A THEORETICAL ANALYSIS OF COSTS, WASTE TREATMENT, POLLUTION IN THE GANGES, AND LEATHER PRODUCTION BY TANNERIES IN KANPUR, INDIA

Amitrajeet A. BATABYAL
Arthur J. Gosnell Professor of Economics, Departments of Economics and Sustainability, Rochester Institute of Technology, Rochester, NY 14623-5604, USA
aabgsh@rit.edu

Seung Jick YOO
Corresponding Author, Professor, Sookmyung Women's University, Seoul, Republic of Korea
sjyoo@sookmyung.ac.kr

Abstract

We theoretically analyze the interaction between two representative and real tanneries, denoted by A and B, that are located on the same bank of the Ganges River in Kanpur, India. Tannery A is situated upstream from tannery B. Both tanneries produce leather and leather production by tannery A also gives rise to chemical waste that adversely affects the cost incurred by tannery B in producing leather. In this setting, we perform four tasks. First, we determine the amount of chemical waste and the leather produced by tanneries A and B in a competitive equilibrium. Second, we explain why this competitive equilibrium is inefficient from a societal standpoint. Third, we ascertain the socially optimal amount of leather produced by the two tanneries. Finally, we illustrate the working of our theoretical model with a specific example in which we use explicit functional forms and numbers.

Keywords: Ganges River, Leather Production, Tannery, Waste Treatment, Water Pollution

JEL classification: R11, R22, R32, Q52, Q53

1. Introduction

There is general agreement on the point that the Ganges (Ganga in Hindi) is the longest and the most prominent river in India. This notwithstanding, Black (2016) has rightly pointed out that in contemporary times, more than a billion gallons of waste are deposited into the Ganges every day. Even though the problem of waste deposition into the Ganges occurs at several points along the river, the prior work of Gallagher (2014), Black (2016), and Jain and Singh (2020) tells us that as far as the flow of water and pollution in the Ganges are concerned, three issues deserve to be highlighted.

The first issue concerns the phenomenon of climate change and the concern here is that this phenomenon is diminishing water flows in the Ganges and, *inter alia*, this factor has, almost certainly, diminished the river's natural capacity to absorb waste that is deposited into it. The second issue is water pollution from the tannery industry which is centered in the city---see Figure 1---of Kanpur. The salience of the tannery industry in Kanpur explains why this city is sometimes referred to as India's "leather city" (go to https://mahileather.com/blogs/news/the-world-s-most-famous-leather-markets for a more detailed discussion of this point; accessed on 18 August 2022). The third issue is waste deposited into the Ganges in the city of Varanasi which is, as shown in Figure 1, situated to the south-east of and roughly two hundred miles downstream from Kanpur.

The question of how climate change affects the Ganges and water pollution caused by tanneries in Kanpur has recently been studied by Batabyal *et al.* (2022a). Similarly, the issue of cleaning up pollution in the Ganges at Varanasi has been analyzed from a variety of standpoints by Batabyal and Beladi (2017, 2019, 2020) and by Xing and Batabyal (2019). In this regard, the particular question of how best to manage polluting tanneries in Kanpur when the water pollution they cause negatively impacts small farmers has been analyzed by Batabyal *et al.* (2022b). Finally and more generally, pollution in the Ganges stemming from the activities of tanneries in Kanpur has been examined by Batabyal (2022).

Figure 1: Path of the Ganges River and the Location of Kanpur

In Batabyal (2022) and in Batabyal *et al.* (2022a), water pollution in the Ganges caused by an upstream tannery negatively influences the downstream tannery's ability to *produce* leather. Even so, what these two studies do *not* take into account is the fact that the negative externality imposed by the upstream tannery on the downstream tannery also affects the downstream tannery's *cost* of producing leather. Second, the two studies mentioned above also do *not* account for the fact that polluting tanneries in Kanpur are frequently required to take one or more actions to *diminish* the environmental damage stemming from their production of leather[1].

