Research note: A note on pollution cleanup investments, signalling, Ganges River resilience, and lessons for Europe

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Abstract: We study pollution cleanup investments, signalling, and the resilience of the Ganges River when investors differ in capability and cleanup projects differ in their ability to enhance resilience. First, we derive the minimal level of signalling necessary to sustain a separating equilibrium in which the government agency can distinguish between more and less capable investors. Larger cleanup efforts require greater signalling, although the marginal increase in signalling declines as the scale of cleanup expands. Second, we analyse the benchmark case in which signalling is impossible. Here, more and less capable investors choose the more resilience enhancing cleanup projects because the expected payment from these projects is larger than the payment from less resilience enhancing projects. Hence, eliminating signalling raises investor welfare and encourages projects that are more beneficial for the resilience of the Ganges.

Keywords: Ganges river, investment, pollution cleanup, resilience, signalling

Introduction

The water pollution problem in the Ganges River is widely recognized to be one of the most serious environmental challenges in the world (Dwivedi et al., 2018). Despite its immense cultural, religious, and economic importance, the Ganges is heavily contaminated by untreated sewage, industrial effluents, agricultural runoff, and solid waste. The rapid urbanization along its banks has overwhelmed existing infrastructure, leading to the discharge of billions of liters of untreated wastewater each day. This has resulted in dangerously high levels of pathogens, toxic chemicals, and heavy metals, posing severe risks to human health, aquatic ecosystems, and biodiversity (Batabyal, 2023; 2025). Efforts such as the National Mission for Clean Ganga have made some progress, but enforcement gaps, population pressures, and institutional challenges continue to hinder meaningful improvement, underscoring the scale and urgency of the crisis.

The Indian government has recognized the severity of the Ganges water pollution problem, and it has sought financial support from a variety of public and private sources to help clean up water pollution in the river. Public and private banks

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are contributing to the cleanup of the Ganges through a structured financing model known as the Hybrid Annuity Model (HAM), which was developed by the World Bank Group to attract private investment (Nayi et al., 2026). Private banks have recently entered this sector, signalling growing confidence in the bankability of water infrastructure projects.

Following the work of Batabyal & Beladi (2023) and many others, we know that the Ganges River is an example of an ecological-economic system. In such systems, economic activities—such as production, consumption, and investment—both depend on and influence ecological processes like nutrient cycling, sediment transport, and climate regulation. For such systems, the notion of Holling resilience, introduced by Holling (1973), is a significant measure of health because it emphasizes the capacity of the system to absorb shocks and disturbances (e.g., pollution, resource depletion, or climate change) without shifting into a qualitatively different and possibly undesirable state. High resilience implies that an ecological-economic system can maintain its structure, functions, and feedbacks despite stress, thereby supporting long-term sustainability and human well-being. Conversely, low resilience raises the risk of abrupt regime shifts—such as a system collapse or the loss of system services—that can have severe economic and social outcomes (Batabyal, 1998).

Recently, Batabyal & Yoo (2026) have used a contract theory perspective to analyse how alternate water pollution cleanup projects, for which investors approach banks for financing, contribute to the resilience of the Ganges River. These researchers show that, inter alia, when banks cannot distinguish between pollution cleanup projects, a so-called pooling equilibrium emerges in which loan repayment terms reflect average project quality and only a restricted set of cleanup projects is financed, thereby limiting potential enhancements in the resilience of the Ganges River.

We continue this line of inquiry in our note for the following reasons: a contract theory perspective is helpful for studying river water pollution cleanup because it directly addresses the informational asymmetry between funders and investors, where investor capability is unobservable at the time of hiring. Inter alia, this perspective allows the design of payment schedules and costly signalling mechanisms that can induce a separating equilibrium, enabling a government agency to distinguish more capable from less capable investors. It also allows us to study the no-signalling benchmark, showing how expected payments drive both types of investors to choose more resilience-enhancing projects. By permitting us to model minimal signalling levels, project selection, and welfare consequences under different information regimes, contract theory provides us with rigorous tools to mitigate informational externalities, align incentives, and improve the efficiency of pollution cleanup investments.

