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

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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 impact of the environmental externalities and technological progress on the stability of economic system development. We considered model of upstream and downstream firms with production negative externality, suppose producer pollutant and farm enterprise along Ingulets river using experimental data and OLS method. The results of the study and practical recommendations will allow participants of the technological process to respond quickly on 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 stability of farm enterprise's output.

Keywords: IT progress, enterprise stability, 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.

The presence of an externality means that someone's (a victim's) utility or production (co)depends on factors that are not under his/her control, but are decided by other humans or organizations ("polluters") in general equilibrium theory. This systems perspective of externalities already illustrates the possible connection with sustainability.

Unsustainability denotes the lack of long term environmental sustainability, which is characterized by falling stocks of natural resources, increasing concentrations of pollution in environmental media, or loss of nature and biodiversity.

Without such externalities the problem of unsustainability vanishes. But sustainability does not require zero externalities in general. A certain positive level of environmental externalities up to a threshold can be consistent with sustainability. Sustainability is all about regenerative capacity of the environment and substitution potential in the economy. Reducing one type of externality usually generates another. Use creates a negative externality via the joint resource (dynamic externality). For a renewable resource the external effect arises when total use exceeds the level of sustainable use, which equals the rate of regeneration.

Sustainability policy can to foster a transition to a sustainable development path or sustainable system. Transition from the current unsustainable system to a sustainable one is prevented by the lock-in of certain technologies, notably fossil fuel based, then un-locking policy is needed [2].

Instruments of sustainability policy: 1) natural capital depreciation tax would stimulate shift from use of (and investment in) non-renewable to use of renewable resources; 2) "precautionary polluter pays principle".

The **purpose** of this paper is to investigate 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 introduces model of upstream and downstream firms with negative externality. Section 5 reveals the practical implementation of the environmental management system in the Ingulets River Basin. Section 6 analyses impact of the environmental externalities and technological progress on the stability of economic system development using experimental data. The last section is the conclusion, which sums up the results of the research.

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 that the extraction is 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 bottom-up approach to quantification of air pollution externalities from electricity generation. It was shown that market-based instruments are not very effective in internalizing these external costs in six CEE countries. Governments in CEE countries have regulated air emissions by imposing strict command-and-control measures, but most of them have also introduced air emission charges and more recently taxes on electricity. As the fuel mix composition was of particular concern, the authors noted, that the level of internalization by such two economic instruments was fairly low for existing fossil-fired power plants. The presented analysis of the internalization of external costs deals only with airborne pollution, while energy generation may also cause other types of negative external effects, 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 most widely accepted way of analysis today is the so-called external cost by which a monetary value is associated with environmental damage. Thus, in article [5] damage to human health caused by the annual operation of Croatian thermal power plants is presented. Existing data on relations between human health degradation and ground concentrations of the analyzed pollutants had been used by authors. Geographic information analysis software was used to account for spatially dependent data. As a result, the total external costs associated with the effects on human health of air emissions of Croatian thermal power plants were calculated.

Since the goal of energy policy is to promote environmentally optimal solutions, in northern Italy to compare the potential environmental impacts of alternative policy options external cost methodology is applied to quantify the impact of atmospheric emissions. They associated with biogas-based energy vectors and their corresponding fossil substitutes. In [6] biogas support schemes in Italy were considered, which are being revised to include subsidies for biomethane production. They were evaluated at supply chain level and incorporated in a spatially explicit optimization model. Although the external costs of biogas-based directions are always lower than the corresponding fossil fuel-based directions. The differences are so small that policies based only on internalizing external costs will not lead to further development of biogas-based technologies.

Agriculture also has a significant impact on the environment and human health [7]. The study estimates the external costs of agricultural production in the United States in the areas of natural resources, wildlife and ecosystem biodiversity, human health. The presence of such costs requires a restructuring of agricultural policy, which shifts production towards methods that reduce external influences.

