Impact of the Environmental Externalities and Technological Progress on the Stability of Economic System Development on the Example of the Ingulets River Basin

Vitaliy Kobets[1[0000-0002-4386-4103]], Iryna Shakhman[2[0000-0001-6204-4410]], Anastasiia Bystriantseva[1[0000-0003-0611-1548]]

[1]Kherson State University, 27 Universitetska st., Kherson, 73000 Ukraine
vkobets@kse.org.ua, abystryantseva@ksu.ks.ua
[2]Kherson State Agrarian University, 23 Stritenskaya st., Kherson, 73006 Ukraine
shakhman.i.a@gmail.com

Abstract. Our study demonstrates the introduction of a market-based mechanism for environmental management in conditions of a shortage of natural (water) resources. The purpose of this paper is to investigate the impact of environmental externalities and technological progress on the stability of economic system development. We considered a model of upstream and downstream firms with production negative externality, taking into account that producer pollutant and farm enterprise are situated along the Ingulets river. Experimental data and OLS method were used in this model. The results of the study and practical recommendations will allow participants of the technological process to respond quickly to changes in the state of the environment and make effective decisions aimed at ensuring the stability of the economic system and environmental safety. We found that enterprise's rate of technological development inspired by IT implementation has to be 0.28 times more than technological development of pollutant to save the stability of farm enterprise's output.

Keywords: IT progress, enterprise stability, IT capital, external environmental costs, wastewater discharges, water quality

1 Introduction

In modern conditions, a relatively new environmental function of the state has been formed and received its constitutional consolidation. It is aimed at harmonizing relations between society and nature [1]. The implementation of this function of the state is carried out through regulation of the ratio of environmental and economic interests of society with the mandatory priority of the human right to a safe environment for life and health. This is carried out through the management of natural resources and environmental protection.

Externality means that results of one agent (individual or firm) depends on factors or actions that are not under his own control but are decided by other agents or nature ("polluters") in general equilibrium theory which is connected with sustainable economic systems.

Unsustainability means lack of long run environmental equilibrium of economic system. Consequences of disequlibrium is characterized by decreasing stocks of exhaustible resources, increasing pollution's concentrations, loss of biodiversity.

Broadly speaking, sustainability does not require absence of positive or negative externalities at all. Reducing one type of externality usually generates another. Joint resource for different economic agents is a reason of negative dynamic externality. "Transition from the current unsustainable system to a sustainable one is prevented by the lock-in of certain technologies, so government policy is needed" [2].

Instruments of sustainability policy includes natural capital depreciation tax which stimulate change from non-renewable resources to renewable ones; "precautionary polluter pays principle".

The **goal** of the paper is to analyze an impact of the environmental externalities and technological progress on the stability of economic system development on the example of the Ingulets River Basin.

The paper has the following structure: section 2 is devoted to the related works; section 3 describes mathematical approach of externalities and sustainability economics; section 4 reveals the practical implementation of the environmental management system in the Ingulets River Basin; section 5 introduces model of upstream and downstream firms with negative externality and IT capital; section 6 analyses impact of the environmental externalities and technological progress on the stability of economic system development using experimental data; the final section concludes.

2 Related works

In our study [3] the issue of the impact of economic activity on the environment has already been considered. Thus, the influence of economic activity on the fish population during sand mining was previously described. It has been shown that internal mining can be carried out without creating adverse effects on the water body provided the extraction to be carried out within the limited optimal amount of sand extraction established by local authorities. To determine the ecological balance in the hydroecosystem during the extraction of sand, the mathematical model was proposed. However, the balance may not always be achievable. And then it becomes necessary to restore natural resources, which should be carried out at the expense of the environmental pollutant.

The authors in [4] considered a quantification of air pollution externalities from electricity production. It was shown that command-and-control measures are more effective than market tools under internalizing of external expenses in CEE countries. This research of the internalization of external costs deals only with airborne pollution, while energy production can also be trigger of other types of negative externalities, which require further research.