Section 1 below describes our theoretical framework. Section 2 determines the minimal level of signalling that leads to a separating equilibrium in which the agency can distinguish between more and less capable investors. Second, assuming no signalling, section 3 analyses which kinds of cleanup projects are undertaken by which types of investors and who gains and who loses from the cleanup projects that are undertaken. Section 4 discusses the implications of our analysis for river water pollution cleanup in Europe. Section 5 concludes and then suggests two extensions of the research described in this note.

1. The theoretical framework

Consider a city along the Ganges River such as Kanpur or Prayagraj or Varanasi in north India. A government agency wishes to hire investors with projects to clean up water pollution in this part of the Ganges River. The available projects are either good, meaning that they are more resilience enhancing, or bad, meaning that they are less resilience enhancing. The resilience under consideration is the resilience of the Ganges River after a particular cleanup project has been undertaken.

The work of Pelletier et al. (2020) and Wohl et al. (2024) suggests that cleaning up water pollution is likely to increase the "absorbing capacity" and therefore, the resilience of the Ganges River. Given this suggestion, it makes sense to interpret a good (bad) cleanup project as one that is more (less) likely to enhance the resilience of the Ganges River in the vicinity of the city where the cleanup is taking place.

There are two kinds of investors that our government agency interacts with. These investors are either more or less capable. To keep the subsequent mathematical analysis straightforward, we now make two assumptions. First, we suppose that ζ percent of the available investors are more capable and the remaining $(1-\zeta)$ percent are less capable. Second, relative to less capable investors, we suppose that there are a greater number of more capable investors. We model this assumption by stipulating that $\zeta > 55$ percent. With a bad or less resilience enhancing project, either type of investor---more or less capable---cleans up the same $w > 0$ units of water pollution. In contrast, with a good or more resilience enhancing project, the more capable investor cleans up $10w$ units of water pollution and the less capable investor cleans up 0 units of water pollution.

There are numerous good and bad pollution cleanup projects in our model. The government agency pays for each type of pollution cleanup project that it expects a hired investor to carry out. The type of investor is unknown to the government agency at the time of hire. This notwithstanding, more capable investors are able to signal their type, potentially by pointing to a track record of having completed water pollution cleanup projects successfully in the past and/or through third-party certification programmes. The cost of signalling to level σ is $\sigma^2/2$ for a more capable investor and it is σ^2 for a less capable investor. This signalling cost is measured in the same units as the amount of output, which is the amount of pollution cleaned up by the various investors.

With this background in place, our next task is to determine the minimal level of signalling that leads to a separating equilibrium in which the government agency can distinguish between more and less capable investors.

2. Minimal level of signalling

Let us proceed to obtain the minimal level of signalling σ that results in a separating equilibrium as follows. Given a payment schedule for our government agency or $\Pi(\sigma)$, more capable investors receive a payoff from signalling to level σ given by

$$\Pi(\sigma) - \frac{\sigma^2}{2}. \quad (1)$$

Similarly, less capable investors receive a payoff that can be written as

$$\Pi(\sigma) - \sigma^2. \quad (2)$$

Now, if $\sigma = \sigma^*$ achieves the separation that we seek then our government agency's payment schedule satisfies

$$\Pi(\sigma) = \begin{cases} w \; if \; \sigma < \sigma^* \\ 10w \; if \; \sigma \geq \sigma^* \end{cases}. \quad (3)$$

Given the above payment schedule, it follows that the minimal level of $\sigma = \sigma^*$ that leads to a separating equilibrium has the property that the less capable investors are indifferent between receiving a payment of w when they are working with a bad or less resilience enhancing cleanup project with no signalling and receiving a higher payment of $10w$ with a good or more resilience enhancing project with minimal signalling of $\sigma = \sigma^*$.

