Collusion or Historical Inertia: Weight vs Sucrose Pricing in the Suagrcane Market of Pakistan

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Abstract

I study the following question: why do sugar mills in Pakistan pay cane farmers by weight instead of sucrose content? I develop a two-stage duopsony pricing game. In the first stage, mills choose the price regime: payment by weight or by sucrose content. In the second stage, for a given pricing regime, mills compete in prices. I show that if both mills choose the same regime, then the equilibrium profits are higher under the weight regime. The intuition behind this result is as follows. The cane starts losing its moisture and weight immediately after the harvest. Mills' revenue from one unit of cane remains the same under both regimes, but the evaporation of moisture increases the effective transportation cost for farmers and hence reduces the competition between mills under weight pricing. Using numerical analysis, I then show that two pure strategy equilibria are both mills paying by weight and both paying by sucrose in the second stage of the game. Numerical analysis generates a coordination game. The fact that mills pay by weight indicates collusive behavior among the mills. I also show that under the parameter values that represent the historical conditions of the market, weight pricing is the only equilibrium; indicating the possibility of historical inertia. Finally, I suggest a price floor as an equilibrium switching policy.

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1 Introduction

Pakistan is the 5^{th} largest sugarcane producer in the world in terms of area under cane cultivation, but 15^{th} in terms of sugar production. Pakistan stands almost at the bottom in the world ranking in terms of per hectare yield. Sugar recovery is slightly above 8%, whereas in many countries, it ranges from 12 to 14 percent (FAS-USDA, 2009). One of the reasons for the poor performance by Pakistan's sugar industry is the low quality of cane. In this paper, I argue that the low quality cane may be due to the pricing structure in the market. Sugarcane delivered to the processing mills is priced entirely on the basis of weight and no consideration is paid to the quality of cane. However, the quality of cane, as measured by the sucrose content, is considered to be the most important determinant of sugar production and profits of the mills. Despite universal recognition that the quality of cane needs to be improved, why mills do not give any price incentives to farmers to improve the quality is a conundrum. In a recent market assessment study, the Competition Commission of Pakistan (CCP) raised similar concerns by blaming mills for not adopting a readily available technology to measure the sucrose content of cane: "*appropriate technology (Core Sampler) is readily available and extensively used in most countries, it is not utilised in Pakistan due to the lack of an entrepreneurial spirit on the part of the mill-owners.*" (CCP 2009, p23). In spite of conducting an extensive investigation in the sugar market, the CCP's report does not provide an explanation for the puzzling pricing behaviour of mills. In this paper, I argue that mills' behaviour can be understood as an equilibrium of a properly specified pricing game. The structure of the game that I propose below reflects the technology of the industry and physiology of the cane. After harvest, sugarcanebecomes a highly perishable crop. It starts losing moisture immediately after harvest and after $72 - 96$ hours the chemical reactions start the inversion of sucrose in harvested cane. Post-harvest deterioration of cane requires processing of cane not too late after harvest to maximize production (Rakkiyappan et al., 2009). Due to this post-harvest sucrose inversion, mills generally do not buy cane from farmers who are located too far from the mill. However, some delay may actually be profitable for the mills. While cane starts losing moisture (tonnage) immediately after harvest, the sucrose content as a percentage of the mass in staling cane reaches its highest at 7296 hours, depending on the age of the crop. From the mill's perspective, this implies that the value of the cane remains constant before sugar inversion starts, but the cost of purchasing cane is reduced if it pays farmers by weight. Since the price of cane is solely linked to its weight, a certain time delay can increase mills' profits. This is the key insight on which I build the model in Section 3.

The need to process cane soon after harvesting confers monopsony power to mills in the procurement of cane. Moreover, poor rural road infrastructure, the need to coordinate harvest and delivery to mill, and the bulkiness of the crop also limit farmers' ability to choose between processing mills. Once the cane is delivered to the mill's gate, farmers are vulnerable to opportunistic behaviour by mills. Mills are often accused of delay in crushing and weighing, under-weighing of the cane, and delay in payments to the farmers (Naseer, 2007). To protect farmers from exploitation, provincial governments intervene in the market by setting a price floor. However, the combination of pricing by weight and the price floor gives no incentives to farmers to invest in the quality of the cane.

In Section 3 below, I present a two-stage pricing game to model mills' pricing behaviour. In the first stage, two mills choose between two pricing regimes; weight pricing and sucrose pricing. Weight pricing disregards the sucrose content in the cane and pays farmers entirely on the basis of weight of the cane. Sucrose pricing pays farmers on the basis of the sucrose content in the cane and gives no consideration to the weight. Once mills have chosen the price regime, they compete in prices. While mills interact with each other strategically, farmer-mill interaction is non-strategic. Farmers observe the prices chosen by the mills they could deliver to and then decide which mill to take their crop to. The model implies that for a given sucrose content level, mills' profits will always be higher under the weight pricing regime as compared to the sucrose regime. This is due to the fact that moisture loss implies that the effective transportation cost (the standard transportation cost plus weight loss due to moisture loss) paid by the farmers is higher under pricing by weight regime. Therefore, pricing by weight reduces the intensity of competition among mills. Mills pay relatively lower prices and make higher profits at the expense of farmers.

Under some plausible assumptions about the parameters of the model, the game simplifies to a coordination game between mills at the first stage of the game. The most crucial parameter is the evaporation rate s. In my numerical calculation, I take s to vary between 5 to 10%, in line with scientific studies. In the duopsony model, there are two pure strategy equilibria, with both mills pricing by weight or both pricing by sucrose content. However, weight pricing is always payoff-dominant and sucrose pricing is risk-dominant. Keeping the transportation cost and the value of cane to mills constant and reducing the evaporation rate from 10 to 5 percent makes sucrose pricing a weakly dominant strategy but weight pricing remains payoff-dominant equilibrium. This result may suggest that mills coordinate on weighting pricing. This conclusion seems especially plausible when mills are regularly involved in delaying weighing and crushing the delivered cane. However, one cannot rule the possibility that selection of the weight pricing equilibrium is due to historical inertia rather than explicit or implicit collusion. To check this possibility, I assume parameter values that would capture the historical condition of the market. In the past, transporting cane to mills would have not only been harder but also more costly to farmers as the transport infrastructure would have been underdeveloped and there were fewer mills in the market. Therefore, I assume a higher evaporation rate, $s = 15\%$, and also a higher transportation cost. With these parameters, the model generates a single equilibrium in the first stage, weight pricing. This implies that historically weight pricing might have been the only equilibrium and as transportation costs and evaporation rate reduced sucrose content pricing also became a possible equilibrium. Whether mills have coordinated to pay by weight or this is due to historical inertia, weight pricing provides no incentive to farmers to improve the quality of the cane which also adversely affect mills with low recovery rates. The industry seems to be stuck in an equilibrium where mills have no incentive to switch to sucrose content pricing and given weight pricing, farmers make no investment in the quality of the cane. Given the quality of the cane, mills' profits are maximized by opting for weight pricing. This is a classic coordination failure due to complementaries. Our theoretical structure in the presence of the multiplicity of equilibria has a striking policy implication. Given that the government already intervenes in the market by setting a price floor for the weight regime, I show that if the government sets the price floor high enough such that it makes mills, at least, indifferent between weight and sucrose pricing, then mills will have no incentive to stick to weight pricing. The policy should be used as a device to move the industry from one equilibrium to another. Once the mills choose the sucrose pricing it becomes self-enforcing. This implies that the policy need not be permanent and becomes impotent once the new equilibrium is achieved.

