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ASSESSMENT OF DAMAGE FROM REDUCTION OF EXPECTED LIFESPAN DUE TO CANCER

This paper presents the theoretical and methodological approaches to the assessment of damage from premature mortality and reduction of life expectancy due to various reasons. The concepts measuring the price of a human life are analyzed: the evaluation from the standpoint of the theory of human capital; indirect estimation taking into account non-monetary social costs; evaluation of individuals' willingness to pay for the elimination of the risk of death; estimation based on the determination of insurance premiums and compensations under court decision; evaluation of the social investments, aimed to reduce the risk of premature mortality of the individual. The following indexes were calculated for all subordinate entities of the Russian Federation: reduction of life expectancy, lost years of potential life in the working age, and gross regional product lost due to the reduction of years of potential life in the working-age population as a result of cancer.

Keywords: economic evaluation of a human life, damage from premature mortality, life expectancy, lost years of potential life

A high death rate is one of the most difficult medical and demographic problems of the social development in modern Russia. One of the aspects of this problem is a high level of premature mortality in the working age. To improve the effectiveness of the risk management for the life of the population instruments of the economic analysis of the premature mortality consequences are necessary. That's why many attempts are taken to estimate the value of a human life or the damage from the early death due to various reasons.

General probability-theoretical basis for the assessment of the death risk

In accordance with established terminology, death risk from a negative factor is a death probability as a result of exposure to such factors. An age-specific death rate $\mu(a)$ is a basic health and demographic index used for assessing the death risk. It is defined as the probability density of death at the age of a, on condition of surviving up to this age. The classical definition of theoretical probability is given as follows:

$$\mu(a) = \lim_{\Delta a \to 0} \Pr(x \mid y) / \Delta a.$$

x — a man died in the interval $(a, a + \Delta a)$, y — a man lived up to age a, Pr $(x \mid y)$ — is a probability of event x under condition y.

Survivorship function $P(a)$ is defined as the unconditional probability of leaving up from birth to the age of a. If N_0 — is a number of people who were born, and $N(a)$ — is the same number of people surviving to age a, then

$$\mu(a) = -\frac{1}{N(a)} \frac{dN(a)}{da}; \qquad (1)$$

$$P(a) = N(a) \big/ N_0 . \qquad (2)$$

These equations show that

$$P(a) = \exp\left(-\int_0^a \mu(a) da \right). \qquad (3)$$

Let us set $P(e, a)$ as a conditional probability for the person at the age e to survive till the age a

$$P(e,a) = P(a) / P(e). \qquad (4)$$

Full (from birth) life expectancy $\Theta(0)$ can be calculated as

$$\Theta(0) = \int_0^\infty P(a) da. \qquad (5)$$

Life expectancy for a man at the age of e is calculated similarly:

$$\Theta(e) = \int_e^\infty P(e,a) da. \qquad (6)$$

The lifelong death risk $R^i(e)$ for a man at the age of e is defined as a probability to die from the i source of risk throughout the expected lifetime

$$R^i(e) = \int_e^\infty P(e,a) \mu^i(a) da. \qquad (7)$$

The condition of normalization is feasible

$$\sum_i R^i(e) = 1. \qquad (8)$$

The intensity of the death risk from the i source of risk $r^i(e, a)$ for a man at the age of e

$$r^i(e,a) = P(e,a) \mu^i(a). \qquad (9)$$

In practice, the mortality rates are usually calculated separately for each age group. In this case, the formulas (1–9) are converted to the discrete form.

If μ_j is a probability to die during the *j* year of life, on condition to survive up to this age, i. e. μ_1 — is a probability of dying from the date of birth to exact age of 1 year, and μ_{70} — is probability of dying from the exact age of 69 till the exact age 70.