Given the above line of reasoning, the minimal level of signalling $\sigma = \sigma^*$ solves

$$w \geq 10w - \sigma^2 \quad (4)$$

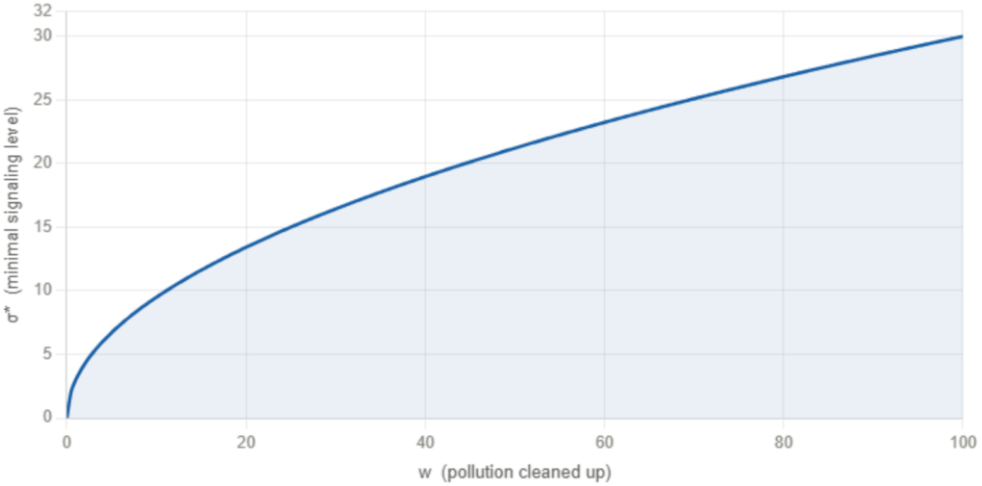
which can also be written as

$$\sigma \geq \sqrt{9w} \Rightarrow \sigma \geq 3\sqrt{w}. \quad (5)$$

Inspecting equation (5), it is clear that the minimal level of signalling that we seek or $\sigma^* = 3\sqrt{w}$.

The above equation describes and Figure 1 shows a simple nonlinear relationship between w and the minimal signal σ^*. We see that the relationship between the amount of pollution cleaned up or w with a bad or less resilience enhancing cleanup project and the minimal signal σ^* is positive. In other words, as $w \uparrow \Rightarrow \sigma^* \uparrow$. Second, we see nonlinear (concave) growth. Put differently, σ^* increases with w but at a decreasing rate. Early increases in w lead to relatively large increase in the minimal signal σ^* but as w gets larger, each additional unit of w adds less to the minimal signal σ^*. Third, there is a diminishing marginal effect at work here. Mathematically, the slope $d\sigma^*/dw = 3/2\sqrt{w}$ decreases as w increases. Finally, there is a scaling interpretation that we can see. Specifically, the minimal signal σ^* is proportional to the square root of w and therefore, if w quadruples, then the minimal signal σ^* doubles.

Figure 1. Properties of the minimal signal level function



Source: author's representation

Our final task in this note is to investigate, when there is no signalling, which kinds of cleanup projects are undertaken by which types of investors and who gains and who loses from the cleanup projects that are undertaken.

3. Water pollution cleanup with no signalling

When signalling is not possible, if both types of investors (more and less capable) select the good or more resilience enhancing project, then the expected payment or Π_g for doing this is

$$\Pi_g = \zeta \times 10w + (1-\zeta) \times 0 = 10\zeta w. \tag{6}$$

On the other hand, the payment for either type of investor when carrying out the bad or less resilience enhancing project or Π_b is

$$\Pi_b = w. \tag{7}$$

Inspecting equations (6) and (7), we see that $\Pi_g = 10\zeta w > w = \Pi_b$ because $\zeta > 0.55$. Therefore, it follows that both types of investors will want to undertake the good or more resilience enhancing pollution cleanup projects and the bad or less resilience enhancing cleanup projects will not be undertaken at all. Compared to the separating equilibrium studied in section 2, the less capable investors now benefit because

$$\Pi_g = 10\zeta w > w = \Pi_b. \tag{8}$$

But observe that the more capable investors also benefit because

$$\Pi_g = 10\zeta w > 10w - \frac{(3\sqrt{w})^2}{2} = 10w - 4.5w = 5.5w. \tag{9}$$

