables as natural logarithms, the coefficients obtained represent elasticity. At first, in order to comprehend the characteristics of *Vol* in terms of elasticity, we will refer to each independent variable. When examining the independent variables, we will review the statistical significance and focus on the random effects models which were accepted by the Hausman test. From Table 1, concerning the overall volunteer participation, the elasticities of the *Chd* are the strongest of the positive elasticities in most cases, ranging from 1.023 to 1.087. The elasticities of the *Snr* are next, ranging from 0.814 to 1.121. The elasticities of the *Media* are third, which ranges from 0.704 to 0.973 followed by the elasticities of the *Inet*, ranging from 0.593 to 0.687. On the other hand, concerning the negative elasticities, result of the *Fem* is the strongest, which represents –1.729. Those of the *PD* come in second, ranging from −0.0840 to −0.106. We will next observe each chosen field of volunteer work. From Table 2, concerning *CommVol*, *Chd* shows the strongest positive elasticities, ranging from 1.391 to 1.900. This is followed by the *Inet*, ranging from 1.039 to 1.049 and *Snr*, ranging from 0.930 to 1.108. *Media* is next, ranging from 0.879 to 0.920 and then *Ed* ranging from 0.449 to 0.523. Concerning negative elasticities, *PD* ranges from −0.230 to −0.266. Results from Table 3 on *SnrVol*, concerning positive elasticities, *Snr* was the strongest in most cases ranging from 0.605 to 1.647 and *Chd* is the next at 0.721 to 1.438. This is followed by *Inet* at 1.042 to 1.069. As for negative elasticities, *PD* shows −0.0895 to −0.0905. Finally, concerning the positive elasticities for *EnvVol*, *Chd* was the strongest in most cases with values of 1.308 to 1.438 followed by *Snr* and *Media* at 0.685 to 1.594 and 1.045 to 1.281, respectively. *Inet* was next at a range of 0.957 to 1.112. Negative elasticities were found with *Fem* at −3.801, followed by *PD* at −0.161 to −0.189. These results identify that the elasticities for *Chd* are relatively the strongest, followed by *Snr* which are the strongest for *SnrVol* and the then the variables representing information. Compared to these variables, the *PD* has a considerably weaker elasticity.

CONCLUSION

With the wide penetration of the concept of sustainable development, society's interest towards the consideration of the wider community, the environment and community participation to support the Local Agenda 21 has grown. Furthermore, it will be difficult for the public sectors alone to support the diverse needs of the community, requiring further local volunteer participation. This research examines the determining factors of volunteer participation, employing panel data at the Japanese prefecture level for the fiscal years 2001, 2006 and 2011.

The main results show that the prefecture with higher share of children population, senior citizen population, internet users and media active users are more active in the overall participation of volunteer work. On the other hand, prefectures with stronger urbanization are less likely to participate in overall volunteer work. The results for volunteer participation in the field of environmental work are also consistent with these overall results. Results for participation in community development work are similar, but they also find that education attainment for each prefecture to have impact on volunteer participation. Concerning participation of elderly care volunteer work, prefectures with a larger share of children population, senior citizens population and internet users and a low rate of urbanization tend to be more active in participation. These results provide the following policy implications. First, the positive impact children have on volunteer participation is a valuable result, considering that children will help shape future social and environmental activities as well as lead future generations. Further study on the factors of the positive impact would be beneficial to understand, such as education on volunteer work or the amount of free time available or if there are other influencing factors that encourage the active participation of children. Secondly, considering the aging population in Japan and the increase in longevity amongst developed countries, the role of volunteers to support elderly care will become increasingly important. It is encouraging to see the positive participation of social citizens in elderly care volunteer work. Arranging social infrastructure so that it is friendlier for social citizens to participate in volunteer work may encourage further participation in this much needed area. Thirdly, considering the effectiveness that information accessibility has on encouraging volunteer participation suggests that further development in information infrastructure as well as support to provide information and promote volunteer work through the media and internet would be beneficial. Finally, learning that strong urbanization reduces volunteer participation, special support and effort may be needed to encourage participation. For example, strong urbanization is usually related to a well-developed information infrastructure that could be used to actively promote volunteer work which may gain further effectiveness by focusing on children and social citizens.

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APPENDIX 1

Table A1 Statistical description

	Unit	Mean	Max	Min	Standard Deviation	Observations
Vol	%	29.27	40.10	19.70	4.40	141
CommVol	%	14.59	24.30	5.70	3.91	141
SnrVol	%	4.84	9.10	2.70	1.19	141
EnvVol	%	7.08	14.00	3.50	2.22	141
Fem	%	51.74	53.31	49.28	1.02	141
Yng	%	13.93	19.74	11.26	1.17	141
Snr	%	22.32	29.67	13.54	3.42	141
Ed	%	47.41	66.40	31.10	7.51	141
Media	%	75.57	84.10	63.40	4.04	141
Inet	%	48.73	70.80	31.50	8.82	94
PD	persons per hectare	13.70	94.80	2.47	16.78	141
RPIpc	millions yen per capita	3.85	6.98	2.70	0.62	141

Note: Unit does not apply to Standard deviation and Observations.
Source: Own construction

APPENDIX 2

Table A2 Data sources

Variable	Sources
Total Volunteer Participation Rate (*Vol*)	Survey on Time Use and Leisure Activities, Ministry of Internal Affairs and Communications

Table A2 (continuation)

Variable	Sources
Environmental Volunteer Participation Rate (*EnvVol*)	Survey on Time Use and Leisure Activities, Ministry of Internal Affairs and Communications
Community Development Volunteer Participation Rate (*CommVol*)	Survey on Time Use and Leisure Activities, Ministry of Internal Affairs and Communications
Elderly Care Volunteer Participation Rate (*SnrVol*)	Survey on Time Use and Leisure Activities, Ministry of Internal Affairs and Communications
Share of Children Population (*Chd*)	Population Census, Population Estimates, Ministry of Internal Affairs and Communications
Share of Female Population (*Fem*)	Population Census, Population Estimates, Ministry of Internal Affairs and Communications
Share of Senior Citizen Population (*Snr*)	Population Census, Population Estimates, Ministry of Internal Affairs and Communications
Educational Attainment (*Ed*)	School Basic Survey, Ministry of Education, Culture, Sports, Science and Technology
Share of Media Active Users (*Media*)	Survey on Time Use and Leisure Activities, Ministry of Internal Affairs and Communications
Share of Internet Users (*Inet*)	Survey on Time Use and Leisure Activities, Ministry of Internal Affairs and Communications
Population Density (*PD*)	Population Census, Population Estimates, Ministry of Internal Affairs and Communications
Real Prefectural Income per capita (*RPIpc*)	Real prefecture income per capita: Prefectural Accounts, Cabinet Office; Population: Population Census, Population Estimates, Ministry of Internal Affairs and Communications

Source: Own construction

Multilevel Analysis of Wage Inequality in Palestine

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Historical data exhibit the imbalance participation rate between genders in the Palestinian labour market in which female participation is among the lowest worldwide. On the other hand, occupational discrimination and wage inequality still exist between males and females. Combining both issues, this study seeks to examine the gender pay gap across occupational groups in Palestine. The data are collected from the Palestinian Labour Force Survey (PLFS) for the year 2017. The multilevel linear regression is applied to model the wage equation. For the robustness purpose, three estimation techniques are applied which are maximum likelihood (ML), restricted maximum likelihood (REML), and Bayesian estimation. The results reveal that occupational groups account for about 23.6% of wage differentials. The gender wage gap varies significantly across occupational groups, where it is decreased after correcting for self-selection bias. Moreover, the Bayesian estimation method provides more efficient estimates than ML and REML methods. Schooling, age, and other socioeconomic variables also contribute significantly to wage inequality in Palestine.

Keywords	***JEL code***
Multilevel modelling, maximum likelihood, restricted maximum likelihood, Bayesian estimation, wage inequality, intra-class correlation coefficient	*C01, C10, C11, E24, J31*

INTRODUCTION

Over the past decade, the Palestinian labour market has exhibited an imbalance participation trend in the labour market. As reported in the first quarter 2018 labour force conducted by the Palestinian Central Bureau of Statistics (PCBS), the women's participation rate was 19.9% compared to that of men 70.3% exhibiting a decreasing trend in the gender participation gap. Although this gap has improved over time, the women's participation rate of Palestine still remains among the lowest in the world. In addition, Palestine is also experiencing a high pay gap in the labour market. The wage gap between males and females was 29% with males earn 119.1 New Israeli Shekels (NIS) while women only earn 84.6 NIS daily pay on average (PCBS, May 2018). According to Brown et al. (1980), occupational gender discrimination is considered as a potential source of wage differentials. The facts and data reveal that the imbalances of gender participation and the higher rates of wage inequality are the two major issues/ phenomena faced by Palestine for a long time. Therefore, there is a need to identify the problems/ reasons behind them follow by appropriate policy action to overcome the problems.