The problem of comparing the impact of electricity production technologies and fuels on the environment due to their differences is quite complex. The appropriate way of analysis today is the external cost approach, by which "a monetary value is associated with environmental damage" and "damage to human health caused by the annual operation of Croatian thermal power plants" were calculated [5].

Since the goal of energy policy is to promote environmentally optimal solutions, in Italy to compare the potential environmental impacts of alternative policy is applied to quantify the impact of atmospheric emissions; so biogas support schemes in Italy were considered and revised to include subsidies for biomethane production process [6]. "Agriculture also has a significant effect on the environment and human health" [7]. In the paper were calculated the external costs of agricultural production in the USA taking into account natural resources, ecosystem biodiversity and human health. The existence of such costs is a reason to transform agricultural policy, which can shift technology that reduce external influences.

In the UK has been established that significant external costs arise due to contamination of drinking water with pesticides, nitrates, cryptosporidium and phosphates because of damage to wildlife, habitats, hedgerows, from gas emissions, soil erosion and organic carbon losses etc [8]. This research estimate such external effects that lead to financial costs, and therefore probably underestimate the overall negative impact of agriculture industry. This involves redirecting government subsidies to stimulate those positive externalities that are underrepresented on the market.

According to the simulation results [9], global warming will make up "from 10% to 40% of all external costs in the 21st century; the internalization of the external cost will cause a decline in economic growth by approximately 5%, whereas forest preservation will increase by 40% and fossil-fuel consumption will be reduced by 15%".

3 Externality versus sustainability economics: mathematical approach

Dynamic general equilibrium model can assess the impacts of environmental pollution on production function for enterprises of different industries.

Cost of enterprises which save environment (TC) is more than TC_{ne} of non-environmental friendly enterprises: $TC > TC_{ne}$. Social welfare for individuals, firms and state authority is the difference between reservation price U and total costs, plus externalities: $W = U - TC - TC_{ne} + E$ [10].

Industry externalities result when agglomeration occurs within an IT industry or sector (i) due to specialization or localization effects, (ii) among firms in different industries of sectors that are located in close proximity due to diversity or urbanization economies. Some authors [11] in Green Solow Model consider each economic activity as technology, $F(K; L)$, which generates pollution. Aforementioned model is suitable to describe long run effects of pollution, but they do not capture short-run effect of pollution in contrast of discrete time models:

$$g(k) = Ck^{\rho}(E - k)^{\omega},$$

where $C > 0$ is a constant, $\rho > 0$ is the capital elasticity, $E > 0$ is the state of environment if production activity is absent and $\omega > 0$ is pollution effect.

The model introduced production function, in which the environmental resource is the stock of natural resource involved in the productive process with positive constants:

$$Y_t = F(K_t, L_t, E_t) = K_t^{\alpha} L_t^{\beta} E_t^{\gamma}.$$

According to [12], there are 3 main sources of pollution, which can have influence on economic systems: byproduct of consumption, pollution as input and pollution as externality. Traditionally a parameter measuring the pollution intensity of output was considered as exogenous, but in modern models [12] pollution was explored as endogenous variable.

Pollution $P(t)$ arises as an externality of technology of the production function of the inputs:

$$P(t) = Q^{-\xi}(t) \sum_{j=1}^{N} X_j^t,$$

where $\xi \in (-1; 1)$ is a constant estimating the effect of technological production $Q(t)$ on pollution $P(t)$. Consequently the more ξ the low pollution and vice versa.

Sustainable resource use and economic dynamics can be described by Cobb-Douglas technology [13, 14]:

$$Y = AK^{\alpha} L^{\beta} R^{1-\alpha-\beta}$$

where A is technology, K and L are capital and labor correspondingly, input R is a pollution.

$$\frac{Y}{K} = A \left(\frac{L}{K}\right)^{\beta} \left(\frac{R}{K}\right)^{1-\alpha-\beta}$$

$$\frac{R}{Y} = A^{-\frac{1}{1-\alpha-\beta}} \left(\frac{Y}{L}\right)^{\frac{\beta}{1-\alpha-\beta}} \left(\frac{Y}{K}\right)^{\frac{\alpha}{1-\alpha-\beta}}$$

Capital productivity increases with pollution. Capital is a clean substitute for polluting inputs in production. Technological change decreases the pollution intensity: the less resources the less pollution level for unchangeable output.

