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by

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Abstract

We study how spillovers from water pollution cleanup in the Ganges affect social welfare in an aggregate economy consisting of Kanpur and Varanasi, two cities through which this river flows. We view pollution cleanup in both cities as a local public good and point out that if Kanpur cleans up pollution in the Ganges then Varanasi obtains some spillover benefit and vice versa. In this setting, we first solve for the Nash equilibrium amounts of pollution cleanup in the two cities when decisions about how much pollution to clean up are made simultaneously; next, we determine the equilibrium welfare levels in each city. Second, on the assumption that decisions about how much pollution to clean up are centralized, we compute the amounts of pollution cleanup that maximize aggregate welfare. Finally, we describe an inter-city transfer scheme that leads each city to choose non-cooperatively in a Nash equilibrium the same pollution cleanup amounts as those that arise when aggregate welfare is maximized.

Keywords: Centralization, Ganges River, Nash Equilibrium, Pollution Cleanup, Spillover

JEL Codes: Q53, Q56, D81

1. Introduction

1.1. Preliminaries

When one looks at the many rivers that flow through the Indian subcontinent, there is no doubt that the Ganges (Ganga in Hindi) river is exceptional because it is both the longest and the most noteworthy river.[3] Even so, Black (2016) has pointed out 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 a number of points along the river, Markandya and Murty (2004), Gallagher (2014), Black (2016), Jain and Singh (2020) and Batabyal *et al*. (2023a) rightly note that as far as the flow of water and pollution in this river are concerned, three issues deserve to be highlighted.

The first issue is water pollution arising from the activities of the tannery industry which is situated mainly in the city of Kanpur in the state of Uttar Pradesh (see Figure 1). The importance

Figure 1 about here

of the tannery industry in Kanpur explains why the moniker "leather city" is occasionally used to refer to this city.[4] The second issue is waste deposited into the Ganges in the city of Varanasi, also in the state of Uttar Pradesh. As demonstrated in Figure 1, Varanasi is situated to the south-east of and roughly two hundred miles downstream from Kanpur. Varanasi is standardly considered to be the spiritual center of Hinduism and therefore a lot of the pollution in this city is the result of Hindu religious activities. In support of this claim, Dhillon (2014) points out that 32,000 bodies are cremated every year in Varanasi and that this process leads to 300 tons of ash and 200 tons of half-

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

4

Go to https://mahileather.com/blogs/news/the-world-s-most-famous-leather-markets for a more detailed discussion of this point. Accessed on 23 May 2023.

burnt human flesh being dumped into the Ganges. The third issue is that global warming or climate change is reducing water flows in the Ganges and this, *inter alia*, has lessened the river's natural capacity to absorb pollutants that are deposited into it.

Several papers in the recent literature by researchers such as Singh and Gundimeda (2021), Batabyal (2022), Batabyal and Yoo (2022), and Batabyal *et al*. (2023b) have analyzed the regulation of water pollution in the Ganges caused primarily by tanneries in Kanpur. Likewise, the topic of how pollution in the Ganges in Varanasi ought to be overseen has been studied by Batabyal and Beladi (2017, 2019, 2020) and by Xing and Batabyal (2019). Finally, the effect that climate change has on the control of pollution caused by the leather producing activities of tanneries in Kanpur has been examined by Batabyal *et al*. (2023b).

