Analysis of methodological approaches to evaluation of complementary and substitution relationships in consumer demand for food

Analýza metodických přístupů pro hodnocení komplementárních a substitučních vazeb ve spotřebitelské poptávce po potravinách

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Abstract: The article is focused on analysis of methodological approaches usable for the analysis of complementary and substitution relationships in consumer demand for food. Demand on food markets is mostly analysed using coefficients of cross elasticities. These coefficients reflect character and intensity of demand relationships of analysed foodstuffs. Besides this traditional approach, another methodological possibility is presented in the paper. This approach is based on correlation and paired regression analysis. Paired indices of determination and correlation, respectively paired regression parameters, may be also used to solve substitution and complementary relationships between the analysed food commodities. Moreover, this methodological approach can be used for analysis of complementary and substitution relationships between aggregate groups of goods, which is not possible if coefficients of indirect price elasticity of demand are used.

Key words: consumer demand for food, substitution relationships in demand, complementary relationships in demand, paired linear correlation, paired linear regression

Abstrakt: Článek se zabývá analýzou metodických přístupů, které lze uplatnit při analýze komplementárních a substitučních vazeb ve spotřebitelské poptávce. Tato forma poptávkových analýz bývá nejčastěji řešena prostřednictvím koeficientů křížové elasticity. Podle jejich dosažené velikosti se pak usuzuje o charakteru a o intenzitě dané mezistatkové vazby v poptávce. Kromě této tradiční metodiky však článek představuje další metodickou možnost, která je založena na korelační a párové regresní analýze. Výpočtem párových indexů determinace a korelace, respektive párových regresních parametrů lze rovněž vyhodnotit tento druh mezistatkových propojení v poptávce. Navíc je tento metodický způsob využitelný i při analýze komplementárních a substitučních vazeb mezi skupinami statků, což při hodnocení na základě koeficientů nepřímé cenové elasticity poptávky není možné.

Klíčová slova: spotřebitelská poptávka po potravinách, substituční vztahy v poptávce, komplementární vztahy v poptávce, korelační analýza, párová regresní analýza

Qualitative and quantitative demand analyses of food markets are very useful for many subjects. First, producers, respectively sellers of food, may use results of these analyses. Based on the knowledge of demand side of the market, they can more adequately accommodate supplied quantity, assortment and quality of foodstuffs. Knowledge of the interrelationship mechanism in food markets is also vital for decision making of all subjects within the particular food verticals, especially for producers and processors of agricultural products.

When analysing consumer demand for particular goods in food markets, these demands are often closely related[1]. The relationship has either complementary or substitution character. These complementary and substitution interactions may have different level of intensity. According to this intensity, food commodities are divided into perfect and imperfect substitutes, respectively complements, or mutual independence is possible. Considering the behaviour of individual consumer, the character of relationship mostly reflects utility and taste of particular food commodities or similarity of followed goods enabling their mutual substitution. Substitution interactions in individual consumer demand for food are also influenced by competition between all consumed goods, as a result of limited income

The paper has arisen within the solution of the grant project of GAČR 402/02/P056 "Research of consumer behaviour in food markets in the Czech Republic", which is linked to the research project of FBE MUAF Brno, MSM 431100007 "Forming of a structure of agriculture and food industry and trends in behaviour of entrepreneurial subjects within the process of Czech Republic integration into EU".

[1] Of course, these close relationships exist also in other non-food markets (Varian 1978, 1995).

of the majority of consumers. In the particular households, complementary and substitution relationships may be further influenced by mutual interactions of consumer demands within the household. Individual demand analysis should be followed by the market analysis of complementarity and substitutability in consumers demand for food (Browning, Browning 1992).

For evaluation of complementary and substitution dependence in consumer demand, there is mostly used indirect price analysis or cross analysis of demand. Many of both domestic and foreign authors publish research results of these analyses. Wold and Jureen (1953) published coefficients of short run cross elasticity of demand for selected food commodities in the USA and United Kingdom (Table 1).

Coefficients of long run cross elasticity for selected food commodities were published for example by Heien (1982). Selected values of these coefficients are presented in Table 2.