4 The practical implementation of the environmental management system in the Ingulets River Basin

In our research, we present an example of the environmental management (internalization of external environmental costs) system model, implemented in the Ingulets River basin. A subject of management is Interdepartmental Commission of the State Agency for Water Resources of Ukraine. It carries out governing influence on the management object – mining enterprises Kryvbas. The management object based on a regulatory document "The regulation for channel flushing and ecological rehabilitation of the Ingulets River, improvement of water quality in the Karachunivske Reservoir and at the water intake of the Ingulets irrigation system" regulates its influence on the formation of quantitative and qualitative indicators of the aquatic environment of the Ingulets River).

In the Kryvyi Rih basin, 8 of 11 Ukrainian enterprises for the extraction and processing of iron ore are located. Here are enterprises serving the metallurgical industry – one of the world's largest metallurgical plants (PJSC “ArcelorMitall Kryvyi Rih”), five mining and processing combines (MPC) – Pivnichnyi MPC (PivnMPC), Pivdennyi MPC (PivdMPC), Tsentralnyi MPC (TMPC), Novokryvorizky MPC (NKMPC), Inhuletskyi MPC (InMPC), three ore repair plants [15]. As a result of iron ore mining in Kryvyi Rih, a huge volume of highly mineralized mine water is being formed, which are discharged into the Ingulets River. Mineralization of mine water very often exceeds the salinity of sea water [16]. Wastewater discharge in the Ingulets River leads to a deterioration in water quality downstream from the city of Kryvyi Rih. At the same time water of the Lower Section of the Ingulets River is taken for irrigation [15-17].

The south of Ukraine is characterized by an insufficient amount and uneven distribution of precipitation with frequent droughts and dry winds, which affects the normal development of crops. Such conditions cause sharp fluctuations in harvest over the years and cause instability of agricultural production. Therefore, the Mykolaiv region is considered as a zone of risky agriculture, where irrigation is urgently needed. Irrigation is carried out by the waters of the Ingulets River. Water enters the main canal through two pressure pipelines with a diameter of 2.8 m and a length of 600 m. The main canal and the entire irrigation network are built in the earthen channel. It consists of 11 first-order inter-farm distributors and 14 lower-order distributors with a total length of more than 410 km.

The total area of irrigated land in the Mykolaiv region is 190.3 thousand hectares. Irrigated lands are located in 19 districts of the region. The reclamation complex of the region includes 22 inter-farm irrigation systems. Water from the Ingulets River flows into systems:

1. Yavkynska IS (Snihurivskyi, Zhovtnevyi, Bereznehuvatskyi, Bashtanskyi areas) was commissioned in 1977, the source of the water intake of the Ingulets River, the irrigation area – 50.3 thousand hectares, the length of the main and distribution channels – 107.4 km;

2. Ingulets IS (Snihurivskyi, Zhovtnevyi areas) was commissioned in 1963, the source of the water intake of the Ingulets River, irrigation area – 42.7 thousand hectares, length of main and distribution channels – 461.2 km (Fig. 1).