Then the probability of survival from birth to the moment of reaching the exact age a $P_{0,a} = P_a$ equals

$$P_{0,a} = \prod_{j=1}^{j=a}(1-\mu_j). \tag{10}$$

$P_{e,a}$ is a probability of surviving till the age *a* for a man, who reached the age of *e*, is calculated similarly to the formula (4):

$$P_{e,a} = P_a / P_e. \tag{11}$$

Full (from birth) life expectancy equals to Θ_0:

$$\Theta_0 = \sum_{k=1}^{k=\infty}\prod_{j=1}^{j=k}(1-\mu_j). \tag{12}$$

For a man, who reached the age of *e*, life expectancy Θ_e is calculated as

$$\Theta_e = \sum_{k=e+1}^{k=\infty}\prod_{j=e+1}^{j=k}(1-\mu_j). \tag{13}$$

Full (from birth) the lifetime death risk from the *i* source of risk R_0^i equals

$$R_0^i = \sum_{k=1}^{k=\infty}\mu_k^i\prod_{j=0}^{j=k-1}(1-\mu_j), \tag{14}$$

Where $\mu_0 = 0$.

R_e^i — the lifetime death risk from the *i* source of risk for a man, who reached the age of *e*, equals

$$R_e^i = \sum_{k=e+1}^{k=\infty}\mu_k^i\prod_{j=e}^{j=k-1}(1-\mu_j). \tag{15}$$

If a man survived till the age of *e*, the probability of dying from all causes during the age interval from *e* to *a* equals $R_{e,a}$

$$R_{e,a} = \sum_{k=e+1}^{k=a}\mu_k\prod_{j=e}^{j=k-1}(1-\mu_j). \tag{16}$$

$R_{e,a}^i$ the death risk from the *i* source of the risk during the arbitrary age interval from *e* to *a*, on a condition that a man, survived till the age of *e*, is calculated similarly

$$R_{e,a}^i = \sum_{k=e+1}^{k=a}\mu_k^i\prod_{j=e}^{j=k-1}(1-\mu_j). \tag{17}$$

To assess the impact of specific causes of death on life expectancy the index of the increase in life expectancy under eliminating the *i* cause of death is used $\Delta\Theta_0^{-i}$:

$$\Delta\Theta_0^{-i} = \Theta_0^{-i} - \Theta_0 = \sum_{k=1}^{k=\infty}\prod_{j=1}^{j=k}(1-\mu_j^{-i}) - \sum_{k=1}^{k=\infty}\prod_{j=1}^{j=k}(1-\mu_j), \tag{18}$$

Where Θ_0^{-i} is a full (from birth) life expectancy under eliminating the *i* cause of death, μ_j^{-i} — the probability of dying during the *j* year of life, on condition of survival up to this age under eliminating the *i* cause of death.

While calculating assessments of the impact of the different death causes on life expectancy for the population of the subordinate entities of the Russian Federation a problem arises. The scientists have to face the lack of published statistical reports on age-specific mortality in the regions. In this case, as a first approximation we can assume that

$$\mu_j^{Reg} = \frac{M^{Reg}}{M^{RF}}\cdot\mu_j^{RF}, \tag{19}$$

Where M^{Reg} and M^{RF} are standardized death rates for the population of the region under examination and for the Russian Federation. Similarly, a quantity μ_j^{-i}. can be estimated. These standardized indexes are regularly published in the cancer and demographic statistics digests.

To characterize the mortality at the population level, the index «lost years of potential life» — *PYLL* (potential years of life lost) is used. It is a number of years, which were not lived by a population up to the normative age, usually 70. It is assumed that each individual can live for 70 years. It is called a «productive» life and therefore death at the age of a results in a loss of 70 — *a*, if *a* < 70. It is assumed that all deaths occur in the middle of the age interval (including usage of 5-year intervals). A so-called unlived years are calculated for each age interval X_j:

$$X_j = T - a_j, \tag{20}$$

Where *T* — is an upper age limit (usually 70 years), a_j — is a middle of the proper age interval. Years of potential life lost are calculated as the sum of productions of the total number of dead in each age group for the years they unlived

$$PYLL = \sum_j D_j X_j, \tag{21}$$

Where D_j — is a number of people who died during the year in the age group *j*. Similarly, the years of potential life lost because of the *i* cause of death can be calculated — $PYLL_i$

$$PYLL^i = \sum_j D_j^i X_j, \tag{22}$$

Where D_j^i — is a number of people who died in the age group *j* from the *i* cause during the year. According to this analysis, «weight» of each person, who died from a specific cause, is the number of years unlived by them to a specified age limit, so the «weight» of an older man is smaller than the «weight» of a newborn. Causes of death, which lead to the biggest losses in a man-year, are considered to be a priority. The absolute number of the potential life years lost gives the opportunity to measure the scale of the problems associated with premature mortality of the population.