Table 1. Short-run cross elasticity of demand for selected food commodities in the USA and United Kingdom

Commodity	Cross elasticity with respect to price of following commodity	Coefficients of cross elasticity
Margarine	butter	+0.81
Butter	margarine	+0.67
Beef	pork	+0.28
Pork	beef	+0.14
Sugar	fruits	–0.28
Cheese	butter	–0.61

Table 2. Long run cross elasticity of demand for some selected food commodities in the USA

Commodity	Cross elasticity with respect to price of following commodity	Coefficients of cross elasticity
Margarine	butter	+1.53
Pork	beef	+0.40
Chicken	pork	+0.29

Tvrdoň (1999) calculated elasticity coefficients of demand for some food commodities in the Czech Republic. Selected data are in Table 3.

From the presented data it is clear, that in many cases are relationships between particular consumer demands are relatively very strong and must be considered if consumer demand is analysed.

Another possibility to evaluate complementarity and substitutability of food commodities at the level of final consumer demand is to use correlation and paired regression analysis, e.g. the approach based on application of statistical methods. Using this method, it is possible to evaluate complementary and substitution relationships between food commodities by paired indices of determination and correlation, respectively by paired regression parameters. An advantage of this approach is, that it may be used for analysis of consumption relationships between food aggregates, which is not possible at the level of cross demand analysis.

INDIRECT PRICE ANALYSIS OF CONSUMER DEMAND FOR FOOD

One of the general instruments of microeconomic analysis to analyse complementary and substitution relationships in consumer demand for food is indirect price (cross) analysis of demand. Cross analysis of individual demand is usually based on the classical Marshall[2] concept of demand function (Soukup J. 1999):

$$Q_i = d_i\,(p_1, p_2, \ldots p_i, \ldots p_j, \ldots p_n, m) \qquad (1)$$

where $p_1, p_2, \ldots, p_i, \ldots, p_j, \ldots, p_n$ is the set of prices of food commodities[3] in the market basket of analysed consumer, m is disposable income, Q_i is the size of consumer demand for food commodity i. Coming of presented demand function (1), it is possible to determine the system of partial derivatives with respect to prices of other food commodities:

$$Q'_{ij} = \frac{\delta Q_i}{\delta p_j} \qquad (j = 1, 2, \ldots, n \wedge j \neq i) \qquad (2)$$

Using the derived relationship (2), it is possible to quantify the impact of other food commodities (using

Table 3. Elasticity coefficients of demand for some selected food commodities in the Czech Republic

	Meat and meat products	Milk and milk products	Eggs	Fats and oils
Meat and meat products	–0.4000	+0.0090	+0.0004	+0.0163
Milk and milk products	+0.0230	–0.6000	+0.0002	+0.0075
Eggs	+0.0383	+0.0070	–0.9000	+0.0125
Fats and oils	-0.531	–0.0730	–0.0897	–0.2000

[2] The analysis may be also based on Hicks concept of demand function.

[3] If more complex analysis of complementary and substitution relationships in consumer demand for food is considered, also non-food goods may be considered.

their prices) at the level of individual consumer demand for *i*th food commodity. For dimensionless indirect evaluation of complementary and substitution relationships in individual demand, there is used the coefficient of cross elasticity η_{ij} (Koutsoyannis 1979, Nicholson 1992 and Soukupová et al. 1998):

$$\eta_{ij} = \frac{\frac{\delta Q_i}{Q_i}}{\frac{\delta p_j}{p_j}} = Q'_{ij} \cdot \frac{p_j}{Q_i}$$

$$(j = 1, 2, ..., n \wedge j \neq i) \qquad (3)$$

If mathematical function of individual consumer demand is not derived, for example when analysing complementarity and substitutability of food commodities in very short time period, it is possible to calculate the coefficient of cross elasticity using point approach. Point cross elasticity calculated with respect to the new period ("after a change") is:

$$\eta_{1ij} = \frac{\frac{Q_{1i} - Q_{0i}}{Q_{1i}}}{\frac{p_{1j} - p_{0j}}{p_{1j}}} \qquad (j = 1, 2, ..., n \wedge j \neq i) \qquad (4a)$$

or with respect to the basic period ("before a change"):

$$\eta_{0ij} = \frac{\frac{Q_{1i} - Q_{0i}}{Q_{0i}}}{\frac{p_{1j} - p_{0j}}{p_{0j}}} \qquad (j = 1, 2, ..., n \wedge j \neq i) \qquad (4b)$$