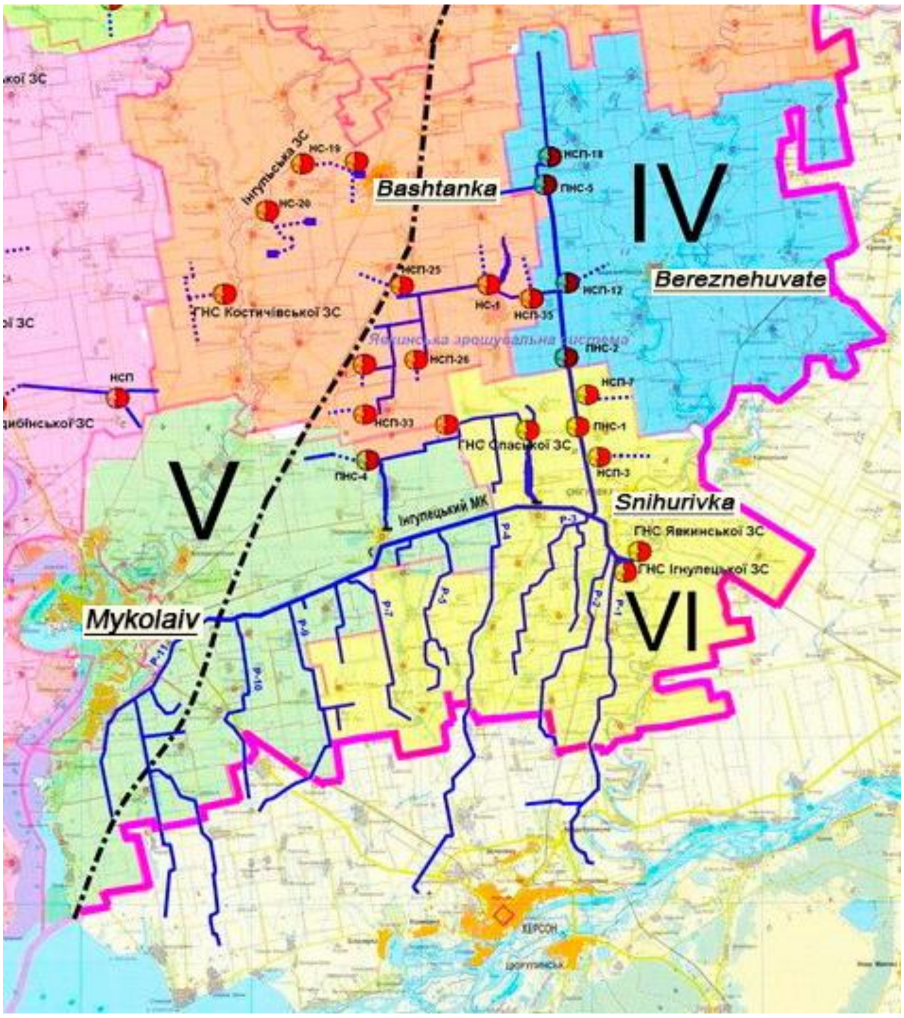

Fig. 1. Water management and reclamation complex of the Mykolaiv region

Irrigation is also possible if the river water quality is controlled and complies with the irrigation standards. Therefore, the Interdepartmental Commission of the State Agency for Water Resources of Ukraine annually approves "The regulation for channel flushing and ecological rehabilitation of the Ingulets River, improvement of water quality in the Karachunivske Reservoir and in the water intake of the Ingulets irrigation system" [18]. The Commission analyzes the hydrometeorological situation in the Ingulets River Basin, information on water quality in the Karachunivske Reservoir, into which wastewater from Kryvbas enterprises is discharged, and from which water enters the Ingulets River.). The Commission adopts a Regulation specifying what compensation volume of water should be added into the reservoir at the expense of the Dnieper-Ingulets channel for dilution of highly mineralized waters and improvement of water quality. It also obliges the mining enterprises that discharged the wastewater to pay for the environmental improvement of the Ingulets River.

The total volume of discharge from the Karachunivske Reservoir is about 120.0 million m^3; under the agreement 105 million m^3 are paid by the mining enterprises of Kryvbas and 15.0 million m^3 are paid by the state budget [18]. Thus, before the start of the irrigation season, there is a gradual increase of discharges from the Karachunivske Reservoir, which is then regulated to ensure the necessary volumes and quality of water of the Lower Section of the Ingulets River in accordance with irrigation standards. And agrarian farms of the Mykolaiv region can use river water for irrigation.

