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by

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Abstract

We study the merits of regulating water pollution in the Ganges river caused by tanneries in Kanpur, India, by unitizing or merging the polluting tanneries. We first describe the $n \geq 2$ polluting tanneries in Kanpur as a Cournot oligopoly in which all tanneries incur fixed and variable costs in producing leather. Second, we derive the Nash equilibrium output of leather and profits and discuss how many tanneries can survive in this equilibrium as a function of the fixed costs. Third, we permit $m < n$ tanneries to merge and determine when this m-tannery merger is profitable to the unitized entity and to the non-unitized tanneries. Finally, we explain how the usefulness of unitization as a regulatory strategy depends on the magnitude of the tannery fixed costs and then comment on what our findings mean for improved water quality in the Ganges.

Keywords: Fixed Cost, Ganges River, Tannery, Unitization, Water Pollution

JEL Codes: G34, Q25, Q28

1. Introduction

The discharge of untreated industrial waste by tanneries into the Ganges river in the city of Kanpur, India, is a severe environmental problem (Khwaja *et al.* 2001). The Kanpur region is home to hundreds of tanneries that process animal hides into leather goods. During this process, large amounts of noxious chemicals such as chromium, sulfides, and arsenic are used (Singh and Rao 2013). Once these chemicals have been used, they are often discharged directly into the Ganges river without proper treatment, leading to acute contamination of the water.

Despite attempts by the central Indian government and environmental organizations to deal with the underlying issue, the problem of water pollution in the Ganges persists due to insufficient waste treatment infrastructure and the absence of efficacious enforcement of environmental regulations (Markandya and Murty 2004). While some tanneries have installed water treatment plants, many do not manage them properly or fail to treat the effluents to the necessary standards (Tare *et al.* 2003). Therefore, the continuing pollution of the Ganges in and around Kanpur remains an urgent public policy problem that requires a comprehensive solution, involving more stringent regulation, improved waste treatment technologies, and greater accountability for industries contributing to the pollution.

Even though the Ganges water pollution problem in Kanpur is acute, there are *very few* studies in the literature that have rigorously analyzed this problem. Recently, Batabyal (2023) and Batabyal *et al*. (2023) have theoretically studied aspects of the Ganges water pollution problem in Kanpur. Both papers maintain that one way to ensure higher water quality in the Ganges is by unitizing or merging[3] the two polluting tanneries under study. In this regard, Batabyal (2023, p. 1121) says that "a straightforward policy implication of our analysis is that the many, often small, tanneries in Kanpur that both pollute the Ganges and impose costs on each other ought to be merged into larger entities. Inter alia, such an action is likely to ameliorate water quality in the Ganges River."

The usefulness of unitization as a regulatory strategy has lately been analyzed by Batabyal (2025) and Batabyal and Beladi (2025). Although both these papers shed valuable light on the circumstances in which it makes sense to pursue unitization as a regulatory strategy, both papers suffer from a drawback in that they focus on instances in which the cost of producing leather incurred by the polluting tanneries is either quadratic (Batabyal and Beladi 2025) or linear with only variable costs (Batabyal 2025). In other words, both studies *ignore* the fixed costs of producing leather.

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[3] We shall use the terms "unitization" and "merger" interchangeably in the remainder of this paper. See Hartwick and Olewiler (1998, p. 194) for a textbook discussion of unitization in the natural resource and environmental economics literature.

Given this state of affairs, two questions now need to be addressed. First, do fixed costs matter when it comes to leather production by the polluting tanneries in the Kanpur area? The answer, almost certainly, is yes. This is because tanneries have to deal with land and building costs which tend to be either fixed or partly fixed. Second, costs associated with the use of tanning drums, splitting machines, and other specialized leather processing equipment tend also to be partly or wholly fixed. Finally, these tanneries must contend with the fixed costs associated with electricity, water supply, and gas connections, irrespective of the actual amount of leather they produce.

Second, given that fixed costs matter in the production of leather, are these fixed costs also relevant in ascertaining the usefulness of unitization as a regulatory strategy? Although there is no direct evidence that points to an answer, several studies---see Perry and Porter (1985), Farrell and Shapiro (1990), and Syverson (2011)---clearly suggest that fixed costs matter in determining the profitability of a merger. Given these two responses, our central objective in this paper is to analyze the role that *fixed costs* play in determining the usefulness of a regulatory strategy that seeks to control water pollution in the Ganges river caused by tanneries in Kanpur, India, by *unitizing* the polluting tanneries.