For this type of analysis of complementary and substitution relationships in consumer demand for food, there may be used also the arc cross elasticity of demand (Tvrdoň 1999):

$$\eta_{(1+0)ij} = \frac{\frac{Q_{1i} - Q_{0i}}{Q_{1i} + Q_{0i}}}{\frac{p_{1j} - p_{0j}}{p_{1j} + p_{0j}}} \qquad (j = 1, 2, ..., n \wedge j \neq i) \qquad (5)$$

Obtained values of coefficients of cross elasticity are mostly interpreted as percentage changes, e.g. what is % change of demand of *i*th food commodity, if the price of *j*th food commodity is increased by 1%. Coefficients of cross elasticity are real numbers. Negative value of cross elasticity coefficients means complementarity between food commodities *i* and *j*, while positive value indicates substitution relationships between these goods. If values of these coefficients are either from the left or from the right approaching zero, there is a complementary independence between analysed food commodities *i* and *j*, respectively substitution independence between goods *i* and *j* exists (Varian 1978).

From above paragraph it is clear, that evaluation of substitution interactions in consumer demand, based on coefficients of cross elasticity η_{ij}, has one-way character. For two-way evaluation of substitution relationship, coefficients η_{ji} with opposite orientation must be calculated. To determine values η_{ji} on principles of marginality, *j*th mathematical function of consumer demand must be used:

$$Q_j = d_j (p_1, p_2, \ldots p_i, \ldots p_j, \ldots p_n, m) \qquad (6)$$

Coefficient of cross elasticity η_{ji} may be analogically derived as follows:

$$\eta_{ji} = \frac{\frac{\delta Q_j}{Q_j}}{\frac{\delta p_i}{p_i}} = Q'_{ji} \cdot \frac{p_i}{Q_j}$$

$$(i = 1, 2, ..., n \wedge i \neq j) \qquad (7)$$

Regarding the fact, demand analysis based on point cross elasticity or arc cross elasticity, e.g. without using mathematical function of consumer demand for food, may be considered easier. A very useful attribute of coefficients of cross elasticity is the fact, that they are dimensionless. This character enables to compare originally incomparable complementary or substitutionary interactions in the individual consumer demand or between individual demands of different consumers.

RESULTS 1

For practical application of cross analysis of consumer demand for food commodities, e.g. analysis of substitution and complementary relationships in consumer demand, there was chosen the market with bakery products. Demand interactions for bread and rolls of bread markets have been analysed[4]. For the analysis, there was constructed and statistically proved the linear regression model of dynamic consumer demand:

$$Q_{1t} = 8,2007 - 0,1775\, p_{1t} + 8,3678 \cdot 10^{-2}\, p_{2t} + 2,0866 \cdot 10^{-4}\, m_t - 0,1375\, t \qquad (8)$$

[4] Data from Czech Bureau of Statistics enable only one direction analysis of demand relationships. Coming of the data, it is not possible to create demand model for rolls of bread.

where:

Q_{1t} purchase of bread by the average Czech household in period t (kg/person)

p_{1t} average price of bread in period t (CZK/kg)

p_{2t} average price of rolls of bread in period t (CZK/kg)

m_t income of the average Czech household in period t (CZK/person)

t time variable used in the following way:

1st quarter of year 1995 $t = 1$

2nd quarter of year 1995 $t = 2$

……..……..

4th quarter of year 1999 $t = 20$

Multiple coefficient of determination of the demand model was 0.8714 and the value of multiple coefficient of correlation was 0.9335. Statistical evidence or multiple coefficient of determination of constructed linear model was at the level above 99%, e.g. constructed model may be indirectly considered statistically significant.