Calculations for flushing of the Ingulets River and bringing the water quality indicators into the Ingulets River at the level of the Main Pumping Station of the Ingulets Irrigation System (MPS IIS) should be based on the chlorine ions ratio in the Dnieper-Ingulets supply channel, since this ion is inert and does not go into any reactions. Volumes of Dnieper water should be calculated in such a way that at the level of MPS IIS (town Snihurivka) mixed waters of Dnieper and Ingulets correspond to the standards of SSTU 2730: 2015 "Quality of natural water for irrigation. Agronomic criteria" for irrigation water of the first class. Water management situation in the Ingulets River Basin for the upper (Andriivka) and lower (Snihurivka) course of river for the 2019 observation period is explained in Table 1 [19].

Table 1. Water management situation in the Ingulets River Basin for the observation period 2019

Water sampling site	Date	The volume of supplied water by the Dnieper-Ingulets canal, thousand m^3	Discharge from the Karachunivs'ke Reservoir, thousand m^3	Chlorides (MPC=350 mg/dm^3)
				actual, mg/dm^3
Andriivka	21.01	–	–	1680
Snihurivka				1660
Andriivka	19.02	–	–	3120
Snihurivka				1900
Andriivka	12.03	–	–	980
Snihurivka				2250
Andriivka	16.04	7603,0	23778,0	220
Snihurivka				400
Andriivka	07.05	27779,0	51928,2	340
Snihurivka				280

Andriivka	18.06	64425,0	91845,0	360
Snihurivka				340
Andriivka	16.07	93623,0	118456,2	420
Snihurivka				330
Andriivka	13.08	–	–	400
Snihurivka				420
Andriivka	17.09	–	–	1800
Snihurivka				480
Andriivka	15.10	–	–	2100
Snihurivka				550
Andriivka	19.11	–	–	1380
Snihurivka				1400
Andriivka	17.12	–	–	1680
Snihurivka				1400

At the beginning of the irrigation season of 2019, the irrigated area was 190 thousand 321.8 hectares in the Mykolaiv region [20]. 16 water samples at 16 observation points were taken for chemical analysis to determine the water quality of irrigation sources. The chemical analysis of water samples was carried out in the laboratory of the Pivdenno-Buzke Basin Department of Water Resources. The determination of water quality was carried out in accordance with the state standard of Ukraine SSTU 2730: 2015 "Quality of natural water for irrigation. Agronomic criteria".

Water sampling results for the observation period 2019 are explained in Table 2.

Table 2. Water quality in the Ingulets IS for the observation period 2019

Ingredient	**2019 year**		
	start of irrigation season 19-21.03	**mean for irrigation period 15.04-15.08**	**end of irrigation season 18-19.09**
Mineralization, mg/dm^3	5673	621	1903
Chlorides, mg/dm^3	2821,82	354,00	482,12
Sulphates, mg/dm^3	666,18	499,16	619,15
pH	8,3	7,2	7,7

Chemical composition	sulfate-chloride, magnesium-sodium	sulfate-chloride	hydrocarbonate-sulfate-chloride, calcium-magnesium-sodium
Water quality characteristic	III class unsuitable for irrigation	I class suitable for irrigation	III class unsuitable for irrigation

So, after washing the channel and improving the Ingulets River irrigation water corresponds to the first class of quality (suitable for irrigation without restrictions) and can be used by agricultural enterprises for irrigation of agricultural land. The high mineralization and chloride content at the beginning and at the end of the irrigation period are explained by the fact that at the time of water sampling, the irrigation season had not yet begun (it had already ended), and the Dnieper-Ingulets canal water supply to the headwater of the Ingulets River, which aims at diluting the river water in order to reach safe for watering criteria, has not yet (already) been carried out.

The content of toxic salts in the mixed waters of the Ingulets main canal on average during the irrigation period is about 420-490 mg/dm^3 with a deviation to 70-140 mg/dm^3 in both directions. That is, the composition is determined by the volume of Dnieper water supplied to the headwater of the Ingulets River to dilute the Ingulets water to criteria that are safe for irrigation. The main polluting factor remains the discharge of mine water in the upper course of the Ingulets River from enterprises of Kryvbas.

