Polluting tanneries and small farmers in Kanpur, India: a theoretical analysis

Batabyal, Amitrajeet and Kourtit, Karima and Nijkamp, Peter

Rochester Institute of Technology, Rochester, United States, Open University, Heerlen, Netherkands, Open University, Heerlen, Netherlands

14 May 2022

Polluting Tanneries and Small Farmers in Kanpur, India: A Theoretical Analysis[1]

by

AMITRAJEET A. BATABYAL,[2]

KARIMA KOURTIT,[3]

and

PETER NIJKAMP[4]

1

We thank the Editor-in-Chief, an Advisory Editor, 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.

2

Corresponding Author. Department of Economics, Rochester Institute of Technology, 92 Lomb Memorial Drive, Rochester, NY 14623-5604, USA. E-mail: aabgsh@rit.edu

3

Open University, Heerlen, The Netherlands. E-mail: k_kourtit@hotmail.com

4

Open University, Heerlen, The Netherlands. E-mail: pnijkamp@hotmail.com

Polluting Tanneries and Small Farmers in Kanpur, India: A Theoretical Analysis

Abstract

We focus on the interaction between a representative polluting tannery and a negatively impacted small farmer in Kanpur, India. The tannery produces leather and toxic chemical waste that ends up in wastewater used by the small farmer to irrigate agricultural land and grow vegetables. The waste generated by the tannery is functionally related to its output of leather. The small farmer faces a capacity constraint that describes the maximum amount of vegetables he can grow. In this setting, we perform three tasks. First, we determine the optimal production of leather when the tannery does not account for the negative effect it has on the small farmer. Second, on the assumption that the tannery compensates the small farmer per unit of waste it generates, we ascertain the optimal compensation amount, the optimal output of leather, and the profit levels of the tannery and the small farmer. Finally, we compare the solutions in the preceding two cases and explain what accounts for the differences between them.

Keywords: Chemical Waste, Irrigation, Leather, Small Farmer, Tannery

JEL Codes: Q15, Q53

1. Introduction

The Ganges (Ganga in Hindi) is the longest and the most significant river in India. Black (2016) notes that more than a billion gallons of waste enter the Ganges every day. Although the problem of waste deposition into the Ganges occurs at various locations along the river, Gallagher (2014) and Black (2016) point out that with regard to pollution in the Ganges, two problems are paramount. The first problem is pollution from the tannery industry which is centered in the city of Kanpur, in the northern state of Uttar Pradesh. The salience of the tannery 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 Varanasi, a city that is located two hundred miles downstream from Kanpur.

It is worth noting that the tannery industry in Kanpur is almost entirely owned by Muslims. In contrast, a lot of the pollution in Varanasi, which is generally understood to be the spiritual center of Hinduism, is the outcome of Hindu religious activities.[6] The point to comprehend is that ridding the Ganges of pollution is a challenging task because this task plays directly into India's charged caste and religious politics.

Recently, the problem of cleaning up pollution in the Ganges at Varanasi has been studied from a number of viewpoints by Batabyal and Beladi (2017, 2019, 2020) and by Xing and Batabyal (2019). Therefore, in this paper, we concentrate on one of two kinds of pollution caused by the tannery industry in the city of Kanpur. The location of Kanpur is shown in the map of India in

---

5

Go to https://mahileather.com/blogs/news/the-world-s-most-famous-leather-markets for a more detailed discussion of this point. Accessed on 22 November 2021.

6

Dhillon (2014) notes 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.

Figure 1 about here

Figure 1. With regard to the first kind of pollution, the writings of Khwaja *et al*. (2001), Gowd *et al*. (2010), and Bhatnagar *et al*. (2013) lucidly tell us that many of the pollutants such as chromium that are deposited *into the Ganges* by the tanneries are extremely toxic to humans and therefore the problem of regulating the deposition of these pollutants is a serious matter.[7] That said, the question of how best to deal with pollution in the Ganges caused by the activities of tanneries in Kanpur has recently been studied by Singh and Gundimeda (2021), Batabyal (2022) and Batabyal and Yoo (2022).

Therefore, we analyze the second kind of pollution that also arises from the production activities of the tannery industry in and around Kanpur and that, to the best of our knowledge, has *not* been studied theoretically thus far in the literature. This second kind concerns the chemical waste that ends up in wastewater that is then used to *irrigate agricultural land* by farmers in the vicinity of Kanpur. Specifically, we focus on the interaction between a representative polluting tannery and a negatively impacted small farmer in the Kanpur area.

