Centralized versus Decentralized Cleanup of River Water Pollution: An Application to the Ganges

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Abstract

We exploit the public good attributes of Ganges water pollution cleanup and theoretically analyze an aggregate economy of two cities---Kanpur and Varanasi---through which the Ganges flows. Our specific objective is to study whether water pollution cleanup in these two cities ought to be provided in a centralized or in a decentralized manner. We first determine the *efficient* cleanup amounts that maximize the aggregate surplus from making the Ganges cleaner in the two cities. Second, we compute the optimal amount of water pollution cleanup in the two cities in a *decentralized* regime in which spending on cleanup is financed by a uniform tax on the city residents. Third, we ascertain the optimal amount of water pollution cleanup in the two cities in a *centralized* regime subject to equal provision of cleanup and cost sharing. Fourth, we show that if the two cities have the *same* preference for pollution cleanup then centralization is preferable to decentralization as long as there is a spillover from pollution cleanup. Finally, we show that if the two cities have *dissimilar* preferences for pollution cleanup then centralization is preferable to decentralization as long as the spillover exceeds a certain threshold.

Keywords: Ganges River, Pollution Cleanup, Spillover, Uncertainty, Water Pollution

JEL Codes: Q53, Q56, D81

1. Introduction

1.1. Preliminaries

The Ganges (Ganga in Hindi) river in the Indian subcontinent is unique in the sense that it is both the longest and the most significant river in this nation.[4] This notwithstanding, Black (2016) notes that more than a billion gallons of waste are deposited into the Ganges every day. Although the problem of waste deposition into the Ganges occurs at various points along the river, Gallagher (2014), Black (2016), Jain and Singh (2020) and Batabyal *et al*. (2023a) point out that with regard to the flow of water and pollution in this river, three problems deserve particular emphasis.

The first problem is water pollution from the tannery industry which is located primarily in the city of Kanpur in the state of Uttar Pradesh (see Figure 1). The significance of the tannery

Figure 1 about here

industry in Kanpur explains why this city is sometimes referred to as India's "leather city."[5] The second problem is waste deposited into the Ganges in the city of Varanasi, also in the state of Uttar Pradesh, which is, as shown in Figure 1, located to the south-east of and approximately two hundred miles downstream from Kanpur. A lot of the pollution in Varanasi, the spiritual center of Hinduism, is the outcome of Hindu religious activities. In this regard, Dhillon (2014) points out that 32,000 bodies are cremated every year in Varanasi and that this process results in 300 tons of ash and 200 tons of half-burnt human flesh being deposited into the Ganges. The third problem is that the phenomenon of climate change is diminishing water flows in the Ganges and this factor,

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See Markandya and Murty (2004) for a more detailed corroboration of this claim.

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Go to https://mahileather.com/blogs/news/the-world-s-most-famous-leather-markets for a more detailed discussion of this point. Accessed on 16 January 2023.

along with other factors, has, most likely, reduced the river's natural capacity to absorb pollutants that are deposited into it.

The question of regulating water pollution in the Ganges caused by tanneries in Kanpur has recently been studied from a variety of perspectives by Batabyal (2022), Batabyal and Yoo (2022), and Batabyal *et al*. (2023b). Similarly, the topic of how pollution in the Ganges in Varanasi ought to be managed has received attention in the literature from Batabyal and Beladi (2017, 2019a, 2020) and Xing and Batabyal (2019). Finally, the impact that climate change has on the regulation of pollution caused by the activities of tanneries in Kanpur has been analyzed by Batabyal *et al*. (2023b).

The above papers have certainly increased our understanding of many aspects of the complex problem that water pollution cleanup in the Ganges actually is. Even so, as noted by Das and Tamminga (2012, p. 1649), it is important to comprehend that "[e]fforts to clean the Ganges have, so far, fallen far short of their stated goals." Das and Tamminga (2012, p. 1649) proceed to point out that this unhappy state of affairs is the result of water pollution cleanup in the Ganges being excessively centralized with pollution abatement programs "imposed from the top…" with little or no attempts being made to collaborate with local institutions. Echoing this refrain and focusing on tanneries in Kanpur, Singh and Gundimeda (2021, p. 73) point out that "[e]nvironmental regulations in the Indian leather industry have been restricted to [command-and-control] policies, with mandatory uniform pollution control norms across all the tanneries." Das and Tamminga (2012, p. 1649) argue persuasively that for pollution cleanup in the Ganges to be effective, it needs to be decentralized, "with the transfer of responsibilities from the state to local or community institutions."