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The studies focused on examining the wage inequality are broad, covering different countries and periods as well as applying different decomposition methods. Some studies relied on individual-level variables to study gender pay gaps such as human capital and some socioeconomic variables (Mincer, 1974; Card, 2001). Other studies relied on examining the effect of occupational gender composition on wage inequality; these studies tried to address the sources of inequality such as between occupation gender inequality and within occupation gender inequality (Huffman and Velasco, 1997; Huffman, 2004; de Ruijter and Huffman, 2003; de Ruijter et al., 2003; Bunel and Guironnet, 2017). In term of modelling approaches, many studies applied the classical estimation approaches to model wage inequality decomposition. Such approaches suffered from the inefficiency estimate (Heckman and Vytlacil, 1998; Card, 2001). In addition, many studies applied the single level modeling, which provided limited information and less accurate estimate.

This study seeks to fill the gaps from the previous studies in occupational gender wage inequality and has the following objectives. First, this study seeks to find out which econometric technique provides more efficient estimates in studying the gender pay gap across occupational groups using a multilevel linear model. Second, the study also examines to what extent the occupational gender discrimination contributes to the gender pay gap in Palestine by utilizing the cross-sectional data from the Palestinian labour force survey for the year 2017 conducted by the Palestinian Central Bureau of Statistics (PCBS). Furthermore, this study follows the guide of Boedeker (2017) to carry out the multilevel analysis.

To highlight, this study contributes to the previous literature in several ways. First, this is the first study that analyses the occupational gender wage gap in Palestine to the best of our knowledge. It does not limit to investigate the between-occupation groups and within-occupation groups variability but also investigates between-gender-within occupation groups wage differentials. This study is focused in Palestine as Palestine exhibits very unique structures/features in its social-economy and labour market which make it stand out differently from the other neighbouring countries. The extremely high gap in the participation rate among males and females and the wage inequality in Palestine are the main issues worth to be explored.

Second, we propose a Bayesian estimation technique and demonstrate that the Bayesian approach provides a better estimate as compared to ML and REML approaches. The third contribution can be considered as an empirical contribution to the literature in the debate on wage inequality. This study demonstrates that gender has contributed significantly to wage inequality across occupational groups in Palestine. The gender wage gap is reduced after corrected for self-selection bias.

Finally, our results are important for policy decision and implication. The results reveal that most occupational sectors in the Palestinian labour market are dominated by males and males receive much higher wages than their females counterparts. Such inequality may lead to unsustainable social-economic growth. The government should play its role through legislation and cooperation with the private sectors as its effort to improve the wage gap and occupational participation gap by genders in Palestine.

The organization of the paper is as follows: Section 1 provides an overview of the Palestinian labour market, Section 2 is the summary of literature review, Section 3 is the description of the data and methodology, Section 4 presents the results and discussion and the last section is the conclusion.

1 AN OVERVIEW OF THE PALESTINIAN LABOUR MARKET

According to the World Bank, the Palestinian economy is classified as a lower-middle income developing country. Its labour market is segmented geographically into two regions i.e., West Bank and Gaza Strip. Moreover, after the political division of 2007 between the West Bank and the Gaza Strip, each region has generated its own stumbling block. Thus, Palestine becomes a unique situation with an underdeveloped labour market.

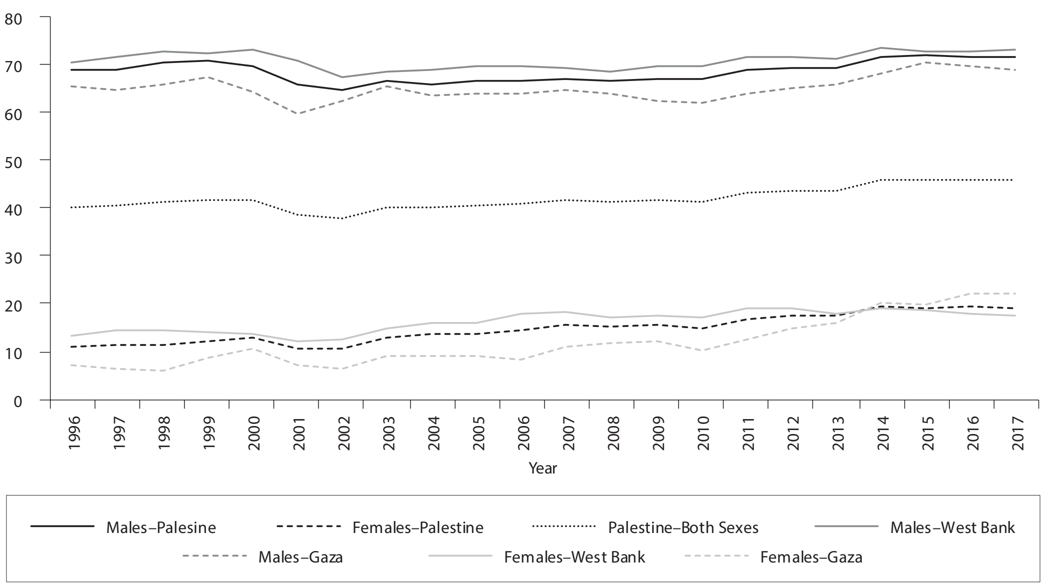
The Palestinian labour market exhibits lower participation rates compared to some neighbouring and developed countries, with extremely lower rates of female participation. The labour force participation rate for individuals aged 15 years or more is approximated as 45.7% in 2017. The participation rate of males was 71.6% while it was 19.2% for females. That is, there is a high gender participation gap. During the period from 1996 to 2017, Palestine exhibits an increasing trend in its labour force participation rate. The females' participation rate has increased slowly. However, this rate is still extremely lower than the world average. Meanwhile, males' participation rate stands near the worldwide average as shown in Table 1 (PECS, 2018).

Table 1 Labour force participation rates and unemployment rates in Palestine and some selected overseas countries by gender for individuals aged 15 years or above, 2017 (%)

Country	Males	Females	Total
Palestine	71.6 (23.2)	19.2 (48.2)	45.7 (28.4)
United States	69.1 (4.4)	57.0 (4.3)	62.9 (4.4)
Canada	70.2 (6.8)	61.5 (5.8)	65.8 (6.3)
United Kingdom	68.9 (4.5)	58.2 (4.2)	63.4 (4.4)
Germany	66.7 (4.1)	55.9 (3.3)	61.2 (3.7)
Czech Republic	68.5 (2.3)	52.3 (3.6)	60.2 (2.9)
Turkey	72.5 (9.4)	33.6 (14.1)	52.8 (10.9)

Note: Unemployment rates are in parentheses.
Source: Palestinian Central Bureau of Statistics, labour force survey (2018) and OECD labour force indicators (2018)

Figure 1 Labour force particiaption rates in Palestine by sex and region,1996–2017 (%)



Source: PCBS labour force surveys, different issues

In terms of geographical region, the labour force participation rate in West Bank was 45.8%, which is a little bit higher than that in Gaza Strip, 45.5%. Males in the West Bank showed a higher participation rate than those in Gaza's. However, females in the Gaza Strip showed a higher participation rate than that in the West Bank (PECS, 2018). This is probably due to the bad economic conditions in the Gaza Strip caused by the Israeli siege and the political division since 2007. Thus, there is a higher attempt by the females to join the labour market in order to compensate for the loss of the males' income (ILO, 2018).

Furthermore, the labour force participation rate reached its peak for females aged 25 to 34 years while for males it was highest between those in the age category between 35 to 44 years as shown in Table 2. This may be explained by the fact that females decide to exit the labour force after married or after having their first child at least. The labour force participation rate for married females was 52.9% while it was 62.3% for married males in 2017.

Table 2 Percentage distribution of individuals aged 15 years and above from Palestine by sex, age and labour force status, 2017 (%)

	Unemployed	**Inside LF**	**Outside LF**
Males			
15–24	47.5	52.5	38.7
25–34	8.5	91.5	24.4
35–44	7.5	92.5	12.8
45–54	13.2	86.8	13.6
55–64	42.7	57.3	15.4
+65	87.9	12.1	6.9
Total	**28.4**	**71.6**	**23.2**
Females			
15–24	87.4	12.6	70.8
25–34	67.7	32.3	59.0
35–44	75.9	24.1	29.5
45–54	82.1	17.9	12.2
55–64	91.0	9.0	7.8
+65	98.6	1.4	-
Total	**80.8**	**19.2**	**48.2**
Both Sexes			
15–24	67.0	33.0	44.7
25–34	37.7	62.3	33.3

Table 2 (continuation)

	Outside LF	Inside LF	Unemployed
35–44	41.4	58.6	16.2
45–54	46.7	53.3	13.3
55–64	66.3	33.7	14.5
+65	93.7	6.3	6.0
Total	**54.3**	**45.7**	**28.4**

Source: Palestinian Labour Force Survey, Revised Annual Report (2018)

Based on the education qualification, the majority of Palestinians in the labour market are educated, with 59.9% have completed at least 13 years of education. Among them, 74.4% were males and 46.5% were females as shown in Table 3. Females with higher education levels are associated with higher chances to join the labour force. Thus, education can be considered as a key determinant for the female to get a job. In general, the lower participation rates among females may be attributed to different factors such as family tie after married and carrying out housekeeping (63.1%) or study and training (24.7%). However, the reasons that hinder males to stay outside the labour force include further study (49.7%) or due to older age or do not have the chance to get a job i.e. 37.0% (PECS, 2018). Moreover, Al-Botmeh and Sotnik (2007) showed that lower rates of females' participation were attributed to social and cultural factors, Israeli restriction on movement, vertical and horizontal segregation and low average female wages.