Water pollution cleanup in the Ganges is clearly a complex problem and the studies mentioned in the preceding paragraph have certainly helped us better comprehend this complex problem. This notwithstanding, Das and Tamminga (2012, p. 1649) are surely right when they claim that "[e]fforts to clean the Ganges have, so far, fallen far short of their stated goals." In this regard, Das and Tamminga (2012, p. 1649) also claim that this saturnine state of affairs is the outcome of water pollution cleanup in the Ganges being unduly *centralized* with pollution abatement programs "imposed from the top…" with little or no attempts being made to cooperate with local institutions.[5]

1.2. Objective

Given this observation, Batabyal and Beladi (2023) have analyzed the circumstances in which water pollution cleanup in the Ganges ought to be centralized and when it ought to be

5
See Kedizor (2017) for a discussion of related issues.

decentralized. These authors point out that the answer to this question depends on whether there are *spillovers* from water pollution cleanup in the Ganges. As such, our objective in this paper is to continue the line of inquiry begun by Batabyal and Beladi (2023) and to provide a detailed analysis of the role that spillovers play in the provision of pollution cleanup in the Ganges. That said, our paper is different from the Batabyal and Beladi (2023) paper in four ways. First, the social welfare function we work with in equation (1) below is different from the social welfare function in Batabyal and Beladi (2023). Second, the way in which we model spillovers in equation (1) is different from the way in which Batabyal and Beladi (2023) model spillovers. Third, the analysis in Batabyal and Beladi (2023) is based on what is sometimes called the "Oates decentralization theorem" (see Oates (1972)), our analysis in the present paper is not. Finally, unlike the present paper, in some parts of their paper, Batabyal and Beladi (2023) analyze dissimilar preferences for water pollution cleanup in the cities under consideration in their paper.

To comprehend the salience of spillovers, let us focus on the cities of Kanpur and Varanasi that were discussed in section 1.1. In this regard, recall that because Varanasi is located about 200 miles *downstream* from Kanpur, pollution cleanup carried out in upstream Kanpur will benefit Varanasi residents because these residents will now be less exposed to contaminated river water flowing down from Kanpur. Put differently, 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 undertaken 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 gain from cleaner river water in Varanasi. In sum, in the context of an aggregate economy consisting of Kanpur and Varanasi, there clearly are bidirectional spillovers from water pollution cleanup in the Ganges.[6]

The remainder of this paper is organized as follows: Section 2 describes our static, theoretical model of an aggregate economy consisting of two cities Kanpur (K) and Varanasi (V), in the state of Uttar Pradesh, in India.[7] Section 3 first solves for the Nash equilibrium amounts of water pollution cleanup in the two cities when decisions about how much pollution to clean up are made *simultaneously*.[8] Next, this section determines the equilibrium welfare level in each city. On the assumption that decisions about how much pollution to clean up are *centralized*, section 4 computes the amounts of pollution cleanup that maximize aggregate welfare. Section 5 describes an inter-city transfer scheme that leads each city to choose non-cooperatively in a Nash equilibrium the same pollution cleanup amounts as those that arise in section 4. Section 6 concludes and then discusses three ways in which the research delineated in this paper might be extended.

2. The Theoretical Framework

Consider an aggregate or total economy consisting of the cities Kanpur and Varanasi in Uttar Pradesh, India, at a point in time.[9] The two cities are denoted by the subscripts $i = K, V$

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It is worth pointing out that the strength of the spillover from Kanpur to Varanasi is likely to be stronger than the spillover in the opposite direction.

7

The model we analyze in our paper is game-theoretic in nature and we focus on the concept of a Nash equilibrium which is the most basic equilibrium concept in game theory. Readers interested in learning more about the kind of modeling we undertake in this paper ought to consult standard textbooks such as Gibbons (1992) or Tadelis (2013). Readers who are familiar with game theory at a more advanced level may benefit by perusing the chapters in part III of Yang and Guizani (2011).

8

The Nash equilibrium we work with in our paper can be determined analytically or, put differently, in closed-form. Specifically, note that it is *not* necessary to use any algorithm to determine the Nash equilibrium of interest. Since no numerical computations of any sort are needed to ascertain the Nash equilibrium, the question of figuring out the complexity of these computations is irrelevant.