1.2. Objective

The above discussion leads naturally to the following salient question: When should water pollution cleanup in the Ganges be centralized and when should it be decentralized? To the best of our knowledge, this question has *not* been studied previously in the literature. Therefore, our central objective in this paper is to analyze this question. However, before we move to the specifics of the paper itself, it is important to point out that we wish to connect our study of the centralization versus decentralization matter to the notion of *spillovers* from water pollution cleanup in the Ganges.

To understand the significance of spillovers, recall that because Varanasi is located about 200 miles *downstream* from Kanpur, pollution cleanup undertaken in upstream Kanpur will benefit Varanasi residents because these residents will now be less exposed to contaminated river water flowing down from Kanpur. In other words, some of the benefits of pollution cleanup in Kanpur will spill over to Varanasi residents. Similarly, given Varanasi's status as the spiritual center of Hinduism, pollution cleanup carried out in Varanasi will benefit some (mainly Hindu) Kanpur residents because when they travel to Varanasi to, *inter alia*, bathe in the Ganges, perform religious rites, and cremate their dead, they will benefit from cleaner river water in Varanasi. In sum, there are spillovers from water pollution cleanup in the Ganges and these spillovers have also *not* been studied in the literature thus far. As such, to reformulate our central objective stated above, we wish to study the role that spillovers play in determining when water pollution cleanup in the Ganges ought to be centralized or decentralized.

The remainder of this paper is organized as follows: Section 2 delineates our theoretical modelof two cities Kanpur (K) and Varanasi (V) that is adapted from the discussion in Batabyal and Beladi (2019b).[6] Section 3 computes the efficient pollution cleanup amounts that maximize the total surplus from cleaning the Ganges in Kanpur and Varanasi. Section 4 calculates the amount of pollution cleanup made available in Kanpur and Varanasi in a decentralized regime in which spending on pollution cleanup is financed by a uniform tax on the residents of the two cities. Section 5 determines the amount of pollution cleanup in Kanpur and Varanasi in a centralized regime subject to the condition that pollution cleanup and the sharing of costs are both the same in the two cities. Section 6 demonstrates that if Kanpur and Varanasi have identical preferences for pollution cleanup then centralization is preferable to decentralization as long as there is a spillover from pollution cleanup in the Ganges. Section 7 shows that if Kanpur and Varanasi have non-identical preferences for pollution cleanup then centralization is, once again, preferable to decentralization but only if the spillover exceeds a certain threshold. Section 8 concludes and then suggests three ways in which the research described in this paper might be extended.

2. The Theoretical Framework

Consider a stylized, aggregate economy of two cities Kanpur and Varanasi. As shown in Figure 1, both cities lie on the Ganges, both cities are located in the state of Uttar Pradesh, and they are denoted by the subscript $i = K, V$. These two cities are assumed to have the same population size. In addition, the population in each city i is represented by a continuum of individuals with a mass of unity. There are three goods that we work with in our model. The first is a private good that is denoted by x. The second and the third goods are the amounts of water pollution cleaned up in the two cities and these amounts are denoted by w_K and w_V.

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See Sheehan and Kogiku (1981) for a general discussion of the role of game-theoretic modeling in the context of water resource problems.

It is now well known that pollution cleanup shares the characteristics of public goods in the sense that this cleanup is both non-excludable and non-rivalrous.[7] In the setting of our paper, non-excludable means that if water pollution cleanup is provided in Kanpur and Varanasi then no resident of either of these two cities can be excluded from benefiting from the cleanup. Non-rivalry means that the benefit obtained by any one resident of either Kanpur or Varanasi from the amount of water pollution cleaned up does not diminish the benefit obtainable by any other resident of these same two cities. Therefore, in the remainder of this paper, we shall think of water pollution cleanup in Kanpur and Varanasi as public goods for all intents and purposes.

