Agro-Industrial Processing and Agricultural Pricing Under Uncertainty

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Processing domestically available materials for export has intuitive appeal, e.g. if transport costs are reduced. Uncertainty in the supply of the raw material can be a crucial factor. The theoretical model of this paper shows how to choose the optimal processing capacity and, relatedly, the optimal price to pay producers of the input. Issues include: decision makers’ preferences; sources and nature of uncertainty; availability of inputs to produce the raw material; and technology and costs of processing. Econometric estimates of the climate-yield relation are used to simulate these decisions for the case of Senegalese groundnut processing.

1. INTRODUCTION

There is an intuitive appeal to industrial strategies based on processing domestically available raw materials for export. For instance, relative to export of the raw material for processing abroad, domestic processing often achieves cost savings based on certain locational advantages, such as the opportunity to decrease the product’s weight prior to transport. In this paper, I analyse the costs and benefits of investing in processing capacity under particular conditions, and the related question of the appropriate domestic pricing of the raw material. The second part of the paper presents an application of the theory to Senegalese groundnut culture and processing.

Especially for agricultural inputs, the domestic supply of the raw material is likely to be uncertain. This uncertainty interacts with locational advantages in important ways affecting both the optimal choice of agro-industrial processing capacity and the optimal choice of the price to be offered agricultural producers of the input. From the viewpoint of the processing mills, the locational advantage means that stochastically low availability of the raw material cannot be (fully) compensated by imports. Thus, the problem of idle processing capacity arises. Similarly, harvests of the input above the level that can be processed imply some loss of the locational advantages, assuming that the input cannot be stored costlessly.

To illustrate these basic notions, consider the simplest case of a single input with a given world price, \( p_t \), transformed at a constant unit cost, \( r \), into an output with a given world price, \( p \). Let the size of the crop also be certain, say of magnitude \( m \). So long as \( (p - p_t) \geq r \), optimal processing capacity is \( m \).

Now consider a situation of uncertainty with two equiprobable states of nature faced by a risk-neutral decision-maker. Good weather yields a crop of \( h \) units, while bad weather yields a crop of \( l \) units, with \( m = 0.5 (l + h) \). Let the cost \( r \) be fixed in that it must be paid once a unit of capacity is installed whether it is used or not. If \( 0.5 (p - p_t) \geq r \) then capacity of \( h \) units is optimal although \( (h - l) \) units of capacity are used only half-time. Otherwise \( l \) units should be chosen, so long as \( (p - p_t) \geq r \). The mean of \( m \) is
not directly relevant, illustrating a basic property of this type of processing capacity problem: even with risk-neutral decision-making, all moments of the distribution of the raw materials supply must be considered. In the example given, optimal capacity can either rise or fall with an increase in the variance of the input supply. This conclusion contrasts with the often-made assertion that uncertainty need not be considered in project evaluation (Arrow and Lind (1970)), and depends on the particular way uncertainty affects the profitability of processing.

Processing in the presence of locational advantages implies the interdependence of decisions about processing capacity and about agricultural prices. In general, a world price rule is appropriate for determining the price received by producers of the input. But which world price when locational advantages mean that \( p - p_I > r \)? A presumption exists that the price should be \( p - r \) rather than \( p_I \): on the margin, the locational advantages should just be exhausted by the costs of producing the input. When production is uncertain, however, the appropriate price is a blend of \( p \) and \( p_I \) determined by all characteristics of the distribution of the uncertain variable, even if decision-makers are risk-neutral.

In the next section, I develop a theoretical model that simultaneously determines optimal processing capacity and agricultural prices. These decisions could be implemented either centrally, as in Senegal, or by a competitive processing industry, and they imply zero expected profits. The model is used to analyse the effects of changes in various exogenous variables: different elements of the costs of processing, factor endowments in agriculture and the nature of uncertainty.