Table 3 Distribution of individuals aged 15 years or more from Palestine by sex, schooling and labour force status, 2017 (%)

Sex and Years of Schooling	Outside LF	Inside LF	Unemployed
Males			
0	80.1	19.9	22.8
1–6	32.8	67.2	26.8
7–9	28.8	71.2	23.2
10–12	27.0	73.0	24.6
13+	25.6	74.4	20.1
Total	**28.4**	**71.6**	**23.2**
Females			
0	97.3	2.7	9.7
1–6	92.0	8.0	14.8
7–9	92.9	7.1	25.5

Table 3			(continuation)
Sex and Years of Schooling	**Outside LF**	**Inside LF**	**Unemployed**
10–12	92.3	7.7	37.3
13+	53.5	46.5	54.6
Total	**80.8**	**19.2**	**48.2**
Both Sexes			
0	93.1	6.9	18.9
1–6	59.7	40.3	25.8
7–9	56.6	43.4	23.4
10–12	59.1	40.9	25.8
13+	40.1	59.9	34.1
Total	**54.3**	**45.7**	**28.4**

Source: Palestinian Labour Force Survey, Revised Annual Report (2018)

The rate of unemployment in Palestine has increased continuously since 2000 because of Israeli closure and barriers restrictions. The unemployment rate was 14.3% in 2000 and it has increased to the highest world level of 28.4% in 2017 with 48.2% and 23.2% for females and males respectively (see Table 1). In Gaza Strip, it reached 44.4% (i.e. 36.6% for males and 69.1% for females) while in West Bank it was 18.7% (i.e. 15.6% for males and 32.1% for females). That is, unemployment is more severe in Gaza Strip as compared to the West Bank especially for females. Moreover, it reached its highest level among youth for both males and females in the age category between 15 and 24 years. Moreover, females with post-secondary education showed a higher rate of unemployment i.e., 54.6% while males who completed 1–6 years of schooling had a higher rate of unemployment i.e., 26.8% as shown in Table 3 (PECS, 2018).

Moreover, wage inequality in Palestine was evident based on the survey data reported for the year 2017. The average daily wages for workers was 101.8 NIS in the West Bank with 105.4 NIS for males and 87.7 NIS for females. However, it was 59.4 NIS in the Gaza Strip, where males received 57.4 NIS and females received 71.3 NIS. This is probably due to the very small sample size, which is not able to represent females in the Gaza Strip. On the other hand, the average daily wage for workers in Israel and its settlements was 226.9 NIS distributed as 228.1 NIS for males and 154.4 NIS for females (PECS, 2018).

2 LITERATURE REVIEW

The wage inequality among males and females has attracted many studies on revealing the causal factors. These studies used various decomposition methods. Blinder (1973) and Oaxaca (1973) applied the decomposition measuring the difference in mean wages, DiNardo et al. (1996) relied on the density distribution of wages, and Fields (2000) decomposed wage inequalities using the regression-based method. Some other studies introduced other types of decomposition. For instance, Lemieux (2006) proposed quantile decomposition models and Huffman (2004) proposed multilevel decompositions.

Budig (2002) applied a fixed effect and OLS regressions to examine the effect of gender composition in jobs on wages. The study concluded that occupations dominated by females showed lower wages than occupations with mixed-gender and male-dominated and the effect on men and women was different in these occupations. Similar results also found from these studies (England, 1992; England et al., 1994; Huffman et al., 1996; and Tomaskovic-Devey, 1995). Therefore, the wage gap was not only attributed to the worker's attributes, but also on the job's attributes to which the worker belongs.

More recently, Xie et al. (2016) conducted a study in examining the earning inequalities between and within occupation groups among the U.S college graduated workers. They decomposed earning inequality into between and within occupation groups for each education level separately. Their results revealed that rising education premium and the variation of earnings due to occupational groups were constant within all education categories. Coelli (2014) studied the occupational differences and gender wage gap in Australia. He showed that occupations have high positive effects on the wage gap in the Australian labour market. The results revealed that occupational groups contributed significantly to wage inequality. However, its effect of decreased markedly after controlling for industrial groups.

A number of studies applied multilevel modelling to analyse wage inequalities. A study by de Ruijter and Huffman (2003) included gender composition effect to study occupational wage inequality in Netherland using Dutch occupational data for the year 1997. The study applied a two-level model to wage equation and compared between gender composition occupational effect and within-occupation gender inequality as a percentage of their influence on the overall pay gap. They found that most of the wage gap was explained by both occupational and individual levels with male dominance the occupation pay. Males received higher wages across all occupations in which occupational gender composition was neglected and this gap was declined across female-dominated occupations. However, de Ruijter et al. (2003) proposed multilevel analysis to analyze the size and the causes of occupational gender inequality in the Netherlands and they showed that both males and females received lower wages in occupations that are dominated by females in the Dutch labour market. Their results were similar to those found by England (1992). In the jobs that demand high skills, high educational levels, and responsibility, their results revealed that in the occupations dominated by females there is a large wage penalty other than occupations dominated by males.

Moreover, Huffman (2004) applied five different multilevel models to investigate the gender wage inequality, taking into account jobs ranking in the hierarchy structure of local wages in the US labour market. He showed that occupational groups account for about 36% of wage differentials. He also showed in the occupations dominated by females, the wage for women is lower than those male-dominated counterparts. The wage gap in female-dominated occupations increased in which males receive wages higher than females when the number of females increased in these jobs.

Meanwhile, Bunel and Guironnet (2017) applied multilevel analysis to explore the influence of gender, occupation, and localization wage inequalities among recently graduated French workers using Génération 2004 survey data. Besides occupational gender compositions, they also included occupational age compositions. They showed that wage inequality due to occupational groups was about 40%, while due to localization (employment area) it was about lower than 10%. They also showed that young workers received higher wages in occupations dominated by seniors and dominated by males. Moreover, in these latter groups, the gender wage gap was also higher.

3 METHODOLOGY AND DATA

3.1 Econometric models

This paper applied the analysis of wage inequality on wage employed workers nested by occupation groups aged 15 years old or more to explore the contributing factors of wage inequality in the Palestinian labour market. Many dummy variables are created to classify for occupational groups. Raudenbush and Bryk (2002) showed that the use of classical linear regressions such as OLS technique to investigate the effect of each dummy group on both intercept and slope would involve many parameters in the model and thus may lead to misleading results. Such a problem is avoided by using multilevel models.

Multilevel (hierarchical) model is applied to help researchers in identifying the variability at both individual and group levels. Intra-class correlation (ICC) can be used to determine the amount of variation due to the group level. The large variability at the group level is associated with higher values of ICC, which means that the independence assumption is violated and hence the use of multilevel models is justified.

3.1.1 Unconditional model

At the very first step, the initial value of the ICC is generated to help in the decision between single level or multilevel model. Starting from the simplest two-level model (model I), which allows for occupation groups effects on daily wages with no explanatory variables at both levels. This model is the so-called unconditional or varying-intercept model and is written as:

$$\begin{aligned} &Level\ 1: \ln(w_{ij}) = \beta_{0j} + e_{ij}, \qquad e_{ij} \sim N(0, \sigma_{lnw}^2), \\ &Level\ 2: \beta_{0j} = \gamma_{00} + u_{0j}, \qquad u_{0j} \sim N(0, \sigma_{\beta 0}^2), \end{aligned} \tag{1}$$

where w_{ij} is the daily wage of individual i in the occupational group j, γ_{00} is the overall mean across occupational groups, β_{0j} is the mean of $ln\ (w_{ij})$ for occupation group j, u_{0j} is the effect of occupation group j on daily wages (i.e., the residuals for the group level), $\sigma_{\beta 0}^2$ is its variance, e_{ij} is the individual level residual, and σ_{lnw}^2 is its variance. The ICC for Equation 1 can be written as:

$$ICC = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_e^2}, \tag{2}$$

where σ_u^2 is level 2 residual variance and σ_e^2 is the total residual variance. In other words, it can be estimated by dividing the variance of between-group; the variance of random intercept, by the overall variance. It is the percentage of the residual variance that is due to the group level. The ICC is ranging between 0 and 1. The value of 0 implies no difference among groups. When $\sigma_u^2 = 0$, there is no need to employ for multilevel analysis. On the other hand, the value of one exhibit that there is no within-group and between individual differences; $\sigma_e^2 = 0$. Meanwhile, the justification for the use of multilevel models has no such rule constraint on the value of the ICC. However, lower values of ICC may be satisfactory (Kreft and de Leeuw, 1998; Boedeker, 2017).