To the best of our knowledge, the extant literature has *not* analyzed the two points mentioned in the preceding paragraph. Given this lacuna in the literature, we extend the analyses in Batabyal (2022) and Batabyal *et al.* (2022a) by constructing and analyzing a theoretical model that explicitly accounts for the above-mentioned two points about water pollution in the Ganges that results from the production of leather by tanneries in Kanpur. The problem we study has broader implications for the sustainability of urban life as studied by Nijkamp (2011). We emphasize that the theoretical model we construct and analyze is our own and therefore this model and our subsequent analysis represent new knowledge in the literature.

The remainder of this paper is organized as follows: Section 2 describes our theoretical model of the interaction between two representative tanneries, A and B, that are located on the same bank of the Ganges river in Kanpur, India. Tannery A is situated upstream from tannery B. Both tanneries produce leather and leather production by tannery A negatively impacts the cost incurred by tannery B in producing leather. Section 3 determines the amount of chemical waste and the leather produced by tanneries A and B in a competitive equilibrium. Section 4 explains why this competitive equilibrium is inefficient from a societal standpoint. Section 5 ascertains the socially optimal amount of leather produced by the two tanneries. Section 6

---

[1] The interested reader may visit https://www.unido.org/news/kanpur-tanneries-win-awards-innovations-reduce-environmental-impact, to https://www.stahl.com/strategy/sustainable-development/partnership-cleaning-ganges, and see Gupta *et al.* (2007) and Singh and Gundimeda (2021) for additional details on this point; accessed on 18 August 2022

provides an example to demonstrate the working of our theoretical model. Section 7 concludes and then suggests three ways in which the research delineated in this paper might be extended.

2. The Theoretical Framework

Consider two real and representative tanneries, denoted by A and B, that are situated on the same bank of the Ganges in Jajmau, an industrial suburb of Kanpur. It makes sense to concentrate on Jajmau because a relatively large number of the tanneries in Kanpur are located in this suburb (go to https://www.incredibleindia.org/content/incredible-india-v2/en/destinations/kanpur/jajmau.html for additional details on Jajmau; accessed on 18 August 2022). The two tanneries under study produce leather and the production of leather requires the use of chemicals that are toxic to humans. Tannery A is situated upstream from tannery B.

Tannery A sells the leather it produces at price $p_A > 0$ per square feet. Its cost of producing leather q_A is given by the function $C_A(q_A)$ and we assume that $C_A'(\cdot) > 0$ and that $C_A''(\cdot) > 0$. For each square feet of leather produced, tannery A also generates one kilogram of chemical waste. The tannery is supposed to treat this chemical waste before it is deposited into the Ganges but enforcement of existing regulations is poor and therefore tanneries can often get away with not complying with existing regulations requiring tanneries to treat the chemical waste they generate.

Let w_{Ae} denote the amount of chemical waste that tannery A deposits into the Ganges *without* first treating it. This action results in *no* cost to the tannery. In contrast, if this tannery first treats the chemical waste it produces before depositing it into the Ganges then it bears a cost given by the function $C_{AT}(w_{At})$ where w_{At} is the amount of waste treated and it is understood that $C_{AT}'(\cdot) > 0$ and that $C_{AT}''(\cdot) > 0$.

Tannery B is located downstream from tannery A on the same bank of the Ganges. Its cost of producing leather q_B is given by the function $C_B(q_B)$, where $C_B'(\cdot) > 0$ and $C_B''(\cdot) > 0$. The untreated chemical waste deposited into the Ganges by tannery A increases tannery $B's$ cost of producing leather. Let us denote this *additional* cost with the function $C_{Be}(w_{Ae})$, where we suppose that $C_{Be}'(\cdot) > 0$ and that $C_{Be}''(\cdot) > 0$. The *spatial* element in the upstream-downstream interaction between the two tanneries that we are studying is accounted for by the *magnitude* of the untreated chemical waste w_{Ae} that tannery A deposits into the Ganges. In other words, assuming a constant flow of the water in the Ganges river and *ceteris paribus,* as the distance between the two tanneries A and B increases, the magnitude of this waste amount w_{Ae} also increases and so does tannery $B's$ cost of producing leather. Finally, tannery B sells the leather it produces at price $p_B > 0$ per square feet. With this description of the theoretical framework in place, we are now in a position to solve for the amount of chemical waste generated by tannery A and the leather produced by these two tanneries in a competitive equilibrium.