9

As noted clearly in section 1.2 and here, our model is static. This means that the model is unable to account for certain dynamic issues emanating from, for instance, the fact that water pollution in the Ganges changes over time and can be thought of as a stock. Since our principal focus in this paper is on analyzing bidirectional spatial spillovers, we believe that the model we have chosen for our analysis is both adequate and sufficiently involved. That said, readers should understand that an analysis of dynamic issues is *beyond* the scope of this paper. Since our model is not dynamic, it does make sense to discuss "the present value of the stream respectively. The regulatory authority responsible for cleaning up pollution in the Ganges in each of these two cities can provide some amount of pollution cleanup. In the remainder of this paper, we shall think of the amount of pollution cleanup provided in Kanpur and Varanasi as local public goods.[10] This provision of pollution cleanup improves the quality of the lives and hence the welfare of the people living in these two cities. Consistent with the discussion in section 1.2, pollution cleanup in either of the two cities under study leads to spillovers. In other words, if Kanpur provides some amount of water pollution cleanup, then Varanasi obtains some spillover benefits, and vice versa.

In general, there are a vast number of sources of pollution in the Ganges. As such, we recognize that a first-best approach to the Ganges water pollution control problem would be an extremely complicated non-point source pollution control problem. An analysis of this complicated problem is *beyond* the scope of this paper. That said, even if a solution to this complicated problem exists, enforcing this solution would, almost certainly, be prohibitively costly. Therefore, as stated in section 1.2, our goal in this paper is more limited. We have picked two cities (Kanpur and Varanasi) along the Ganges where the incidence of water pollution---for different reasons---is known to be severe and we are interested in analyzing how *bidirectional spillovers* between these two cities impacts water pollution cleanup in these same two cities. Finally, we emphasize that to the best of our knowledge, we are the *first* to study how spatial spillovers affect water pollution cleanup in the Ganges.

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of revenue and cost generated…" Finally, readers interested in an analysis of dynamic issues in the context of Ganges water pollution cleanup should consult the recent work of Batabyal *et al.* (2023b).

10 As pointed out by Hindriks and Myles (2013, p. 191), "public goods provided in a particular geographic location…" are called local public goods. That said, it is important to comprehend that in our analysis in this paper, we are treating the amount of *water pollution cleaned up* in Kanpur and Varanasi and *not* the body of water in the Ganges itself, as local public goods. So, focusing on Kanpur, for instance, the *benefit* from a certain amount of *clean water*, as a result of cleanup activities, enjoyed by one citizen of Kanpur does *not* reduce the benefit experienced by any other citizen. Of course, this line of reasoning assumes that there are *no* congestion externalities to contend with but such an assumption is standardly made when defining public goods. See Hindriks and Myles (2013, pp. 148-149) for more details.

As shown in figure 1, Prayagraj (formerly known as Allahabad) is a city along the Ganges that lies in between Kanpur and Varanasi. Every twelve years, a significant religious festival known as the Kumbh Mela[11] is held at the confluence of the Ganges and Yamuna rivers adjacent to Prayagraj. During the Kumbh Mela and, more generally, during the festive season in the state of Uttar Pradesh, a significant amount of pollutants are deposited into the Ganges. This deposition has two noteworthy effects. First, it *reduces* the strength of the spillover that downstream Varanasi citizens experience as a result of pollution cleanup in upstream Kanpur. Second, it *increases* the cost of cleaning up pollution in downstream locations such as Varanasi. In addition, there is a seasonal dimension to the deposition of these pollutants and, in actuality, water pollution cleanup in Kanpur and Varanasi may well not occur at the same point in time.[12] That said, it is important to emphasize that although the points mentioned in this paragraph are true they do not detract from the primary objective of this paper which is to study how *bidirectional spatial spillovers* affect pollution cleanup in Kanpur and Varanasi.