Thus, the enterprises of Kryvbas, along with other production costs, include environmental costs in the total (internal). That is, the costs that ensure the elimination of environmental (water) pollution are external for polluting enterprises, since for the metallurgical and mining enterprises, the damage caused by their activities does not affect production costs. In this case, external costs are manifested in an increase in the costs of industrial, rather than agricultural, enterprises for the subsequent treatment of polluted water of the Ingulets River.

Of course, such a scheme provides an opportunity for agricultural holdings, which are located downstream of the Ingulets River, to use water for irrigation. However, the annual flushing of the Ingulets River by feeding Dnieper water through the Dnieper-Ingulets canal, does not lead to self-regulation of the chemical composition of the water and the possibility of using the river for fishing purposes [17]. The development of environmental measures is recommended, primarily aimed at reducing the volume of wastewater in the source of their formation (at the enterprises of Kryvbas), as well as the introduction of closed water production cycles, which will positively affect the resumption of the ability of the aquatic ecosystem to self-regulation and self-purification).

5 Model of upstream and downstream firms with negative externality and production function with IT capital

IT capital into a production function of firm include personal computers, servers, storage capacity and nodes for information workflow. These factors have effects on production function and cost efficiency.

There is a positive effect of IT capital (i.e., intangibles as well as the tangible assets, such as computer hardware and software) on productivity of firms. ICT "allows companies to perform activities in a faster, more accurate, and more flexible manner" [21]. ICT as a rule includes innovations. Improved production function due to innovations includes "significant changes in techniques, equipment, or software" [21].

ICT can enter into a production function equation as exogenous variable. Use of ICT allow introducing processes, which can reason of higher productivity and lower average cost in firms. Thus ICT has direct (IT capital) and indirect impact (product innovations and business process innovations) on production technology of a firm. A change in production technology causes a change in average cost (Fig. 2) [22].

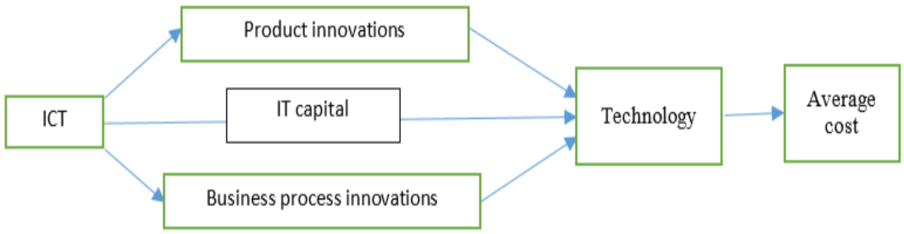

Fig. 2. Direct and indirect impact of ICT on technology of production function

Let's consider production negative externality for producer pollutant (public corporation ArcelorMittal, Kryvyy Rih, Ukraine) and farm enterprise situated along the Ingulets River. The upstream firm (pollutant) x has a production function of the form:

$$x = e^{h_x t} k^{\alpha_1} l^{\beta_1}, \quad (1)$$

where k is the number of machine hours per day, l is the number of labor hours per day [23], h is the rate of technological development during period t due to implementation of information technology. The downstream firm y has own production function and its output may be affected by the chemicals firm x into the river:

$$y = e^{h_y t} k^{\alpha} l^{\beta} (x - x_0)^{-|\gamma|} \quad (2)$$

where x_0 demonstrates the river's natural capacity for pollutants. If $\gamma = 0$, x's production process has no effect on firm y, whereas if $\gamma < 0$, increase in x above x_0 causes y's output to decline.

