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Pannon University of Agriculture, Faculty of Animal Science, Kaposvár

Analysis of the value of information

L. Cselők
Csokonai Vitéz Mihály Teachers' Training College, Kaposvár, H-7400 Bajcsy-Zs. u.10.
Pannon University of Agriculture, Faculty of Animal Science, Kaposvár, H-7400 Guba S.u.40.

ABSTRACT

Information, which means the interpretation of different data by people, represents different values for different users. The determination of the value of information is subjective for two reasons. It is difficult to determine the volume of profit gained by having the information, while the value of information is also influenced by its authenticity. This article describes a method for objective decision-making, using the theory of probability to determine the value of information. The value of information is determined by the analysis of the expected value of the income. Changes in the expected value of the income are presented in the form of four cases, in which the degree of available information is varied. Information can be absolutely reliable, unreliable, absolutely incorrect or missing. The value of information is then determined by the increase in the expected value of the income.
(Keywords: information, expected value, income)

ÖSSZEFOGLALÁS

Az információ értékének elemzése

Cselők L.
Csokonai Vitéz Mihály Tanítóképző Főiskola, Kaposvár, 7400 Bajcsy-Zs. u. 10.
Pannon Agrártudományi Egyetem, Állattenyésztési Kar, Kaposvár, 7400 Guba S. u. 40.

Egy információ, amely a különféle típusú és formájú adatok emberek által történő értelmezését jelenti, a különböző felhasználók számára valószínűleg más értéket képvisel. Az információ értékének meghatározása szubjektívnek tűnik, hiszen nehéz meghatározni annak a nyereségnek a mértékét, amelyre az információ ismeretében szert tehetünk, ráadásul az információ megbízhatósága is befolyásolja annak értékét. A cikk az objektív döntések meghozatalára olyan módszert mutat be, amely a valószínűségszámítás felhasználásával segít abban, hogy meghatározzuk egy információ értékét. Ez a várható bevételek elemzésével történik. Bemutatásra kerül ezek alakulása információ hiányában, tökéletesen helytálló információ birtokában, nem megbízható információ esetén és tökéletesen helytelen információ vásárlásakor. Az információ értékét a bevételel várható értékének növekedésével adjuk meg.
(Kulcsszavak: információ, várható érték, bevétel)

INTRODUCTION

The evaluation of information may also depend on the investigator carrying out the analysis. For example, if prices on the stock market are decreasing, then this information means nothing for someone not involved in the stock market. However, if you are going to buy stocks, then this information is valuable for you, because you can obtain stocks at lower prices or you can postpone your purchase in the hope that the price decrease will continue. If you want to sell your stocks, then this information is also important for you, because you probably do not want to sell your stocks at the moment, because the low prices are unfavourable for you or you may be afraid of a further decrease in prices and want to make a transaction as soon as possible.

A question arises: what is the value of information, that is, the maximum cost an individual is willing to pay for it? It is obvious you may pay for information if its cost is less than the possible amount of the increase in your income. However, it is likely that you do not know exactly by how much your income will increase of before acquiring the information. So you can only make calculations of the expected value of your income.

Buying information does not necessarily mean the maximizing of the income, and even purchase appears as an expense in these case. It is obvious that correct information is more valuable than information derived from suspicious sources which may result in the buyer making incorrect decisions that ultimately lead to an unprofitable situation. Consequently, it is important to know the reliability of the source of information.

The method shown in this article demonstrates the numerical expression of the value of information.

MATERIALS AND METHODS

The method for the determination of the value of information will be demonstrated by means of an example given with parameters. The problem is mentioned in the work of *Kovács* (1994). Now we shall discuss the whole elaboration of the generalization of the problem, graduating the information in four different categories using the theory of probability (see *Neumann, Morgenstern* (1944)):

- lack of information
- reliable information sources
- unreliable information sources
- absolutely incorrect information sources

Decision made in the lack of information

Let us assume you want to sell pigs. One of the buyers (v_1), offers b_1 dollars for the animals. Another buyer (v_2) is also interested in buying the animals. But his agent knows only that his client (let us take this case as a_1) would pay more than b_1 with the probability $p(a_1)$. This amount can be designated as b_{21}. However, it is also possible (let us take this case as a_2) that v_2 will pay b_{22}, less than b_1, with the probability $p(a_2)$. So the following inequality is true: $b_{22}<b_1<b_{21}$. The following equality is true because of the theorem of the probability:

$$p(a_1)+p(a_2)=1 \qquad (1)$$

A question arises: who should you sell the animals to? To the certain buyer v_1? Or should you take the chance of being paid more money for the animals from buyer v_2, but risk being paid even less than b_1? Is it worth taking the risk? Would you be willing to pay for the information, and how much would you be prepared to pay if you did?