The rest of the paper is structured as follows. Section 2 gives a brief review of the market structure of Pakistan's sugarcane market. It also briefly explains the production process of sugar and post-harvest deterioration of sugarcane. Section 3describes the theoretical framework used to explain mills' pricing and equilibrium behaviour. Section 4 examines the possibility of historical inertia. Section 5 gives the policy implication from the analysis in section 3. Finally, section 6 concludes.

2 Sugarcane Market in Pakistan

Sugarcane is one of the most important industrial and cash crop in Pakistan. Its share in value-added by major crops has ranged between 10-13 percent during the last five years. Cane is grown on over a million hectares and provides the raw material for Pakistan's 84 sugar mills – which comprise the country's second largest agro-industry after textiles. In addition to sugar, sugarcane produces numerous valuable by-products, such as alcohol used by pharmaceutical industry, ethanol used as a fuel, bagasse used for paper and fuel, chip board manufacturing, and as a rich source of organic matter for crop production (APCom, 2006). Historically, most mills were public enterprises and each mill was granted an exclusive zone around the mill to purchase crop. However, the market went under considerable change when reforms and liberalization started in 1987. Farmers were allowed to sell their crop to any mill and the zoning system was completely abolished. All public sugar mills were privatized and entry of new mills was encouraged. Consequently, there was a massive surge in investment. The increase in competition among mills and an upward trend of support price have increased farmers' profits, but on average the sugar recovery rate has not increased. Furthermore, the industry suffers from excess capacity. Most of the mills are producing only $50 - 60$ % of their output capacity. Despite this under-utilization, the number of mills has increased from 43 in 1987 to 84 in 2009. A sugar mill operates for $4 - 5$ months (December to April) during the processing season each year. Mills buy sugar cane from a large number of small farmers from surrounding villages and there is hardly any vertical integration between field and mills. This is in contrast to other major sugar producing regions, Brazil, Africa, Australia and Caribbean countries, where there is high vertical integration and farm size is extremely large compared with Pakistan and South Asia. For example, in Australia the average sugarcane farm is 100 hectares and in Pakistan, it is just 3 hectares (SDPI, 2012 and USDA-FAS, 2015). In contrast to other major sugar producing regions, historically the land in South Asia was already settled by a large number of peasant farmers that the colonial government did not want to displace. As a consequence, South Asian cane cultivation is still carried out by large numbers of small farmers (Amin, 1984). There are more than 500 thousand farms under sugarcane cultivation across three provinces in Pakistan. A cane farmer, assuming the average farm size and cane yield, produces nearly 50 ton/hectares of sugarcane in a year, whereas the capacity of a typical mill is nearly 5000 tons of cane per day (SDPI, 2012). This big difference in the size of the typical farm and the typical mill justifies the assumption that mills have all the bargaining power, and hence farmers are price takers. What protects the farmer from mill exploitation is the competition among the mills. For this reason, stimulating competition among the mills can be very important.

To protect and represent sugar mills' interests, mills have established the Pakistan Sugar Mill Association (PSMA). Recently, the Competition Commission of Pakistan has accused PSMA of leading a cartel in the sugarcane and the sugar market. According to the commission's report, mills were working "collusively and collectively" in both markets (CCP, 2009).

2.1 Technology of Sugarcane Processing

Sugar production involves both farmers and processing mills. Farmers grow, harvest, and then transport cane to the mill or to the weighing stations established by mills. Sugarcane is a water and fertilizer intensive crop that is harvested yearly. Farmer's actions such as choice of a variety of sugarcane, timing, amount and type of fertilizer, provision of adequate water supply, and pest control directly determine the quality and sucrose content of the cane. The quality of sugarcane, measured as sucrose content in the cane, is considered to be the most important determinant of mill's profitability. It is nearly impossible for mills to verify if these actions were taken appropriately. Once the cane arrives at the processing mill, it is crushed to extract juice and then boiled till it crystallizes as raw sugar. Raw sugar is then washed and filtered to remove non-sugar ingredients and colour. The amount of sugar that a mill can extract from cane not only depends on the sucrose and water content of sugarcane, but also on the efficiency, hygiene, and organization at the mill. The cost of acquiring sugarcane accounts for $80 - 85$ % of the total cost of sugar production.

Given the perishable nature of the cane, mills and farmers coordinate cane harvesting. A mill decides on a time window during which it will purchase cane from a particular village and let it be known through its agent in the field, Naseer (2007).

2.2 Pricing and Incentive Structure

Pricing of the cane is one of the most controversial issues in Pakistan's agriculture policy. Currently, farmers are paid exclusively by weight of cane (tonnage). The quality of the cane is not incorporated into the pricing. Despite the universal recognition that the quality of the cane needs to be improved, mills do not give any price incentives to farmers to grow better quality cane.

Mills often claim that their technical staff conducts a visual inspection of cane to check the quality and sign of nutrient stress when the cane reaches the mill. Once the quality is assessed by visual inspection, mills pay an informal premium to farmers to encourage them to raise the quality of cane. However, no scientific method is employed to check the sucrose content of incoming cane. Technology for measuring quality as a percentage of sucrose content is widely available, cheap, and used in other regions. Naseer (2007) tests the hypothesis that if the price paid to farmers has a quality component, then the price farmers receive ought to relate to quality enhancing inputs, fertilizer and irrigation usage. Using household data from Punjab and Sindh, two provinces that constitute almost 80% area under sugarcane production in Pakistan, he does not find evidence for price returns for quality enhancing inputs.