3. The Competitive Equilibrium

The profit function of tannery A or Π_A can be written as

$$\Pi_A = p_A q_A - C_A(q_A) - C_{AT}(w_{At}) \tag{1}$$

and the profit function of tannery B or Π_B is given by

$$\Pi_B = p_B q_B - C_B(q_B) - C_{Be}(w_{Ae}). \tag{2}$$

In a competitive equilibrium, both tanneries maximize their profit Π_A and Π_B. Specifically, tannery A chooses the amount of leather to produce or q_A and the amount of chemical waste to treat or w_{At}. The two first-order necessary conditions for a maximum are (the second-order sufficiency conditions are satisfied)

$$\frac{\partial \Pi_A}{\partial q_A} = p_A - C_A'(q_A) = 0 \tag{3}$$

and

$$\frac{\partial \Pi_A}{\partial w_{At}} = -C'_{AT}(w_{At}) < 0. \tag{4}$$

From (3) and (4), we deduce that the optimal solution for tannery A---denoted with a star (*)---is given by $q_A^* = \{C'_A\}^{-1}(p_A)$ and $w_{At}^* = 0$.

For tannery B, the first-order necessary condition for a maximum is given by (the second-order sufficiency condition is satisfied)

$$\frac{\partial \Pi_B}{\partial q_B} = p_B - C'_B(q_B) = 0. \tag{5}$$

Manipulating equation (5), the optimal solution for tannery B---denoted with a star (*)---can be expressed as $q_B^* = \{C'_B\}^{-1}(p_B)$. Now, writing the three solutions that arise in a competitive equilibrium together, we obtain

$$q_A^* = \{C'_A\}^{-1}(p_A), w_{At}^* = 0, and\ q_B^* = \{C'_B\}^{-1}(p_B). \tag{6}$$

Let us now explain why the competitive equilibrium that we have just solved for is inefficient from a societal standpoint.

4. The Inefficiency

The competitive equilibrium described in section 3 is inefficient because of the presence of a production externality. Put differently, leather production by the upstream tannery A *reduces* the profit of the downstream tannery B because of the presence of the cost term $C_{Be}(w_{Ae})$ in this tannery's profit function given by equation (2). In addition, the relevant externality is an external *diseconomy* and therefore, in general, leather production by tannery A is inefficiently *high*. In other words, tannery $A's$ production of leather is higher than the socially optimal level of leather production. Our next task is to compute, *inter alia*, the socially optimal amount of leather produced by the two tanneries.

5. The Socially Optimal Level of Leather Production

To determine the socially optimal level of leather production by the two tanneries and the optimal amount of chemical waste to treat by tannery A, we need to maximize the *sum* of the profits earned by these two tanneries. In other words, we need to solve

$$max_{\{q_A, q_B, w_{At}\}} \Pi = \Pi_A + \Pi_B. \tag{7}$$

Substituting for the two profit functions Π_A and Π_B from equations (1) and (2) into equation (7), the maximization problem of interest can be rewritten as

$$max_{\{q_A, q_B, w_{At}\}} p_A q_A - C_A(q_A) - C_{AT}(w_{At}) + p_B q_B - C_B(q_B) - C_{Be}(q_A - w_{At}). \tag{8}$$

The reader will note that we have used the fact that $w_{Ae} = q_A - w_{At}$ to substitute for w_{Ae} in the last cost expression in equation (8).