An assessment of the total external environmental and health costs of modern agriculture in the UK was carried out in [8]. A wide range of data sets was analyzed to estimate the distribution of costs by sectors, and the annual total external costs of agriculture in the UK were determined. It has been established that significant costs arise due to contamination of drinking water with pesticides, nitrates, cryptosporidium and phosphates and as a result of damage to wildlife, habitats, hedgerows, from emissions of gases, from soil erosion and organic carbon losses, from food poisoning, and from bovine spongiform encephalopathy. This research evaluated only those external effects that lead to financial costs, and therefore probably underestimate the overall negative impact of modern agriculture. This involves redirecting government subsidies to stimulate those positive externalities that are underrepresented in the market.

The study [9] presents the simulation of internalization of external costs of major global environmental problems using the model of optimal economic growth. It uses two existing models: integrated assessment model and life cycle impact assessment model. According to the simulation results, 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

The relationship between environmental pollution and economic growth presents an inverted U-shaped environmental Kuznets curve. Environmental pollution increases the cost of social health and hinders sustained economic development and social welfare. Social welfare effects of environmental regulation policies (environmental taxation and environmental subsidy) are influenced by externalities, market structure, and consumer preferences, which can cause social welfare losses due to environmental regulation policies.

Dynamic general equilibrium model can assess the impacts of environmental pollution on production function for different types of firms, environmental protection firms and non-environmental protection firms, whose outputs are environmentally friendly commodities and non-environmentally friendly ones. Production process uses clean technology and pollution technology, respectively, there is no difference in the output of goods.

Cost of environmental protection firms (TC) is higher than $\mathrm{TC_{ne}}$ of non-environmental protection firms: $\mathrm{TC} > \mathrm{TC_{ne}}$. Social welfare for individuals, firms and state authority is the difference between utility U and costs, plus any externalities: $\mathrm{W} = \mathrm{U} - \mathrm{TC} - \mathrm{TC_{ne}} + \Phi + \Psi$, where Φ represents positive externalities and is greater than or equal to zero, and Ψ represents negative externalities and is less than or equal to zero [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.

Coevolution of economic and environmental systems can give rise to nonlinear dynamic effects as the emergence of chaotic dynamics, multistability and indeterminacy. Some authors [11] consider the environment as productive input or as consumption good. For example, Green Solow Model assumes that each unit of economic activity (technology), $F(K; L)$, generates Ω units of pollution P:

$$P = \Omega F - \Omega A(F),$$

where $A(F)$ is natural capacity of environment which can absorb some part of pollution. Aforementioned model is suitable to describe long run trends, but they are not able to capture the occurrence of short-run nonlinear phenomena in contrast of discrete time models:

$$f(k) = Ak^{\beta}(m - k)^{\gamma},$$

where $A > 0$ is a productivity parameter, $\beta > 0$ is the elasticity of capital, $m > 0$ is the state of environment if private production is not performed and $\gamma > 0$ weighs the effects of pollution.

The model introduced production function in which the environmental resource is taken as an input in the production of a private good:

$$Y_t = F(K_t, L_t, E_t) = K_t^{\alpha} L_t^{\beta} E_t^{\gamma}, \text{ with } \alpha, \beta, \gamma > 0 \text{ and } \alpha + \beta \leq 1,$$

where E_t is the stock of natural resource involved in the productive process.

Dynamics of the environmental resource are modeled with the logistic equation augmented by the negative impact of production process:

$$\frac{dE}{dt} = E(\overline{E} - E) - \delta \cdot \overline{Y},$$

in which $E > 0$ is the carrying capacity of the natural resource, $\overline{Y}$ represents the economy-wide average output and the parameter $\delta > 0$ measures the negative impact of production on E.

According to Xepapadeas [12], there are three main source of pollution which can be generated in an economic model:

1) pollution can be seen as a byproduct of consumption;

2) pollution may arise because it is needed as an input in the production process. Here, the firms decide directly how much pollution will be present in the economy when choosing which inputs they will use and what amount of output they will produce;

3) flow of pollution is being related to an externality of the production process, so that pollution is a necessary byproduct of production. They do it rather indirectly by choosing an appropriate level of output.