3.1.2 Conditional model

In this model, predictor or independent variables are included in the fixed part (i.e., individual level) sex is allowed to vary across occupational groups (i.e., second level). Adding a set of the covariate in the fixed as well as in the second level will reduce the intra-class correlation. The conditional model is also can be called a varying-intercept and varying-slope model (model II). Thus, Formula 1 can be generalized as:

$$\begin{aligned} &Level\ 1: \ln(w_{ij}) = \beta_{0j} + \beta_{1j} sex_{ij} + \sum_p \beta_p X_{ij} + e_{ij}, \qquad e_{ij} \sim N(0, \sigma_{lnw}^2), \\ &Level\ 2: \beta_{0j} = \gamma_{00} + u_{0j}, \\ &\beta_{1j} = \gamma_{10} + u_{1j}, \\ &\begin{bmatrix} u_{0j} \\ u_{1j} \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \tau_{01}^2 & \tau_{11} \\ \tau_{11} & \tau_{11}^2 \end{bmatrix} \right). \end{aligned} \tag{3}$$

Raudenbush and Bryk (2002) and Snijders and Bosker (1999) provided more detailed assumptions of the above model. w_{ij} is the same as in Formula 1, the sex dummy is coded 1 for females and 0 for males, β_{0j} is the mean of $ln\ (w_{ij})$ for occupation group j, β_{1j} is the effect of sex on $ln\ (w_{ij})$ in occupation group j, γ_{10} is the coefficient of sex dummy, X_{ij} is the set of predictors such as years of schooling, age, marital status, etc., β_p is the set of parameters for these predictors, e_{ij} is level-1 residual, $\sigma_{lnw}{}^2$ is its variance, u_0j is the intercept (group) residual and $\tau_{01}{}^2$ is its variance, u_{1j} is the gender slope residual and $\tau_{11}{}^2$ is its variance, and τ_{11} is the covariance between u_{0j} and u_{1j}. Schooling and age are continuous variables and we centered them about their means, which allow us to interpret the intercept as the expected value of the response variable when these predictors have their mean values and zero values of all binary individual-level predictors. Hox (2002) showed that grand mean centering help us to differentiate between-group variability from within-group variability, demonstrating worker's daily wages relative to others. According to Kreft et al. (1995), the group means centering leads to an increase in the complexity of the model and thus extends the interpretation of the results. Huffman (2004) and Bunel and Guironnet (2017) showed that the mean estimates of the coefficient for group mean centering slightly different from those resulting from grand mean centering. For the predictors in level one, their results suggested relative homogeneity between the group and grand mean values. Thus, we use the grand mean centering to simplify our results and since the use of group means centering was not based on theoretical intuition for our research.

We allow for sex to varying across occupation groups to see whether there is a gender wage gap in each group. That is, for each occupational group, there are two slopes for both males and females.

3.1.3 Model with a selection

Sample-selection or self-selection is a common problem encountered when studying wage inequality. This problem appears when the wage is conditionally observed on the value of the reservation wage. Heckman (1979) two-step procedure is a well-known framework that has been applied to the single linear regression and panel data linear models (Vella, 1998), where the bias due to self-selection occurred when the selection is influenced by the unobserved characteristics that are correlated with error terms. Such a procedure was employed to find consistent estimates of wage inequality factors. In multilevel setting, the selection will be more complex than in the single level models which involves different patterns at different levels, a more complex structure of the variance-covariance matrix as well as alteration of the multilevel structure of the data in terms of cluster sizes (for more details, see Grilli and Rampichini, 2005).

This paper considers the case when the selection equation is single level and the wage equation is two-level in which this procedure can be applied by two-step econometric technique. First, the probability that an individual is employed in the labour market is estimated using the following probit model:

$$H_i = \alpha_0 + \textstyle\sum_k \alpha_k X_{ik} + u_i \,. \tag{4}$$

It is known as the participation equation, where H_i is a dummy variable that represents the individual's employment status; 1 is coded for employed and 0 for those who are unemployed and out of the labour force, α_0 is the intercept, X_{ik} is a set of k predictors, which may affect an individual's decision for participation like age, schooling, and marital status, α_k is the coefficient of k^{th} predictor, and u_i is the error term. From the probit model expressed in Formula (4), we calculate the inverse Mills ratio (IMR), λ, which is the ratio of the probability density function over the cumulative distribution function of a distribution. Second, Formula (3) will be adjusted to include the inverse Mills ratio as a predictor variable in the fixed part component, which can be expressed as follows:

$$Level\ 1\text{: } \ln\,(w_{ij}) = \beta_{0j} + \beta_{1j} sex_{ij} + \sum_p \beta_p X_{ij} + \alpha\lambda_{ij} + e_{ij}\,, \qquad e_{ij} \sim N(0, \sigma_{lnw}{}^2)\,,$$

$$Level\ 2: \beta_{0j} = \gamma_{00} + u_{0j}\ ,$$

$$\beta_{1j} = \gamma_{10} + u_{1j}\ , \tag{5}$$

$$\begin{bmatrix} u_{0j} \\ u_{1j} \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \tau_{01}{}^{2} & \tau_{11} \\ \tau_{11} & \tau_{11}{}^{2} \end{bmatrix}\right).$$

Model III expressed in Formula (5) is then implemented on wage employees only. All the parameters are the same as described in Formula (3), but λ_{ij} is the IMR in the fixed part calculated from Formula (4) and α is its coefficient. The significance of the IMR is very important to determine if the self-selection exists. If it is significant, then self-selection is evident. The negative value of this ratio indicates that the unobservable attributes are negatively affecting wages while positive values mean that wages are positively influenced by these unobservable attributes. Moreover, the marginal effect of each predictor in the fixed part can be estimated by differentiating level one equation of model III with respect to each predictor. In other words, it is the estimated coefficient for each predictor.

Finally, the former models will be estimated via three different econometric techniques, i.e., ML, REML Bayesian estimation methods for the purpose of comparisons where each one of them has its own assumptions and limitations (for more details see Boedeker, 2017). Bayesian estimation method, in particular, requires specifying the type of the prior distribution; informative or uninformative in which it can be specified based on past researches or researcher's beliefs. Since we have a small number of groups, the present study will use an uninformative prior distribution because of its low credibility to extreme values, where it has a higher influence on the posterior distribution. In this case, an uninformative prior will lead to lower standard errors and thus wider highest density intervals (HDIs) compared with ML and REML because of its low credibility to extreme values. Moreover, the posterior mode should be interpreted instead of the posterior mean (Boedeker, 2017).

3.2 Data Description

The empirical analysis is based on the Palestinian Labour Force Survey (PLFS) carried out by the department of economic statistics in the Palestinian Central Bureau of Statistics (PCBS) for the year 2017. Since October 1995, the department provides both a quarterly and yearly basis for the data, where the present study uses the yearly data. The population is comprised of all individuals aged 10 years and above. The sample is a two-stage stratified cluster random sampling in which the first stage consists of selecting a systematic random sample of size 494 enumeration areas, excluding the areas that constitute lower than 40 households. In the second stage, a random sample of an average of 16 households from each selected area is selected randomly. This data provides useful information about the structure and the size of the labour market in Palestine and offers inclusive measures of individual wages in Palestine.

One limitation of the data is that the Palestinian PCBS do not provide some variables like household total wages, household size and number of children due to their own privacy and confidentiality of the data. The lack of such variables will limit our attempts to correct for self-selection bias as is known in the literature (see Heckman, 1979). The data cover a total of 91 230 persons aged from 10 to 98 years. We eliminate individuals aged less than 15 years to avoid inferring with child labour and those who are out of the labour force. We exclude working abroad workers to study inside country differences and to avoid external factors. As a result, the sample size dropped to 76 111, which is used to estimate the probit model to correct for self-selection bias. Such bias that appeared after we restrict our analysis on individuals aged 15 years or more and wage employed. There are 28 758 individuals in the labour force aged 15 years or more. Among them, we select wage employed individuals and thus, the sample size dropped to 14 061 workers, which constitutes 11 878 males and 2 183 females. This high number of drops are the sample is attributed to about 16.5% who aged less than 15 years or work outside the country in addition to the lower labour force participation rate, which is about 37.78% as estimated from the data in our hands. Table 4 provides a description of the variables used in this study. These variables are included as the factors contributing to the gender pay gap across occupations. The dependent variable used in this study is the natural logarithm of daily wages measured in New Israeli Shekels. The study includes continuous predictors of age and years of schooling centered about their means measured in years. Moreover, the data in categorical type (qualitative) are coded either 1 or 0 represented by a set of dummies. These variables include gender, marital status, region, locality type (camp), refugee status, place of work, employment sector, industry, and employment contract.