Because Kanpur is located upstream from Varanasi along the Ganges, in reality, we expect the spillovers to be *positive* and *stronger* when the relevant regulatory authority in Kanpur takes concrete steps to clean up pollution in the Ganges. Even so, in the interest of generality and consistent with our prior discussion of spillovers in section 1.2, we permit the spillovers to be bidirectional, i.e., from Kanpur to Varanasi and vice versa.[13]

11

Go to https://mittalsouthasiainstitute.harvard.edu/wp-content/uploads/2012/11/Introduction-to-the-Kumbh-Mela1.pdf for additional details on the Kumbh Mela. Accessed on 23 May 2023.

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One way to model the potential non-simultaneity in the actions taken by the relevant players in Kanpur and Varanasi would be to permit and model sequential actions. This would complicate our subsequent analysis in this paper but would still *not* affect the basic points we make about spatial spillovers.

13

Suppose the two cities in our model were Kanpur and Prayagraj in place of Varanasi. Since Prayagraj is located downstream from Kanpur, pollution cleanup in Kanpur would result in a *positive* spillover for any citizen of Prayagraj who uses water from the Ganges for any purpose. Similarly, any Kanpur citizen visiting Prayagraj to participate in either the Kumbh Mela or some other festival would *benefit* from water pollution cleanup undertaken in Prayagraj. In other words, compared to our model with Kanpur

Let p_K and p_V denote the amount of water pollution cleaned up in Kanpur and in Varanasi. In addition, let the social welfare function in each city i be given by

$$U^i(p_i, p_j) = 2\{\alpha\sqrt{p_i} + \beta\sqrt{p_i p_j}\} - \gamma p_i, \tag{1}$$

for $i \neq j$, $i, j = K, V$, $\alpha > 0$, and $0 < \beta < \gamma$.[14] Our next task is to solve for the Nash equilibrium

Table 1 about here

amounts of Ganges water pollution cleanup in Kanpur and Varanasi when the pollution cleanup decisions are made simultaneously.

3. The Nash Equilibrium Pollution Cleanup Amounts

In this section, the regulatory authorities responsible for pollution cleanup in the two cities make their cleanup decisions *simultaneously*. We know that social welfare in region i as a function of the two pollution cleanup amounts p_i and p_j is given by equation (1). Therefore, differentiating both sides of equation (1) with respect to p_i gives us

$$\frac{\partial U^i(p_i, p_j)}{\partial p_i} = \frac{\alpha}{\sqrt{p_i}} + \frac{\beta p_j}{\sqrt{p_i p_j}} - \gamma. \tag{2}$$

Simplifying equation (2), the first-order necessary condition for the optimal choice of p_i is[15]

and Varanasi, the *magnitudes* of the spillovers in this alternate model with Kanpur and Prayagraj would certainly be *different*. That said, the spillovers would still remain and this would need to be considered when carrying out efficient water pollution cleanup activities.

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We are not requiring that the condition $\gamma < \beta$ hold.

15

The second-order sufficiency condition is satisfied.

$$\frac{\alpha}{\sqrt{p_i}} + \frac{\beta p_j}{\sqrt{p_i p_j}} = \gamma. \qquad (3)$$

Equation (3) can also be expressed as

$$\alpha + \beta\sqrt{p_j} = \gamma\sqrt{p_i}. \qquad (4)$$

Given equation (4), the best response function, also known as the reaction function, of the regulatory authority in city i to pollution cleanup of amount p_j is

$$p_i = \frac{(\alpha+\beta\sqrt{p_j})^2}{\gamma^2}. \qquad (5)$$

Similarly, the best response function of the regulatory authority in city j to pollution cleanup of amount p_i is

$$p_j = \frac{(\alpha+\beta\sqrt{p_i})^2}{\gamma^2}. \qquad (6)$$

Now, the Nash equilibrium amounts of the Kanpur and Varanasi pollution cleanup p_K and p_V are given by solving equations (5) and (6) simultaneously. That said, the reader should understand that because of the symmetry in our theoretical framework, we can write the two Nash equilibrium amounts we seek as $p_K = p_V = p$ which solves, after dropping the subscripts, the equation

$$\alpha + \beta\sqrt{p} = \gamma\sqrt{p}. \qquad (7)$$

Simplifying equation (7),[16] we get a distinct value for p_{NE} and that value is

$$p_{NE} = \left(\frac{\alpha}{\gamma-\beta}\right)^2 > 0, \tag{8}$$

for $\alpha > 0$ and $\gamma > \beta > 0$. Inspecting equation (8) we see that there is no corner solution in our model. In other words, it is optimal in both Kanpur and Varanasi to provide a *strictly positive* amount of water pollution cleanup.[17]