Total cost of downstream firm y is

$$TC(y) = r \cdot k + w \cdot l \quad (3)$$

where r is rate of capital per hour, w is wage per hour. Express l from equation (2):

$$l = e^{-\frac{h_y}{\beta}t} k^{-\frac{\alpha}{\beta}} (x - x_0)^{-\frac{|\gamma|}{\beta}} y^{\frac{1}{\beta}} \tag{4}$$

After substitution (4) in (3) we obtain:

$$TC(y) = r \cdot k + w \cdot e^{-\frac{h_y}{\beta}t} k^{-\frac{\alpha}{\beta}} (x - x_0)^{-\frac{|\gamma|}{\beta}} y^{\frac{1}{\beta}}. \tag{5}$$

To get equilibrium capital hours, calculate FOC $\frac{\partial TC(y)}{\partial y} = 0$:

$$\frac{\partial TC(y)}{\partial y} = r + w \cdot e^{-\frac{h_y}{\beta}t} \left(-\frac{\alpha}{\beta}\right) k^{-\frac{\alpha}{\beta}-1} (x - x_0)^{-\frac{|\gamma|}{\beta}} y^{\frac{1}{\beta}} = 0.$$

From the last equation we can formulate k as following function:

$$k = \left(\frac{w}{r}\right)^{\frac{\beta}{\alpha+\beta}} \cdot \left(\frac{\alpha}{\beta}\right)^{\frac{\beta}{\alpha+\beta}} \cdot e^{-\frac{h_y}{\beta}t} (x - x_0)^{\frac{|\gamma|}{\alpha+\beta}} y^{\frac{1}{\alpha+\beta}}. \tag{6}$$

Using substitution (6) to (5) we have:

$$TC(y) = (w^{\beta} r^{\alpha}) \cdot \left[\left(\frac{\alpha}{\beta}\right)^{\frac{\beta}{\alpha+\beta}} + \left(\frac{\beta}{\alpha}\right)^{\frac{\alpha}{\alpha+\beta}}\right] \cdot e^{-\frac{h_y}{\alpha+\beta}t} \cdot (x - x_0)^{\frac{|\gamma|}{\alpha+\beta}} y^{\frac{1}{\alpha+\beta}}. \tag{7}$$

where $e^{-\frac{h_y}{\alpha+\beta}t}$ is impact of IT during each year t (decrease of total cost of farm enterprise for same output), $-\frac{|\gamma|}{\alpha+\beta}$ is impact of negative externality of producer pollutant.

Using the same transformation we can obtain total cost of pollutant:

$$TC(x) = (w^{\beta_1} r^{\alpha_1}) \cdot \left[\left(\frac{\alpha_1}{\beta_1}\right)^{\frac{\beta_1}{\alpha_1+\beta_1}} + \left(\frac{\beta_1}{\alpha_1}\right)^{\frac{\alpha_1}{\alpha_1+\beta_1}}\right] \cdot e^{-\frac{h_x}{\alpha_1+\beta_1}t} \cdot x^{\frac{1}{\alpha_1+\beta_1}}. \tag{8}$$

Taking into account production function (1) we can rewrite $TC(y)$ as

$$TC(y) = (w^{\beta} r^{\alpha}) \cdot \left[\left(\frac{\alpha}{\beta}\right)^{\frac{\beta}{\alpha+\beta}} + \left(\frac{\beta}{\alpha}\right)^{\frac{\alpha}{\alpha+\beta}}\right] \cdot e^{-\frac{h_y}{\alpha+\beta}t} \cdot (e^{h_x t} k^{\alpha_1} l^{\beta_1} - x_0)^{\frac{|\gamma|}{\alpha+\beta}} y^{\frac{1}{\alpha+\beta}}. \tag{9}$$

Total cost will change over time as follows $\frac{\partial TC(y)}{\partial t}$ and will be equivalent to the following expression: $\frac{1}{\alpha+\beta} \cdot \left[-h_y + \frac{|\gamma| \cdot h_x \cdot x}{x - x_0}\right]$. If $x_0 = 0$, then total cost of downstream firm will decrease if and only if $-h_y + |\gamma| \cdot h_x < 0$. It means that $\frac{h_y}{h_x} > |\gamma|$, i.e. stability of farm enterprise is reached then ratio of technological development of downstream and upstream firm has to be more than externality value $|\gamma|$.

6 Experiment

Using open data of ArcelorMittal (table 3), and linear transformation of Cobb-Douglas equation (1) we got new variables: $lnx = A + \alpha_1 lnl + \beta_1 lnk$ (table 4).