Table 4 Weighted descriptive statistics for individuals(a) aged 15 years or more variables for the year, 2017

Continuous Variables	**Definition**	**All**		**Wage employment**	
		Mean	**SD**	**Mean**	**SD**
Daily wages	In New Israeli Shekels (NIS)	-	-	111.3	82.3
Natural logarithm of daily wages	Dependent variable in (NIS)	-	-	4.44	0.78
Age	In years	36.32 (76 111)	12.8	34.87 (14 061)	11.8
Years of schooling	In years	11.38 (76 111)	3.7	11.78 (14 061)	3.7
Categorical variables	Definition	No. obs.	Percent	No. obs.	Percent
Employed	1 if employed; 0 for unemployed and out of LF	23 677	31.1	-	-
Gender	Male ref. category	37 958	49.9	2 183	16
Marry	1 if married; 0 if not married	49 625	65.2	8 795	62.6
Region	1 if West Bank; 0 if Gaza Strip	51 070	67.1	9 930	70.6
Camp dwellers	1 if camp locality; 0 if urban or rural	8 068	10.6	10.7 1 505	10.7
Refugee	1 if registered refugee; 0 if not refugee	30 386	39.9	5 456	38.8
National Government	1 if works in national gov.; 0 if other sectors	13 167	17.3	3 199	22.8
Construction	if industry is construction; 0 if other	18.9 14 385	18.9	2 912	20.7
Work in Israel and settlement	1 if works in Israel or settlements; 0 if West Bank or Gaza	10 351	13.6	2 740	19.5
No contract	1 if worker has no employment contract; 0 if yes	17 658	23.2	6 488	46.1

Note: (a) individual aged 15 years or more and work in Palestine or in Israel and settlement. Weighted by the Palestinian central bureau of statistics (PCBS) sampling weights.
Source: Authors calculations based on Palestinian Labour Force Survey (PLFS, 2017)

Another limitation of the data is that most occupations are dominated by males and none of them is dominated by females. Table 5 shows the distribution of employment and daily wages by occupational groups and gender of waged individuals aged 15 or more in 2017. It appears that the females' employment percentage is higher in professional, technical, associates and clerks occupations, while males mainly get employed in elementary occupations. However, among the lowest employed jobs for females are legislators, senior officials and managers and plant and machine operators and assemblers, while those for males are legislators, senior officials, and managers. However, males earn daily wages higher than those females' counterparts across all occupational groups. The gender pay gap is higher for craft and related trade workers' occupational group. The low pay is found in jobs like professional, technical, associates and clerks.

Table 5 The distribution of employment and daily wages by occupation group and gender for individuals aged 15 or more in Palestine, 2017

Occupation Group		Employment (%)	Average daily wage (NIS)
Legislators, senior officials and managers	Male	3.5	180.56
	Female	3.9	135.85
Professional, technical, associates and clerks	Male	20.7	112.29
	Female	54.1	95.00
Service, shop, and market workers	Male	19.4	81.41
	Female	16.3	47.95
Skilled, agricultural and fishery workers	Male	3.6	86.10
	Female	8.1	56.67
Craft and related trade workers	Male	20.4	170.17
	Female	5.5	51.18
Plant and machine operators and assemblers	Male	10.7	97.64
	Female	3.9	56.55
Elementary occupations	Male	21.7	98.60
	Female	8.2	66.06
Group total	Male	100.00	115.07
	Female	100.00	87.97

Source: Authors calculations based on the Palestinian Labour Force Survey (PLFS, 2017)

Palestine has its own country-specific factors that affect worker's wages and the gender pay gap. These factors can be related to social or cultural factors and economic factors. Among the social factors are: males can receive bonus on behalf of their family members while females did not receive this type of bonus, women are more likely to focus on taking care of their families after marriage, employers believed that women are not the ones who are the breadwinners for their families and therefore paid them less, and females in higher paying jobs were paid less than those males counterparts despite they have equal education levels because of their time off for family or childcare, which justifies their lower employment rates in these jobs. Meanwhile, some sector job specifications are more suitable for males like construction and manufacturing sectors is attributed among the economic factors (Al-Botmeh, 2013; ILO, 2018).

4 RESULTS AND DISCUSSION

Tables 6, 7 and 9 show the results of the estimated multilevel models in our study. For reliability, we report estimated coefficients with their respective confidence (highest density) intervals in parenthesis. We mainly propose two different models: Model I is a two-level model, which contains no explanatory variables and we call it the unconditional model. This model can be used as a preliminary step to check if the value of the intra-class correlation coefficient (ICC) supports the use of multilevel analysis. Moreover, it allows decomposition of the variations in the wages into within-and between-occupation group variances, which is equivalent to one way ANOVA. Model II is a two-level model, which consists of several predictors in the fixed part such as age, education, region, etc. in addition to gender dummy in the random part. These models were estimated by the maximum likelihood (ML), restricted maximum likelihood (REML), and Bayesian methods for the purpose of comparisons. Moreover, Model II is extended to control for the self-selection bias, which is termed as Model III.

First of all, the values of the intra-class correlation coefficients (ICCs) based on the model I estimated using the three methods reveal that there are substantial differences in daily wages. Such differences are due to between occupational group differences and thus multilevel modelling is an appropriate approach to advance our analysis. From this model, the value of ICC estimated by the Bayesian method suggests that about 23.6% of the overall variability in daily wages is attributed to variations between occupation groups, while the remaining 76.4% variation is attributed to the variations among workers i.e., within-occupational group differences (see Table 6). Our results are in line with the literature such as Huffman (2004) and Bunel & Guironnet (2017). The intercept shows that the overall average natural logarithm of daily wages across all occupational groups is estimated as 4.46.

Table 6 ML, REML, and Bayesian estimation results for model I, 2017

Estimation Techniques

	Component	ML [95% CI]	REML [95% CI]	Bayesian Mean [95% HDI]	Bayesian Mode
Fixed	Constant	4.46** [4.19, 4.74]	4.46** [4.21, 4.74]	4.47** [4.08, 4.83]	4.46
Random	Intercept	0.335** [0.143, 0.485]	0.362** [0.165, 0.564]	0.450** [0.231, 0.921]	0.389 0.151321
	Residual	0.731** [0.725, 739]	0.731** [0.722, 0.741]	0.707** [0.701, 0.710]	0.699
ICC		0.173** (0.012)	0.197** (0.014)	0.280** [0.091, 0.481]	0.236
Model fit		AIC = 31 151.6	REML criterion = 31 147.8	DIC = 31 134.1	

Note: Estimates were weighted by the Palestinian central bureau of statistics (PCBS) sampling weights. ** significant at 1%, * significant at 5%.
Source: Authors calculations based on the Palestinian Labour Force Survey (PLFS, 2017)

We also compare the results obtained using the three econometric techniques, specifically for Model II. As shown in Table 7, it is found that the estimated level-two residual standard deviations for intercept and gender using Bayesian approach are higher than those obtained from ML and REML methods. Furthermore, the residual standard deviations for both intercept and gender obtained by REML are greater than those obtained from ML. This reflects the negative bias of the estimated standard deviations resulted when the number of groups is small; which is in our case (Peugh, 2010; Raudenbush and Bryk, 2002). However, the estimated level-one residual standard deviations, as well as the estimated coefficients in the fixed part, are almost the same or identical using these techniques. Additionally, it is evident that the highest density intervals obtained from the Bayesian method for all estimated coefficients and standard deviations are wider than from the bootstrap confidence intervals found in both maximum likelihood (ML) and restricted maximum likelihood methods (REML). This is probably because we use an uninformative prior in case of a small number of groups; this leads to wider HDIs because of its low credibility to extreme values. Therefore, Bayesian estimation method provides a better fix with more efficient estimates overall. On this occasion, the below explanation is interpreted based on the posterior mode estimates instead of the posterior mean for all models in our study (Boedeker, 2017).