Similarly, an index of «years of potential life lost in the working-age» $PYLL_{Work}$ can be introduced. In this case the age limit T is assumed to be 60 years for men and 55 — for women. For individuals who died at the age of 16, $PYLL_{Work}$ is calculated according to the formulas similar to (20)–(22). For individuals who died before the age of 16, $PYLL_{Work}$ is assumed to be 44 years for men and 39 years for women.

Table 1

The expected reduction in life expectancy at birth as a result of malignant neoplasms, years

Subject of Federation	Sex		Subject of Federation	Sex	
	male	female		male	fem.
Belgorod region	2.10	1.88	Republic of Bashkortostan	1.48	1.57
Bryansk region	2.09	1.61	Republic of Mari El	1.75	1.52
Vladimir region	1.99	1.92	Republic of Mordovia	1.99	1.74
Voronezh region	1.87	1.70	Republic of Tatarstan	1.87	1.77
Ivanovo region	1.82	1.83	Udmurt Republic	1.81	1.61
Kaluga region	1.99	1.93	Chuvash Republic	1.62	1.47
Kostroma region	1.75	1.79	Perm Krai	1.77	1.79
Kursk region	2.20	1.78	Kirov region	1.79	1.68
Lipetsk region	1.79	1.51	Nizhny Novgorod region	1.78	1.84
Moscow region	2.09	2.26	Orenburg region	2.10	1.97
Oryol region	2.15	1.79	Penza region	1.97	1.71
Ryazan region	2.08	1.90	Samara region	1.82	1.91
Smolensk region	1.64	1.71	Saratov region	1.78	1.76
Tambov region	2.19	1.78	Ulyanovsk region	2.03	1.81
Tver region	1.74	1.84	Kurgan region	2.20	2.01
Tula region	2.02	1.97	Sverdlovsk region	2.20	2.03
Yaroslavl region	2.09	1.93	The Tyumen region (without Autonomous Area)	1.60	1.69
Moscow city	2.22	2.66	Khanty-Mansi Autonomous Area	2.15	2.11
Republic of Karelia	1.95	1.98	Yamalo-Nenets Autonomous Area	2.27	2.09
Komi Republic	1.91	1.74	Chelyabinsk region	2.18	2.16
Arkhangelsk region	1.98	1.86	Altai Republic	1.78	1.82
Vologda region	1.80	1.68	Republic of Buryatia	1.76	1.90
Kaliningrad region	1.79	1.98	Republic of Tyva	1.31	1.65
Leningrad region	2.01	1.94	Republic of Khakassia	1.90	2.00
Murmansk region	1.90	1.87	Altai Territory	2.19	1.99
Novgorod region	1.60	1.63	Zabaykalsky Krai	1.56	1.90
Pskov region	1.65	1.69	Krasnoyarsk Krai	2.21	2.11
St. Petersburg	2.41	2.81	Irkutsk region	1.80	1.94
Republic of Adygea	2.11	2.10	Kemerovo region	1.82	1.96
Republic of Kalmykia	1.76	1.82	Novosibirsk region	2.30	2.06
Krasnodar Krai	2.13	2.11	Omsk region	2.04	2.01
Astrakhan region	2.00	1.96	Tomsk region	2.39	2.26
Volgograd region	2.05	2.01	Republic of Sakha (Yakutia)	1.52	1.84
Rostov region	1.93	2.04	Kamchatka Krai	1.77	1.92
Republic of Dagestan	1.76	1.63	Primorsky Krai	1.89	2.08
Republic of Ingushetia	1.49	1.40	Khabarovsk Krai	1.83	1.84
Kabardino-Balkar Republic	1.88	1.87	Amur region	1.48	1.60
Karachay-Cherkess Republic	1.97	1.93	Magadan region	1.74	2.08
Republic Northern Ossetia — Alania	1.99	1.84	Sakhalin region	2.01	2.04
Chechen Republic	1.90	1.77	Jewish Autonomous Province	1.61	1.73
Stavropol Krai	1.93	1.89	Chukot Autonomous Area	1.12	1.94

Table 2

The years of potential life lost in the working age due to malignant neoplasms, years