Our second and final task in this section is to ascertain the equilibrium level of welfare in Kanpur and Varanasi. We do this in three steps. First, substitute the result from equation (8) into the Kanpur and the Varanasi social welfare functions given in equation (1). This gives us

$$U^i(p_{NE}, p_{NE}) = 2\{\alpha\sqrt{p_{NE}} + \beta\sqrt{p_{NE}, p_{NE}}\} - \gamma p_{NE}. \tag{9}$$

Second, using equation (8), equation (9) can be simplified. This simplification yields

$$U^i(p_{NE}, p_{NE}) = 2\alpha\left(\frac{\alpha}{\gamma-\beta}\right) + (2\beta - \gamma)\left(\frac{\alpha}{\gamma-\beta}\right)^2. \tag{10}$$

Finally, simplifying equation (10), we get

16

Note that we are analyzing a *symmetric* Nash equilibrium here. That is why the assumption $p_K = p_V = p$ about the cleanup amounts makes complete sense. That said, in an alternate model, it may be possible to obtain a corner solution in which either $p_K = p_V = p = 0$ or $p_K = p_V = p_{MAX}$ and p_{MAX} is the maximum cleanup possible in the time period under consideration.

17

Although a corner solution is impossible in our model, it is possible that in an alternate model, there would be one or more circumstances in which a corner solution is optimal.

$$U^i(p_{NE}, p_{NE}) = \gamma \left(\frac{\alpha}{\gamma-\beta}\right)^2 > 0. \quad (11)$$

Inspecting equations (8) and (11) we see that because the Nash equilibrium amounts of pollution cleanup in Kanpur and Varanasi are positive, *so is* the equilibrium level of welfare in each of these two cities. In addition, the equilibrium welfare level in each city is a *constant* multiple of the Nash equilibrium pollution cleanup amounts. In symbols, we have $U^i(\cdot,\cdot) = \gamma p_{NE}$. We now proceed to compute the amounts of pollution cleanup that maximize *aggregate* welfare on the assumption that the Ganges pollution cleanup decisions in Kanpur and Varanasi are centralized, potentially at the level of the government of the state of Uttar Pradesh based in Lucknow or, in principle, even at the level of the central government of India situated in New Delhi.

Before we do so, we would like to emphasize the point that the water pollution cleanup that does take place in Kanpur and Varanasi does so in an institutional context made up of laws and regulations. Irrespective of the actual amount of water pollution cleaned up, water quality in the Ganges in Kanpur and Varanasi and, more generally, elsewhere along the Ganges, will need to be monitored periodically to ensure that actual pollution does not cross certain scientifically mandated thresholds. This means that given ongoing industrial and human activities, the cleanup of water pollution in the Ganges will need to be a periodic activity if the river is to be kept sufficiently clean into the indefinite future. In fact, as pointed out in Batabyal (2022), keeping the Ganges clean is one of the key objectives of the current Prime Minister Mr. Narendra Modi. Mr. Modi has initiated an ambitious plan to clean the Ganges called the *Namami Gange Program* and he has also promised to convert Varanasi into a vibrant city for religious and other tourists and, more generally, to rejuvenate the Ganges.[18]

[18]