Provincial governments in Pakistan intervene in the market by estimating the cost of producing sugarcane and then setting a price floor after consulting farmers and mills. The rationale for government intervention is to protect farmers against the monopsony power of mills and to ensure that farmers do not make losses on their production. The Pakistan sugar mill association has repeatedly urged the government to abolish the price floor. Historically, Indian sugar mills have also paid by weight, however, since 2009 the government of India changed policy and the Statutory Minimum Price (SMP) was replaced by the Fair and Remunerative Price (FRP)[1]. In the same, year Pakistan also

[1] In the Indian market, about 50% of the 550+ sugar mills are either Government owned and operated or managed by farmers' co-operative societies.

announced a new policy but ironically without changing the sugarcane pricing mechanism. FRP not only takes account of sugar but also of all-India recovery rate of sugar from sugarcane (CACP, 2014). In Pakistan, sugar mills in Sindh once made premium payments based on sucrose content, above the price floor, to all farmers (CCP, 2009). This, however, creates a classic incentive problem, where each farmer is paid a premium on the overall recovery rate achieved by all mills in any particular year. Hence, farmers have incentives to free-ride on others.

2.3 Post-harvest Deterioration of Sugarcane

Sugarcane is a highly perishable crop. After harvest, a series of physiological reactions start deteriorating cane. Deterioration is often exacerbated by transportation, storage, method of harvesting, and climatic conditions. From field to processing, cane can considerably lose tonnage and quality. There are three different reasons for the deterioration of sugarcane: loss in moisture, biochemical deterioration, and microbial deterioration (Solomon, 2009). The first adversely affects the farmers and the other two the mills.

Right after the harvest, cane rapidly starts losing moisture, which results in the reduction of cane tonnage. There is a steady increase in moisture loss from 3% within 24 hours of harvest to 10% within 72 hours in subtropical regions (Rakkiyappan et al. 2009 and Solomon, 2009). Loss of moisture from harvested cane reduces its weight and hence the payment to farmers. Biochemical deterioration involves inversion of sucrose. After harvest, sugarcane cells and respiration get damaged. The exposed sucrose is subjected to physiological acidic pHs that can start its acid inversion, and the higher the acidity the faster the inversion. Many hydrolytic enzymes are also activated after harvest that eventually reduce the quality of the cane. The principal cause of deterioration to cane quality and sucrose recovery is microbial deterioration, caused by lactic acid bacterium, *Leuconostoc mesenteroides*. The microbes infect cane wherever the stalk is cut. It rapidly colonizes the damaged tissue which is followed by falling sucrose content, juice purity, and pH. Microbial infection is linked with humidity, temperature, mud attached to the culm, factory hygiene and delay between harvest and processing. This accounts for 93

It is important to emphasize that while moisture loss starts immediately, the sucrose content (measured as Pol (Rakkiyappan et al., 2009). Any delay in crushing cane reduces the moisture and weight of cane. Since the price of the cane is solely linked to its weight, delay decreases the revenue farmers receive. Farmers avoid supplying to a mill that is located beyond a day's travel. Mills too generally do not buy from farmers that are located too far from the mill. The theoretical model in section 3 below is built on the premise that after the harvest mill can start crushing the cane before the sucrose inversion starts. Throughout the analysis, I assume that the sucrose content remains same. This assumption is based on the fact that sucrose content only starts reducing after 3 to 4 days and mills, being aware of this, do not buy cane from farmers located too far from the mill.

3 The Model

3.1 Environment

Consider a rural region in a developing country where cane farmers are located uniformly over a unit interval, $[0, 1]$. There are two identical sugar processing mills, each located at one end of the interval. Mill 0 is located at 0 and mill 1 is located at 1. The only difference among mills is their location. Each farmer grows and supplies one unit of cane to the mills and bears the transportation cost. For simplicity, I assume linear transportation cost. The transportation cost per unit of distance is t, the total cost of transporting one unit of cane is tx when the farmer is located at x. Mills compete with each other in two stages. In the first stage, both mills decide which price regime to adopt, weight or sucrose pricing, $\{p^w, p^s\}$. Weight pricing gives no consideration to the sucrose content and pays solely by weight of the cane. Sucrose pricing pays only for the sucrose content in a unit of cane, which I assume is fixed throughout the analysis. In the second stage, given their choice of price regime, mills compete in prices. Formally, in the first stage each mill's action set is $K_i \in \{Weightpricing,\ Sucrosepricing\}_{i=0,1}$ and in the second stage mill's choose $p_i^k \in \|brack 0, \infty)_{i=0,1}^{k=w,s}$, where k is the price regime chosen by mill i in the first stage. p_0^s denotes mill 0 pays farmer by sucrose content in the cane and p_0^w denotes mill 0 pays by weight of the cane. The two prices may not directly be comparable. At each stage, mills choose their strategies simultaneously. I look for the subgame perfect equilibrium in this two-stage game. Our strategy will be to first fix the pricing regimes for both mills and then find the equilibrium prices at the second stage. Given these equilibrium prices, I then find the equilibrium pricing regime at the first stage. A farmer's payoff is given by the price he receives net of the transportation cost. I assume that the cost of growing cane for farmers is zero. The payoff of a farmer located at location x and receiving payment by sucrose content is given by:

$$\nu_x = \begin{cases} p_0^s - tx & if\ cane\ is\ sold\ to\ mill\ 0 \\ p_1^s - t(1-x) & if\ cane\ is\ sold\ to\ mill\ 1 \end{cases}$$

In the case of weight pricing, I assume that post-harvest cane loses its moisture and hence the weight at a constant rate, $s \in (0,1)$. A farmer located at x receives revenue of $p_0^w(1-sx)$ if he delivers to mill 0. Since the cane loses its moisture at a constant rate s, $1-sx$ is the remaining proportion of the cane when mill 0 weighs the cane, and the farmer only receives the payment on this remaining proportion. As mentioned above, I assume that sucrose content does not change; it is only the moisture that evaporates. The payoff of a farmer located at x is:

$$\nu_x = \begin{cases} p_0^w(1-sx) - tx & if\ cane\ is\ sold\ to\ mill\ 0 \\ p_1^w(1-s(1-x)) - t(1-x) & if\ cane\ is\ sold\ to\ mill\ 1 \end{cases}$$

Note that under sucrose pricing the farmer bears just the standard transportation cost which depends on his location x. However, under weight pricing, in addition to the standard transportation cost, farmers are also subject to a constant evaporation loss and that too depends on his location. Hence, a farmer located closer to the mill suffers less weight loss and receives relatively higher payment for the cane he delivers to the mill. Assuming that the marginal cost of production of sugar is zero, under a given price regime, mills profits are given by

$$\Pi_i^k = (R - p_i^k) S_i^k(.)$$

Where R is the value of one unit of cane to the mill and remains fixed, and $R > t$. $S_i^k(.)$ is the supply of cane to mill i under pricing regime k. I now look for the equilibrium in this two-stage game.