Traditional pollution output relation by explicitly introducing a parameter measuring the pollution intensity of output, even though this parameter remained exogenous, until for instance the work of Grimaud or Hart [12] who finally endogenize the pollution intensity of the production process.

Pollution $P(t)$ arises as an externality of the production process of the intermediate goods $X(t)$

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

where $-1 < \xi < 1$ is a constant determining the effect the level of technological progress $Q(t)$ has on pollution $P(t)$. Consequently, if ξ is high (low), the production of intermediate goods entails a low (high) pollution generation.

Effect of pollution consists in allowing pollution to have an influence on firms. Specify the model that firms need pollution as an input for the production process. Firms may be forced to alter their production and innovation decisions if pollution is bound to stay below a certain threshold. Another method is to make the productivity of firms (workforce) subject to the amount of pollution present in the economy. A balanced growth path is defined as a state in which the variables of the model, namely $Y(t)$, $X(t)$, $Q(t)$ and $P(t)$, grow at constant rates.

One of the main questions is whether economic growth is sustainable if the agents can only cope with a certain amount of pollution. Whereas in this context, sustainability is associated with the ability to support the growth rate prevailing in the equilibrium.

There are different approaches in the economic policy of how pollution abatement can be modeled in an environmental growth model. The first is to introduce a government into the model, which finances abatement spending. Social optimum can be implemented through the introduction of a subsidy to the final good sector, a subsidy towards the research sector and tradable pollution permits. The other consists of allowing private firms to undertake abatement activities.

The extraction and use of natural resources causes pollution while the abatement of pollution requires equipment and the expenditure of resources. The concept of an externality is central in environmental economics. An externality is an important instance of market failure which produces a deviation from the first-best (Pareto optimal) solution.

Production generates pollution which is measured by the dynamic size of the stock $S(t)$. A firm's pollution emission rate $\sum_{i=1}^{n} e_i(t)$ equals its production rate. The pollution dynamics are simple [13]:

$$\frac{dS}{dt} = Q(t) - \delta S(t).$$

The profit function of firm i is its long-run, discounted profit:

$$\pi_i = \int_0^\infty e^{-rt} \Big(P\big(Q(t)\big) - c - f\big(S(t)\big)\Big) q_i(t) dt$$

The problem of the government is to find an efficient tax rule which achieves a social optimum in which aggregate welfare of the society is maximized.

Sustainable Resource Use and Economic Dynamics can be described by Cobb-Douglas technology [14]:

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

where A is technology, K capital, L labour, and R a polluting input.

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

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

Capital productivity increases with energy use (and hence with pollution). Capital is a clean substitute for polluting inputs in production. Technological change (increases in *A*) reduces the pollution intensity: it reduces inputs per unit of output and therefore reduces pollution per unit of output.

4 Model of upstream and downstream firms with negative externality

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

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

where k is the number of machine hours per day, l is the number of labor hours per day, 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:

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

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 cause y's output to decline.

Total cost of downstream firm y is

$$TC(y) = r \cdot k + w \cdot l \tag{3}$$

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 total cost of farm enterprise for same output), $-\frac{|\gamma|}{\alpha+\beta}$ is impact of negative externality of producer pollutant.

Using same transformation we can obtain total cost of pollutant:

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

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

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

Total cost will change over time as follows $\frac{\partial TC(y)}{\partial t}$ and will be equivalent 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 $|\gamma|$.

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

In our research, we present an example of the environmental management 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 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).