In the third section, some aspects of Senegalese groundnut culture and processing are analysed. The Senegalese case is a particularly good example of this type of cost-benefit calculation: climatic variability is an important determinant of the quantity of groundnuts available for processing, and this relationship can be modelled econometrically. Groundnuts, whether unprocessed or processed, are primarily exported. Senegal has recently expanded its processing capacity and relatively current cost figures are available. The application to Senegal shows how the theoretical notions can be implemented, and emphasizes a number of methodological decisions that will often be faced in practice.

2. THEORETICAL CONSIDERATIONS

I assume a simple agricultural sector producing two crops, groundnuts \( G \) and millet \( M \). Groundnuts can be processed into oil and cake if processing capacity is available. Unprocessed groundnuts cannot be stored, so that they must be processed or exported, and it is too expensive to import groundnuts if the domestic crop falls short of processing capacity. Millet is not processed.

Two factors, land \( (T_G \text{ and } T_M) \) and labour \( (L_G \text{ and } L_M) \) are used to produce the two crops:

\[
G = \theta \phi (T_G, L_G)
\] (1)

and

\[
M = g(\theta)\Omega (T_M, L_M).
\] (2)

The random variable \( \theta \), with p.d.f. \( f(\theta) \) and c.d.f. \( F(\theta) \), represents the effect of weather on groundnut production. Let \( \bar{\theta} = E(\theta) = 1 \) so that \( \phi \) is the expected size of the groundnut crop. The function \( g(\theta) \) represents the effect of weather on millet output with \( g' \equiv 0 \) and
mean $\bar{g} = \int_0^\infty g(\theta)f(\theta)d\theta$. The total supplies of each factor are fixed:

$$T_G + T_M = \bar{T} \tag{3}$$

and

$$L_G + L_M = \bar{L} \tag{4}$$

Both crops are assumed to trade on world markets at fixed prices $p_G$ and $p_M$. In addition one unit of groundnuts can be processed into oil and cake that sell at $p_0$ in world markets. Processing technology requires both processing capacity and variable inputs. A unit of processing capacity costs $r$. The fixed costs of capacity of amount $K$, $rK$, must be paid regardless of whether the capacity is used or not, while variable costs per unit processed, $v$, are incurred only to the extent that groundnuts are processed.

Year-to-year climatic variation influences the amount of each crop produced, and therefore the degree of capacity utilization in processing. But allocations of agricultural inputs and investments in processing capacity must be made before the actual realization of weather is known to decision-makers. Thus the criterion for these decisions must be based on the distribution of weather possibilities and on the expected consequences of different allocations and investment strategies.

The expected income from agricultural activity in any year, $EY$, inclusive of returns to processing is:

$$EY = \int_0^\alpha \theta(p_0-v)\phi f(\theta)d\theta + \int_\alpha^\infty (p_0-v)Kf(\theta)d\theta$$

$$-rK + \int_\alpha^\infty p_G(\theta\phi-K)f(\theta)d\theta + \int_0^\infty p_M g(\theta)\Omega f(\theta)d\theta, \tag{5}$$

where $\alpha = K/\phi$ is the ratio of capacity to expected crop when $\bar{\theta} = 1$. The components of expected income in (5) are: (1) the expected benefits from processing net of variable costs when $\theta\phi < K$, i.e. processing capacity is in excess; (2) the corresponding benefits if the crop is so large ($\theta\phi > K$) that capacity is inadequate and only $(p_0-v)K$ is earned in processing; (3) the fixed costs of capacity, incurred regardless of the crop’s size; (4) the excess amount of groundnuts that are exported at price $p_G$ when $\theta\phi > K$; and (5) the expected value of the millet harvest.