4. Aggregate Welfare

Aggregate or total welfare in Kanpur and Varanasi is given by $U^K(p_K, p_V) + U^V(p_V, p_K)$. This specification tells us that mathematically, the task before us is to solve[19]

$$max_{\{p_K, p_V\}} U^K(p_K, p_V) + U^V(p_V, p_K). \tag{12}$$

The two first-order necessary conditions for an optimum are given by[20]

$$\frac{\partial U^K(\cdot,\cdot)}{\partial p_K} + \frac{\partial U^V(\cdot,\cdot)}{\partial p_K} = \left(\frac{\alpha}{\sqrt{p_K}} + \frac{\beta p_V}{\sqrt{p_K p_V}} - \gamma\right) + \frac{\beta p_V}{\sqrt{p_K p_V}} = 0, \tag{13}$$

and

$$\frac{\partial U^V(\cdot,\cdot)}{\partial p_V} + \frac{\partial U^K(\cdot,\cdot)}{\partial p_V} = \left(\frac{\alpha}{\sqrt{p_V}} + \frac{\beta p_K}{\sqrt{p_K p_V}} - \gamma\right) + \frac{\beta p_K}{\sqrt{p_K p_V}} = 0. \tag{14}$$

Observe that in both equations (13) and (14), the last ratio term denotes the *spillover* benefit that accrues to each city from cleaning up water pollution.[21] We can now write these two equations differently. This gives us

Go to https://nmcg.nic.in/NamamiGanga.aspx for more details on the Namami Gange Program. Accessed on 23 May 2023.

19 Because there is no favoritism in our model, the implicit weights on $U^K(\cdot,\cdot)$ and $U^V(\cdot,\cdot)$ are identical and equal to unity.

20 The second-order sufficiency conditions are satisfied.

21 Inspecting these two equations carefully, it should be clear to the reader that these two spillover benefit terms are the same because our analysis in this paper is based on water pollution cleanup amounts that arise in a symmetric Nash equilibrium. If, instead, we were to analyze an asymmetric Nash equilibrium or an alternate model then these two spillover terms would not be the same because p_K would not necessarily equal p_V.

$$\frac{\alpha}{\sqrt{p_K}} + \frac{2\beta p_V}{\sqrt{p_K p_V}} = \frac{\alpha}{\sqrt{p_V}} + \frac{2\beta p_K}{\sqrt{p_K p_V}} = \gamma. \tag{15}$$

Inspection of equation (15) and some thought together tell us that the solution we seek must be symmetric. Put differently, it must be the case that we have $p_K = p_V = p_T$ where the subscript T denotes the fact that we are now studying the *total* or aggregate welfare maximization case. Using this preceding condition, we reason that the optimal pollution cleanup amounts in Kanpur and Varanasi solve

$$\frac{\alpha}{\sqrt{p}} + 2\beta = \gamma, \tag{16}$$

where we have omitted the subscript because of symmetry. Simplifying equation (16), we obtain

$$p_T = \left(\frac{\alpha}{\gamma - 2\beta}\right)^2 > p_{NE}, \tag{17}$$

and we assume that $\gamma > 2\beta$.

Equation (17) tells us that in the Nash equilibrium studied in section 3, there is *underprovision* of water pollution cleanup in Kanpur and Varanasi. This underprovision result stems from the fact that in the case studied in section 3, the regulatory authority in Kanpur (Varanasi) *ignores* the spillover benefit stemming from its pollution cleanup decision to Varanasi (Kanpur). Our final task in this paper is to delineate an inter-city transfer scheme that leads the regulatory authority in each city to choose non-cooperatively in a Nash equilibrium the same pollution cleanup amounts as those we have obtained in this section.

Given Das and Tamminga's (2012) criticism of the excessively centralized nature of pollution cleanup in the Ganges, while perusing this next section, the reader should keep in mind the general salience of cooperation among local or city institutions in ensuring the efficient cleanup of water pollution in the Ganges.