For the analysis of demand linkages between bread and rolls of bread, there was used regression parameter at the price of rolls of bread. Based on the value of this parameter, it is possible to say, that price increase of 1 kg of rolls of bread by 1 CZK meant increase of bread consumption of the average Czech family by 8.3678×10^{-2} kg per person in observed period (1995–1999). Because of the direction of the consumer reaction, it is possible to declare, that the observed foodstuffs are substitutes. Using this model, there was determined the average coefficient of cross elasticity for given time period, which was 0.14. It means that the average Czech household reacted in the observed period on 1% price increase of 1 kg of rolls of bread by increase of bread consumption by 0.14% per person. Positive value of this coefficient reveals substitution relationship in the direction bread – rolls of bread. On the other hand, the analysed consumer demand is, from this view, very inelastic. Substitution relationships have relatively a very weak character (Sy-rovátka 2000).

CORRELATION AND PAIRED REGRESSION ANALYSIS BETWEEN DEMANDS FOR FOOD COMMODITIES

For analysis of complementary and substitution relationships in consumer demand for food commodities, there may be also used correlation and paired regression analysis. Comparing, previous methodological approach, it is applicable for analysis of substitution and complementary relationships also if groups of food commodities are considered.

Using paired regression analysis, two-way evaluation of analysed relationships is based on formulation and solution of paired associated regression problems (Zvára 1989):

$$Q_i = f_{ij}\,(Q_j) \tag{9a}$$

$$Q_j = f_{ij}\,(Q_i) \tag{9b}$$

Presence of complementary and substitution relationships in consumer demand for food may be evaluated using computed paired correlation indices (I_{ij}, I_{ij}). These indices enable to evaluate correlation between demand for ith and jth food commodity. Correlation indices are dimensionless quantities, when the value fluctuates from 0 to 1. The closer is the value to 1, the higher is the observed correlation and vice versa. The level of correlation indices reflects not only the existence of relationship between analysed food commodities but it is also influenced by the choice of appropriate smoothing function (Minařík 1995).

Character and intensity of interactions between food commodities can be analysed using 1. differential of associated pairs of regression functions (9a) and (9b):

$$Q'_i = \frac{\delta Q_i}{\delta Q_j} \tag{10a}$$

$$Q'_j = \frac{\delta Q_j}{\delta Q_i} \tag{10b}$$

If relations (10a) and (10b) are positive, analysed food commodities have complementary character. If they are negative, substitution dependence in the given direction exists. If relations (9a) and (9b) are approaching from right or from the left to zero, there are neither complementary nor substitution relationships in the given direction between the observed food commodities. Derived relations may be interpreted in marginal way, e.g. if there is an unitary change of jth demand, the level of ith demand is changed in accordance with relation (10a), respectively in accordance with relation (10b), if observed variables are in the opposite order. To get dimensionless form of intensity of paired regression analysis at the level of interactions between consumer demands for food commodities, it is possible to transform the original database [Q_i, Q_j] to normalised one [Ω_i, Ω_j] according to the following relations:

$$\Omega_i = \frac{Q_i - \overline{Q}_i}{s_{Q_i}} \tag{11a}$$

$$\Omega_j = \frac{Q_j - \overline{Q}_j}{s_{Q_j}} \tag{11b}$$

where:

$\overline{Q}_i$, $\overline{Q}_j$ average levels of Q_i and Q_j

S_{Qi}, S_{Qj} standard deviations of Q_i and Q_j levels

After this database transformation, calculated regression parameters in paired associated models will be dimensionless and easily comparable (Minařík 1995).