Table 7 ML, REML, and Bayesian estimation results for model II, 2017

Estimation Techniques

	Component	ML [95% CI]	REML [95% CI]	Bayesian Mean [95% HDI]	Bayesian Mode
Fixed	Constant	3.855** [3.757, 3.958]	3.855** [3.742, 3.961]	3.854** [3.740, 3.971]	3.855
	Years of schooling	0.0335** [0.0306, 0.0360]	0.0335** [0.0312, 0.0360]	0.034** [0.0310, 0.0362]	0.0342
	Squared years of schooling	0.00298** [0.0026, 0.0034]	0.00298** [0.0025, 0.0034]	0.00294** [0.0023, 0.0041]	0.00297
	Age	0.01089** [0.0099, 0.0118]	0.01089** [0.0099, 0.0]	0.01087** [0.0098, 0.0134]	0.01089
	Squared age	−0.0003** [−0.0003, −0.0002]	−0.0003** [−0.0003, −0.0002]	−0.0003** [−0.0004, −0.0002]	−0.0003
	Gender	−0.3901** [−0.517, −0.264]	−0.3905** [−0.515, −0.260]	−0.3901** [−0.517, −0.259]	−0.3904
	Marry	0.0906** [0.065, 0.117]	0.0905** [0.068, 0.115]	0.0903** [0.065, 0.117]	0.0905
	Region	0.662** [0.644, 0.681]	0.662** [0.644, 0.680]	0.661** [0.640, 0.689]	0.662
	Camp dwellers	−0.0645** [−0.091, −0.038]	−0.0646** [−0.090, −0.037]	−0.0644** [−0.093, −0.033]	−0.0646
	Refugees	0.0112 [−0.005, 0.029]	0.0111 [−0.006, 0.029]	0.0112 [−0.007, 0.041]	0.0111
	National government	0.166** [0.143, 0.187]	0.166** [0.144, 0.189]	0.164** [0.140, 0.192]	0.165
	Construction	0.339** [0.318, 0.362]	0.339** [0.315, 0.363]	0.337** [0.313, 0.369]	0.338
	Work in Israel	0.8235** [0.802, 0.846]	0.824** [0.803, 0.843]	0.823** [0.799, 0.851]	0.824
	No Contract	−0.282 ** [−0.301, −0.264]	−0.282** [−0.300, −0.262]	−0.284** [−0.304, −0.267]	−0.282
Random	Intercept	0.1251** [0.043, 0.182]	0.1359** [0.0669, 0.2122]	0.1402** [0.0662, 0.2101]	0.1395
	Gender	0.1440** [0.0362, 0.2234]	0.1576** [0.0305, 0.2516]	0.1596** [0.0299, 0.2509]	0.1581
	Residual	0.4297** [0.4245, 0.4345]	0.4299** [0.4248, 0.4352]	0.4298** [0.4244, 0.4348]	0.4299
Correlation		0.21 [−0.871, 1.000]	0.20 [−0.778, 0.922]	0.20 [−0.911, 1.000]	0.20
ICC		7.8%**	9.1%**	9.6**%	9.5%
Model fit	0.01966	AIC = 16 237.5	REML criterion = 16 328.1	DIC = 16 316.8	

Note: Estimates were weighted by the Palestinian central bureau of statistics (PCBS) sampling weights. ** significant at 1%, * significant at 5%.
Source: Authors calculations based on the Palestinian Labour Force Survey (PLFS, 2017)

However, after adding predictors in the fixed part as well as adding gender dummy in the random part, the value of the ICC declines to 9.5% as indicated by the results of Model II. Huffman (2004) and Bunel and Guironnet (2017) found that the ICC has declined after accounting for level-one predictors, which is confirmed with our finding. The gender dummy is negative and highly significant. That is, females received daily wages 39.04% lower than those males' counterparts with a significant standard deviation of 0.1581. Moreover, the residual standard deviation of the gender dummy in the random part is highly significant, which indicates that the gender pay gap is significant in each occupational group. The intercept is estimated as 3.855 and we may interpret it as the average natural logarithm of daily wages of workers with an average age (35.87) and average years of schooling (11.31) and zero values of the qualitative variables since we use grand mean centering. Additionally, it seems that all predictors in the fixed part are significant and contribute to wage inequality. That is, wage inequality among workers can be explained by several attributes such as age, education, geographical region, marital status, etc. The results are confirmed by the descriptive statistics discussed above based on PECS (2018) report.

To correct for self-selection bias, we estimate a probit model using the classical generalized linear model (for REML) and Bayesian methods. We find that the estimated coefficients are almost the same in both methods. However, the standard error of estimated coefficients obtained from the Bayesian method is lower than those obtained from the classical method as shown in Table 8. It appears that all variables have significant effects on participation decision using both the classical generalized linear model and Bayesian methods. For example, the effect of years of schooling is significant and positively affects the participation decision, which implies that participation increases as the schooling increase. This result is in line with the labour market specific factors in Palestine as discussed earlier and with the study by Al-Botmeh and Sotnik (2007) that have been examined the determinants of female labour force participation in Palestine.

Table 8 Estimated probability that an individual is employed in the labour market, 2017

Component	Probit (S.E)	Bayes probit
Constant	0.249** (0.041)	0.254** [0.161, 0.334]
Years of schooling	0.0197** (0.003)	0.0201** [0.0139, 0.0286]
Squared years of schooling	0.0016** (0.0006)	0.0015** [0.0125, 0.0158]
Age	0.012** (0.001)	0.014** [0.011, 0.018]
Squared age	–0.0005** (0.00006)	–0.0005** [–0.0006, –0.0004]
Gender	–0.416** (0.029)	–0.413** [–0.472, –0.352]
Marry	0.177** (0.033)	0.179** [0.111, 0.247]
Region	0.815** (0.026)	0.817** [0.765, 0.874]
Camp dwellers	–0.190** (0.038)	–0.038** [–0.053, –0.024]
Refugees	–0.051* (0.026)	–0.048* [–0.067, –0.025]
National government	2.521** (0.077)	2.524** [2.368, 2.678]
Work in Israel	–0.349** (0.035)	–0.345** [–0.419, –0.271]

Table 8		(continuation)
Component	**Probit (S.E)**	**Bayes probit**
Construction	–0.736** (0.028)	–0.730** [–0.791, –0.668]
No contract	3.476** (0.087)	3.472** [3.297, 3.639]
Log. Likelihood	–9 274.363	–9 282.725
N	76 111	76 111

Note: ** significant at 1%, * significant at 5%.
Source: Authors calculations based on Palestinian Labour Force Survey (PLFS, 2017)

The coefficient of self-selection; IMR, is negative and highly significant as shown in Table 9, which means that the unobservable characteristics negatively affect the daily wages. In other words, the sample selection bias plays a substantial role in the examination of gender wage gaps. After controlling for self-selection, the gender pay gap decreases to 38.14% and the ICC decreases to 8.5%, which is confirmed with the finding by Bunel and Guironnet (2017). That is, REML and Bayesian methods overestimate the gender pay gap and the ICC in the case without self-selection control.

Table 9 REML and Bayesian estimation results for model III corrected for self-selection, 2017

		Estimation Techniques		
	Component	**REML [95% CI]**	**Bayesian Mean [95% HDI]**	**Bayesian Mode**
Fixed	Constant	3.991** [3.881, 4.122]	3.992** [3.871, 4.138]	3.991
	Years of schooling	0.0316** [0.0292, 0.0339]	0.0315** [0.0284, 0.0348]	0.0316
	Squared years of schooling	0.00247** [0.0021, 0.0029]	0.00246** [0.0018, 0.0045]	0.00247
	Age	0.0122** [0.0113, 0.0130]	0.0120** [0.0095, 0.0136]	0.0121
	Squared age	–0.0003** [–0.0003, –0.0002]	–0.0003** [–0.0004, –0.0002]	–0.0003
	Gender	–0.3815** [–0.499, –0.251]	–0.3812** [–0.511, –0.242]	–0.3814
	Marry	0.0725** [0.053, 0.095]	0.0724** [0.048, 0.115]	0.0726
	Region	0.562** [0.545, 0.579]	0.560** [0.539, 0.594]	0.562
	Camp dwellers	–0.0374** [–0.058, –0.016]	–0.0372** [–0.067, –0.011]	–0.0373
	National government	0.197** [0.159, 0.230]	0.196** [0.153, 0.241]	0.196
	Work in Israel	0.854** [0.832, 0.877]	0.851** [0.825, 0.887]	0.853
	Construction	0.362** [0.336, 0.388]	0.359** [0.325, 0.421]	0.361
	No contract	–0.346** [–0.384, –0.308]	–0.348** [–0.405, –0.287]	–0.346

Table 9 (continuation)

Estimation Techniques

	Component	REML [95% CI]	Bayesian Mean [95% HDI]	Bayesian Mode
Fixed	IMR	–0.0699** [–0.137, –0.001]	–0.0697** [–0.141, –0.001]	–0.0698
Random	Intercept	0.1296** [0.0533, 0.2028]	0.1328** [0.0423, 0.2094]	0.1314
	Gender	0.1600** [0.0433, 0.2649]	0.1634** [0.0421, 0.2851]	0.1619
	Residual	0.4299** [0.4255, 0.4347]	0.4298** [0.4234, 0.4352]	0.4299
Correlation		0.07 [–0.88, 0.96]	0.07 [–1.021, 1.005]	0.07
ICC		8.3%	8.7%	8.5%
Model fit		REML criterion = 16 326.3	DIC =1 319.6	

Note: ** significant at 1%, * significant at 5%.
Source: Authors calculations based on Palestinian Labour Force Survey (PLFS, 2017)

For robustness checking, we have performed the analysis for the year 2016 in which the results are not attached. We find the results from both years are very similar, which confirm our results that the gender pay gap across occupational groups is the main determinant to the wage inequality in Palestine.