The remainder of this paper is organized as follows. Section 2 describes the theoretical framework. In this framework, the tannery produces leather and chemical waste that finds its way into wastewater that is used by the small farmer to irrigate agricultural land and grow vegetables. The waste generated by the tannery is functionally related to its output of leather. The small farmer is small in the sense that he faces a capacity constraint that describes the maximum amount of vegetables he can grow. Section 3 determines the optimal production of leather when the tannery

7 The government of Uttar Pradesh periodically takes "stern" actions such as closing down some tanneries in Kanpur in advance of important events such as the Kumbh Mela in Prayagraj (formerly known as Allahabad) but these actions have had little, long-term impact on reducing the discharge of toxic pollutants into the Ganges. See Anonymous (2019) for additional details on this point.

does not account for the negative effect it has on the small farmer. On the assumption that the tannery compensates the small farmer per unit of waste it generates, section 4 computes the optimal compensation amount, the optimal output of leather, and the profit levels of the tannery and the small farmer. Section 5 conducts numerical analysis, it discusses the solutions obtained in sections 3 and 4, and then explains what accounts for the differences between them. Section 6 concludes and then suggests two ways in which the research delineated in this paper might be extended.

2. The Theoretical Framework

Consider a representative tannery, denoted by L, that produces leather but also generates noxious chemical waste. This waste ends up in wastewater that is then used by a representative small farmer to irrigate agricultural land and grow vegetables.[8] The work of Sinha *et al*. (2006), Alam *et al*. (2009), and Gowd *et al*. (2010) tells us that the various effluents from the tanneries in Kanpur that end up on nearby irrigated land pollute the soil, the groundwater, and they can also have very detrimental impacts on humans who consume the resulting contaminated vegetables. The leather produced by the tannery can be sold for $\$p_l$ per unit such as a kilogram. Cost functions in economic analysis are generally assumed to be convex functions and therefore we shall describe the cost function of the tannery by the quadratic function

$$c_L(l) = l^2, \tag{1}$$

where l denotes the produced leather. The level of chemical waste w is related to the ourput of

8

The scenario described here is very common in the Kanpur area. Go to https://pulitzercenter.org/stories/india-toxic-price-leather for a more detailed discussion of this point. Accessed on 26 August 2022.

leather and is given by the function

$$w = \zeta l, \tag{2}$$

where $\zeta > 0$ is the constant of proportionality. The reader should note that even though the waste function is equation (2) is a linear function, in some situations, it may make more sense to model waste generation with a non-linear function.

The small farmer, denoted by $F,$ owns agricultural land and he grows vegetables on this land by irrigating it using the chemical effluent laden wastewater. Every vegetable v produced by our small farmer can be sold for $\$p_v.$ The small farmer's cost of growing vegetables is given by the function

$$c_F(v, w) = v + w^2. \tag{3}$$

Finally, we model the point that our farmer is small by supposing that he is faced with a capacity constraint given by $v \leq V.$ With this description of the theoretical framework out of the way, we are now in a position to determine the optimal production of leather when the tannery does not account for the negative effect it has on the small farmer.

3. The Tannery's Preferred Output

The profit function of tannery L is given by

$$\pi_L = p_l l - l^2. \tag{4}$$

The first-order necessary condition for an optimum is[9]

$$\frac{d\pi_L}{dl} = p_l - 2l = 0 \Rightarrow l^* = \frac{p_l}{2} \ . \tag{5}$$

Equation (5) tells us that the optimal amount of leather production l^* is one-half times the price p_l at which the produced leather can be sold.

Substituting this value of l^* into the tannery's profit function in equation (4) and then simplifying gives us an expression for the optimized value of its profit when it produces l^* units of leather. That expression is

$$\pi_L^* = p_l\left(\frac{p_l}{2}\right) - \left(\frac{p_l}{2}\right)^2 \Rightarrow \pi_L^* = \frac{p_l^2}{4}. \tag{6}$$

From equation (6) we see that the optimized value of the tannery's profit is one-fourth times the square of the price at which the produced leather can be sold. The values of l^* and π_L^* that we have obtained in equations (5) and (6) denote the tannery's *desired* solution in which this firm does *not* account for the fact that its joint production of leather and chemical waste imposes a cost on the small farmer who uses the effluent-laden wastewater to irrigate his land and grow vegetables.