3.2 Equilibrium

3.2.1 The Second Stage

In the second stage mills compete in prices for cane, for a given strategy chosen in the first stage. I first consider the case when both mills have chosen to pay by sucrose content.

Both Mills Pay by Sucrose Content

It is clear from the above setup that if both mills choose sucrose pricing then the second stage of price competition is same as in the standard Hotelling model. A farmer located at $x \in [0,1]$ will trade with mill 0 if and only if $p_0^s - tx \geq 0$ and $p_0^s - tx \geq p_1^s - t(1-x)$. Let $\overline{x}^s$ be the farmer who is indifferent between two mills, then $\overline{x}^s$ must satisfy:

$$\begin{aligned} p_0^s - t\overline{x}^s &= p_1^s - t(1-\overline{x}^s) \\ \overline{x}^s &= \frac{1}{2t}\left(t + p_0^s - p_1^s\right) \end{aligned}$$

Hence, the supply to mill 0, S_0^s, and mill 1, S_1^s, are given by:

$$\begin{aligned} S_0^s &= \frac{1}{2t}\left(t + p_0^s - p_1^s\right) \\ S_1^s &= 1 - S_0^s \end{aligned}$$

Mills profits are then given by:

$$\begin{aligned} \Pi_0^s &= (R - p_0^s)S_0^s \\ \Pi_1^s &= (R - p_1^s)S_1^s \end{aligned}$$

Since both mills are symmetric, equilibrium prices are then given by:

$$P^{s*} = R - t$$

which gives the equilibrium profits:

$$\Pi^{s*} = \frac{1}{2}t \tag{1}$$

Both Mills Pay by Weight

If both mills pay by weight of the cane, then a farmer located at $x \in [0,1]$ will trade with mill 0 if and only if $p_0^w(1-sx)-tx \geq 0$ and $p_0^w(1-sx)-tx \geq p_1^w(1-s(1-x))-t(1-x)$. Since cane starts losing moisture as soon as it is harvested, farmers' revenue also decline at the rate of evaporation and the farther from the mill a farmer's location is, the more he will lose. An indifferent farmer, $\overline{x}^w$, must satisfy:

$$\begin{aligned} p_0^w(1-s\overline{x}^w)-t\overline{x}^w &= p_1^w(1-s(1-\overline{x}^w))-t(1-\overline{x}^w) \\ \overline{x}^w &= \frac{t+p_0^w-p_1^w\,(1-s)}{2t+s(p_0^w+p_1^w)} \end{aligned}$$

Supply to mill 0, S_0^w and mill 1, S_1^w are given by:

$$\begin{aligned} S_0^w &= \frac{t+p_0^w-p_1^w\,(1-s)}{2t+s(p_0^w+p_1^w)}=\overline{x}^w \\ S_1^w &= 1-S_0^w \end{aligned} \tag{2}$$

Mill 0's profit maximizing problem is:

$$\begin{aligned} \max_{p_0^w}\pi_0 &= R\overline{x}^w-p_0^w\int_0^{\overline{x}^w}(1-sx)\,dx \\ &= \left(R-p_0^w(1-\frac{s\overline{x}^w}{2})\right)\overline{x}^w \end{aligned} \tag{3}$$

Setting FOC equal to zero gives the equilibrium prices and profits[2]:

$$\begin{aligned} P^{w^*} &= R(1-\frac{s}{2})-t(1-\frac{s}{4}) \\ \Pi^{w^*} &= \frac{1}{2}t+\frac{s}{32}\left((12-2s)\,R-(8-s)\,t\right) \end{aligned} \tag{4}$$

Comparing (1) with (4) gives the following result:

Proposition 1 *If both mills choose the same price regime, then the equilibrium profits are higher under the weight regime.*

$$\Pi^{w^*}>\Pi^{s^*}$$

Proof. $\Pi^{w^*}>\Pi^{s^*}$ *iff*

$$\frac{1}{2}t+\frac{s}{32}\left((12-2s)\,R-(8-s)\,t\right)>\frac{1}{2}t$$

which reduces to

$$R\,(6-s)>t\left(4-\frac{s}{2}\right)$$

Noting that $R>t$ *and* $0<s<1$ *, this inequality will always hold* ■

[2]The FOC with respect to P^w and the solution is given in the appendix.

The intuition behind Proposition 1 is that once cane is harvested, it will immediately start losing its weight while the sucrose content remains the same. Mills' revenue from one unit of cane is kept constant under both regimes, but per unit cost of purchasing cane is lower under the weight regime. Evaporation of moisture increases the effective transportation cost for farmers and hence reduces the competition between mills. Higher profits under the weight regime implies that mills make higher profits at the expense of farmers by paying realtively lower prices. Farmers' revenue decreases with the increase in distance from the mill.

Next I consider the case in which one mill pays by sucrose content and the other by weight.

Separating Strategies

Now let us suppose that each mill follows a different strategy. Without loss of generality, I assume that mill 0 pays by sucrose content and mill 1 pays by weight. The indifferent farmer and supply to the mills is given by:

$$p_0^s - tx = p_1^w(1 - s\,(1 - x)) - t(1 - x)$$

$$S_0^s = \overline{x} = \frac{1}{2t + sp_1^w}\left(t + p_0^s - p_1^w\,(1 - s)\right) \tag{5}$$

$$S_1^w = 1 - \overline{x} = \frac{1}{2t + sp_1^w}\left(t + p_1^w - p_0^s\right) \tag{6}$$

Expression (5) and (6) give the supply to both mills. Supply to mill 0 is higher and lower to mill 1 the higher the rate of evaporation[3]. The indifferent farmer shifts to the right as supplying to mill 1 becomes less attractive under higher s. Mill 0's problem is

$$\underset{p_0^s}{Max}\ \pi_0 = (R - p_0^s)\left(\frac{1}{2t + sp_1^w}\left(t + p_0^s + p_1^w\,(s - 1)\right)\right)$$

FOC gives mill 0's best response function:

$$p_0^{s^*} = \frac{1}{2}(R - t + p_1^w(1 - s)) \tag{7}$$

Mill 0 lowers its price, $p_0^{s^*}$, by $\frac{p_1^w}{2}$ if the evaporation rate goes up and increases $p_0^{s^*}$ by $\frac{(1-s)}{2}$ if p_1^w increases. Increases in the evaporation rate reduce the competition for mill 0.