CONCLUSIONS

In this paper, we investigate the gender pay gap across occupational groups based on the PLFS data for the year 2017 obtained from the Palestinian central bureau of statistics (PCBS). The study applies the multilevel linear model and seeks to compare the results using three estimation approaches which are maximum likelihood (ML), restricted maximum likelihood (REML), and Bayesian estimation. The results of this study reveal that the Bayesian estimation method provides more efficient estimates than ML and REML.

Moreover, the present study finds various important empirical results yielded by the multilevel analysis. First, the results show that wage inequality due to between occupation groups is evident and it is estimated as 23.6% and the remaining is due to disparities among observed and unobserved worker's attributes. This proportion is less than those found in the United States by Huffman (2004) and in France among recently graduated workers by Bunel and Guironnet (2017). However, it was estimated at 18% in the UK by Olsen et al. (2018).

Second, allowing gender to vary across occupational groups, the results reveal that the gender pay gap is significant and varies across occupation groups. Moreover, adding predictors in the fixed part, the results reveal that variables such as schooling, age, region, marital status, locality, sector, industry, place of work, and work contract contribute significantly to wage inequality among workers. Third, the gender pay gap reduces to 38.14% after correcting for self-selection bias. However, this gap is still persistent and high. The empirical analysis of the present study is confirmed with the country-specific factors mentioned earlier.

Since there is pay discrimination among genders and the wage gap persists across occupation groups, immediate action from the policymaker is of atmos. This issue needs to be resolved as it may lead to gender unequal treatment and bad practices in the society and labour market, as well as barriers to economic growth. Women could contribute to significant economic growth and their skills and efforts should be appreciated and encouraged. The enforcement of equal pay through enforcement and equity laws could be one of the ways to close the gender pay gap. Also, the awareness of equal pay and treatment in the labour market, the encouragement of women to enter the job market through campaign and education day can be another good practice.

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Enhancing the Awareness of Official Statistics in Egypt: the Approach to Increase their Value

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The paper demonstrates the role of the Central Agency for Public Mobilization and Statistics (CAPMAS) in increasing official statistics value in Egypt using the two following methods. First, the applied approach to facilitate the use of understood official statistics. It involves enhancing statistics literacy for the public, training the current staff members who produce official statistics and summer training for university graduates. Second, the indicators used to monitor the progress, which provides information on a specific aspect of the value of official statistics. The number of downloads, the number of citations of media, evaluation of training the staff members and university graduates, and user satisfaction are the essential means for evaluation. Media and internet are important means to facilitate statistical literacy in CAPMAS.

Training staff members and university graduates enhances their statistical literacy, which raises their performance in the official statistics field. A great effort is still needed to increase the value of official statistics. Collaboration with The International Statistical Literacy Project (ISLP) is important to promote statistical literacy.[2]

Keywords	JEL code
Enhancing statistical literacy, academic bodies, media, NCST, metadata	*I20, A20*

INTRODUCTION

Statistical literacy is a term used to describe the ability of an individual or a group to understand and comprehend statistics (Unece, 2012). Most definitions, as cited by Ferligoj (2015), are based on Katherine K. Wallman (1993) who said: "Statistical Literacy is the ability to understand and critically evaluate statistical results that permeate our daily lives coupled with the ability to appreciate the contribution that statistical thinking can bring to public and private, professional and personal decisions". Since CAPMAS is the main source of official statistics in Egypt that embrace data production with high quality according to fundamental principles of official statistics (United Nations, 2014), and without high-quality data providing the right information on the right things at the right time; designing, monitoring and evaluating effective policies becomes almost impossible (A World That Counts, 2014). Since the last decade, data has witnessed an increasing demand because of technological advances, which facilitated its availability

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2 Based on contribution presented at the *European Conference on Quality in Official Statistics (Q2018)* in Krakow, Poland, June 2018.

and accessibility on the Internet. That was entailed keeping pace that advancement and applying the approach that enables all segments of the society to possess the statistical skills to use, understand and interpret data and increase their awareness of official statistics. Providing the necessary training for both the staff members who produce official statistics to release clear statistical outputs, and users who need to understand the data produced to use it correctly were the main issues to enhance statistical literacy, which, accordingly, will raise the value of the data produced.

1 PROVIDING STATISTICAL LITERACY FOR THE PUBLIC

Communication with media (newspapers, radio, television, and the internet) is an important factor for the public in increasing their literacy and providing them with the latest information and events related to official statistics. To achieve that, a set of measures have been adopted by CAPMAS to enhance statistical literacy using media. A daily radio program called "Egypt in figures" is broadcasted every morning in the timing when the employees go to work to enable listeners to receive a piece of specific statistical information easily in a short time. Another event is held annually through cooperation between CAPMAS and Egyptian Radio Station during the Ramadan month. A daily broadcasted program called "Ramadan quiz" which contains one piece of general statistical information followed by a question about the information ever mentioned during the program. All contestants are invited to collect the answers of the thirty questions and send them to CAPMAS. At the end of the month, CAPMAS sorts the right answers, announces the winners of the competitors, and holds a ceremony of prize award. To evaluate the progress; CAPMAS compares the number of current participating contestants' trend with their numbers in the previous years, and the comments of the quiz's executives as well as the contestants. That information is reviewed and analyzed to determine the Pros and Cons of that activity to make future adjustments if necessary. Another important measure is monitoring the statistical events held on media and focussing on the most important public and current events that appear on the scene such as prices, inflation, unemployment, and population growth rates and their related comment on Facebook, Twitter, and other social media. That monitoring reflects the awareness achieved for the public and their interaction with those events. Participation in the international annual book fair is one of the methods for enhancing statistical literacy of the public, where the products of the CAPMAS are displayed in presence of statistician experts who provide answers to any inquiries. Monitoring the achieved value can be done by knowing the attitudes of the public towards specific statistical products and their future expectations through a questionnaire distributed to them, analyzed, and preparation of an action plan to modify the performance according to the outputs' evaluation.

CAPMAS is highly interested in communication with journalists and media professionals as they represent the main channel for bringing statistical literacy closer to the public. Supporting them with the right statistical information leaves a positive reflection on all community segments. The staff members in the General Management of Public Relations in CAPMAS is responsible for monitoring the materials published in the media. They review the data and communicate it with the publisher or the media to correct the concepts if it was presented differently or in need of more clarification. The value here is measured by recognizing the number of positive and negative news published in the media regarding the statistical CAPMAS' products; the feedback is analyzed and suitable steps are taken by subject matter experts to send the right information if required.

Enhancing statistical literacy at school is very important as it represents the next generation who will lead the country. Moreover, they inform their parents and reletives about the importance of statistics. CAPMAS has included specific statistical curriculum according to the different school levelsstages to include simple information about statistics and activities carried out by CAPMAS. The most important of these materials was the population census, which showed that the students possess good information about it during the implementation of the 2017 census, where the children were informing their parents about the role of census representative when the interview between the census representative and the household members took place.

At present, the Internet plays an important role in transmitting information to decision-makers, researchers and the public. CAPMAS is interested in targeting all segments of the society to Internet users to enhance their statistical literacy. That represents a great challenge due to their different kinds of culture and statistical knowledge they want to get. Therefore, it should enhance open data for them, which, accordingly, will increase its value (Open Data Watch, 2018). The history of CAPMAS in communication using the Internet shows that little data is disseminated without its related metadata that explains that data. Most of the data are requested from the National Information Center (NIC), which is responsible for receiving customer data requests. NIC transfers that request to the relevant departments which prepare and resend it to the center, which, accordingly, delivers it to the customer. The same measure occurs in Presidency of CAPMAS' office concerning the data required for international statistical organizations, agencies, universities and research institutes. Moreover, departments within CAPMAS obtain their data from other departments in the same building.

Since the beginning of 2010, CAPMAS' experts, have cooperated with the Organization for Economic Co-operation and Development (OECD) that provided them with software (Nesster Publisher) to document the data with its related metadata and published it using National Data Archive (NADA). That measures have enabled all segments of the society (inside and outside CAPMAS) to access the website called "Metadata" and download microdata and data with its related metadata which made it understood without the need to ask experts or specialists to explain any piece of information.[3]

To measure the value, a monthly report is prepared and send to the president of CAPMAS which include the information about:

- Number of bulletins or surveys published on the site compared with the previous month and with the same month in the previous year to measure the progress;
- Number of downloads for each statistical product to judge which is the most and the less important to take a decision toward them; and
- Information about persons who visit and download data (by country; job; agency; kind of downloaded data, etc.).

The subject matter specialists study the notes mentioned in the report to take the right decision for the solution in order to raise the value of that data.