One unit of either w_K or w_V requires c units of the private good to produce. The residents of Kanpur and Varanasi are *heterogeneous* in the sense that they differ in their preference for water pollution cleanup. So, a resident of type θ who lives in city i has a utility function given by

$$u_\theta(x, w_i, w_{-i}) = x + \theta\{(1-\delta)\log(w_i) + \delta\log(w_{-i})\}, \tag{1}$$

where $\delta \in [0,\ 1/2]$ measures the extent of the inter-city spillover from cleaning up water pollution in the Ganges. As explained in section 1.2, this means that pollution cleanup in Kanpur leads to a spillover in Varanasi and vice versa. The two extreme cases are given by the endpoints of the closed interval $[0, 1/2]$. Specifically, when $\delta = 0$ there is no inter-city spillover and the residents of city i care only about pollution cleanup in their own city. In contrast, when $\delta = 1/2$ the residents in our aggregate economy care equally about pollution cleanup in the two cities under study.

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7 Go to https://resources.environment.yale.edu/kotchen/pubs/pgchap.pdf and to https://plato.stanford.edu/entries/public-goods/ for a more detailed corroboration of this claim. Accessed on 16 January 2023. See Hindriks and Myles (2013, pp. 147-190), for a textbook discussion of public goods.

In each city i, residents with preference type θ are assumed to be distributed in accordance with a cumulative distribution function $F_i(\theta)$ that is defined on the interval $[0, \bar{\theta}]$ and has mean[8] denoted by $\zeta_i < \bar{\theta}/2$. Now, consistent with the discussion in the preceding paragraph of the heterogeneity of the residents in the two cities, we suppose that compared to Varanasi, Kanpur displays a stronger mean preference for water pollution cleanup. In symbols, this means that $\zeta_K > \zeta_V$. This concludes the description of our theoretical framework. We now compute the efficient pollution cleanup amounts that maximize the total surplus from cleaning up pollution in the Ganges in Kanpur and Varanasi.

3. Efficient Pollution Cleanup Amounts

We begin by denoting the income of a type θ resident of city i by M_{θ_i}. We can now express the *total* welfare in city i as

$$U_i = \int_0^{\bar{\theta}} dF_i(\theta)[x_{\theta_i} - cw_i + \theta\{(1-\delta)\log(w_i) + \delta\log(w_{-i})\}]. \tag{2}$$

The aggregate welfare in the two cities under study can be written as $W = U_K + U_V$. We also have an aggregate budget constraint and this constraint tells us that we must have

$$\int_0^{\bar{\theta}} dF_K(\theta)x_{\theta_A} + \int_0^{\bar{\theta}} dF_V(\theta)x_{\theta_B} = \int_0^{\bar{\theta}} dF_K(\theta)M_{\theta_A} + \int_0^{\bar{\theta}} dF_V(\theta)M_{\theta_B} - c(w_K + w_V). \tag{3}$$

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We assume that the mean is equal to the median in both cities under study. This means that the preference type distribution functions are symmetrical in nature.

In order to maximize the welfare of our aggregate economy, we need to set $\partial W/\partial w_i = 0, i = K, V.$[9] So, let us use equations (2), (3), and then differentiate $W(\cdot)$ with respect to w_K. This gives us

$$\frac{\partial\{U_K+U_V\}}{\partial w_K} = \int_0^{\overline{\theta}} dF_K(\theta)\left\{\frac{\theta(1-\delta)}{w_K} - c\right\} + \int_0^{\overline{\theta}} dF_V(\theta)\frac{\theta\delta}{w_K} = 0 \qquad (4)$$

and we get a similar equation when setting $\partial\{U_K + U_V\}/\partial w_V = 0$. We can now use standard expressions from statistics for the expected value of a random variable---see Taylor and Karlin (1998, pp. 9-15)---to simplify the two first-order necessary conditions for an optimum. This gives us

$$\frac{\zeta_i(1-\delta)}{w_i} + \frac{\zeta_{-i}\delta}{w_{-i}} = c, i = K, V. \qquad (5)$$

Solving the system of two equations described by (5) in the two unknowns w_K and w_V, we get the efficient pollution cleanup amounts that maximize the total surplus in our aggregate economy consisting of Kanpur and Varanasi. Let us denote these *efficient* levels by $w_i^E, i = K, V$. We obtain

$$w_i^E = \frac{\zeta_i(1-\delta)+\zeta_{-i}\delta}{c}, i = K, V. \qquad (6)$$

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We assume that the resulting solution is an interior solution.