[3] as $\frac{\partial \overline{x}}{\partial s} > 0$ and $\frac{\partial (1-\overline{x})}{\partial s} < 0$.

Mill 1's profit maximization is given by:

$$
\begin{aligned}
\underset{p_1^w}{Max}\ \pi_1 &= \left(R - p_1^w(1 - \frac{s(1-x)}{2})\right)(1-\overline{x}) \\
&= \left(R - p_1^w(1 - \frac{s(\frac{1}{2t+sp_1^w}(t + p_1^w - p_0^s))}{2})\right)(\frac{1}{2t+sp_1^w}(t + p_1^w - p_0^s))
\end{aligned}
$$

Taking derivative with respect to p_1^w and setting it equal to zero and then substituting 7 gives:

$$\alpha p_1^3 + \beta p_1^2 + \gamma p_1 + \delta = 0 \tag{8}$$

where

$\alpha = \frac{1}{4}s^4 - \frac{1}{2}s^3 + \frac{5}{4}s^2$

$\beta = \frac{1}{2}Rs^3 - \frac{1}{2}Rs^2 + s^3t - \frac{5}{2}s^2t + \frac{15}{2}st$

$\gamma = 4st^2 - 3R^2s^2 - 3s^2t^2 + 48t^2 + 18Rs^2t - 20Rst$

$\delta = 2t^3 - \frac{5}{2}R^2st + 9Rst^2 - 12Rt^2 - \frac{9}{2}st^3$

Equation (8) has one real root but the explicit expression for it is unmanageable. Therefore, for finding the equilibrium, I opt for the numerical solution. To have a meaningful analysis, I keep the value of cane to mills, R, and transportation cost, t, fixed. The central parameter in the analysis is the evaporation rate and I consider two values of s, $s \in \{0.05,\ 0.10\}$, each supported by scientific studies, as reported in section 2. I start the analysis with $s = 0.10$ and then later also consider $s = 0.05$. I believe that this is the most reasonable approximation for the current state of affairs in the market. As mentioned above, most farmers in Pakistan harvest cane manually, which is time-consuming and the harvested cane will only be transported to the mill when a farmer has harvested a big enough bulk to be transported. Secondly, transporting harvested cane to the mill on the rural road network is an extremely slow process. Unlike more developed countries, where the cane is transported via train, cane in south Asia is transported by tractor and trollies which is a slow mode of transportation. Finally, mills often delay weighing of the cane even after cane reaches the mill. In light of all these factors, it is fair to assume that from harvesting to weighing of the cane at the mill on average it takes two to three days. Hence, assuming $s \in \{0.05,\ 0.10\}$ is a reasonable approximation. In our setup, the evaporation of cane is directly linked to the distance between the farmer and the mill. For any given rate of evaporation, a farmer who is closer to the mill loses less than the farmer who is located further away.

Let $R = 2t$, $t = 0.65$, and $s = 0.10$. $R = 2t$ will ensure that the entire market is covered. The choice of t depends on the properties of the Hotelling model. In the hotelling model when $t \in (0, \frac{2}{3}]$, the Nash equilibrium is unique and the competitive regime is obtained. For $t \in (\frac{2}{3}, 1]$, there is an infinity of Nash equilibria, and finally if $t > 1$, then each mill is a monopsonist (Merel and Sexton, 2010). I assume that t is close to the upper bound that implements the competitive regime and gives a unique Nash equilibrium. Substituting these values in (7) and (8) and then into respective mill's profits give the equilibrium prices and profits. For mill 0 these are 0.61, 0.35 and for mill 1 are 0.63, 0.32 respectively[4]. I conclude that if R is high enough, the transportation costs are not prohibitively high, the evaporation rate is $s = 0.10$, and mills choose different price regimes, then the equilibrium profits will be higher under sucrose pricing than weight pricing. The intuition behind this result is that supplying to mill 1 become less attractive to farmers who are distant from mill 1 relative to mill 0 because mill 1 makes the payment on the remaining weight of the cane. The evaporation rate decreases the competition for mill 0 and therefore it will offer a lower price to farmers. Matrix 1 below shows the equilibrium prices.

		Mill 1	
		Weight	*Sucrose*
Mill 0	*Weight*	0.60 0.60	0.63 0.61
	Sucrose	0.61 0.63	0.65 0.65

Matrix 1: Equilibrium Prices : R=2t=1.3, t=0.65,s=0.10

Matrix 1 shows that mill 0, paying by sucrose, offers a lower price (0.61) when the rival mill pays the farmer by weight relative to when the rival mill also pay by sucrose content; then both mills pay (0.65)[5]. Mill 1 pays a higher price when the rival opts for the sucrose pricing (0.63) relative to when the rival chooses the weight pricing (0.60) and

[4]All figures are rounded to 2 digits.

[5]Calculations for all matrices are given in the appendix.

vice versa. In the case when $s = 0.05$ the equilibrium prices are presented below.

		Mill 1	
		Weight	*Sucrose*
Mill 0	*Weight*	0.62 0.62	0.64 0.63
	Sucrose	0.63 0.64	0.65 0.65

Matrix 2: Equilibrium Prices : R=2t=1.3, t=0.65,s=0.05

I now turn to the first stage equilibrium analysis.

3.3 The First Stage

Given the equilibrium prices and profits in the second stage of the game, mills choose what price regime to follow in the first stage of the game. Matrix 3 below shows the equilibrium payoffs in the first stage under different pricing regimes when the evaporation rate is set at 10%, $s = 0.10$.

		Mill 1	
		Weight	*Sucrose*
Mill 0	*Weight*	0.36 0.36	0.32 0.35
	Sucrose	0.35 0.32	0.33 0.33

Matrix 3: Equilibrium Profits: R=2t=1.3, t=0.65,s=0.10

Matrix 3 shows that if one mill is paying by weight (sucrose), then the rival's best response is to pay by weight (sucrose)[6]. Hence, we have two equilibria (*Weight, Weight*) and (*Sucrose, Sucrose*). Our simple model generates the familiar stag hunt game in matrix 3. A mill that pays by weight takes a risk that the rival may opt to play sucrose instead of weight, and it will end up with the lowest possible profits. The rival may want to encourage farmers to produce cane that has higher sucrose content. Any mill that chooses sucrose pricing is better off if the rival plays weight instead of sucrose; however, the best response for the rival is to play sucrose. This creates a slightly different payoff structure than the standard stag hunt game; nevertheless matrix 1 produces two equilibria. Playing weight is still risky and attracts mills towards sucrose pricing equilibrium while playing

[6]Profit figures are rounded to 2 values. Complete calculations are given in the appendix A-1

weight is mutually beneficial for both mills. In fact, the game in Matrix 3 is a variant of a coordination game called the assurance problem. The assurance problem was first introduced by Sen (1967) in the discussion of appropriate discount rate, and what policy measures might help produce an optimal saving rate or investment in an intertemporal economy. Both players would like to be assured that the other will choose the weight pricing, to which weight pricing is the best response. But without sufficient confidence that this is what the rival will choose, the unique best response is sucrose pricing.