Lack of information means that you do not know if case a_1 or a_2 will occur. Let us designate as e_1 the event that buyer v_1 buys the animals and let e_2 be the event that buyer v_2 buys the animals. We shall modify the sign b_1 to have better review. Let us mark b_1 with b_{11} in the case of event e_1 and b_{12} in the case of event e_2.

$$b_1=b_{11}=b_{12} \tag{2}$$

Taking all this into consideration our condition is:

$$b_{22}<b_{11}=b_{12}<b_{21} \tag{3}$$

The following table shows the possible incomes depending on the different cases and events:

Table 1

The possible incomes depending on cases and events

	case a_1 (1)	case a_2 (2)
event e_1 (3)	b_{11} (unfavourable situation) (6)	b_{12} (favourable situation)
event e_2 (4)	b_{21} (favourable situation) (7)	b_{22} (unfavourable situation)
the probability of case a_i (5)	$p(a_1)$	$p(a_2)$

1. táblázat: A lehetséges bevételek az esetek és események függvényében

a_1 eset(1), a_2 eset(2), e_1 esemény(3), e_2 esemény(4), Az eset valószínűsége(5), Kedvezőtlen szituáció(6), Kedvező szitáció(7)

b_{ij} signifies the possible incomes depending on the cases and the events.
The expected income in the case of event e_1 is:

$$m(b|e_1)=b_{11}p(a_1)+b_{12}p(a_2)=b_{11}=b_{12}=b_1 \tag{4}$$

and in the case of event e_2 it is:

$$m(b|e_2)=b_{21}p(a_1)+b_{22}p(a_2) \tag{5}$$

using the following formula:

$$m(b|e_i)=\sum_{j=1}^{2} b_{ij}\,p(a_j) \tag{6}$$

The expected value of the income cannot be determined if you make your decision in a subjective way. If you are enterprising and take the risk of loss, hoping to obtain a higher profit, you will sell the animals to buyer $v_{2,}$ who will probably pay more than buyer v_1, but this may prove not to be the case. However, if you do not want to take the risk and give up the possibility of deriving more profit, being afraid of suffering loss, you will offer your animals to the certain buyer v_1. If you want to make your decision in an objective way, then you will select the buyer whose involvement results in greater expected value of income after comparison of the expected values of income in the case of different events.

Table 2

Making decisions

	$m(b\|e_1)>m(b\|e_2)$	$m(b\|e_1)<m(b\|e_2)$	$m(b\|e_1)=m(b\|e_2)$
decision (1)	buyer v_1 is selected (2)	buyer v_2 is selected (3)	any buyer can be selected (4)

2. táblázat: Döntés hozatal

Döntés(1), v1 vevő kiválasztása(2), v2 vevő kiválasztása(3), Bármelyik vevőt ki lehet választani(4)

You can make sure of the correctness of your decision only after finding out which event has taken place. But unfortunately you do not know this fact at the moment of making your decision. The table of decisions shows only if it is worth taking the risk, if the probability is greater for the selection of this decision to result in higher income.
The expected income is the maximum of the conditional probabilities of different events:

$$m(b)=\max_i(b|e_i) \qquad (7)$$

The case of reliable information source
A question arises: what is it worth paying for information in order to know what v_2 will pay for the animals? If you knew he would pay the higher price, you would certainly sell the animals to him, but in the other case to v_1. The expected income in the case of reliable information is the following, using condition 3:

$$m(b_m)=b_m=\sum_{j=1}^{2}\max_i(b_{ij})p(a_j)=$$

$$=\max(b_{11},b_{21})p(a_1)+\max(b_{12},b_{22})p(a_2)=$$

$$=b_{21}p(a_1)+b_{12}p(a_2) \qquad (8)$$

where b_m is the income in the case of a reliable information source. The real income and its expected value are the same in this case, because you know the real income at the time of making your decision. The increase in the income is:

$$\Delta b=m(b_m)-m(b) \qquad (9)$$

The maximum value you would pay for the information is covered by the increase in expected income.
If the price of information is higher than the expected value of the increase in income, then the income will probably increase less than the price of the information, so a loss will probably be incurred in the purchase of the information. If the price equals Δb, it will probably make no difference what you do. If the price is less than the expected value of the increase in income, the information will be worth buying, although it should be emphasised that this fact only increases the probability of deriving more profit, but is not necessarily certain.