Subject of Federation	Sex		Sex	Sex	
	male	female		male	female
Belgorod region	4451	2409	Republic of Bashkortostan	9735	5811
Bryansk region	4377	1900	Republic of Mari El	2297	1054
Vladimir region	5131	2672	Republic of Mordovia	2759	1334
Voronezh region	6983	3518	Republic of Tatarstan	10096	5796
Ivanovo region	3356	1846	Udmurt Republic	4494	2308
Kaluga region	3348	1776	Chuvash Republic	3382	1717
Kostroma region	2098	1137	Perm Krai	8150	4581
Kursk region	4104	1843	Kirov region	4195	2064
Lipetsk region	3567	1649	Nizhny Novgorod region	10333	5804
Moscow region	24290	14948	Orenburg region	6969	3704
Oryol region	2698	1269	Penza region	4228	2079
Ryazan region	3904	1945	Samara region	9724	5804
Smolensk region	3103	1673	Saratov region	7097	4052
Tambov region	3878	1710	Ulyanovsk region	4406	2199
Tver region	4519	2441	Kurgan region	3201	1617
Tula region	5366	2820	Sverdlovsk region	14064	7741
Yaroslavl region	4126	2213	The Tyumen region (without Autonomous Area)	9025	5554
Moscow city	28684	23411	Khanty-Mansi Autonomous Area	5366	3145
Republic of Karelia	2277	1251	Yamalo-Nenets Autonomous Area	1707	1015
Komi Republic	3341	1629	Chelyabinsk region	11366	6681
Arkhangelsk region	4393	2209	Altai Republic	667	374
Vologda region	4000	1964	Republic of Buryatia	3099	1821
Kaliningrad region	2750	1684	Republic of Tyva	884	625
Leningrad region	5934	3062	Republic of Khakassia	1718	1014
Murmansk region	2857	1499	Altai Krai	8446	4330
Novgorod region	2042	1053	Zabaykalsky Krai	3465	2140
Pskov region	2304	1145	Krasnoyarsk Krai	10397	5683
St. Petersburg	14419	11149	Irkutsk region	7769	4621
Republic of Adygea	1287	767	Kemerovo region	9255	5362
Republic of Kalmykia	875	491	Novosibirsk region	9135	4802
Krasnodar Krai	14927	9086	Omsk region	6399	3661
Astrakhan region	3281	1801	Tomsk region	3889	2138
Volgograd region	7752	4454	Republic of Sakha (Yakutia)	2669	1741
Rostov region	12114	7513	Kamchatka Krai	1238	641
Republic of Dagestan	4975	3537	Primorsky Krai	6708	3857
Republic of Ingushetia	387	366	Khabarovsk Krai	4556	2441
Kabardino-Balkar Republic	1849	1292	Amur region	2643	1417
Karachay-Cherkess Republic	1159	774	Magadan region	644	355
Republic of North Ossetia — Alania	1523	1008	Sakhalin region	2196	1067
Chechen Republic	2439	1645	Jewish Autonomous Province	597	319
Stavropol Krai	7063	4305	Chukotka Autonomous Area	240	149

Table 1 shows results of calculation of the expected reduction in life expectancy at birth as a result of malignant neoplasms (as on 2010). Calculations were executed by formula (19) using the statistics [3].

Table 2 shows results of calculation of years of potential life lost in the working age due to malignant neoplasms (as on 2010). Calculations were executed formulas (20) and (22) using a statistics [3].

Damage from mortality due to malignant neoplasms

In order to assess the damage from mortality due to malignant neoplasms it is necessary to get a monetary evaluation of a human life or years of the potential years of life lost.

The problem of the monetary expression of the price of a human life is extremely difficult. Many philosophical and ethical doctrines are based on the principle that «human life is priceless», thereby eliminating any possibility to discuss this matter. However, in a market economy, it is a very pressing problem.

Analysis of the literature allows us to say that the following concepts, measuring the price of a human life were formed [1, 6]:

— evaluation from the standpoint of the theory of human capital;

— indirect estimation taking into account non-monetary social costs;

— evaluation of individuals' willingness to pay for the elimination of the death risk;

— estimation based on the determination of insurance premiums and compensations under court decision;

— evaluation of the social investments, aimed to reduce the risk of premature mortality of the individual.