Table 3. Production technology of ArcelorMittal

Year	Output x, hrn.	Labor l, hours	Capital k, hours
1	12767,5	375,2	131427
2	16347,1	402,5	134267
3	19542,7	478	139038
4	21075,9	553,4	146450
5	23052	616,7	153714
6	26128,2	695,7	164783
7	29563,7	790,3	176864
8	33376,6	816	188146
9	38354,3	848,8	205841
10	46868,3	873,1	221748
11	54308	999,2	239715

Table 4. Log transformation of production technology of ArcelorMittal

Year	$ln(x)$	$ln(l)$	$ln(k)$
1	9,45	5,93	11,79
2	9,70	6,00	11,81
3	9,88	6,17	11,84
4	9,96	6,32	11,89
5	10,05	6,42	11,94
6	10,17	6,54	12,01
7	10,29	6,67	12,08
8	10,42	6,70	12,14
9	10,55	6,74	12,23
10	10,76	6,77	12,31
11	10,90	6,91	12,39

Using OLS method we have $\ln(x) = -9.68 + 0.46 \cdot \ln(l) + 1.4 \cdot \ln(k)$ ($R^2 = 0.98$) or $x = 6.28 \cdot 10^{-5} k^{1.4} l^{0.46}$.

Using open data of farm enterprise (table 4), output of pollutant (table 3) and linear transformation of Cobb-Douglas equation (2) we obtain new variables $\ln(y) = B + \alpha \cdot \ln(l) + \beta \cdot \ln(k) + \gamma \cdot \ln(x)$.

Table 5. Production technology of farm enterprise

Year	Output y, hrn.	Labor l, hours	Capital k, hours	Output x, hrn.	$ln(y)$	$ln(l)$	$ln(k)$	$ln(x)$
1	78360	128245	43	12767,5	11,27	11,76	3,76	9,45
2	15007	20774	30	16347,1	9,62	9,94	3,40	9,70
3	27802	77211	35	19542,7	10,23	11,25	3,56	9,88
4	21458	21444	71	21075,9	9,97	9,97	4,26	9,96
5	6242	7836	93	23052	8,74	8,97	4,53	10,05
6	33855	31514	142	26128,2	10,43	10,36	4,96	10,17
7	3162	6728	18	29563,7	8,06	8,81	2,89	10,29
8	20006	23967	183	33376,6	9,90	10,08	5,21	10,42

9	8007	5649	33	38354,3	8,99	8,64	3,50	10,55
10	18389	33494	87	46868,3	9,82	10,42	4,47	10,76

Similarly using OLS method we have $\ln(y) = 4.02 + 0.73 \cdot \ln(k) + 0.31 \cdot \ln(k) - 0.28 \cdot \ln(x)$ ($R^2 = 0.89$) or $y = 55.57 \cdot k^{0.73} \cdot l^{0.31} \cdot x^{-0,28}$.

Each 1% increasing of pollutant stocks will decrease on 0.28% of farm enterprise's output. Thus farm enterprise's rate of technological development inspired by IT implementation has to be 0.28 times more than technological development of pollutant to save the stability of its output.

7 Conclusions

Our study investigated the impact of environmental externalities and technological progress on the stability of economic system development using market-based mechanism for environmental management in conditions of a shortage of natural (water) resources. We considered a model of upstream (pollutant) and downstream (farm enterprise) firms with production negative externality, taking into account that producer pollutant and farm enterprise are situated along Ingulets river. The results of the study and practical recommendations will allow participants of the technological process to respond quickly to changes in the state of the environment and make effective decisions aimed at ensuring the stability of the economic system and environmental safety.

We found that stability of farm enterprise is reached then ratio of technological development of downstream and upstream firm has to be more than externality value. For our data we reveal that each 1% increasing of pollutant stocks of ArcelorMittal will decrease on 0.28% of farm enterprise's output along the Ingulets river basin. Thus, farm enterprise's rate of technological development inspired by IT implementation has to be 0.28 times more than technological development of pollutant to save the stability of its output.

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