In practice, there is for its simplicity and some specific characters the most frequently used method to evaluate relationships between variables linear form of paired regression analysis (Zvára 1989):

$$Q_i = A_{ij} + B_{ij}\, Q_j \quad (12a)$$

$$Q_j = A_{ji} + B_{ji}\, Q_i \quad (12b)$$

Existence of linear linkages between the observed levels of *i*th and *j*th food demand can be evaluated by paired correlation coefficient r_{ij} and r_{ji}, which represents a specific example of paired correlation index. Contrary to the coefficients of cross elasticity, the correlation coefficients hold symmetrical the relations:

$$r_{ij} = r_{ji} \quad (13)$$

From relation (13) it follows, that it is not necessary to specify the direction of analysis of relationship between food commodities demands. Coefficient of paired correlation varies from –1 to +1. The value of this coefficient reflects the character of the interaction between goods. For complementary goods the coefficient positive is and for substitutes the coefficient is negative. Paired correlation coefficient is can be calculated based on paired regression coefficients (B_{ij}) a (B_{ji}):

$$r_{ij} = r_{ji} = \mathrm{sgn}(Bij) \cdot \sqrt{B_{ij} \cdot B_{ji}} \quad (14)$$

However, the magnitude of paired correlation coefficients is possible to determine also without the preceding solution of paired regression problem (Seger at al. 1998).

Except for the correlation coefficient, it is possible to evaluate the character of the relationship between food commodities in consumer demand according to the sign of paired regression coefficients. Regarding relations (13) and (14) it is obvious, that both paired regression coefficients have the same sign. It is possible to use regression coefficients (B_{ij}), (B_{ji}) for description of intensity of relationships between the demanded goods, because:

$$Q'_i = \frac{\delta Q_i}{\delta Q_j} = B_{ij} \quad (15a)$$

$$Q'_j = \frac{\delta Q_j}{\delta Q_i} = B_{ji} \quad (15b)$$

It is possible to carry out dimensionless analysis of intensity of linear complementary and substitution relationships in individual consumer demand, based on paired beta coefficients (β_{ij}), (β_{ji}). For the linear form of paired regression analyses, the value of (β_{ij}) and (β_{ji}) may be determined according regression coefficients (B_{ij}) and (B_{ji}):

$$\beta_{ij} = \frac{s_{Q_j}}{s_{Q_i}} \cdot B_{ij} \quad (16a)$$

$$\beta_{ji} = \frac{s_{Q_i}}{s_{Qj}} \cdot B_{ji} \quad (16b)$$

Simple mathematical transformation relations (16a), (16b) is possible to acquire following equation:

$$\beta_{ij} = \beta_{ji} = r_{ij} = r_{ji} \quad (17)$$

Equation (17) is also possible to use for calculation values of (β_{ij}), (β_{ji}) regression coefficients (Minařík 1995).

However linear formulations in paired regression analysis sometimes may lead to the great distortion of analysed interactions between the demanded food commodities. This holds true especially if asymmetric relationships between goods in directions *ij* and *ji* exist. These problems may appear for example if there exist substitution relationships between inferior and favourite, or between luxury and necessary goods.

Further problem of classical paired regression (linear and non-linear) approach is connected with one-factor simplification of the analysed dependence. This simplification may bring serious distortion of analysed complementary and substitution relationships in consumer demand for food, because demand relationships have typically multifunctional character. For these purposes, it is convenient to extend basic model equations (9a) and (9b) to the following forms:

$$Q_i = f_1(Q_1, Q_2, \ldots, Q_{i-1}, Q_{i+1}, \ldots, Q_j, \ldots, Q_n) \quad (18a)$$

$$Q_j = f_2(Q_1, Q_2, \ldots, Q_i, \ldots, Q_{i-1}, Q_{i+1}, \ldots, Q_n) \quad (18b)$$

For identification of complementary or substitution linkages between *i*th food commodity and *j*th food commodity in this extended approach, it is necessary to use partial correlation indices. Considering multiple linear forms of regression, it is necessary to use partial correlation coefficients. It is possible to solve intensity of complementary and substitution paired relationships in consumer demand for food using adequate partial derivative of function (18a), respectively (18b). Resulting relations may be interpreted in marginal way. For dimensionless analysis of the observed interactions in consumer demand, it is again necessary to transform original database to normalised one, according to relations (11a) and (11b). Based on this transformed database, it is possible to determine dimensionless regression parameters in models (18a) and (18b), which enable essentially any comparison of complementary and substitution relationships in consumer demand for food or between consumers' demands for food.