Next I reduce the evaporation rate to 0.05; this represents the case if cane is crushed relatively early. Matrix 4 below gives us the equilibrium profits from the first stage.

		Mill 1	
		Weight	*Sucrose*
Mill 0	*Weight*	0.34 0.34	0.32 0.34
	Sucrose	0.34 0.32	0.33 0.33

Matrix 4: Equilibrium Profits: R=2t=1.3, t=0.65, s=0.05

The model still retains the same two equilibria (*Weight, Weight*) and (*Sucrose, Sucrose*) and the resulting game is akin to stag hunt. However, now playing sucrose pricing is a (weakly) dominant strategy. This creates an interesting scenario where the resulting game has a prisoner's dilemma like incentive structure for both mills but multiple equilibria like the stag hunt. It suggests that individually rational mills will choose to play sucrose pricing, but mutual cooperation is also an equilibrium, unlike the prisoner's dilemma. As compared to the previous case when $s = 0.10$, the risk that if a mill plays weight and the rival may play sucrose has increased since rival is indifferent between weight and sucrose. Reduced profits under the weight pricing equilibrium relative to $s = 0.10$ and a higher risk that the rival may opt sucrose pricing increase the likelihood of (*Sucrose, Sucrose*) equilibrium. However, the weight pricing equilibrium remains payoff dominant.

The fact that the processing mills in Pakistan choose to pay by weight suggests that mills may have overcome the tension between risk and mutual cooperation and coordinate on payoff dominant equilibrium. Weight pricing, however, is not a desirable equilibrium for the industry as a whole. As mentioned above, paying by weight gives farmers no incentives to improve the quality of the cane.

4 What Creates the Persistence of Weight Pricing?

The above analysis shows that there are two pure strategy equilibria. The fundamental question is why mills opted for weight pricing. Is it that the mills coordinate and collude on the weight pricing equilibrium or is it chosen by historical inertia? Answering this question without extensive data is almost impossible, and data on processing mills is not publicly available. Secondly, the coordination game framework is generally not of much use to pin down the forces of historical inertia. Constructing a dynamic model or repeating the coordination game can generate even more equilibria, including those in which mills switch from weight pricing to sucrose pricing and then back under different strategies. However, as I show below, different parameter values, based on reasonable supposition, can shed some light on this question.

Historically the transportation cost would have been higher as the transportation infrastructure was underdeveloped and the number of mills was relatively low. Transporting cane to mills was not only costly but also harder. By transporting at a slower pace and traveling a longer distance, the cane must have lost more weight before it reached the mill. Therefore, to explain history dependence I consider the case when $s = 0.15$ and the transportation cost is $t = 0.70$[7]. Matrix 5 below gives the equilibrium profits for different price regimes. Now weight pricing is the dominant strategy and there is only one pure

[7] Keeping the transportation cost at 0.65 and increasing s to 0.15 changes the payoff values but $(Weight, Weight)$ is the dominant strategy.

Mill 1

		Weight	*Soucrose*
Mill 0	*Weight*	0.37 , 0.37	0.34, 0.36
	Soucrose	0.36, 0.34	0.33, 0.33

Matrix 6: equilibrium profits: R=2t=1.3, t=0.65, s=0.15

strategy Nash equilibrium, (*Weight, Weight*).

		Mill 1	
		Weight	*Sucrose*
Mill 0	*Weight*	0.40 , 0.40	0.37, 0.39
	Sucrose	0.36, 0.37	0.35, 0.35

Matrix 5 Equilibrium Profits:R=2t=1.4, t=0.70, s=0.15

One could argue that at the initial stages of development of the industry, when the infrastructure was underdeveloped and the moisture loss was high, weight price was the only equilibrium. Mills continue to pay by weight as they did in the past and they have no incentive to switch to sucrose content as long as others don't change their pricing regime. The weight pricing equilibrium could be history dependent. The lack of scientific knowledge about the physiology of the cane could have also played the role in choosing weight pricing. However, at the current stage of development, practicing delay in weighing and under-weighing the cane does indicate that mills try to increase their profits by increasing the moisture loss. If a mill observes that the rival has been delaying the weighing of cane in the past, then it may serve as a signal that the rival will stick to weight pricing. Hence, the risk of rival switching to sucrose pricing diminishes. This helps mills coordinate on weight pricing equilibrium. Coordination and collaboration through PSMA reduce this risk to a minimum even before mills start crushing the cane. The higher profits associated with weight pricing also explains the persistence of weight pricing equilibrium.

5 Policy Implications

In this section, I look at the policy implication of the above analysis. I used a two-period game to explain why mills pay by weight. Farmers and mills interact repeatedly and both players' actions in one period affect others choices in the next. As outlined in section 2 above that mills do not pay any price returns to the quality of the cane and payments to the farmer are entirely based on the weight of the cane. The low quality of the cane is the primary reason why Pakistan's sugar production is low. Both farmers and mills can take actions that can improve the overall industry. If farmers are paid by sucrose content, then they can exert more effort to improve the quality of cane and the higher the quality, the higher the payment they will receive. Mills will always prefer paying by weight, but over the long run, mills will become better off if farmers improve the quality of the cane. It will increase mills' sugar recovery. However, for a given sucrose content level mills do not have an incentive to switch away from weight pricing. I do not model the interaction between farmers and mills, but it is easy to see that this situation is also similar to a coordination game with multiple equilibria. Mills choosing to pay by weight and farmers not investing in the quality of cane, and mills paying by sucrose content and farmers investing in the quality being two equilibria. The current situation in the industry suggests that the industry is stuck in the bad equilibrium, and indicates a coordination failure, where neither party has the incentive to move away from this bad equilibrium. Can government intervention help the industry to adopt sucrose pricing regime? I consider a government intervention that is already present in the market; a price floor. Below I show that the price floor can be used to move the industry from weight pricing to sucrose pricing.