Section 2 below describes the $n \geq 2$ polluting tanneries in Kanpur as a Cournot oligopoly in which all tanneries incur fixed and variable costs in producing leather. Section 3 derives the Nash equilibrium output of leather and profits and discusses how many tanneries can survive in this equilibrium as a function of the fixed costs. Section 4 permits $m < n$ tanneries to merge and then determines when this m-tannery merger is profitable to the unitized entity and to the non-unitized tanneries. Section 5 first explains how the usefulness of unitization as a regulatory strategy depends on the magnitude of the tannery fixed costs and then comments on what our findings mean for improved water quality in the Ganges. Section 6 concludes and then suggests three ways in which the research delineated in this paper might be extended.

2. The Cournot Oligopoly

According to Sahu (2019), there are more than 400 tanneries in the Jajmau region of Kanpur and many of these tanneries are responsible for water pollution in the Ganges. Therefore, to address the usefulness of unitization as a regulatory strategy, we shall consider a stylized version of the Jajmau economy in which the leather manufacturing industry consists of $n \geq 2$ tanneries.

Each tannery in this leather manufacturing industry possesses some market power. Therefore, in game-theoretic terms, it makes sense to think of this industry as a Cournot oligopoly.[4] The quantity of leather produced by the ith tannery is $q_i, i = 1, \ldots, n$. Aggregate production of leather is given by $Q = \sum_{i=1}^{n} q_i$ and it is understood that $Q \geq 0$. Following

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See Tirole (1988, pp. 218-221) for a textbook discussion of a Cournot oligopoly.

Batabyal (2025) and Batabyal and Beladi (2025), we work with a linear inverse demand function for leather in our n tannery leather manufacturing industry and this function is given by $P(Q) = a - bQ$, where $a > 0$ and $b > 0$.

An individual tannery incurs three kinds of costs in producing leather. The first cost is the fixed cost of producing leather which is given by $F > 0$.[5] The second cost is the direct cost of producing leather which is described by the linear cost function $\alpha q, \alpha > 0$. The third or indirect cost stems from the *requirement* that tanneries treat the waste they generate (Hussain 2024). Let us describe this cost with the linear cost function $\beta q, \beta > 0$. We have no reason to believe that the direct marginal cost of leather production is equal to the marginal cost of treating waste. Therefore, *faute de mieux*, we assume that $\alpha \neq \beta$ and this assumption allows us to treat these two marginal costs as heterogeneous. That said, the total cost of producing leather confronting an arbitrary tannery is $C(q) = F + \alpha q + \beta q = F + (\alpha + \beta)q = F + \gamma q$ where $\alpha + \beta = \gamma, \alpha \neq \beta$, and $a > \gamma$.

In other words, to an arbitrary tannery in the leather manufacturing industry, the total cost of producing leather is the sum of the fixed cost (F) and the variable cost (γq). With this description of the theoretical framework in place, our next task is to determine

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The presence of fixed costs ensures that average fixed costs decline with output, which can contribute to economies of scale.

the Cournot-Nash equilibrium output of leather and the profits earned by an arbitrary tannery.

3. The Cournot-Nash Equilibrium

Tannery i chooses its output of leather q_i to maximize its profits. This ith tannery's profit function is

$$\Pi_i = \left\{a - b\left(q_i + \sum_{\forall j \neq i} q_j\right)\right\} q_i - F - \gamma q_i. \tag{1}$$

This profit maximization task is carried out, given the leather output choices of all the other tanneries. The first-order necessary condition for the above profit maximization problem tells us that we must have

$$\frac{\partial \pi_i}{\partial q_i} = a - 2bq_i - b\sum_{\forall j \neq i} q_j - \gamma = 0. \tag{2}$$

Rewriting equation (2), we can state the ith tannery's best response or reaction function. This function is given by

$$q_i = \frac{a - b\sum_{\forall j \neq i} q_j - \gamma}{2b}. \tag{3}$$

Inspecting the numerator of equation (3), it follows that a needs to be sufficiently large to ensure that this numerator and hence the output q_i are both positive.