The three first-order necessary conditions that together delineate the social optimum are given by (the second-order sufficiency conditions are satisfied)

$$\frac{\partial \Pi}{\partial q_A} = p_A - C'_A(q_A) - C'_{Be}(q_A - w_{At}) = 0, \tag{9}$$

$$\frac{\partial \Pi}{\partial w_{At}} = -C'_{AT}(w_{At}) + C'_{Be}(q_A - w_{At}) = 0, \tag{10}$$

and

$$\frac{\partial \Pi}{\partial q_B} = p_B - C_B'(q_B) = 0. \tag{11}$$

Let us denote the socially optimal levels of the three choice variables q_A, w_{At}, and q_B with the superscript O. Then, from equation (11), we infer that $p_B = C_B'(q_B)$. Therefore, the socially optimal output of leather produced by tannery B or $q_B^O = \{C_B'\}^{-1}(p_B)$. Moving on, equations (10) and (9) tell us that $C_{AT}'(w_{AT}) = C_{Be}'(q_A - w_{At})$ and that $p_A - C_A'(q_A) = C_{Be}'(q_A - w_{At})$. Equating the right-hand-sides (RHSs) of the two preceding equations and then simplifying the resulting expression, we obtain the socially optimal output of leather produced by tannery A. This output is given by $q_A^O = \{C_A'\}^{-1}[p_A - \{C_{AT}'\}^{-1}(w_{At})]$. The optimal amount of chemical waste or w_{At}^O that is treated by tannery A is given implicitly by equation (10). Once this value of w_{At}^O is known, we can determine the optimal amount of untreated chemical waste that is deposited into the Ganges by tannery A or w_{Ae}^O by using the relationship $w_{Ae}^O = q_A^O - w_{At}^O$.

Let us now compare leather production by the two tanneries in a competitive equilibrium with that produced in the social optimum. We begin with tannery A. The two outputs to compare are q_A^* with q_A^O. In this regard, observe first that $p_A - \{C_{AT}'\}^{-1}(\cdot) < p_A$. Second, recall that tannery $A's$ marginal cost of producing leather function or $C_A'(\cdot)$ is strictly increasing. Since the inverse function of a strictly increasing function is also strictly increasing, it follows that $q_A^* > q_A^O$. In words, determining the socially optimal output of leather produced by tannery A is equivalent to tannery A *internalizing* the negative impact that its discharge of untreated chemical waste into the Ganges has on tannery $B's$ ability to produce leather. When this internalization takes place, it is optimal for tannery A to *reduce* its optimal output of leather.

What about the output of leather produced by the downstream tannery B? To compare the output of leather produced by tannery B in the competitive equilibrium with that produced in the social optimum, we need to relate q_B^* from equation (6) with q_B^O from the paragraph right after equation (11). This comparison clearly shows that $q_B^* = q_B^O = \{C_B'\}^{-1}(p_B)$. This last result tells us that the downstream tannery $B's$ optimal production of leather is the same in both the competitive equilibrium and in the social optimum. Our last task in this paper is to illustrate the working of our theoretical model with an example in which we use explicit functional forms and numbers.

6. A Specific Example with Numbers

Suppose the two leather output prices are $p_A = US\$10$ per square feet and $p_B = US\$5$ per square feet. Using an exchange rate of Rupees $75 = US\$1$, the US\$ prices translate to $p_A = 750$ rupees per square feet and $p_B = 375$ rupees per square meter. These are reasonable ranges for the price of finished leather in Kanpur, India (go to https://www.exportersindia.com/kanpur/raw-leather.htm for more details; accessed on 18 August 2022). That said, we stress that the above choices for the two prices are meant to illustrate how our model can be applied in a *variety* of different settings. As such, one could use *any real price* for the two leather outputs and this would allow us to conduct an analysis that is very similar to that conducted in this section.

The two cost functions for producing leather are quadratic and given by $C_A(q_A) = 0.5q_A^2$ and $C_B(q_B) = 0.5q_B^2$. The extra cost borne by tannery B as a result of the discharge of untreated waste into the Ganges by tannery A is also quadratic and given by $C_{Be}(w_{Ae}) = 0.5w_{Ae}^2$. Finally, the linear cost of treating chemical waste by tannery A is $C_{AT}(w_{At}) = 2w_{At}$.