Table 3

Evalution of the purchase of information

the price of information (1)	>Δb	=Δb	<Δb
evalution of the decision (2)	it seems not to be profitable (3)	indifferent (4)	it seems to be profitable (5)

3. táblázat: Az információ vásárlás értékelése

Az információ ára(1), A döntés minősítése(2), Nem tűnik nyereségesnek(3), Közömbös(4), Nyereségesnek tűnik(5)

The case of unreliable information

No information source can be considered totally reliable in reality. Let x_1 be a proposal that the information source predicts the realization of case a_1. Let x_2 be a proposal when case a_2 is to be realized. Let us take it that the reliability of the information source is known. Let the probability of a correct proposal, which means that the information source predicts x_1 in the case of e_1 and x_2 in the case of e_2, be $p(x_1|a_1)$ and $p(x_2|a_2)$. Let the probability of bad proposals be $p(x_2|a_1)$ and $p(x_1|a_2)$. The following equations are true under these conditions:

$$p(x_1|a_1)=p(x_2|a_2) \tag{10}$$

$$p(x_2|a_1)=p(x_1|a_2) \tag{11}$$

$$p(x_1|a_1)+p(x_2|a_1)=1 \tag{12}$$

$$p(x_1|a_2)+p(x_2|a_2)=1 \tag{13}$$

The evalution of the proposals is shown in the table below:

Table 4

The evalution of the proposals

	case a_1 (1)	case a_2
proposal x_1 (2)	correct (3)	incorrect
proposal x_2	incorrect (4)	correct

4. táblázat: A javaslatok értékelése

Eset(1), Javaslat(2), Helyes(3), Helytelen(4)

The probability of making correct and incorrect proposals, depending on the probability of the cases and the probability of the proposals, is shown in the following table:

Table 5

The probability of making correct and incorrect proposals

	case a_1 (1)	case a_2
proposal x_1 (2)	$p(x_1|a_1)p(a_1)$	$p(x_1|a_2)p(a_2)$
proposal x_2	$p(x_2|a_1)p(a_1)$	$p(x_2|a_2)p(a_2)$

5. táblázat: A helyes és helytelen javaslatok bekövetkezésének valószínűségei

Eset(1), Javaslat(2)

The following connection is true on the grounds of the theorem of full probability:

$$p(x_1|a_1)p(a_1)+p(x_1|a_2)p(a_2)+p(x_2|a_1)p(a_1)+p(x_2|a_2)p(a_2)=1 \quad (14)$$

The real incomes, depending on the cases and the proposals, are shown in the table below, using condition 3:

Table 6

The building of incomes depending on the cases and the proposals

	case a_1 (1)	case a_2
proposal x_1 (2)	$\max(b_{21},b_{11})=b_{21}$	$\min(b_{22},b_{12})=b_{22}$
proposal x_2	$\min(b_{21},b_{11})=b_{11}$	$\max(b_{22},b_{12})=b_{12}$

6. táblázat: A bevételek alakulása az esetek és javaslatok függvényében

Eset(1), Javaslat(2)

The expected income is in this case:

$$m(b_{nm})=\max(b_{21},b_{11})p(x_1|a_1)p(a_1)+\min(b_{21},b_{11})p(x_2|a_1)p(a_1)+$$
$$+\min(b_{22},b_{12})p(x_1|a_2)p(a_2)+\max(b_{22},b_{12})p(x_2|a_2)p(a_2)=$$
$$=b_{21}p(x_1|a_1)p(a_1)+b_{11}p(x_2|a_1)p(a_1)+b_{22}p(x_1|a_2)p(a_2)+$$
$$+b_{12}p(x_2|a_2)p(a_2) \quad (15)$$

where b_{nm} is the income in the case of using an unreliable information source.