In a symmetric Cournot-Nash equilibrium, we must have $q_i = q, \forall i$. [6] Using this last condition, the best response function in equation (3) can be written as

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6 Note that in an asymmetric Cournot-Nash equilibrium, this $q_i = q, \forall i$ condition will not hold.

$$q = \frac{a-\gamma}{b(1+n)}. \quad (4)$$

Using equation (4) and the inverse demand function for industry leather, we can compute the equilibrium price of leather that is received by an arbitrary tannery in our leather manufacturing industry. This equilibrium price is given by

$$p = \frac{a+n\gamma}{1+n}. \quad (5)$$

Knowing the equilibrium output and the price of leather, we can substitute these expressions into equation (1) to obtain the maximal profit (Π^n) in the leather manufacturing industry consisting of n tanneries. After some steps of algebra, we get

$$\Pi^n = \left\{\frac{a+n\gamma}{1+n} - \gamma\right\}\left\{\frac{a-\gamma}{b(1+n)}\right\} - F = \frac{(a-\gamma)^2}{b(1+n)^2} - F. \quad (6)$$

We can use equations (4)-(6) to shed light on how the water pollution in the Ganges generated as a byproduct of leather production affects an arbitrary tannery's Nash equilibrium output, price, and profit. Looking at the coefficient of the total cost function γq, we know that $\gamma = \alpha + \beta$. Now, *ceteris paribus*, suppose that there is an increase in water pollution in the Ganges. Then this leads to a greater amount of required tannery waste treatment. In turn, this increase can be expected to raise the cost of this treatment or βq. This last effect can be captured by postulating a rise in the coefficient β. In symbols, $\beta \uparrow \Rightarrow \gamma \uparrow$.

Inspecting equation (4), we see that $\gamma \uparrow \Rightarrow q \downarrow$. In other words, *ceteris paribus*, a rise in water pollution increases the total cost of producing leather and this reduces the equilibrium output of leather in our stylized Jajmau economy. Next, consider the equilibrium price in equation (5). Inspecting this equation, it is clear that $\gamma \uparrow \Rightarrow p \uparrow$. Put differently, all else being equal, an increase in water pollution in the Ganges raises the equilibrium price received by the leather producing tanneries in our model. Observe that this is to be expected because we just determined that an increase in water pollution reduces the equilibrium output of leather. Finally, let us consider the impact of rising water pollution in the Ganges on tannery profits. Partially differentiating both sides of equation (6) with respect to the parameter γ, we get

$$\frac{\partial \Pi^n}{\partial \gamma} = \frac{-2(a-\gamma)}{b(1+n)^2} < 0. \tag{7}$$

Equation (7) tells us that an increase in water pollution in the Ganges leads to a decrease in the profits of the tanneries under study.

Let us now assume that the individual tanneries remain in the leather manufacturing industry as long as they make positive profit. This means that the *largest possible* number of surviving tanneries or n satisfies the inequality

$$\frac{(a-\gamma)^2}{b(1+n)^2} - F \geq 0. \tag{8}$$

Solving for n from the above inequality, we get

$$n \leq \frac{a-\gamma}{\sqrt{bF}} - 1. \tag{9}$$

Our next task is to let $m < n$ tanneries merge. We then want to ascertain when this m-tannery merger is profitable for the unitized entity and for the non-unitized tanneries.

4. Unitization and Profitability

After m tanneries have been unitized, the total number of tanneries in the leather manufacturing industry is $(n-m+1)$. Now, if we replace n in equations (4) and (5) with $(n-m+1)$ then we get

$$q=\frac{a-\gamma}{b(n-m+2)}, p=\frac{\{a+\gamma(n-m+1)\}}{n-m+2}. \tag{10}$$

Using these expressions for the optimal leather output q and price p from equation (10) in the profit function and then simplifying, we get an expression for each tannery's profit after unitization or Π^{n-m+1}. That expression is

$$\Pi^{n-m+1}=\frac{(a-\gamma)^2}{b(n-m+2)^2}-F. \tag{11}$$

Comparing the two expressions for profit Π^n from equation (6) before unitization with profit Π^{n-m+1} in equation (11) after unitization, we see that

$$\Pi^n=\frac{(a-\gamma)^2}{b(1+n)^2}-F<\frac{(a-\gamma)^2}{b(n-m+2)^2}-F=\Pi^{n-m+1}. \tag{12}$$

The profit comparison in (12) tells us clearly that because $\Pi^n<\Pi^{n-m+1}$, unitization always *benefits* the non-unitized tanneries. Therefore, polluting tanneries that are not unitized will have a clear incentive to support the unitization of $m<n$ tanneries in the leather manufacturing industry.