The mill will be indifferent between paying by weight or sucrose content if the equilibrium profits from weight and sucrose pricing regime are the same, $\pi^{s^*} = \pi^{w}(P)$. I propose that a price floor under weight pricing should be set such that it makes weight pricing profits equal to the equilibrium profits under sucrose pricing. Equation (9) below gives the condition that makes these two profits equal.

$$\frac{1}{2}t = \left(R - p(1 - s\left(\frac{\frac{t+p-p(1-s)}{2t+s(p+p)}}{2}\right))\right)\left(\frac{t + p - p\,(1 - s)}{2t + s(p + p)}\right) \tag{9}$$

The left hand side of the equation (9) is the equilibrium profits when both mills choose to pay by sucrose content. The right hand side is the profit function when both mills pay by weight. A binding price floor implies that all mills will be at least paying each farmer the price floor. The price floor that equates these two profits is given by:

$$p^f = \frac{4(R - t)}{4 - s}$$

Comparing p^f with P^{w^*} shows that $p^f > P^*_w$. Using the same parameter values $R = 2t$, $t = 0.65$ and $s = 0.10$ gives $p^f = 0.67$ and $P^*_w = 0.61$. Choosing a price floor $p^f \geq \frac{4(R-t)}{4-s}$ gives mills an incentive to switch to the sucrose pricing regime, as profits from weight pricing reduce to at most Π^{s^*}. Setting a higher price floor should be viewed as a mechanism for moving the industry out of one equilibrium into another. Note that this policy change need not be permanent because once the desired price regime is adopted, no mill will have an incentive to deviate and switch to weight pricing again. This policy view is in contrast to the view that government should heavily invest in the infrastructure so that moisture loss can be minimized. My analysis shows that mills will always prefer weight pricing because, given the sucrose content, weight pricing is always more profitable. Delivering cane to the mill will always take some time and mills can deliberately delay weighing the cane, as is often practiced in Pakistan.

It is important to emphasize that I am not suggesting that the government or mills should not invest in the infrastructure to facilitate farmers' delivery of cane to mills. The argument is that investing in transport infrastructure will not give mills incentives to change their pricing regime and hence for farmers to invest in the quality of the cane. Improving the infrastructure for transportation will make mills worse off and farmers better off because farmers will be able to deliver the cane quicker than before and receive higher payments for the same quality of the cane. Secondly, improved infrastructure will increase competition among mills and farmers will be able to benefit from this increase in the competition. Finally, investing in the road infrastructure is an extremely expensive government intervention, while setting a higher price floor is costless. However, setting a higher price floor may have its own challenges. The biggest challenge will be the implementation of the new price floor. At the time of implementing the policy, it is not optimal to follow the policy, but the government is forcing mills to switch by setting a high price floor. Farmers too will have to exert more effort and invest more resources to make the quality of the cane better. Therefore, before implementing any equilibrium switching policy, the government should announce well in advance its intentions to change the policy. Farmers can choose if they want to continue growing cane and if so, then take appropriate actions to increase the quality of the cane. As mentioned above, farmers' and mills' interests have always been at odds with each other, and there is a persistent mistrust between both players. During the transition period and once the new pricing regime is adopted, the market also needs to adopt new standards and rules for transparency as sucrose content testing is conducted on the premises of mills. The industry will need to standardize testing procedures. In the past, mills have often reacted to any increase in price floor by delaying the crushing season or delaying weighing the cane. If the government does not play the intermediary role to make the transition smooth, the industry may end up with a worse outcome.

6 Conclusion

In this chapter, we asked the question: why do sugar processing mills in Pakistan pay by weight and not by the quality of the cane? The two-stage pricing game suggests that both weight and sucrose pricing can be equilibrium, but weight pricing is payoff dominant. Several practices by mills, delay in crushing, under weighing cane, the formation and functioning of PSMA, etc., indicate that mills coordinate at the weight pricing. However, as I have argued in section 4.3, the persistence of weight pricing could be due to historical inertia, and the structure of the market makes it persistent. Therefore, I cannot claim for sure that mills are involved in collusive practices, but our analysis does explain why mills stick to weight pricing. Based on the analysis, I have proposed one possible government intervention that could switch the market to sucrose pricing: setting a high enough price floor in weight pricing that could make mills at least indifferent between two equilibria. Since the sucrose pricing is equilibrium, it is self-enforcing. However, the equilibrium tipping policy needs to be carefully implemented during the transition, or it can fail badly.

Appendix

Equilibrium Prices and Profits under Weight Pricing:

Mill 0's profits are given by:

$$\pi_0 = \left(R - p_0(1 - \frac{s\overline{x}}{2})\right)\overline{x}$$

from (2) we know that $\overline{x} = \frac{t+p_0-p_1(1-s)}{2t+s(p_0+p_1)}$

The first order condition w.r.t. p_0 can be written as:

$$\begin{aligned} \frac{\partial \pi_0}{\partial p_0} &= \frac{\partial \overline{x}}{\partial p_0}\left(R - p_0 + sp_0\overline{x}\right) - \overline{x}\left(1 - \frac{s\overline{x}}{2}\right) = 0 \\ &\implies \frac{\partial \overline{x}}{\partial p_0}\left(R - p_0 + sp_0\overline{x}\right) = \overline{x}\left(1 - \frac{s\overline{x}}{2}\right) \end{aligned}$$

Now using the expression for $\overline{x}$ we can evaluate $\frac{\partial \overline{x}}{\partial p_0}$

$$\frac{\partial \overline{x}}{\partial p_0} = \frac{(2-s)\,(t+sp_1)}{(2t+s\,(p_0+p_1))^2}$$

Since mills are symmetric, in equilibrium $p_0^* = p_1^* = p^*$ which implies that in equilibrium $\overline{x}^* = \frac{1}{2}$ and $\frac{\partial \overline{x}}{\partial p_0} = \frac{2-s}{4(ps+t)}$. Substituting these values into the first order condition above gives:

$$\frac{2-s}{4\,(p^*s+t)}\left(R - p^* + \frac{sp^*}{2}\right) = \frac{1}{2}\left(1 - \frac{s}{4}\right)$$