Let us first determine the competitive equilibrium. To do this, we need to set up the equivalents of equations (3), (4), and (5). Doing this, we get

$$\frac{\partial \Pi_A}{\partial q_A} = 10 - q_A = 0, \tag{12}$$

$$\frac{\partial \Pi_A}{\partial w_{At}} = -2 < 0, \tag{13}$$

and

$$\frac{\partial \Pi_B}{\partial q_B} = 5 - q_B = 0. \tag{14}$$

Solving (12)-(14) for the choice variables of interest, we get $q_A^* = 10, q_B^* = 5$, and $w_{At}^* = 0$. Also, because $w_{Ae}^* = q_A^* - w_{At}^* = 10 - 0 = 10$, the Ganges water pollution cost imposed on tannery B by tannery A is $0.5(10)^2 = 50$.

Moving on to ascertain the social optimum, we now need to set up the equivalents of equations (9), (10), and (11). Doing this, we obtain

$$\frac{\partial \Pi}{\partial q_A} = 10 - 2q_A + w_{At} = 0, \tag{15}$$

$$\frac{\partial \Pi}{\partial w_{At}} = q_A - 2 - w_{At} = 0, \tag{16}$$

and

$$\frac{\partial \Pi}{\partial q_B} = 5 - q_B = 0. \tag{17}$$

Simplifying equations (15)-(17), we obtain the values of the pertinent decision variables in the social optimum. Specifically, we get $q_A^O = 8, q_B^O = 5, w_{At}^O = 6$, and $w_{Ae}^O = 2$. Three results are now worth emphasizing. First, because $q_A^* = 10 > 8 = q_A^O$, this example confirms our previous general finding in section 5 that tannery A produces an inefficiently *high* amount of leather in the competitive equilibrium and that social optimality requires this tannery to produce *less* leather. Second, since $w_{At}^O = 6 > 0 = w_{At}^*$, this example confirms that it is socially *suboptimal* to treat no chemical waste, as tannery A does in the competitive equilibrium. Instead, it is socially optimal for this tannery to treat 6 units of chemical waste and this action results in a cleaner Ganges. Finally, because tannery A *internalizes* the negative impact of the chemical waste it generates on tannery B in the social optimum, the corresponding water pollution cost now equals $0.5(2)^2 = 2$ and this number is obviously far *lower* than the corresponding cost in the competitive equilibrium which equals is $0.5(10)^2 = 50$. This completes our theoretical analysis of costs, waste treatment, pollution in the Ganges, and leather production by tanneries in Kanpur, India.

7. Conclusions

Given the lacuna in the existing literature identified in section 1, we theoretically examined the interaction between two representative and real tanneries, A and B, that were located on the same bank of the Ganges River in Kanpur, India. Our analysis led us to first ascertain the socially optimal amount of leather produced by the two tanneries and to then demonstrate the working of our theoretical model with an example in which we used overt functional forms and realistic numbers for prices.

Here are three suggestions for extending the research described in this paper. First, it would be useful to determine the scope of fiscal policy (see Karras (2015)) in determining the location choices (see Cao (2021)) of tanneries and in alleviating the Ganges water pollution problem in Kanpur. Second, it would be useful to analyze the interaction between tanneries A and B when the cost of enforcing the requirement to treat chemical waste before it is deposited into the Ganges is explicitly modeled in the underlying analysis. Such an interaction could be studied as a problem of implementing the right regional development policies (see Lincaru *et al.* (2010), Stilianos and Ladias (2011), Goula *et al.* (2015), and Mitsopoulos and Pelagidis (2021)) or as a Principal-Agent game, potentially repeated over time, in which the regulator is the principal and the two tanneries are the two agents. Third, it would also be helpful to study the interaction between tanneries A and B when, potentially because of the natural cleansing capacity of the Ganges, the impact of not treating chemical waste before it is deposited into the Ganges is stochastic and not deterministic. Studies of the prevention of water pollution caused by tanneries in Kanpur that incorporate these facets of the problem into the analysis will provide new perspectives on the ways in which tanneries can avoid a threat to their continued existence and, simultaneously, the environmental damage done to the

Ganges and to humans living in the neighborhood of these tanneries is assuaged to the extent possible.