Evaluation according to the theory of human capital is based on the assumption that the utility of the individual to society depends primarily on his productivity, because in the theory of human capital, every individual is considered from the point of view of his ability to participate in social production and to earn money at the same time. A life loss, according to this theory, leads to a decrease in the productive capacity of society. A total salary of an individual couldn't earn due to premature death is proposed to be a measure of value of a human live [2, 4, 5]. But this concept has several serious disadvantages. The theory of human capital has a discrimination against employee's age. This concept gives more weight to an accident at work that caused death of a young worker, than to incurable occupational disease of an older one.

Secondly, the approach under consideration creates unequal conditions for individuals who receive different payment for their work, which leads to an underestimation of the poor segments of society. Thirdly, it is unclear how to evaluate the life of individuals who are not involved in the process of production, for example receive a pension or live on welfare. One of the variant of this approach is the estimation of human life on the basis of the gross domestic product, per capita, this method is characterized by similar shortcoming to those listed above.

Indirect estimation taking into account non-monetary social costs is based on the analysis of the political decisions aimed at reducing the number of fatal accidents and the following comparison of the achieved effect with the society's costs and received damage. A good illustration of the practical use of this concept is the history and consequences of enacting of the speed limits in the U.S. after an embargo on oil exports to the United States, established by a number of Arab countries in 1973. [3] This concept does not require neither information on the salary of individuals, nor data about themselves (for example, their age doesn't matter), and thus it is free from a number of shortcomings listed above. It can be used in cases related to the actual number of deaths, which have already occurred. It can help to make decisions about voluntary risk-taking or, conversely, to prevent it. The possibilities of indirect estimation attracted attention of the scientists, but it didn't receive practical application so far. The probable reason for that is the fact that the indirect estimate of the preservation of life does not always coincide with the assets established by the direct estimation. A discrepancy can be big.

Evaluation of individuals' willingness to pay for the elimination of the death risk, based on public opinion polls. Respondents were asked about the sum of money they were willing to pay for elimination of the death risk, caused by participation in a particular hazardous activity. The main drawback of this method is that a perception of individual risk is subjective and inadequate. Specifics of the risk perception by individuals and by social groups, is the subject of numerous psychological and socio-psychological researches. The main factors that influence the process of risk perception and the mechanisms, controlling it are revealed. A nature of risk, the form of its display, a degree of awareness (ignorance) about it, the ability to understand, the significance of the positive effects associated with the risk, media coverage, the degree of controllability, voluntary assumption, reversibility (irreversibility), the impact on children and future generations, etc., are among these factors. It is known that people tend to underestimate the risk they take voluntarily; voluntary risks include the usage of a car, smoking, extreme sports such as mountain climbing, etc. Another psychological effect is the high probability of underestimation of the risk, caused by hazardous events and overestimation of highly unlikely events. That's why people tend to underestimate the death risk of a car accident and at the same time, fear to fly by planes, even though the probabilities vary greatly. Thus, the subjective underestimation (overestimation) of the death risk leads to an underestimation (overestimation) of the life value. The concept of the individuals' willingness to pay for the elimination of the death risk can't be considered as correct, due to inadequate risk perception.

Estimation based on the determination of insurance premiums and compensations for the rel-

Table 3

Short-received Gross Regional Product because of the years of potential life lost in the working age due to malignant neoplasms, million rub. and % out of available Gross Regional Product