Equation (5) provides the maximand if dynamic intertemporal factors can be ignored and if decision makers are risk neutral (see Appendix A for risk aversion). Equations (1)-(4) are the constraints. Setting first-order conditions with respect to $K$, $T_G$, $T_M$, $L_M$ and $L_G$ to zero and rearranging, yields:

$$(p_0-v-p_G)[1-F(K/\phi)] = r \tag{6}$$

and

$$\frac{(p_0-v)w + p_G(1-w)}{p_M} g\Omega = \bar{g}\Omega_1 \frac{\delta\phi_1}{\bar{\theta}\phi_1} = \bar{g}\Omega_2 \frac{\delta\phi_2}{\bar{\theta}\phi_2}, \tag{7}$$

where situations of excess capacity account for the proportion $w = \int_0^\alpha \theta f(\theta)d\theta/\bar{\theta}$ of $\bar{\theta}^3$.

The left-hand side of (6) states that the expected benefit of increasing capacity by one unit is the probability of the increase resulting in additional utilized capacity $(1-F)$ times the benefit net of both variable costs and the return from exporting unprocessed groundnuts. The marginal cost of the capacity is the right-hand side, $r$. From (6), $p_0-v-p_G$ must exceed $r$ otherwise it would never be profitable to install $K$. 


The left-hand side of (7) is the ratio of a weighted average of \((p_0 - v)\), the benefit of oil processing net of variable costs and \(p_G\), the price of groundnuts, to the price of millet. The weight, \(w\), is the fraction of the expected value of the effect of weather on groundnut production attributable to situations when processing capacity is underutilized. The middle expression is the ratio of the expected marginal product of land in millet production and in groundnut production. The third part of (7) equates the ratio of the expected marginal product of labour in the production of each good to the ratio of the expected marginal product of land in the production of each good, a standard optimality condition.

If risk-neutral groundnut producers were faced with a domestic price for groundnuts, \(p_F\),

\[
p_F = (p_0 - v)w + p_G(1 - w)
\]  

(8)

they would maximize their own expected income by allocating their land and labour to fulfill equation (7). Thus \(p_F\) represents the appropriate domestic price to offer groundnut producers if the overall maximization problem of (6) and (7) is to be decentralized so that peasants respond to market incentives. This price is a blend of the difference between the world price of oil (and cake) and the variable costs of processing, and the world price of groundnuts. Since \(p_0 - v - p_G > 0\), \(p_F\) exceeds \(p_G\). At the optimum, \(p_F = p_0 - v - \frac{(1 - w)r}{(1 - F)} < p_0 - v - r\), proved by substituting (6) into (8).

The price \(p_F\) is also the (output-weighted) average paid if the price to peasants were not fixed beforehand, but were instead equal to \(p_0 - v\) if capacity were underutilized and \(p_G\) otherwise. This outcome would occur if processing mills competed for groundnuts after the harvest, rather than setting a fixed price beforehand. The model is thus consistent with several institutional setups: (1) the price is fixed before the harvest by the government, the crop is produced by independent peasant producers and is sold to mills, as in Senegal; (2) competitive mills set prices to independent producers once the harvest is known; (3) mills and farms are integrated so that the crop pattern decisions are made directly by the mills; or (4) the mills own some but not all the land, a combination of (1) or (2) with (3).

Equation (7) applies even if the available processing capacity is not optimal. In this case, (6) is dropped since \(K\) is not a choice variable, and the given \(K\) is substituted in (7). The higher is the exogenous level of \(K\), the higher is \(p_F\) since a higher \(K\) always increases the optimal level of groundnut production (in Figure 1, following, an increase in \(K\) is represented by a movement up the \(GM\) curve).

If peasants are paid \(p_F\) and capacity is at the optimal level, then the expected profits on processing, \(E\Pi\), including the sales of groundnuts in excess of \(K\) on world markets, is:

\[
E\Pi = \int_0^\alpha (p_0 - v - p_F)\theta f(\theta)d\theta + \int_\alpha^\infty (p_0 - v - p_F)Kf(\theta)d\theta
- \int_\alpha^\infty (p_F - p_G)(\theta f - K)f(\theta)d\theta - rK.
\]

From (6), \(E\Pi = 0\). That is, for the optimal \(K\) and optimal \(p_F\), the processing mills should just break even on average. Thus any locational advantage in processing groundnuts should be passed on to the peasants via the producer price, \(p_F\), to provide proper incentives to maximize the income of the agricultural sector.