Inspecting equation (6), we see that the efficient pollution cleanup amounts depend *positively* on the mean preference for pollution cleanup (ζ_i, ζ_{-i}) in the two cities and *negatively* on the number of units of the private good (c) needed to produce and provide the two efficient cleanup amounts. Our next task is to determine the pollution cleanup amounts in Kanpur and Varanasi in a decentralized setting in which spending on water pollution cleanup is financed by a uniform tax on the residents of the two cities.

4. Decentralized Provision of Pollution Cleanup

In the decentralized regime, each city *independently* chooses water pollution cleanup amount w_i to maximize the total city welfare U_i. Public spending on pollution cleanup in each city is financed by a uniform tax on the residents of the city. This means that if the ith city provides pollution cleanup of amount w_i then each resident of city i pays a tax given by $t_i = cw_i$. Given these changes, the expression for U_i is now given by

$$U_i = \int_0^{\bar{\theta}} dF_i(\theta)\left[M_{\theta_i} - cw_i + \theta\{(1-\delta)\log(w_i) + \delta\log(w_{-i})\}\right]. \tag{7}$$

The first order necessary conditions for an interior optimum are given by setting $\partial U_i / \partial w_i = 0, i = K, V$. Doing this and then simplifying the resulting expressions gives us the two optimal pollution cleanup amounts under decentralization. Denoting these two amounts by $w_i^D, i = K, V$, we get

$$w_i^D = \frac{\zeta_i(1-\delta)}{c}, i = K, V. \tag{8}$$

Inspecting equation (8), we see that like the efficient pollution cleanup amounts case analyzed in section 3 and described by equation (6), the optimal decentralized pollution cleanup amounts also depend *positively* on the mean preference for pollution cleanup (ζ_i) in the two cities and *negatively* on the number of units of the private good (c) needed to provide the two decentralized pollution cleanup amounts. That said, subtracting the right-hand-side (RHS) of equation (8) from the RHS of equation (6), we see that

$$w_i^E - w_i^D = \frac{\zeta_{-i}\delta}{c} > 0 \quad (9)$$

as long as $\delta > 0$.

Equation (9) tells us that as long as there is a pollution cleanup related spillover between Kanpur and Varanasi, the efficient pollution cleanup amounts that are provided are *greater* in magnitude than the pollution cleanup amounts provided in the decentralized regime. Further, in the special case in which there is no spillover and therefore $\delta = 0$, the efficient and the decentralized pollution cleanup amounts coincide. We now ascertain the amount of pollution cleanup that is made available in a centralized regime subject to the condition that cleaning up water pollution in the Ganges and the sharing of costs are the same in Kanpur and Varanasi.

5. Centralized Provision of Pollution Cleanup

In the centralized regime, the pertinent pollution cleanup amounts in the two cities are chosen by a central authority with two specific conditions. First, there is the equal provision of pollution cleanup requirement and this means that $w_K = w_V = w$. Second, there is equal cost sharing of the pollution cleanup that is provided and this means that each resident in either city pays $t_i = c(w_K + w_V)/2$. These two conditions together ensure that the central authority displays no favoritism towards either Kanpur or Varanasi. With these two changes, the expression for U_i now is

$$U_i = \int_0^{\overline{\theta}} dF_i\,(\theta)\big[M_{\theta_i} - cw + \theta\log(w)\big]. \tag{10}$$

To determine the optimal pollution cleanup amount or w, we need to solve for $d\{U_K + U_V\}/dw = 0$. Using equation (10) and then differentiating with respect to w, we get

$$\frac{d\{U_K+U_V\}}{dw} = \int_0^{\overline{\theta}} dF_K\,(\theta)\left\{\frac{\theta}{w} - c\right\} + \int_0^{\overline{\theta}} dF_V(\theta)\left\{\frac{\theta}{w} - c\right\} = 0. \tag{11}$$