RESULTS 2

To demonstrate applicability of correlation and paired regression analysis for analysis of complementary and substitution relationships in consumer demand for food, there was again chosen market with bakery products. Analysis of relationships between demands for bread and rolls of bread was based on paired regression linear

Table 4. Results of correlation and paired regression analysis

	Bread e_1	Rolls of bread e_2
Bread e_1		$B_{12} = 0.3546$ $t(B_{12}) = 1.9365$ $r_{12}^2 = 0.2113$ $r_{12} = +0.4597$ $F(r_{12}^2) = 3.7499$ $\alpha(F) = \alpha(t) = 7.33\times10^{-2}$
Rolls of bread e_2	$B_{21} = 0.5957$ $t(B_{21}) = 1.9365$ $r_{21}^2 = 0.2113$ $r_{21} = +0.4597$ $F(r_{21}^2) = 3.7499$ $\alpha(F) = \alpha(t) = 7.33\times10^{-2}$	

models. Because data from the Czech Bureau of Statistics are in form of time series, original forms of paired linear models (12a) and (12b) were transformed to the form:

$$e_1 = B_{12} \cdot e_2 \quad (19a)$$

$$e_2 = B_{21} \cdot e_1 \quad (19b)$$

where:

e_1 purchase of bread by the average Czech household after removal of systematic time component,

e_2 purchase of rolls of bread by the average Czech household after removal of systematic time component.

Obtained results are summarized in Table 4.

From Table 4 it follows, that demand interactions between bread and rolls of bread do not reach too high values. Coefficient of paired determination was only 0.2113; the respective coefficient of paired correlation was +0.4597. Calculated value of the coefficient of paired determination is statistically significant at the level less than 93%. Based on the value of paired correlation coefficient, it is possible to say, that there exists a weak complementarity of bread and rolls of bread or both food commodities may be considered as nearly independent. To complete this form of analysis of complementary and substitution relationships in consumer demand for food commodities, it is necessary to say, that found values of paired regression coefficients (B_{12}, B_{21}) may be interpreted marginally: increasing of the purchase of rolls of bread by the average Czech household by 1 kg/person is accompanied by the growth of purchase of bread by 0.3546 kg/person. From the other side, if the purchase of bread by the average Czech household is increased by 1 kg per person, the purchase of rolls of bread is increased by 0.5957 kg/person (Syrovátka, Brázda 2000).

RESULTS AND DISCUSSION

The article is dealing with analysis of methodological approaches, which may be used for observation of complementary and substitution relationships in consumer demand for food. In the introductory part, attention was paid to the traditional microeconomic approach, which is based on indirect price analysis of demand. On this background, there have been presented both possibilities of dimensional evaluation of analysed interactions between food commodities – marginal indirect price analysis of consumer demand – and dimensionless evaluation of analysed consumption linkages between food commodities – cross elasticity analysis of consumer demand. The paper has pointed to another possible theoretical approach, based on correlation and paired regression analysis. Within this framework, there are presented and analysed statistical characteristics, which may be used for evaluation of complementary and substitution relationships in individual demand for food. Possibilities of using regression parameters for marginal analysis of dependence between observed food commodities are presented. The article also aims at the pos-

sibilities of dimensionless evaluation of intensity of complementary and substitution interactions between food commodities, using construction of paired regression models, based on the normalised database. For linear form of paired regression analysis there is presented calculation of regression beta coefficient for dimensionless analysis of intensity. Presented methodological approaches to analysis of complementary and substitution relationships were applied for demand analysis on markets with bakery products. The application was focused on the analyses of demand relationships between bread and rolls of bread. At the level of indirect price analysis it was found, that in direction bread – rolls of bread then exists weak substitution between observed goods (average coefficient of cross price elasticity equals 0.14). Correlation and paired regression analysis between the given food commodities revealed weak complementary relationship (coefficient of paired correlation equals 0.4597). However, these results cannot be viewed as contradictory, because both commodities may be interpreted as independent in consumption. Moreover, there must be considered simplification of used regression models (8) and (18a), (18b), especially as for the number of included explanatory variables. For practical purposes, it is for analysis of demand relationships in food markets convenient to apply both methodological approaches together.

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Arrived on 25th May 2002

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