Subject of Federation	GRP reduction	% out of GRP	Subject of Federation	GRP reduction	% out of GRP
Belgorod region	2916	0.73	Republic of Bashkortostan	4693	0.62
Bryansk region	1173	0.81	Republic of Mari El	631	0.77
Vladimir region	1975	0.90	Republic of Mordovia	823	0.79
Voronezh region	2458	0.75	Republic of Tatarstan	6811	0.68
Ivanovo region	804	0.82	Udmurt Republic	1909	0.72
Kaluga region	1540	0.83	Chuvash Republic	1001	0.66
Kostroma region	746	0.81	Perm Krai	4999	0.79
Kursk region	1703	0.89	Kirov region	1283	0.77
Lipetsk region	1882	0.74	Nizhny Novgorod Region	5203	0.80
Moscow region	16012	0.89	Orenburg region	3897	0.86
Oryol region	865	0.84	Penza region	1197	0.76
Ryazan region	1487	0.86	Samara region	5438	0.78
Smolensk region	1176	0.79	Saratov region	2701	0.73
Tambov region	1196	0.86	Ulyanovsk region	1451	0.83
Tver region	1901	0.87	Kurgan region	1034	0.90
Tula region	2112	0.89	Sverdlovsk region	8587	0.93
Yaroslavl region	1972	0.84	The Tyumen region (without Autonomous Area)	3497	0.64
Moscow city	59928	0.71	Khanty-Mansi Autonomous Area	15900	0.80
Republic of Karelia	1144	0.90	Yamalo-Nenets Autonomous Area	5727	0.74
Komi Republic	3005	0.85	Chelyabinsk region	5512	0.85
Arkhangelsk region	3002	0.84	Altai Republic	182	0.84
Vologda region	2048	0.81	Republic of Buryatia	1112	0.82
Kaliningrad region	1469	0.75	Republic of Tyva	251	0.82
Leningrad region	4266	0.85	Republic of Khakassia	779	0.83
Murmansk region	1963	0.84	Altai territory	2605	0.87
Novgorod region	1050	0.83	Zabaykalsky Krai	1318	0.81
Pskov region	729	0.86	Krasnoyarsk Krai	9463	0.90
St. Petersburg	14050	0.84	Irkutsk region	4474	0.83
Republic of Adygea	366	0.79	Kemerovo region	5382	0.86
Republic of Kalmykia	181	0.74	Novosibirsk region	4037	0.84
Krasnodar Krai	7748	0.77	Omsk region	3019	0.81
Astrakhan region	1188	0.82	Tomsk region	2571	0.90
Volgograd region	3383	0.77	Republic of Sakha (Yakutia)	2768	0.72
Rostov region	4771	0.75	Kamchatka Krai	905	0.89
Republic of Dagestan	1341	0.47	Primorsky Krai	3974	0.86
Republic of Ingushetia	66	0.31	Khabarovsk Krai	2873	0.82
Kabardino-Balkar Republic	442	0.58	Amur region	1407	0.78
Karachay-Cherkess Republic	285	0.66	Magadan region	557	0.96
Republic of North Ossetia — Alania	446	0.60	Sakhalin region	5068	1.03
Chechen Republic	387	0.56	Jewish Autonomous Province	272	0.83
Stavropol Krai	2112	0.67	Chukotka Autonomous Area	481	1.15

atives proceeding from common insurance practice, assuming that the life insurance is connected with two main factors — the value of the client's life from his own point of view and the probability of a life loss due to any activity. The weak points of this approach are as following reasons. First of all, the insurance premium, no matter how big it is, can't reduce the death risk (as shown below, this reduction takes place in the concept of life assessment based on investments aimed at reducing the risk of premature death). Secondly, a client of the insurance company does not protect his own life, he acts in favor of the family members or other dear people. Civil suit in the courts about premature death, and insurance activities, can't reduce the probability of fatal accidents. And the compensational payments by the court are going to the victim's family. In addition, such claims are often based on the theory of human capital, they are enacted for the recovery of the total payroll lost, due to premature death. Therefore, these assessments have the same shortcomings as the concept of the human capital.

The concept of evaluation, based on the social investments, aimed to reduce the risk of premature mortality of the individual, gives an assessment to a so-called statistical life. A statistical life is considered to be saved, if the risk for the whole society was reduced so much that unidentifiable individual escaped death. Reduction of the death risk is connected with certain steps for decrease of threats (for example, universal vaccination). Such steps have a precise monetary value, which makes the estimation procedure easier. However, despite the remarkable progress in the development of the concept of life assessment, based on evaluation of the social investments, aimed to reduce the risk of premature mortality of the individual, it is still far from being perfect.

In this research we used index of reduction of the gross regional product due to the loss of potential life years in the working-age population because of malignant neoplasms (as on 2010). The results are presented in Table 3.

This analysis shows that none of the formed concepts of human life estimation can serve as an operating tool. All existing concept of life estimation are simplified or incorrect. This is a complex issue and it requires a new study approach. That lives a wide field for the new interdisciplinary researches.

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