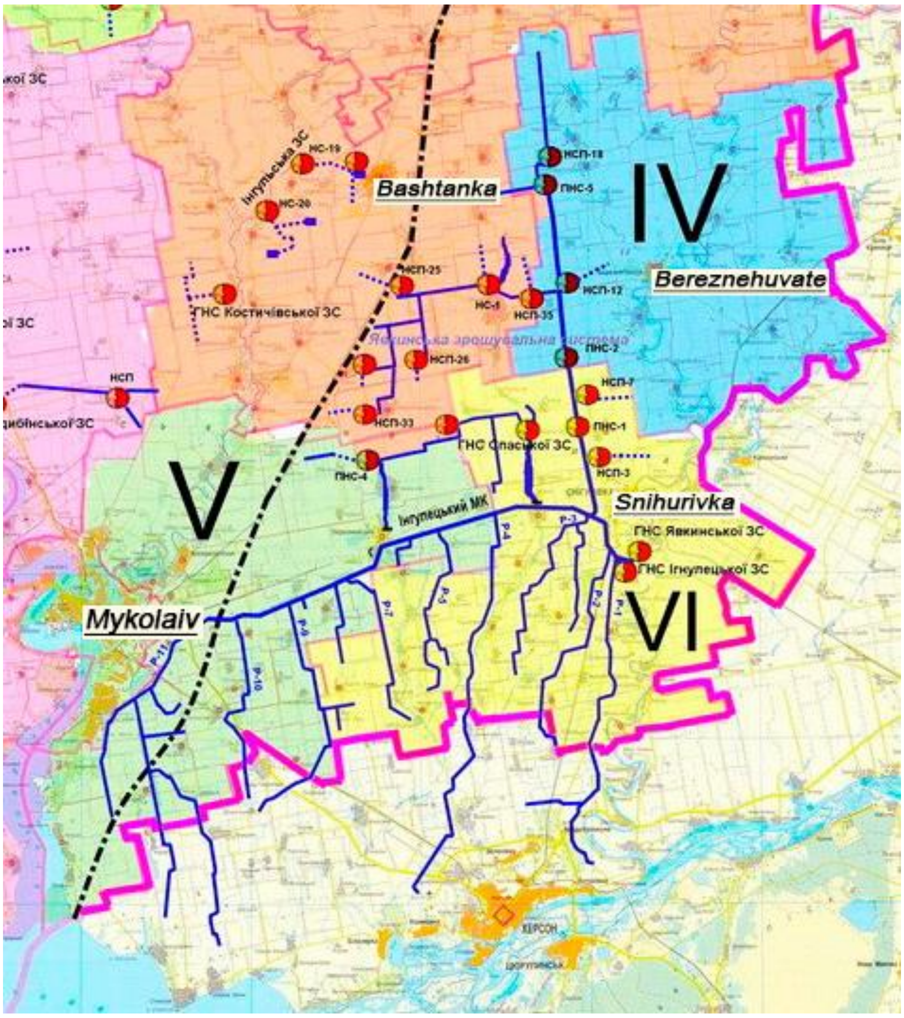

Fig. 1. Water management and reclamation complex of the Mykolaiv region

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 enter in what 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 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	I class	III class

	unsuitable for irrigation	suitable for irrigation	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 was supplied to the headwater the Ingulets River to dilute the river water to safe for watering the 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, do 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).

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	$\boldsymbol{ln}(\boldsymbol{x})$	$\boldsymbol{ln}(\boldsymbol{l})$	$\boldsymbol{ln}(\boldsymbol{k})$
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 $\boldsymbol{y}$, hrn.**	**Labor $\boldsymbol{l}$, hours**	**Capital $\boldsymbol{k}$, hours**	**Output $\boldsymbol{x}$, hrn.**	$\boldsymbol{ln}(\boldsymbol{y})$	$\boldsymbol{ln}(\boldsymbol{l})$	$\boldsymbol{ln}(\boldsymbol{k})$	$\boldsymbol{ln}(\boldsymbol{x})$
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 stability of its output.

7 Conclusions

Our study investigated impact of the 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 model of upstream (pollutant) and downstream (farm enterprise) firms with production negative externality, suppose producer pollutant and farm enterprise along Ingulets river using experimental data and OLS method. The results of the study and practical recommendations will allow participants of the technological process to respond quickly on 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 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 stability of its output.

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