As such, suppose we have a regulation in place that requires the tannery to compensate the small farmer an amount $\$\theta$ per unit of chemical waste it produces. How would the solution obtained in equations (5) and (6) change and what would the optimal amount of the compensation

9

The second-order sufficiency condition is satisfied.

be? We now anser these questions.

4. The Tannery Pays Compensation

When the tannery is forced to pay compensation to the small farmer, equation (4) is no longer the accurate profit function for this tannery. Specifically, this equation will need to be modified to account for the extra cost of paying compensation. With this necessary modification, the tannery's profit function becomes

$$\pi_L = p_l l - l^2 - \theta w(l) = p_l l - l^2 - \theta\zeta l, \tag{7}$$

where we have used equation (2) to substitute for $w(l)$ on the right-hand-side (RHS) of equation (7).

The first-order necessary condition for an optimum now is[10]

$$\frac{d\pi_L}{dl} = p_l - 2l - \zeta\theta = 0 \Rightarrow l^* = \frac{p_l - \zeta\theta}{2}. \tag{8}$$

Comparing the RHSs of equations (5) and (8) we see that when the tannery is forced to compensate the small farmer for the negative impact its production of leather has on this farmer, the tannery produces *less* leather than it previously did.

Now, to determine the optimal value of the compensation or θ^o, note that this value must give rise to the *socially* optimal amount of leather production by our tannery or l^o. We can express this relationship in symbols by writing

10
The second-order sufficieny condition is satisfied.

$$l(\theta^o) = l^o. \tag{9}$$

To find the socially optimal level of leather production, we will need to maximize the *sum* of the profits of the tannery and that of the small farmer. In other words, we need to solve

$$max_{\{l,v\}} \pi_L + \pi_F = p_l l - l^2 + p_v v - v - (\zeta l)^2, \tag{10}$$

where we have used equation (2) to substitute for w (also see equation (3)). The two first-order necessary conditions for an optimum to the above maximization problem are[11]

$$\frac{\partial(\pi_L + \pi_F)}{\partial l} = p_l - 2l - 2l\zeta^2 = 0 \tag{11}$$

and

$$\frac{\partial(\pi_L + \pi_F)}{\partial v} = p_v - 1 > 0. \tag{12}$$

Simplifying equation (11), we get an expression for the optimal level of leather production by our tannery. That expression is

$$l^o = \frac{p_l}{2 + 2\zeta^2}. \tag{13}$$

11
The second-order sufficiency conditions are satisfied.

To find the optimal value of the per unit compensation amount or θ^o, let us use equations (8), (9), and (13). This gives us

$$\frac{p_l - \zeta\theta^o}{2} = \frac{p_l}{2+2\zeta^2}. \quad (14)$$

Solving for θ^o in equation (14), we get

$$\theta^o = \frac{p_l \zeta}{1+\zeta^2}. \quad (15)$$

Inspecting equation (15), it is clear that the optimal value of the per unit compensation to be paid by the tannery to the small farmer is an *increasing* function of the price of leather or p_l.

We can now write the tannery's optimized profit function when it pays compensation to the small farmer for the negative impact it gives rise to. That expression is

$$\pi_L^o\{l(\theta^o)\} = p_l l(\theta^o) - \{l(\theta^o)\}^2 - \theta^o \zeta l(\theta^o). \quad (16)$$

Using equations (13) and (15), we can substitute for l^o and θ^o in equation (16). This gives us

$$\pi_L^o = \frac{p_l^2}{2+2\zeta^2} - \frac{p_l^2}{(2+2\zeta^2)^2} - \frac{(p_l\zeta)^2}{(1+\zeta^2)(2+2\zeta^2)}. \quad (17)$$

Because of the extra cost to the tannery from having to pay compensation to the small farmer, we generally expect its optimal profit with compensation to be *lower* than its profit without compensation. Inspecting equation (6) and the first fraction on the RHS of equation (17), we see that this claim is certainly true whenever the constant of proportionality $\zeta \geq 1$. In our numerical analysis below, we show that the preceding claim is also true when $\zeta \in (0, 1)$.