8. Acknowledgments

We thank the Academic Editor Dimitrios Tsiotas and two anonymous reviewers for their helpful comments on a previous version of this paper. In addition, Batabyal acknowledges financial support from the Gosnell endowment at RIT. The usual disclaimer applies.

9. References

Alexiadis, S., and Christos Ap. Ladias. 2011. “Optimal allocation of investment and regional disparities.” Regional Science Inquiry, 3, 45-59.

Batabyal, A.A. 2022. “Tanneries in Kanpur and pollution in the Ganges: A theoretical analysis.” Unpublished Manuscript, Rochester Institute of Technology.

Batabyal, A.A., and H. Beladi. 2017. “Cleaning the Ganges in Varanasi to attract tourists.” Atlantic Economic Journal, 45, 511-513.

Batabyal, A.A., and H. Beladi. 2019. “Probabilistic approaches to cleaning the Ganges in Varanasi to attract tourists.” Natural Resource Modeling, 32, e12177, 1-11.

Batabyal, A.A., and H. Beladi. 2020. “A political economy model of the Ganges pollution cleanup problem.” Natural Resource Modeling, 33, e12285, 1-12.

Batabyal, A.A., Kourtit, K., and P. Nijkamp. 2022a. “Climate change and river water pollution: An application to the Ganges in Kanpur.” Unpublished Manuscript, Rochester Institute of Technology.

Batabyal, A.A., Kourtit, K., and P. Nijkamp. 2022b. “Polluting tanneries and small farmers in Kanpur, India: A theoretical analysis.” Unpublished Manuscript, Rochester Institute of Technology.

Black, G. 2016. “Purifying the goddess.” The New Yorker, 92, 46-53.

Cao, Y.N. 2021. “Factors affecting on urban location choice decisions of enterprises.” Regional Science Inquiry, 13, 217-224.

Gallagher, S. 2014. “India: The toxic price of leather.” Pulitzer Center, February 4. https://pulitzercenter.org/reporting/india-toxic-price-leather-0. Accessed on 18 August 2022.

Goula, M., Ladias, C.A., Gioti-Papadaki, O., Hasanagas, N. 2015. “The spatial dimension of environment-related attitudes: Does urban or rural origin matter?” Regional Science Inquiry, 7, 115-129.

Gupta, S., Gupta, R., and R. Tamra. 2007. “Challenges faced by leather industry in Kanpur.” Project Report, Indian Institute of Technology, Kanpur. https://home.iitk.ac.in/~sgupta/tannery_report.pdf. Accessed on 18 August 2022.

Jain, C.K., and S. Singh. 2020. “Impact of climate change on the hydrological dynamics of river Ganga, India.” Journal of Water and Climate Change, 11, 274-290.

Karras, G. 2015. “Fiscal activism in European regions: Evidence on fiscal rules before and after the Euro.” Regional Science Inquiry, 7, 21-34.

Lincaru, C., Ghenta, M., Atanasiu, D., Ciuca, V., Dragoiu, C., and B. Chiriac. 2010. “Regional development and diversity/variety of firms: The case of Romania.” Regional Science Inquiry, 2, 119-132.

Mitsopoulos, M., and T. Pelagidis. 2021. “Labor taxation and investment in developed countries: The impact on employment.” Regional Science Inquiry, 13, 13-31.

Nijkamp, P. 2011. “The role of evaluation in supporting a human sustainable development: A cosmonomic perspective.” Regional Science Inquiry, 3, 13-22.

Singh, A., and H. Gundimeda. 2021. “Measuring technical efficiency and shadow price of water pollutants for the leather industry in India: A directional distance function approach.” Journal of Regulatory Economics, 59, 71-93.

Xing, S., and A.A. Batabyal. 2019. “A safe minimum standard, an elasticity of substitution, and the cleanup of the Ganges in Varanasi.” Natural Resource Modeling, 32, e12223, 1-11.