Using standard expressions from statistics for the expected value of a random variable---see Taylor and Karlin (1998, pp. 9-15)---we can simplify the RHS of equation (11). This gives us

$$\frac{\zeta_K+\zeta_V}{w} - 2c = 0. \tag{12}$$

Denoting the optimal pollution cleanup amount in the centralized setting by w^C, we get

$$w^C = \frac{\zeta_K+\zeta_V}{2c}. \tag{13}$$

Inspecting equation (13), we see that like the cases analyzed in sections 3 and 4, the optimal centralized pollution cleanup amount depends *positively* on the mean preference for pollution cleanup in the two cities (ζ_K, ζ_V) and *negatively* on the number of units of the private good (c) needed to provide the centralized pollution cleanup amount. Subtracting the right-hand-side (RHS) of equation (13) from the RHS of equation (6), we see that

$$w_i^E - w^C = \frac{(\zeta_i-\zeta_{-i})(1-2\delta)}{2c}. \tag{14}$$

Now recall that the spillover parameter $\delta \in [0, 1/2]$ and that $\zeta_K > \zeta_V$. Using these two pieces of information along with the result contained in equation (14), we deduce that

$$w_K^E \geq w^C \geq w_V^E. \quad (15)$$

The result in (15) contains an interesting but negative finding about the centralized provision of pollution cleanup in the two cities under study. Specifically, we see that in the centralized regime, pollution cleanup will be *underprovided* in the city (Kanpur) that has a stronger mean preference for pollution cleanup ($w_K^E \geq w^C$) and *overprovided* in the city (Varanasi) that has a weaker mean preference for pollution cleanup ($w^C \geq w_V^E$). We now want to show that if Kanpur and Varanasi have identical preferences for pollution cleanup then centralization is preferable to decentralization as long as there is a spillover from cleaning up water pollution in the Ganges.

6. Identical Preferences for Pollution Cleanup

We model the identical preferences for pollution cleanup in Kanpur and Varanasi by supposing that $\zeta_K = \zeta_V$. Also, since the spillover from the cleanup of water pollution in the Ganges is positive, we have $\delta > 0$. The welfare of the ith city in the decentralized regime is given by equation (7) and therefore equation (8) gives us the optimal pollution cleanup amounts in this regime. So, using this last result and denoting the total income in the ith city by M_i, we can now write

$$U_i^D = M_i - \zeta_i(1-\delta) + \zeta_i\left[(1-\delta)log\left\{\frac{\zeta_i(1-\delta)}{c}\right\} + \delta log\left\{\frac{\zeta_{-i}(1-\delta)}{c}\right\}\right]. \quad (16)$$

Given equation (16), the welfare in our aggregate economy of the two cities Kanpur and Varanasi can be written as

$$W^D = M - (\zeta_K + \zeta_V)(1-\delta) + (\zeta_K + \zeta_V)log\left\{\frac{1-\delta}{c}\right\} + \{\zeta_K(1-\delta) + \zeta_V\delta\}\log(\zeta_K) + \{\zeta_K\delta + \zeta_V(1-\delta)\}\log(\zeta_V), \quad (17)$$

where we have used $M = M_K + M_V$ to denote the total income in our aggregate economy.

When water pollution is cleaned up in Kanpur and Varanasi in the centralized regime, the welfare of the ith city is given by equation (10) and the optimal amount of pollution cleaned up or w^C is given by equation (13). Using these two pieces of information, we can write the welfare of the ith city as

$$U_i^C = M_i - \frac{\zeta_i + \zeta_{-i}}{2} + \zeta_i log\left\{\frac{\zeta_i + \zeta_{-i}}{2c}\right\}, \quad (18)$$

and the welfare of our aggregate economy as

$$W^C = M - (\zeta_K + \zeta_V) + (\zeta_K + \zeta_V)log\left\{\frac{\zeta_K + \zeta_V}{2c}\right\}. \quad (19)$$