2 TRAINING THE CURRENT STAFF MEMBERS

Staff members and partners in the public and government sector who are responsible for collecting and providing data are the most important bodies responsible for producing high quality of official statistics. CAPMAS is interested in providing them with varied statistical training from basic to advanced skills according to the level of each category. To this end, CAPMAS works through several pillars.

2.1 Cooperation between CAPMAS and Academic Bodies

Nathan (2007) stated, "The active involvement of academic university staff in consulting and advising to the statistical agency's activities ensures that the teaching programme will not become too theoretical or divorced from the application requirements of the statistical agency". However, the interaction between the two groups is not widespread (Murphy, 2002). CAPMAS has statistical advisers from the university professors working to make the university academic study gets along with its practical side.

[3] The Arabic website, which has more than 1 200 studies, is: <http://capmas.gov.eg/Pages/ShowPDF.aspx?page_id=http://www.censusinfo.capmas.gov.eg/Metadata-ar-v4.2/index.php/catalog>. The English website, which has more than 250 studies, is: <http://www.censusinfo.capmas.gov.eg/Metadata-en-v4.2/index.php/catalog>.

On the other hand, CAPMAS is interested in raising the statistical scientific level of its employees which shows a positive impact on the quality of the statistical product and increases the users' confidence and demand. Therefore, it is interested in strengthening cooperation with statistical institutes and universities, which grant diplomas to employees, master's degrees and Ph.D. Egypt has the Graduate School of Statistical Research and Cairo Demographic Center as well as the Faculty of Economics and Political Science where different branches of statistics are taught. CAPMAS announces annually the information about participation in these bodies for studying in specified times. In addition, CAPMAS covers all tuition fees at all study stages for staff who are serious in their work and have a desire to increase their statistical literacy.

2.2 National Center for Statistical Training (NCST)

It has been established according to the Ministerial Decree number 415 in 1970 (CAPMAS, n.d). It is located within the administrative structure of CAPMAS under demographic and censuses sector. It strengthens the statistical capacity of its staff members and partners in the public and government sector who work in the statistics field to provide CAPMAS with the required data to produce trusty official statistics. It conducts free annual training program applied in 175 hours in seven weeks (five hours a day and five days a week) consisting of unified academic statistics curriculum part for employees with lower than university qualification (lectures on methods of presenting statistical data; statistical measures; introduction to mathematics for statisticians; introduction to the preparation of statistical report; etc.).

Another curriculum part about the practical activities applied in CAPMAS demonstrating the nature of its activity (role and missions of CAPMAS; phases of statistical work to produce statistics; questionnaire design; methods of data collection; methodology of conducting Population Census and Household Income; Expenditure; and Consumption Survey "HICS"….etc.).

Additional three weeks' training program (seventy-five hours) for the university qualified employees includes additional academic and practical curriculum. Advanced training program (six weeks) for higher than university graduates plus those university graduates who got high degree in the university training program held in CAPMAS to complete their statistical training. To measure the value of statistical literacy which they obtained and will convey to their colleagues in their work, a periodic evaluation is carried out during the training program.

In addition, at the end of the training program, all participants are committed to submit a research paper (each in their work field) using statistical analysis tools that were applied in the training program to analyze data related to the trainee's work. Appreciation certificates are awarded to the first three trainees who had achieved the highest marks. Finally, a questionnaire is distributed to the trainees to find out their opinions of all program components in order to modify the performance and avoid the shortcomings in the next training program.

2.3 The Central Statistics Departments

Within each government body and the public sector companies a central statistics department collecting data from its branches and providing it to CAPMAS. Communication between CAPMAS and the agencies is necessary to bring together their viewpoints and support discussions to produce accurate statistics. For example, they may discuss the unclear questions in the questionnaire used in collecting data which may result incorrect statistics production; a necessary change in data collection methodology; or the need to include detailed data for a specific statistics that may appear to enrich the statistical product.

The NCST coordinates the activity among departments of data collection, those who are concerned with the bulletin production in CAPMAS, and the central statistics members in government body and the public sector companies. All the three departments conduct meetings according to a schedule for coordination to discuss the obstacles they encounter. Finally, the three departments write a report includes their conclusion and recommendations to activate them and avoid the shortcomings that have arisen during the meeting in the following statistical year.

2.4 The Monthly Training Day

The history of CAPMAS shows that there were isolated islands of departments with experts responsible for producing official statistics (Hathoot, 2018). Each department is interested in finishing its task without searching for any information that might help to improve its statistical product. Moreover, staff members within each department attend workshops and do not transfer the knowledge they have gained to the colleagues. To overcome that challenge, CAPMAS has established The Monthly Training Day (MTD) after conducting census 2006 to mediate statistical literacy to all employees.

On that particular day, the staff members of CAPMAS coming from all governorates of Egypt to attend in the large hall (more than 1000 people) to present the most important activities carried out during the month. The activities include the workshops held inside and outside Egypt, the most important information about the surveys being carried out and their current situation; the meetings held and their importance; success and shortcomings of CAPMAS during performance of its missions; etc.

At the end of the day, recommendations are presented based on what has been discussed for implementation. A report is prepared and distributed to all departments including all events and recommendations ever presented on that day to inform all the staff members about all events and activities performed by CAPMAS.

3 SUMMER TRAINING FOR UNIVERSITY GRADUATES

The statistical studies in universities are characterized by academic curriculum. Many university graduates in statistics field need to practice official statistics in order to obtain a complete statistical vision. CAPMAS looks at those graduates as the future partners who will work in that field. Therefore, it is interested in providing them with practical training to promote their practical experience to enable them to understand how official statistics is produced; the subject matter departments involved in producing the output; the workflow; ...etc.

A summer training program is scheduled for a month and includes visits to the departments contributing to the statistical output production. After they had taken an overview about the nature of the work in the CAPMAS, they are distributed to the departments (each according to his/her specialization) to perform a specific statistical task within the statistical metadata system to be accomplished. The departments prepare a report about these trainees in order to choose the best of them to work in CAPMAS after a personal interview with them by the internal managers and university experts from specialized colleges and institutes.

CONCLUSIONS

The paper attempted to demonstrate the approach applied in CAPMAS with the aim to increase the value of official statistics and the ways of enhancing it to the different segments of the society. Providing statistical literacy for the public using media and internet enable them to get the statistical information easily as it became usual tools to use. Census at school and other statistical curricula are effective factors to create next enlightened generation. Statistical Training for CAPMAS staff members and their partners from the government and public sector and active collaboration between them reflected positively on the quality of the statistical product. Finally, official statistical training for university graduates will complete their vision by adding official statistical experience to their academic studies and will increase their statistical capabilities.

RECOMMENDATIONS

A great effort should be spent on the increase of the value of official statistics. The support of top management is necessary to achieve that challenge. To measure customer satisfaction accurately, providing web users with feedback on each page of the website is crucial for future improvements by asking them about the usefulness of the contents and their comment. To promote statistical literacy in Egypt, CAPMAS should be aware of the role of The International Statistical Literacy Project (ISLP) and the services they provide.

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Recent Events

Conferences

The ***22nd AMSE 2019 Conference*** was held in ***Nižná, Slovakia, from 28th August to 1st September 2019***. The conference was dedicated to the 100th anniversary of statistics in Czechoslovakia. More information available at: <*http://www.amse-conference.eu*>.

The ***27th Interdisciplinary Information Management Talks (IDIMT 2019 Conference)*** took place in ***Kutná Hora, Czech Republic, during 4–6 September 2018***. More information available at: <*http://idimt.org*>.

The ***13th International Days of Statistics and Economics (MSED 2019 Conference)*** was held ***in the University of Economics, Prague, Czech Republic, from 5th to 7th September 2019***. More information available at: <*https://msed.vse.cz*>.

The ***37th International Conference on Mathematical Methods in Economics (MME 2019)*** took place ***in České Budějovice, Czech Republic, during 11–13 September 2019***. The conference is traditional meeting of professionals from universities and businesses interested in the theory and applications of operations research and econometrics. More information available at: <*https://mme2019.ef.jcu.cz*>.

Papers
We publish articles focused at theoretical and applied statistics, mathematical and statistical methods, conception of official (state) statistics, statistical education, applied economics and econometrics, economic, social and environmental analyses, economic indicators, social and environmental issues in terms of statistics or economics, and regional development issues.

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Language
The submission language is English only. Authors are expected to refer to a native language speaker in case they are not sure of language quality of their papers.

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1.1.1 Third-level heading (Times New Roman 12, bold italic)

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Footnotes should be used sparingly. Do not use endnotes. Do not use footnotes for citing references.

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Place reference in the text enclosing authors' names and the year of the reference, e.g. "White (2009) points out that…", "… recent literature (Atkinson et Black, 2010a, 2010b, 2011; Chase et al., 2011, pp. 12–14) conclude…". Note the use of alphabetical order. Include page numbers if appropriate.

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Tables
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