What about the merged tanneries? Will they be in favor of unitization? To answer these two questions, we need to compare the profits after unitization or Π^{n-m+1} with the total profits earned by the m tanneries before unitization or $m\Pi^n$. Algebraic computations show that

$$\Pi^{n-m+1} - m\Pi^n = \tfrac{(a-\gamma)^2}{b(n-m+2)^2} - F - m\left\{\tfrac{(a-\gamma)^2}{b(1+n)^2} - F\right\}. \tag{13}$$

The right-hand-side (RHS) of equation (13) can be simplified further. This simplification gives us

$$\Pi^{n-m+1} - m\Pi^n = F(m-1) - \tfrac{(a-\gamma)^2}{b}\left\{\tfrac{m}{(1+n)^2} - \tfrac{1}{(n-m+2)^2}\right\}. \tag{14}$$

Unitization is profitable to the merged entity if and only if the RHS of equation (14) is positive or when $\Pi^{n-m+1} - m\Pi^n > 0$. Now, isolating the $F(m-1)$ term in equation (14) on the left-hand-side (LHS) and then rewriting as an inequality, we get

$$F(m-1) > \tfrac{(a-\gamma)^2}{b}\left\{\tfrac{m}{(1+n)^2} - \tfrac{1}{(n-m+2)^2}\right\}. \tag{15}$$

Dividing both sides of the inequality in (15) by $(m-1)$ yields

$$F > \tfrac{(a-\gamma)^2}{b(m-1)}\left\{\tfrac{m}{(1+n)^2} - \tfrac{1}{(n-m+2)^2}\right\}. \tag{16}$$

Since the expression $(a-\gamma)^2/b(m-1)$ on the RHS of (16) is always positive, let us focus attention on the expression inside the curly brackets on the RHS of the inequality in (16). Tedious but straightforward algebraic computations show that the expression in the curly bracket in (16) is negative as long as

$$n + \tfrac{3}{2} - \tfrac{\sqrt{4n+5}}{2} < m < n + \tfrac{3}{2} + \tfrac{\sqrt{4n+5}}{2}. \tag{17}$$

The reader will note that for the profitability issue that we are exploring, it is clear that $m < n$ and therefore the question of m being "very large" does not arise. Also, it is obvious that $n < n + 3/2 + \sqrt{4n+5}/2$. Using these last two pieces of information, we can modify the inequality condition in (17) and focus on the relevant part. This relevant part is

$$m > n + \tfrac{3}{2} - \tfrac{\sqrt{4n+5}}{2}. \tag{18}$$

We know that fixed costs or $F > 0$. Putting the result in (18) and the positivity of the fixed costs together, we infer that unitization is profitable to the merged entity as long as the number of merging tanneries is above the threshold given in (18), independent of the fixed costs.

We now briefly discuss how the usefulness of unitization as a regulatory strategy depends on the magnitude of the tannery fixed costs and then comment on what our findings mean for improved water quality in the Ganges.

5. Fixed Costs and Ganges Water Quality

In section 2, we pointed out that there are more than 400 tanneries in the Jajmau region of Kanpur. Hence, substituting $n = 400$ in the RHS of the inequality in (18), we deduce that in this case, unitization makes economic sense or is profitable if at least 382 tanneries are merged. When the potential number of tanneries to be unitized or m lies between 1 and $n + (3/2) - \sqrt{(4n+5)}/2$, the expression in the curly brackets in (16) is positive. Therefore, in this instance, unitization is profitable for the merged entity if the fixed costs are sufficiently *high*. When this happens, the unitized tanneries benefit from being able to take advantage of economies of scale.

When fixed costs are zero or when $F = 0$, despite the potential environmental benefits, there are no economies of scale from unitization and therefore unitization is profitable to the merged entity if and only if a sufficiently *large* number of tanneries are unitized. In this last instance, with a sufficiently small number of tanneries remaining in the leather manufacturing industry, the oligopoly price of leather is high enough to ensure profitability.

Our results do depend on some key model features such as the fixed costs or F and the number of tanneries that might be unitized or m. That said, it is important to keep in mind that merging 382 out of 400 firms would be considered a large-scale merger with a very high threshold for profitability. This suggests two points. First, the benefits from merging only become relevant when almost the entire tannery industry is consolidated. Second, there would appear to be strong diminishing returns to partial mergers. In other words, merging only some tanneries does not produce meaningful gains—only near-total consolidation brings significant advantages.