5. An Inter-City Transfer Scheme

The inter-city transfer scheme we have in mind is based on pollution cleanup in the *other* city that induces the regulatory authorities in Kanpur and Varanasi to select non-cooperatively in a Nash equilibrium the same pollution cleanup amounts as those obtained in section 4. That said, we would like to point out that as already specified in section 1.2 and in greater detail in footnote 6, our model is static and therefore this model is unable to account for the dynamics of this transfer scheme.

Suppose that each city $i, i = K, V$, receives a subsidy μ_i per unit of the pollution cleanup amount provided or p_i.[22] In this case, the ith city's welfare is

$$U^i(p_i, p_j) + \mu_i p_i. \tag{18}$$

As such, the first-order necessary condition for an optimum for Kanpur---see equations (2) and (3)---becomes[23]

22 We do not study the manner in which this subsidy is financed. One possibility is that the subsidy is financed through a lump-sum tax. The design of such a tax would, ordinarily, need to pay some attention to the disutility coefficient γ in the social welfare function in equation (1). Although this is beyond the scope of our paper, the design of an optimal tax could also be informed by information about how much the citizens of Kanpur and Varanasi are willing to pay (WTP) for the cleanup of water pollution in the Ganges.

23 The second-order sufficiency condition is satisfied.

$$\frac{\partial U^K(p_K, p_V)}{\partial p_K} + \mu_K = 0. \tag{19}$$

Now, if we set the monetary subsidy equal to the spillover benefit so that $\mu_K = \partial U^V(\cdot,\cdot)/\partial p_K > 0$, then we obtain

$$\frac{\partial U^K(p_K, p_V)}{\partial p_K} + \frac{\partial U^V(p_V, p_K)}{\partial p_K} = 0. \tag{20}$$

From equation (13), we know that equation (20) represents the condition for the efficient provision of pollution cleanup. Therefore, by setting the subsidy equal to the spillover benefit, we can alter the Nash equilibrium studied in section 3 and guarantee an efficient amount of pollution cleanup in both Kanpur and Varanasi. This completes our discussion of spillovers from pollution cleanup in the Ganges and welfare in Kanpur and Varanasi.

6. Conclusions

In this paper, we analyzed spillovers in an aggregate economy consisting of two cities Kanpur and Varanasi where the source of the spillovers was the provision of water pollution cleanup in the Ganges. In particular, if Kanpur undertook pollution cleanup then Varanasi obtained a spillover benefit and vice versa. We first solved for the Nash equilibrium amounts of pollution cleanup in the two cities when the decisions about how much water pollution to clean up were made simultaneously. Next, we determined the equilibrium welfare levels in Kanpur and Varanasi. Second, on the supposition that the decisions about how much pollution to clean up were centralized, we calculated the amounts of water pollution cleanup that maximized aggregate or total welfare. Finally, we delineated a subsidy based inter-city transfer scheme that led the regulatory authority in each city to choose non-cooperatively in a Nash equilibrium the same pollution cleanup amounts as the ones that arose when decisions about how much pollution to clean up were centralized.

The analysis in this paper can be extended in several different directions. Here are three possible extensions. First, one could analyze the extent to which the "theory of social situations," described in Oladi (2005), can be used to study how much Ganges water pollution is cleaned up when appropriate officials in Kanpur and Varanasi negotiate the cleanup amounts among themselves. Second, it would be helpful to explicitly model the financing of the subsidy and to study how, for instance, a "revenue neutrality" condition affects the decentralized cleanup of pollution in Kanpur and Varanasi. Finally, it would also be useful to analyze a scenario in which the spillovers that arise from the decentralized cleanup of pollution are not bilateral only but multilateral, occurring between multiple cities through which the Ganges flows. Studies that analyze these aspects of the underlying problem about pollution cleanup will provide additional insights into the nexuses between the centralized and the decentralized cleanup of water pollution in the Ganges on the one hand and social welfare of the millions of individuals who live in the many cities through which the Ganges flows on the other.