Because $\zeta_K = \zeta_V = \zeta$, the two aggregate welfare expressions in equations (17) and (19) simplify to

$$W^D = M - 2\zeta(1-\delta) + 2\zeta log\left\{\frac{1-\delta}{c}\right\} + 2\zeta\log\{\zeta\} \quad (20)$$

and

$$W^C = M - 2\zeta + 2\zeta log\left\{\frac{\zeta}{c}\right\}. \quad (21)$$

Subtracting the RHS of equation (20) from the RHS of equation (21), we are able to confirm that

$$W^C - W^D = -2\zeta\{\delta + \log(1-\delta)\} > 0, \tag{22}$$

as long as $\delta \in [0, 1/2]$. We have just demonstrated that when there is an inter-city spillover from the provision of pollution cleanup, relative to decentralization, the centralized provision of pollution cleanup gives rise to a *higher* level of welfare. In contrast, when there is no spillover and hence $\delta = 0$, the two city welfare levels under centralization and decentralization are *identical*. We now proceed to our final task in this paper and that is to demonstrate that if the two cities Kanpur and Varanasi have non-identical preferences for pollution cleanup then, once again, centralization is preferable to decentralization as long as the spillover δ from cleaning up pollution in the Ganges exceeds a certain threshold.

7. Dissimilar Preferences for Pollution Cleanup

We account for the dissimilar preferences for pollution cleanup in Kanpur and Varanasi by supposing that the inequality $\zeta_K > \zeta_V$ holds. Next, we write the expression corresponding to equation (22) in the case where the two cities have dissimilar preferences for pollution cleanup. After some algebraic steps, we get

$$W^C - W^D = -\delta(\zeta_K + \zeta_V) - (\zeta_K + \zeta_V)\log(1-\delta) + (\zeta_K + \zeta_V) log\left\{\frac{\zeta_K + \zeta_V}{2}\right\} - [\{\zeta_K(1-\delta) + \zeta_V\delta\}\log(\zeta_K) + \{\zeta_K\delta + \zeta_V(1-\delta)\}\log(\zeta_V)]. \tag{23}$$

Focusing for the moment on the parameter δ denoting the spillover associated with cleaning up pollution in the Ganges, we can rewrite the expression on the RHS of equation (23) as

$$W^C - W^D = \Delta W(\delta), \tag{24}$$

where Δ denotes the change in welfare.

Evaluating $\Delta W(\delta)$ at $\delta = 0$, we get

$$\Delta W(0) = (\zeta_K + \zeta_V) log\left\{\frac{\zeta_K+\zeta_V}{2}\right\} - \zeta_K \log(\zeta_K) - \zeta_V \log(\zeta_V). \tag{25}$$

After some algebraic steps, the RHS of equation (25) can be simplified and signed. In particular, because $\zeta_K > \zeta_V$, this process gives us

$$\Delta W(0) = \zeta_K \left[log\left\{\frac{1}{2}\left(\frac{\zeta_V}{\zeta_K} + 1\right)\right\} + \frac{\zeta_V}{\zeta_K} log\left\{\frac{1}{2}\left(\frac{\zeta_K}{\zeta_V} + 1\right)\right\}\right] < 0. \tag{26}$$

Next, we want to evaluate $\Delta W(\delta)$ at $\delta = 1/2$. This gives us

$$\Delta W\left(\frac{1}{2}\right) = (\zeta_K + \zeta_V) log\left\{\frac{\zeta_K+\zeta_V}{2}\right\} - \frac{(\zeta_K+\zeta_V)}{2} - (\zeta_K + \zeta_V) log\left(\frac{1}{2}\right) - \frac{(\zeta_K+\zeta_V)}{2}\{\log(\zeta_K) + \log(\zeta_V)\}. \tag{27}$$

After a couple of steps of algebra, the RHS of equation (27) can also be simplified and signed. This time we get

$$\Delta W\left(\frac{1}{2}\right) = (\zeta_K + \zeta_V)\left[log\left\{\frac{\zeta_K+\zeta_V}{\sqrt{\zeta_K\zeta_V}}\right\} - \frac{1}{2}\right] > 0. \tag{28}$$