The case of absolutely incorrect information

Absolutely incorrect information is a special case of an unreliable information source. The information source serves the opposite purpose of correct information for you. The following conditions are true in this case:

$$p(x_1|a_1)=p(x_2|a_2)=0 \text{ és} \quad (16)$$
$$p(x_1|a_2)=p(x_2|a_1)=1 \quad (17)$$

The expected value of the income (b_t) using these values:

$$m(b_t)=b_{21}p(x_1|a_1)p(a_1)$$

$+b_{11}p(x_2|a_1)p(a_1)+b_{22}p(x_1|a_2)p(a_2)$

$$+b_{12}p(x_2|a_2)p(a_2)=b_{11}p(a_1)+b_{22}p(a_2) \quad (18)$$

Comparing the expected values

The expected incomes in the case of lack of information, and in the case of unreliable, absolutely incorrect and correct information, are shown in the table below:

Table 7

The expected values of income

lack of information $m(b)$ (1)	unreliable information $m(b_{nm})$ (2)	absolutely incorrect information $m(b_t)$ (3)	correct information $m(b_m)$ (4)
$\max(b_{11},b_{21}p(a_1)+b_{22}p(a_2))$	$b_{21}p(x_1|a_1)p(a_1)+b_{11}p(x_2|a_1)p(a_1)+b_{22}p(x_1|a_2)p(a_2)+b_{12}p(x_2|a_2)p(a_2)$	$b_{11}p(a_1)+b_{22}p(a_2)$	$b_{21}p(a_1)+b_{12}p(a_2)$

7. táblázat: A bevételek várható értékei

Információ hiányában(1), Megbízhatatlan információ(2), Tökéletesen helytelen információ(3), Megbízható információ(4)

The following comparisons will be performed in the following examinations:

- the comparison of $m(b)$ and $m(b_m)$
- the comparison $m(b)$ and $m(b_{nm})$
- the comparison $m(b)$ and $m(b_t)$
- the comparison of $m(b_{nm})$ and $m(b_m)$

The comparison of $m(b)$ and $m(b_m)$

$m(b)$ can have two different values (see 7). Let us make the comparison in both cases. The assumption $m(b)<m(b_m)$ will be proved in the following.

Suppose $\max(b_{11}, b_{21}p(a_1)+b_{22}p(a_2))=b_{11}$ is true (see 7), then the following inequality should be proved:

$m(b)<m(b_m)$

$b_{11}<b_{21}p(a_1)+b_{12}p(a_2)$; using (2)

$b_{11}<b_{21}p(a_1)+b_{11}p(a_2)$; $-b_{11}p(a_2)$

$b_{11}(1-p(a_2))<b_{21}p(a_1)$; using (1)

$b_{11}p(a_1)<b_{21}p(a_1)$; $/p(a_1)$

$b_{11}<b_{21}$

This relation was an assumption at the beginning (see 3), so if it is true, then the original comparison should also be true.

Supposing the other opportunity:

$\max(b_{11}, b_{21}p(a_1)+b_{22}p(a_2))=b_{21}p(a_1)+b_{22}p(a_2)$ (see 7), then if $m(b)<m(b_m)$ is true:

$$b_{21}p(a_1)+b_{22}p(a_2)<b_{21}p(a_1)+b_{12}p(a_2) \qquad ; -b_{21}p(a_1)$$

$$b_{22}p(a_2)<b_{12}p(a_2) \qquad ; /p(a_2)$$

$$b_{22}<b_{12}$$

Again, this is an original assumption (see 3), so the inequality has been proved to be correct.
It can be stated that the expected value of the income in the case of reliable information is greater than that in the case of lack of information:

$$m(b)<m(b_m) \qquad (19)$$

The maximum price worth paying for information is the difference between the two expected incomes, that is $m(b_m)-m(b)$.

The comparison of $m(b)$ and $m(b_{nm})$

It can be stated that the expected value of the income using unreliable information can be lower or higher than that if no information is used; these values may also be equal. We shall now prove that the relation between $m(b)$ and $m(b_{nm})$ is not unambiguous.

Let us take the proof in two parts, depending on the value of $m(b)$:
Suppose that $m(b)=\max(b_{11}, b_{21}p(a_1)+b_{22}p(a_2))=b_{11}$ is true (see (7)):

$$m(b) \; ? \; m(b_{nm}) \qquad ; \text{see (8) and (15)}$$

$$b_{11} \; ? \; b_{21}p(x_1|a_1)p(a_1)+b_{11}p(x_2|a_1)p(a_1)+$$

$$b_{22}p(x_1|a_2)p(a_2)+b_{12}p(x_2|a_2)p(a_2)$$

where "?" means an unknown sign in relation. In increasing b_{21} it can be seen that the right part of the inequality will be greater.
Let b_{21} approach to the value of b_{11} from above and let b_{22} approach the value of b_{11} from below with some precision. That means the following conditions:

$$b_{21}\sim b_{11}$$

$$\text{and } b_{22}\sim b_{11}$$

The right side of the comparison can be approached in the following way using condition 14:

$$b_{21}p(x_1|a_1)p(a_1)+b_{11}(x_2|a_1)p(a_1)+b_{22}p(x_1|a_2)p(a_2)+b_{12}p(x_2|a_2)p(a_2)\sim$$

$$\sim b_{11}p(x_1|a_1)p(a_1)+b_{11}p(x_2|a_1)p(a_1)+b_{11}p(x_1|a_2)p(a_2)+b_{11}p(x_2|a_2)p(a_2)\sim$$

$$\sim b_{11}(p(x_1|a_1)p(a_1)+p(x_2|a_1)p(a_1)+p(x_1|a_2)p(a_2)+p(x_2|a_2)p(a_2))\sim b_{11}$$

The right side of the comparison can be equal to the left one. If b_{12} is decreased the right side will obviously be less than the left.
It has been proved that the relation between $m(b)$ and $m(b_{nm})$ can be of any kind.
Suppose that $\max(b_{11}, b_{21}p(a_1)+b_{22}p(a_2))=b_{21}p(a_1)+b_{22}p(a_2)$ is true (see (7)):

$$m(b) \; ? \; m(b_{nm})$$

$$b_{21}p(a_1)+b_{22}p(a_2) \; ? \; b_{21}p(x_1|a_1)p(a_1)+b_{11}p(x_2|a_1)p(a_1)+$$

$$+b_{22}p(x_1|a_2)p(a_2)+b_{12}p(x_2|a_2)x\ p(a_2)$$

$$b_{21}p(a_1)(1-p(x_1|a_1))+b_{22}p(a_2)(1-p(x_1|a_2)) \; ? \; b_{11}p(x_2|a_1)p(a_1)+b_{12}p(x_2|a_2)p(a_2)$$

$$b_{21}p(a_1)p(x_2|a_1))+b_{22}p(a_2)p(x_1|a_1) \; ? \; b_{11}p(x_2|a_1)p(a_1)+b_{12}p(x_2|a_2)(a_2)$$

In increasing b_{21} the left side can be greater than the right. b_{21} can approach b_{11} from above with some precision and b_{22} can approach b_{11} from below with some precision. In this case the result of the comparison is an equality. Decreasing b_{22} after that makes the left side less than the right.
The relation between m(b) and $m(b_{nm})$ has proved not to be unambiguous. (20)

The comparison of m(b) and $m(b_t)$

It can be stated that the expected value of the income in the case of absolutely incorrect information is less than that in the case of not having information.
Suppose that $\max(b_{11}, b_{21}p(a_1)+b_{22}p(a_2))=b_{11}$ is true; it will be proved that:

$$m(b)>m(b_t) \quad \text{; using (18) and (7)}$$

$$b_{11}>b_{11}p(a_1)+b_{22}p(a_2)$$

In increasing b_{22} to the value of b_{11} the right side of the comparison could be equal to the left using condition 1:

$$b_{11}=b_{11}p(a_1)+b_{11}p(a_2) \quad \text{; using (1)}$$

$$b_{11}=b_{11}$$

If condition 3 is used the comparison is true in the form of the supposed inequality.
Supposing that $\max(b_{11}, b_{21}p(a_1)+b_{22}p(a_2))=b_{21}p(a_1)+b_{22}p(a_2)$ is true, the next inequality will be proved in the following part:

$$m(b)>m(b_t)$$

$$b_{21}p(a_1)+b_{22}p(a_2)>b_{21}p(x_1|a_1)p(a_1)+b_{11}p(x_2|a_1)p(a_1)+$$

$$b_{22}p(x_1|a_2)p(a_2)+b_{12}p(x_2|a_2)p(a_2)$$

$$b_{21}p(a_1)+b_{22}p(a_2) >b_{11}p(a_1)+b_{22}p(a_2)$$

$$b_{21}p(a_1)>b_{11}p(a_1)$$

$$b_{21}>b_{11}$$

This relation is an original assumption (see 3), so the next inequality is true:

$$m(b)>m(b_t) \quad (21)$$

The comparison of $m(b_{nm})$ and $m(b_m)$

It can be asserted that the expected value of the income in the case of reliable information is greater than that in the case unreliable information; that is:

$$m(b_{nm})<m(b_m)$$

$$b_{21}p(x_1|a_1)p(a_1)+b_{11}p(x_2|a_1)p(a_1)+$$

$$+b_{22}p(x_1|a_2)p(a_2)+b_{12}p(x_2|a_2)p(a_2)<b_{21}p(a_1)+b_{12}p(a_2)$$

Diminish both sides with $b_{21}p(x_1|a_1)p(a_1)$

$$b_{11}p(x_2|a_1)p(a_1)+$$

$$+b_{22}p(x_1|a_2)p(a_2)+b_{12}p(x_2|a_2)p(a_2)<b_{21}p(a_1)(1-p(x_1|a_1))+b_{12}p(a_2)$$

Using condition 12:

$$b_{11}p(x_2|a_1)p(a_1)+$$

$$+b_{22}p(x_1|a_2)p(a_2)+b_{12}p(x_2|a_2)p(a_2)<b_{21}p(a_1)p(x_2|a_1)+b_{12}p(a_2)$$

Diminish both sides with $b_{12}p(x_2|a_2)p(a_2)$.

$$b_{11}p(x_2|a_1)p(a_1)+b_{22}p(x_1|a_2)p(a_2)<b_{21}p(a_1)p(x_2|a_1)+b_{12}p(a_2)x$$

$$(1-p(x_2|a_2))$$

Using condition 13:

$$b_{11}p(x_{2|}a_1)p(a_1)+b_{22}p(x_{1|}a_2)p(a_2)<b_{21}p(a_1)p(x_{2|}a_1)+b_{12}p(a_2)p(x_{1|}a_2)$$

Compare the sides in two parts.

$$b_{11}p(x_{2|}a_1)p(a_1)<b_{21}p(a_1)p(x_{2|}a_1)$$

$$b_{22}p(x_{1|}a_2)p(a_2)<b_{12}p(a_2)p(x_{1|}a_2)$$

After reduction:

$$b_{11}<b_{21}$$

$$b_{22}<b_{12}$$

These two inequalities correspond to the original assumption (see 3), so going backward the supposed inequality has been proved to be true. It can be stated that

$$m(b_{nm})<m(b_m) \quad (22)$$

is true, which means that the expected value of the income in the case of reliable information is greater than that in the case of unreliable information.

RESULTS AND DISCUSSION

- The expected value of the income in the case of reliable information is always greater than that in the case of not having information (see 19); that is:

  $$m(b)<m(b_m).$$

- The expected value of the income in the case of unreliable information can be greater or less than that in the case of not having information; these values may also be equal (see 20).
- The expected value of the income in the case of absolutely incorrect information is always less than that in the case of not having information (see 21); that is:

  $$m(b_t)<m(b).$$

- The expected value of the income in the case of unreliable information is always less than that in the case of reliable information (see 22); that is:

  $$m(b_{nm})<m(b_m).$$

- The value of information is determined by the difference between the expected value of the income in the case of having information and that in the case of not having information.

CONCLUSION

The expected value of the income is maximum when the information used comes from a reliable source. The expected value of the income in the case of unreliable information is always less than that in the case of reliable information. Depending on the reliability of the information, the expected value of the income may be lower or higher than that where no information is used; these values may also be equal. The higher the reliability of the information, the more closely the expected value of the income in the case of unreliable information approaches that in the case of reliable information, and the more it is possible that this value is greater than that in the case of no information being used. The lower the reliability of the information source, the more it is possible that this value is less than that in the case of no information being used. In an extreme case, when reliability is 0 per cent, the information source is absolutely incorrect and the expected value of the income is certainly less than that in the case of no information being used. Of course, if you knew that the information source was absolutely incorrect then you would have a correct information source by the negation of all the data.

Information is worth buying from the aspect of the information buyer if the price of the information is less than the value of the information. However, this purchase does not guarantee higher profit; it only means that the expected value of the income will probably be greater.

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Corresponding author (*levelezési cím*):

László Cselők
Csokonai Vitéz Mihály Teachers' Training College
H-7401 Kaposvár, P.O.Box 30.
Csokonai Vitéz Mihály Tanítóképző Főiskola
7401 Kaposvár, Pf. 30.
Tel.: 36-82-319-011, Fax: 36-82-312-175
e-mail: cselok@csoki.csvmtkf.hu