Figure 1 represents equation (6) by the \(KK\) curve and equation (7) by the \(GM\) curve, with their intersection determining \(\phi\) and \(K\). These curves divide \((\phi, K)\) space into four zones with the following interpretation: above \(KK\), capacity has been chosen too high
for the value \( \phi \), i.e. the right-hand side of (6) exceeds the left-hand side. Above \( GM, \phi \) is too low for the given \( K \), so that \( p_M/p_F \) is too high, and groundnut prices should be raised, i.e. the right-hand and middle terms of (7) exceed the left-hand side. The interpretation of these zones combined with the empirical analysis of the next section will be used to test for the optimality of policy in Senegal.

Various exogenous variables in the model affect the values of \( \phi, K \) and \( \phi/K \). Some of these are potential policy instruments; others cannot be altered but may vary from country to country. By total differentiation, an increase in \( p_M \) decreases \( \phi \) and \( K \) while keeping \( K/\phi \) constant. An increase in \( r, v \) or \( p_G \), or a decrease in \( p_0 \) all cause \( \phi, K \) and \( K/\phi \) to fall. If total unit costs \( (v+r) \) are kept constant but \( v \) rises and \( r \) falls, \( K/\phi, \phi \) and \( K \) all rise. This last result can be proved by total differentiation of (6) and (8) for \( p_F \) to show that \( p_F/p_M \) and hence \( \phi \), rise. It points up the importance of classifying costs correctly between the \( v \) and \( r \) categories. Note that in all these cases where \( \phi \) rises (or falls) so does \( p_F/p_M \).

If the total amount of land \( (\bar{T}) \) increases then \( \bar{\phi} \phi \) increases for any given \( \alpha \) if groundnuts are land-intensive relative to millet, and actually decreases otherwise. This result follows from the Rybczynski Theorem. Capacity \( (K) \) changes in proportion to \( \phi \). Similarly, if the total amount of labour \( (\bar{L}) \) increases then \( \bar{\phi} \phi \) and \( K \) decrease if groundnuts are land-intensive and increase otherwise.

The form of the distribution of \( \theta \) may be influenced by such policies as investing in irrigation, but, in any case, it may vary from one place to another. Further, in applying the model, there are different ways to characterize the distribution of \( \theta \) as discussed in Section 3. It is thus of interest to understand how differences in the nature of uncertainty affect the decisions under consideration. The structure of the problem is, however, such that it is difficult to characterize general changes in the distribution of uncertainty that will produce unambiguous changes in \( K, \phi \) and \( K/(\bar{\phi}) \).

**Figure 1**

Solutions of equations (6) and (7) for \( K \) and \( \Phi \)
For instance, replace $\theta$ by a variable $\tilde{\theta}$ obtained by a mean-preserving spread, so that $\tilde{\theta}$ is riskier. In this case $E(\tilde{\theta}) = E(\theta) = 1$ and there exists at least one point at which the two cumulative distributions cross. It is clear from (6) that if equilibrium is initially in the range where $F < \tilde{F}$, then $K/\phi$ must fall to restore this equality, and conversely for $\tilde{F} > F$. This result can also be derived using the theorems in Kanbur (1982). Furthermore, the change to $\tilde{\theta}$ has ambiguous effects on the value of $w$. In particular, the numerator of $w$ can rise or fall. Because $\int_0^a \theta f(\theta)d\theta = x_1F(\alpha) - \int_0^a F(\theta)d\theta$, either the first part of the right-hand-side or the second part can rise relatively more in the transition to $\tilde{\theta}$. Hence the effect on $p_F$ and $\phi$ is ambiguous even if $\tilde{g}$ is unchanged. Similar ambiguities arise for changes to distributions that are first-order stochastic dominated by $\theta$, i.e. for which $F < \tilde{F}$ everywhere (Hadar and Russell (1969)).