Moving on to the small farmer, note first that the first-order necessary condition in equation (12) tells us that this individual will grow vegetables at maximal capacity which means that $v = V$. Using this result, the small farmer's profit function when he *is* paid compensation by the tannery is

$$\pi_F^o(v, \theta^o) = p_v V - V - \zeta^2 \left(\frac{p_l}{2+2\zeta^2}\right)^2 + \theta^o \zeta \left(\frac{p_l}{2+2\zeta^2}\right). \quad (18)$$

Setting $\theta^o = 0$ in equation (18) and using l^* from equation (5) instead of l^o to denote the tannery's optimal output of leather, we obtain an expression for the small farmer's profit function *without* compensation. That expression is

$$\pi_F(v) = p_v V - V - \zeta^2 \left(\frac{p_l}{2}\right)^2. \quad (19)$$

Let us now compare the ratio $\{p_l/(2 + 2\zeta^2)\}^2$ in equation (18) with the ratio $(p_l/2)^2$ in equation (19). Because $\zeta > 0$, some thought tells us that the square of first ratio in curly brackets is smaller than the square of the second ratio is parentheses. This finding permits us to conclude that, as we would expect, the small farmer's profit with compensation or $\pi_F^o(v, \theta^o)$ is always *higher* than his profit or $\pi_F(v)$ without compensation. Our final task in this paper is to conduct numerical analysis and explain what accounts for the differences between the solutions obtained in sections 3 and 4.

5. Discussion

To illustrate the meaning of the results we have obtained in sections 3 and 4, suppose that $p_l = \$10, p_v = \$2, \zeta = 0.1,$ and that $V = 10$. Then, using equations (5) and (6) we get $l^* = 5$ and $\pi_L^* = 25$. Using equations (13) and (15) we get $l^o = 4.95$ and $\theta^o \approx 1$. Using these numerical values in equations (17), (18), and (19) respectively, we obtain $\pi_L^o = 24.5, \pi_F^o = 10.25,$ and $\pi_F = 9.75$.

Our analysis shows that leather production by the tannery imposes a negative production externality on the small farmer and therefore it reduces the small farmer's profit from growing vegetables. The level of leather production is inefficiently high. In other words, the output of leather is *higher* than the socially optimal level. When the tannery is required to *compensate* the small farmer for the damage it causes, this tannery effectively internalizes the negative externality and, as a result, it reduces its output of leather, from 5 units to 4.95 units in our numerical example. An implication of this internalization is that the profit of the small farmer *increases*, from \$9.75 to \$10.25 in the numerical example. The production externality that we have been studying is fully internalized when the amount of compensation is chosen---$\theta^o = 1$ in the numerical example---so that the *socially* optimal level of leather output is achieved.

As noted by Tsujita (2007), the importance of requiring polluting tanneries to pay compensation to the negatively impacted parties in Kanpur and elsewhere in India is increasingly being recognized by means of public interest litigation. In this regard, it is worth pointing out that

Indian courts have, on occasion, ordered tanneries to pay compensation to the aggrieved parties.[12] Even so, enforcement of court orders has been weak thus far and hence many tanneries have continued to operate and to cause negative externalities on small farmers and, more generally, to contaminate the Ganges. One hopes that recent decisions of the National Green Tribunal that have resulted in the imposition of large fines[13] not only on the offending tanneries in Kanpur but also on the Uttar Pradesh state government for not doing its part to regulate the tanneries in Kanpur will improve the lives of people living in and around this city. This completes our analysis of the interaction between polluting tanneries and small farmers in Kanpur, India.

6. Conclusions

In this paper, we studied the interaction between a representative polluting tannery and a negatively impacted small farmer in Kanpur, India. The tannery produced leather and noxious chemical waste that ended up in wastewater used by a small farmer to irrigate agricultural land and grow vegetables. The waste generated by the tannery was functionally related to its output of leather. The small farmer faced a capacity constraint that described the maximum amount of vegetables he could grow. In this setting, we performed three tasks. First, we determined the optimal production of leather when the tannery did not account for the negative effect it had on the small farmer. Second, on the assumption that the tannery had to compensate the small farmer per unit of waste it generated, we ascertained the optimal compensation amount, the optimal output of leather, and the profit levels of the tannery and the small farmer. Finally, we compared the solutions

12 Go to https://elaw.org/content/india-mc-mehta-v-union-india-wp-37271985-19880112-tanneries-case-kanpur for additional details on this point. Accessed on 26 August 2022.