Equations (8) and (9) together tell us that, in the case we are analyzing, everyone benefits by banning signalling because the cost of obtaining a separating equilibrium is too high. The reader should note that this result in our model depends on our assumption that $\zeta > 0.55$ or that relative to the less capable investors, there are a greater number of more capable investors. We now briefly discuss the implications of our analysis for river water pollution cleanup in Europe.

4. Implications for Europe

The analysis in this note suggests that river water pollution cleanup in Europe should not focus solely on maximizing technical capability or screening investors through increasingly elaborate selection mechanisms. Instead, policymakers should pay greater attention to the incentives embedded in cleanup financing and governance arrangements. In our model, when signalling is costly—that is, when investors must expend resources to demonstrate their capability—some of the resources that could have gone into environmental restoration are diverted toward proving project quality. Our analysis shows that larger cleanup efforts require greater signalling effort, although at a diminishing rate, implying that administrative and certification burdens can rise substantially as projects scale up. For European river systems such as the Rhine River, the Danube River, or the Seine River, this finding points to the value of designing procurement and funding institutions that minimize unnecessary transactions and signalling costs while still maintaining accountability.

More broadly, the analysis here implies that European river pollution cleanup policy should prioritize outcome-based incentives that reward projects according to their contribution to ecological resilience rather than emphasizing *ex ante* distinctions among project developers. In the benchmark case without signalling, both more and less capable investors selected projects that generated greater resilience because expected returns were aligned with environmental performance. Applied to Europe, this suggests that cleanup programmes may perform better when subsidies, contracts, and public-private partnerships are structured around measurable improvements in river resilience—such as enhanced pollutant absorption capacity, ecosystem recovery, and long-run water quality outcomes—rather than relying excessively on certifications, reputational screening, or procedural compliance. Such an approach can direct more financial resources into actual pollution reduction and strengthen the long-term resilience of European river ecosystems. This concludes our discussion of pollution cleanup investments, signalling, and the resilience of the Ganges River.

Conclusions

In this note, we have studied pollution cleanup investments, signalling, and the resilience of the Ganges River in a setting in which investors differed in capability and cleanup projects differed in their ability to enhance resilience. We modelled a government agency attempting to hire investors to undertake water pollution cleanup projects when investor capability was initially unobservable. In this environment, more capable investors could distinguish themselves from less capable investors through costly signalling.

Our analysis yielded two principal findings. First, we derived the minimal level of signalling necessary to sustain a separating equilibrium in which the government agency could distinguish between more and less capable investors. The resulting signalling function displayed a positive but concave relationship between the amount of pollution cleaned up and the minimal signalling level. This result implies that larger cleanup efforts require greater signalling, although the marginal increase in signalling declines as the scale of cleanup expands.

Second, we examined the benchmark case in which signalling was not possible. In this scenario, both more and less capable investors selected the more resilience enhancing cleanup projects because the expected payment from undertaking these projects exceeded the payment from undertaking less resilience enhancing projects. Importantly, both kinds of investors benefited when signalling was banned because they no longer incurred the costs associated with signalling. Therefore, in the specific setting analysed here, eliminating signalling increased investor welfare and encouraged the undertaking of projects that were more beneficial for the resilience of the Ganges River.

The analysis in this paper can be extended in at least two directions. First, future research could explicitly incorporate uncertainty about the long-run ecological effects of alternate cleanup projects on the Ganges River’s resilience. Second, it would be useful to study an intertemporal version of the model in which investor reputation evolves over time as cleanup outcomes become publicly observable. Such extensions will enhance our understanding of how institutional design and informational asymmetries influence environmental restoration efforts in ecological-economic systems such as the Ganges River.

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