3. APPLICATION TO SENEGAL

In this section I indicate how to test for the optimality of decisions that have been made on processing capacity and on agricultural prices, identifying where the agricultural sector is in terms of Figure 1. Data are from Senegal. These data have limitations as will be indicated, and so the calculations illustrate a methodology, and do not establish a firm conclusion on the social profitability of Senegalese policy.

In the case of Senegalese groundnuts, the basic locational advantage of domestic processing derives from the opportunity to use groundnut shells as fuel in the processing mills (Guillon (1966)). When unprocessed groundnuts are exported, they are shelled first. It appears to be inefficient to export the groundnuts in the shell, thereby using the shells as fuel in mills abroad. The best alternative use for the shells in Senegal appears to be as fuel in the form of briquets as a substitute for charcoal, but other uses have been suggested (Gillier (1964)).

When Senegalese processing capacity was lower, and at times when the groundnut crop has been large, Senegal has exported unprocessed groundnuts. I have not come across any information that storage is a preferred option. Marketing channels for Senegalese unprocessed groundnuts are well established. Thus observed behaviour is consistent with adoption of (5) as the maximand rather than the alternatives discussed in footnote 2.

From 1947 to 1980 the mean yield on groundnuts at the national level was 0.82 tonnes per hectare, with a standard deviation of 0.16 tonnes. To operationalize the theoretical analysis, this variation must be decomposed into factors that are random (corresponding to $\theta$) and those that reflect shifts in choices by producers ($T_G$ and $L_G$, for instance) consequent on government policies ($p_F/p_M$) or on changes in aggregate factor supplies ($\tilde{T}$ and $\tilde{L}$). Other inputs, such as fertilizer and farm equipment, or their prices, should also be taken into account, a complication being that they have often been rationed by government agencies. Lack of data, however, especially on labour input and wages, makes impossible a fully specified production or cost function approach to the decomposition of the random and systematic influences on groundnut production.

Instead, I have focussed on estimating the effect of climatic uncertainty on yield, neglecting the role of inputs. This procedure seems justified because climatic and input variables are likely to be orthogonal, so that omission of the input variables should not bias the estimates of the climate-yield relationships. To represent the effect of output prices, the equation includes the one-year lag of the ratio of the groundnut price to the millet price as set by the government, $\rho_{-1}$.
The relationship between average rainfall during the growing season at Diourbel weather station in the groundnut region and national yield is given in Table I. Yield data were available for 1946–1980, but 1946 was excluded as atypical, perhaps reflecting the end of the war. Data on the relative price ratio were unavailable before 1958. This problem was treated by setting $\rho = 0$ before 1958 and including a dummy variable $D = 1$ before 1958 and $D = 0$ after, see Maddala (1977, p. 202). Results were similar when the sample period was restricted to 1959–1980.

The rainfall variables are highly statistically significant, although with omitted variables and missing observations these conventional tests of significance must be interpreted loosely. The negative coefficient on the squared term indicates that yield is relatively more sensitive to changes in rainfall at low levels than at high levels of rainfall, as is to be expected. The coefficients $\gamma_4$ and $\gamma_1$ imply a not unreasonable average value for $\rho_{-1}$ of $4.85/3.88 = 1.25$ for the years before 1959.

Using the equation of Table I, predicted values of yield ($y_i$) conditional on weather for each year that I have data (1919–1980) and on 1981 relative prices (1-40) are:

$$\hat{y}_i = \hat{\gamma}_0 + \hat{\gamma}_1 \cdot (1.4) + \hat{\gamma}_2 R_i + \hat{\gamma}_3 R_i^2.$$

(9)

Because a longer series exists on the $R_i$ than on the $y_i$ it seems desirable to use all the $R_i$, and therefore the period of simulation exceeds that of estimation. Restricting the simulation period to that of the estimation produces similar results in the analysis that follows, but the curves of Figures 2 and 3 are more jagged. These $\hat{y}_i$ give the variability in yields attributed to variation in the climatic variables.