13 Go to https://www.business-standard.com/article/pti-stories/ngt-slaps-rs-280-cr-fine-on-22-tanneries-in-kanpur-for-dumping-chromium-into-ganga-119111801169_1.html for more details on this point. Accessed on 26 August 2022.

in the preceding two cases and then explained what accounted for the differences between them.

Here are two suggestions for extending the research described in this paper.[14] First, it would be useful to explicitly introduce public abatement activities as in Beladi *et al*. (2013) into the model and then study how such activities affect the production behavior of the tannery and the small farmer. Second, it would also be helpful to study the tannery-small farmer interaction in a repeated game framework to see how repeated interactions over time between the same parties influence the trajectories of the production of leather, chemical waste, and vegetables. Studies of pollution prevention by tanneries in Kanpur that incorporate these aspects of the problem into the analysis will provide additional perspectives on the ways in which tanneries can continue to exist as an industry and, at the same time, the environmental harm that is presently borne by small farmers and residents is mitigated to the extent possible.

---

14 See Cosgrove and Loucks (2015) for a more elaborate discussion of research needs.

Figure 1: Flow of the Ganges and the Location of Kanpur

References

Alam, M.Z., Ahmad, S., and Malik, A. 2009. Genotoxic and mutagenic potential of agricultural soil irrigated with tannery effluents at Jajmau (Kanpur), India, *Archives of Environmental Contamination and Toxicology*, 57, 463-476.

Anonymous. 2019. 91 Kanpur tanneries 'polluting' Ganga closed, *Business Standard*, January 8. https://www.business-standard.com/article/news-ians/91-kanpur-tanneries-polluting-ganga-closed-119010800177_1.html. Accessed on 26 August 2022.

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 Beladi, H. 2017. Cleaning the Ganges in Varanasi to attract tourists, *Atlantic Economic Journal*, 45, 511-513.

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

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

Batabyal, A.A., and Yoo, S.J. 2022. A theoretical analysis of costs, waste treatment, pollution in the Ganges, and leather production by tanneries in Kanpur, India. Forthcoming, *Regional Science Inquiry*.

Beladi, H., Liu, L., and Oladi, R. 2013. On pollution permits and abatement, *Economics Letters*, 119, 302-305.

Bhatnagar, M.K., Singh, R., Gupta, S., Bhatnagar, P. 2013. Study of tannery effluents and its effects on sediments of river Ganga in special reference to heavy metals at Jajmau, Kanpur, India, *Journal of Environmental Research and Development*, 8, 56-59.

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

Cosgrove, W.J., and Loucks, D.P. 2015. Water management: Current and future challenges and research directions, *Water Resources Research*, 51, 4823-4839.

Dhillon, A. 2014. Ganga management, Post Magazine, *South China Morning Post*, September 14. http://www.scmp.com/magazines/post-magazine/article/1589301/ganga-management. Accessed on 26 August 2022.

Gallagher, S. 2014. India: The toxic price of leather, *Pulitzer Center*, February 4. https://pulitzercenter.org/reporting/india-toxic-price-leather-0. Accessed on 26 August 2022.

Gowd, S.S., Reddy, M.R., and Govil, P.K. 2010. Assessment of heavy metal contamination in soils at Jajmau (Kanpur) and Unnao industrial areas of the Ganga plain, Uttar Pradesh, India, *Journal of Hazardous Materials*, 174, 113-121.

Khwaja, A.R., Singh, R., and Tandon, S.N. 2001. Monitoring of Ganga water and sediments vis-à-vis tannery pollution at Kanpur (India): A case study, *Environmental Monitoring and Assessment*, 68, 19-35.

Singh, A., and Gundimeda, H. 2021. 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.

Sinha, S., Gupta, A.K., Bhatt, K., Pandey, K., Rai, U.N., and Singh, K.P. 2006. Distribution of metals in the edible plants grown at Jajmau, Kanpur (India) receiving treated tannery wastewater: Relation with physico-chemical properties of the soil, *Environmental Monitoring and Assessment*, 115, 1-22.

Tsujita, Y. 2007. Industrial pollution control in India: Public interest litigation re-examined, in T.

Terao and K. Otsuka, (Eds.), *Development of Environmental Policy in Japan and Asian Countries*, 176-198. Palgrave Macmillan, New York, NY.

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