That said, a large-scale merger of this sort does raise the possibility of anticompetitive risk. Put differently, a merger of this magnitude will create a near-monopoly and this certainly has the potential to reduce competition drastically in the leather manufacturing industry. If this happens then this could, *inter alia*, lead to higher prices and lower consumer choice which would be issues for a regulator to consider. Finally, our analysis clearly suggests that small-scale mergers of tanneries are unlikely to be beneficial. There are probably little or no efficiency gains and the transaction and integration costs of such small-scale mergers are likely to outweigh the benefits even if such benefits exist.

Finally, coming to the Batabyal (2023) and Batabyal *et al.* (2023) contention about unitization likely leading to a decrease in water pollution in the Ganges in Kanpur, let us assume, as these two papers tacitly do, that water quality (water pollution) in the Ganges is an increasing (decreasing) function of the number of unitized tanneries m in the Jajmau region of Kanpur. This means that as the unitized entity becomes large, water quality in the Ganges improves because the individual tanneries now no longer impose costs on each other. Put differently, water pollution declines. If this assumption is valid then policy makers have an incentive to create a large, unitized entity because such an action can be justified on economic grounds because it increases the profits of both the unitized and the non-unitized tanneries *and* on environmental grounds because it lowers water pollution in the Ganges river.

Let us now briefly discuss four mechanisms by which a large-scale merger of the sort that we have been studying thus far in this paper might reduce water pollution in the Ganges. To this end, first, consider economies of scale in waste treatment. Pre-unitization, we have small or mid-sized tanneries that often cannot afford modern effluent treatment technologies. Post-unitization, we would have a larger, consolidated entity that can invest in centralized or advanced common effluent treatment plants.

Second, there is the distinct possibility of stronger regulatory compliance. Pre-unitization, we have many small tanneries that operate informally and/or evade regulation because of fragmentation and weak regulatory enforcement. Post-unitization, we would have a unified entity that is more visible, traceable, and accountable, thereby making regulatory enforcement simpler.

Third, we may well have improved resource management. Pre-merger, there are inefficiencies in water use, chemical handling, and waste disposal. Post-merger, a larger entity would be better able to optimize resource use and waste management across all its operations.

Finally, consider the incentives for innovation. Pre-merger, individual tanneries may well lack either the technical expertise or the incentive to innovate. Post-merger, the unitized entity may have more access to capital and technical partnerships and hence be more willing to innovate and adopt cleaner production methods. This, in turn, will result in less use of toxic chemicals and better recycling of water and waste.

If the above assumption that water quality (water pollution) in the Ganges is an increasing (decreasing) function of the number of unitized tanneries m does not hold then economic and environmental considerations are in *conflict*. Specifically, economic or profitability considerations alone would suggest that a policy maker create a large, unitized entity but environmental considerations would suggest that this policy maker not engage in unitization. This completes our discussion of unitization as a way of addressing water pollution in the Ganges river in Kanpur, India.

6. Conclusions

In this paper, we studied the merits of regulating water pollution in the Ganges river caused by tanneries in Kanpur, India, by unitizing the polluting tanneries. We first delineated the $n \geq 2$ polluting tanneries in Kanpur as a Cournot oligopoly in which all tanneries incurred fixed and variable costs in producing leather. Second, we derived the Nash equilibrium output of leather and profits and discussed how many tanneries could survive in this equilibrium as a function of the fixed costs. Third, we permitted $m < n$ tanneries to merge and determined when this m-tannery merger was profitable to the unitized entity and to the non-unitized tanneries. Finally, we explained how the usefulness of unitization as a regulatory strategy depended on the magnitude of the tannery fixed costs and then commented on what our findings meant for enhanced water quality in the Ganges.

The analysis in this paper can be extended in several ways. Here are three examples. First, it would be interesting to focus on a scenario in which the n tanneries in Jajmau are charged a specific tax $\tau > 0$ on each unit of leather produced.[7] The objective here would be to study the extent to which these tanneries are able to tax shift and how this shifting is impacted by allowing more tanneries to enter the leather manufacturing industry. Second, it would be instructive to analyze the dynamic interactions between the unitized entity and the non-unitized tanneries as either a differential or as a repeated game. Finally, one could also study a scenario in which repeated interactions between the polluting tanneries and a regulator potentially alters the fixed costs of producing leather that these tanneries face. Studies that analyze these aspects of the underlying problem will provide additional insights into the effects of alternate kinds of regulation on the profitability of the unitized and the non-unitized tanneries and water quality in the vitally important Ganges river in India.

[7] See Beladi *et al.* (2013) for an alternate perspective.

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