Solving for p^* gives the equilibrium prices under weight regime:

$$p^{w*} = R(1 - \frac{s}{2}) - t(1 - \frac{s}{4})$$

Finally, substituting p^{w*} and $\overline{x}^*$ into the profit function π_0 gives:

$$\begin{aligned} \pi_0^w &= \left(R - \left(R(1 - \frac{s}{2}) - t(1 - \frac{s}{4})\right)(1 - \frac{s}{4})\right)\frac{1}{2} \\ &= \frac{1}{2}t + \frac{s}{32}\left((12-2s)\,R - (8-s)\,t\right) \end{aligned}$$

Calculations for Matrix 1: Equilibrium Prices: Let $R = 2t = 1.3,\ t = 0.65,\ s = 0.10$

If both mills pay by weight, then the equilibrium prices are given by:

$$\begin{aligned} P^{w^*} &= R(1 - \frac{s}{2}) - t(1 - \frac{s}{4}) \\ &= 2(0.65)\left(1 - \frac{0.10}{2}\right) - 0.65\left(1 - \frac{0.10}{4}\right) = 0.60125 \end{aligned}$$

If both mills pay by Sucrose content, then the equilibrium prices are given by:

$$\begin{aligned} P^{s*} &= R - t \\ &= 2(0.65) - 0.65 = 0.65 \end{aligned}$$

If one mill pays by Weight and the other pay by Sucrose Content:

Weight pricing mill (the real root): p_w

$p_w = -\frac{3}{4}(1.3)^2(0.10)^2 p_1 - \frac{5}{2}(1.3)^2(0.10)(0.65) + \frac{1}{2}(1.3)(0.10)^3 p_1^2$
$+\frac{9}{2}(1.3)(0.10)^2(0.65)p_1 - \frac{1}{2}(1.3)(0.10)^2 p_1^2 + 9(1.3)(0.10)(0.65)^2$
$-5(1.3)(0.10)(0.65)p_1 - 12(1.3)(0.65)^2 + \frac{1}{4}(0.10)^4 p_1^3 + (0.10)^3(0.65)p_1^2$
$-\frac{1}{2}(0.10)^3 p_1^3 - \frac{3}{4}(0.10)^2(0.65)^2 p_1 - \frac{5}{2}(0.10)^2(0.65)p_1^2 + \frac{5}{4}(0.10)^2 p_1^3$
$-\frac{9}{2}(0.10)(0.65)^3 + (0.10)(0.65)^2 p_1 + \frac{15}{2}(0.10)(0.65)p_1^2 + 12(0.65)^3$
$+12(0.65)^2 p_1 = 1.2025 \times 10^{-2} p_1^3 + 0.46605 p_1^2 + 4.7119 p_1 - 3.1994 = 0$
$p_w^* = 0.63407$
Sucrose pricing mill: p_s
$p_0 = \frac{1}{2}((1.3) - (0.65) + 0.63407 - (0.10)(0.63407)) = 0.61033$

<u>Calculations for Matrix 2: Equilibrium Prices</u>: $R = 2t = 1.3,\ t = 0.65,\ s = 0.05$

If both mills pay by weight, then the equilibrium prices are given by:

$$\begin{aligned} P^{w^*} &= R(1 - \frac{s}{2}) - t(1 - \frac{s}{4}) \\ &= 2(0.65)\left(1 - \frac{0.05}{2}\right) - 0.65\left(1 - \frac{0.05}{4}\right) =: 0.62563 \end{aligned}$$

If both mills pay by Sucrose content, then the equilibrium prices are given by:

$$\begin{aligned} P^{s*} &= R - t \\ &= 2(0.65) - 0.65 = 0.65 \end{aligned}$$

If one mill pays by Weight and the other pay by Sucrose Content:

Weight pricing mill: p_w

$p_w = p_1 = -\frac{3}{4}(1.3)^2(0.05)^2 p_1 - \frac{5}{2}(1.3)^2(0.05)(0.65)$
$+\frac{1}{2}(1.3)(0.05)^3 p_1^2 + \frac{9}{2}(1.3)(0.05)^2(0.65)p_1$

$-\frac{1}{2}(1.3)(0.05)^2 p_1^2 + 9(1.3)(0.05)(0.65)^2$

$-5(1.3)(0.05)(0.65)p_1 - 12(1.3)(0.65)^2 + \frac{1}{4}(0.05)^4 p_1^3$

$+(0.05)^3(0.65)p_1^2 - \frac{1}{2}(0.05)^3 p_1^3 - \frac{3}{4}(0.05)^2(0.65)^2 p_1$

$-\frac{5}{2}(0.05)^2(0.65)p_1^2 + \frac{5}{4}(0.05)^2 p_1^3 - \frac{9}{2}(0.05)(0.65)^3$

$+(0.05)(0.65)^2 p_1 + \frac{15}{2}(0.05)(0.65)p_1^2 + 12(0.65)^3 + 12(0.65)^2 p_1$

$= 3.0641 \times 10^{-3} p_1^3 + 0.23823 p_1^2 + 4.8854 p_1 - 3.2474 = 0$

$p_w^* = 0.6443$

Sucrose pricing mill: p_s

$p_0 = \frac{1}{2}((1.3) - (0.65) + 0.63407 - (0.05)(0.63407)) = 0.62618$

<u>Calculations for Matrix 3: Equilibrium Profits:</u> $R = 2t = 1.3,\ t = 0.65,\ s = 0.10$

If both mills pay by weight

$$\pi_0^* = \frac{1}{2}t + \frac{s}{32}((12 - 2s)R - (8 - s)t)$$

$$\pi_0 = \frac{1}{2}(0.65) + \frac{0.10}{32}((12 - 2(0.10))(1.3)a - (8 - (0.10))(0.65)) = 0.35689$$

If both mills pay by Sucrose Content:

$$\Pi^{s*} = \frac{1}{2}t = \frac{0.65}{2} = 0.325$$

If one mill pays by Weight and the other by Sucrose Content:

$$\pi_w^* = ((1.3) - (0.61033))\left(\frac{1}{2(0.65)+(0.10)(0.63407)}\left(\begin{array}{c}(0.65) + (0.61033) \\ +(0.63407)((0.10) - 1)\end{array}\right)\right)$$

$= 0.34886$

$$\pi_w^* = -\frac{1}{2(2(0.65)+(0.10)(0.63407))^2}((0.65) - (0.61213) + (0.63407))\left(\begin{array}{c}(0.10)(0.61033)^2 + 4(0.65)(0.63407) \\ -4(1.3)(0.65) + (0.10)(0.61033)(0.63407) \\ -2(1.3)(0.10)(0.63407) - (0.10)(0.65)(0.63407)\end{array}\right) = 0.32456$$

Equilibrium Profits in matrix 4, 5, and 6 are similarly calculated.

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