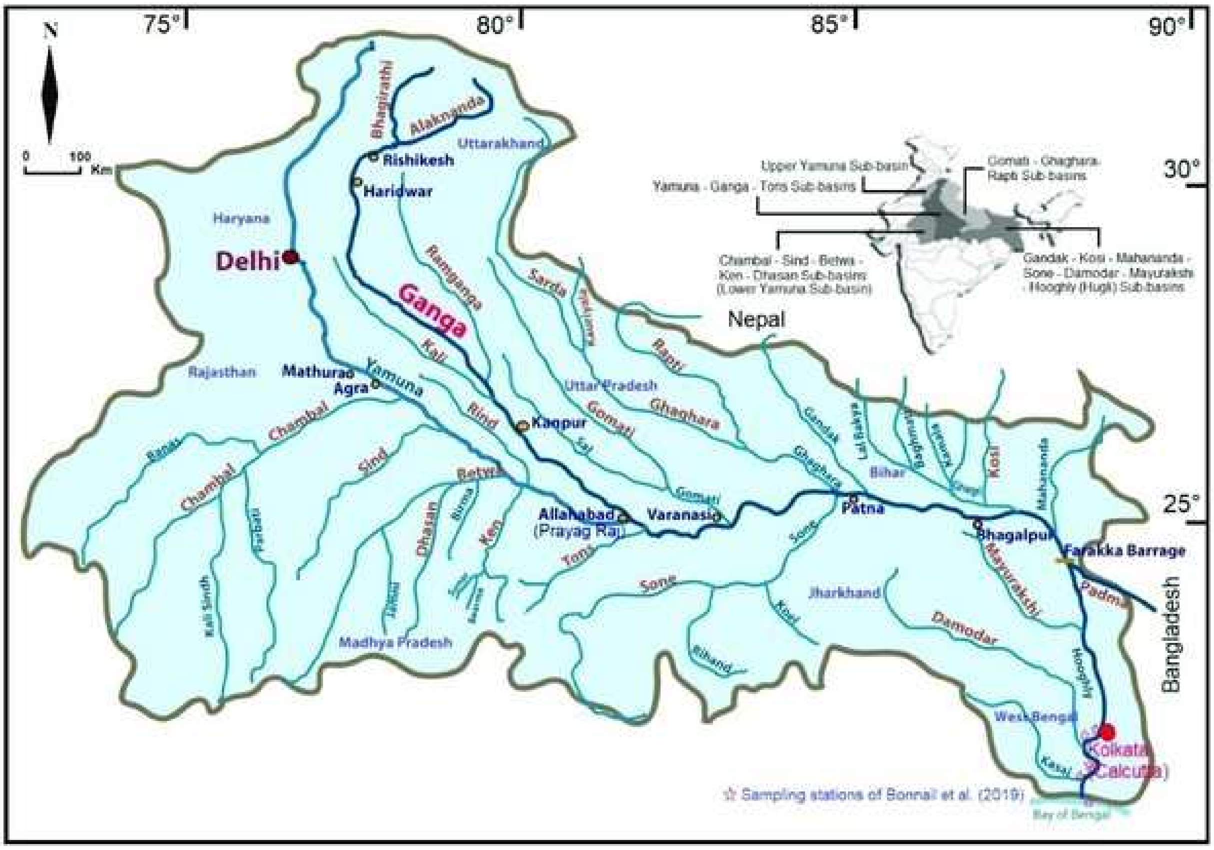

Figure 1: Flow of the Ganges and the Locations of Kanpur and Varanasi

Notation Used in Analysis	Explanation of Notation
p_K	Water pollution cleaned up in Kanpur
p_V	Water pollution cleaned up in Varanasi
$U^i(\cdot,\cdot)$	Social welfare in ith city
α	Model parameter
β	Model parameter
p_{NE}	Water pollution cleaned up in Nash equilibrium
p_T	Water pollution cleaned up when total welfare is maximized
μ_i	Subsidy in ith city

Table 1: Explanation of notation used in the model

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