Let us now differentiate the expression for $\Delta W(\delta)$ in equation (23) with respect to the spillover parameter δ. This gives us

$$\frac{d\{\Delta W(\delta)\}}{d\delta} = (\zeta_K + \zeta_V)\frac{\delta}{1-\delta} + (\zeta_K - \zeta_V)log\left(\frac{\zeta_K}{\zeta_V}\right) > 0, \tag{29}$$

as long as $\zeta_K > \zeta_V$. Our analysis thus far in this section leads to three results. First, we showed that $\Delta W(0) < 0$. Second, we pointed out that $\Delta W(1/2) > 0$. Finally, since differentiability implies continuity,[10] we have shown that $d\{\Delta W(\delta)\}/d\delta$ is both continuous and monotonically increasing in δ. These three results and the mean value theorem[11] together tell us that there exists a *threshold* $\delta^* \in (0, 1/2)$ such that $\Delta W(\delta^*) = 0$ and $\Delta W(\delta) > 0$ for $\delta \in (\delta^*, 1/2]$.

Our analysis of the provision of pollution cleanup in the aggregate economy consisting of Kanpur and Varanasi shows that there is a clear *tradeoff* between the centralization and the decentralization regimes. Specifically, under centralization, an excessively *high* amount of pollution cleanup is provided in the city with a *lower* preference for pollution cleanup (Varanasi) and an insufficiently *low* amount of pollution cleanup is provided in the city with a *higher* preference for pollution cleanup (Kanpur). In addition, if the inter-city spillover from cleaning up pollution in the Ganges is sufficiently strong ($\delta > \delta^*$), then the extra utility obtained by the residents of the city with a stronger preference for the pollution cleanup provided in the city with a weaker preference for such cleanup compensates them for the *loss* of utility stemming from the *underprovision* of pollution cleanup in their own city. As a result, total welfare in this last instance with pollution cleanup being provided in a centralized manner is *higher* than what it would be with decentralized provision. This completes our analysis of the optimal provision of Ganges water pollution cleanup in an aggregate economy consisting of the two cities Kanpur and Varanasi.

[10] See Theorem 5.2 in Rudin (1976, p. 104) for additional details.

[11] See Rudin (1976, pp. 107-108) for a textbook exposition of the mean value theorem.

8. Conclusions

In this paper, we exploited the public good features of pollution cleanup and theoretically analyzed an aggregate economy of two cities Kanpur and Varanasi in which pollution cleanup could be provided in either a decentralized or a centralized manner. We first determined the efficient pollution cleanup amounts that maximized the aggregate welfare from cleaning water pollution in the Ganges in Kanpur and Varanasi. Second, we computed the optimal amounts of pollution cleanup in the two cities in a decentralized regime in which spending on pollution cleanup was financed by a uniform tax on the city residents. Third, we ascertained the optimal amount of pollution cleanup in the two cities in a centralized regime subject to the equal provision of pollution cleanup and cost sharing. Fourth, we showed that if the two cities have the same preference for pollution cleanup, then centralization was preferable to decentralization as long as there was a spillover from cleaning water pollution in the Ganges. Finally, we showed that if the two cities have dissimilar preferences for pollution cleanup then centralization was, once again, preferable to decentralization as long as the spillover exceeded a critical threshold.

The analysis in this paper can be extended in a number of different directions. In what follows, we suggest three potential extensions. First, in an ecological-economic analysis that is both dynamic and stochastic, we can ask how cleaning water pollution in the Ganges in Kanpur and Varanasi affects the provision of specific ecosystem services such as water for drinking, water for irrigation, the cycling of nutrients, and the maintenance of populations and habitats. Second, in either a centralized or a decentralized regime, it would be helpful to determine the relative merits of using price versus quantity control instruments to clean up pollution in the Ganges. Finally, one could examine how alternate ways of cleaning up water pollution in the Ganges might be used to bring about enhancements in the governance and the sustainability of the tannery industry in

Kanpur and religious tourism in Varanasi. Studies that analyze these aspects of the acute water pollution problem in the Ganges will provide additional insights into the nexuses between the ecological health of the Ganges and the welfare of the millions of people who live in the basin of this river.

Figure 1: Flow of the Ganges and the Locations of Kanpur and Varanasi

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