<table>
<thead>
<tr>
<th>TABLE I</th>
</tr>
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<tbody>
<tr>
<td><strong>Climate-Yield Relationships</strong></td>
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<tr>
<td><strong>Time Period:</strong></td>
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<tr>
<td><strong>Variable Definitions:</strong></td>
</tr>
<tr>
<td>$y$: national yield of groundnuts, tonnes per hectare</td>
</tr>
<tr>
<td>$R$: average rainfall at Diourbel in June through September, millimeters</td>
</tr>
<tr>
<td>$\rho_{-1}$: one-year lag of the ratio of official groundnut to millet prices from 1959, and 0 before 1959</td>
</tr>
<tr>
<td>$D$: dummy = 1 before 1959 and 0 from 1959</td>
</tr>
<tr>
<td><strong>Statistics on the Variables:</strong></td>
</tr>
<tr>
<td>$x$ &amp; $\bar{x}$ &amp; $\sigma$ &amp; min $x$ &amp; max $x$</td>
</tr>
<tr>
<td>$y$ &amp; $8.22 \cdot 10^{-1}$ &amp; $1.59 \cdot 10^{-1}$ &amp; $4.38 \cdot 10^{-1}$ &amp; $1.09$</td>
</tr>
<tr>
<td>$R$ &amp; $1.46 \cdot 10^2$ &amp; $4.19 \cdot 10$ &amp; $8.20 \cdot 10$ &amp; $2.48 \cdot 10^2$</td>
</tr>
<tr>
<td>$\rho$ &amp; $1.18$ &amp; $1.53 \cdot 10^{-1}$ &amp; $9.00 \cdot 10^{-1}$ &amp; $1.39$</td>
</tr>
</tbody>
</table>

where $\bar{x}$ = mean, $\sigma$ = standard deviation.

<table>
<thead>
<tr>
<th><strong>Regression Results:</strong> $y = \gamma_0 + \gamma_{1,\rho_{-1}} + \gamma_2 R + \gamma_3 R^2 + \gamma_4 D + u$</th>
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<tbody>
<tr>
<td>Coefficient</td>
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<tr>
<td>$\gamma_0$</td>
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<tr>
<td>$\gamma_1$</td>
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<td>$\gamma_2$</td>
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<tr>
<td>$\gamma_3$</td>
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<tr>
<td>$\gamma_4$</td>
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</tbody>
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$R^2 = 0.547$ $\quad$ SSE = 0.3784 $\quad$ $DW = 2.00$

**Source of Data:** Appendix B.
MARKETED GROUNDNUTS, PROCESSING CAPACITY

**FIGURE 2**
Probability of excess capacity as a function of installed capacity
*Source:* Calculations described in text
Figure 3
The weight on price of groundnut products as a function of capacity

Source: Calculations described in text
An alternative to the $\hat{y}_i$ series is

$$\hat{y}_i = y_i + \gamma_1 (1.4 - \rho_{-1}). \quad (9')$$

By keeping prices at 1981 levels, this series removes from the actual $y_i$'s only the effect of variation in prices paid by the government. In comparison to (9), this series incorporates aspects of weather-yield relationships lost because the rainfall variables do not represent all weather-related influences. Further, $(9')$ captures the effects of other random variables not related to weather. But the $\hat{y}_i$ series also includes the effects of variation in omitted input variables that are not truly random, as well as possibly considerable errors in measurement of $y_r$. Given the data problems, there is no completely satisfactory choice between the two series, and I present results using both series. The $\hat{y}_i$ series tends to include too little of the true randomness relevant to the decisions under consideration, while the $\hat{y}_i$ series tends to include too much. (The $\hat{y}_i$ could only be calculated for the years 1959–1980 when all variables were available.)

The total crop in any year is the product of the yield (discussed above) and the total area planted to groundnuts. The total area planted has shown considerable variation along a generally upward trend; over the last few years, however, there has been a clear decline. As a rough estimate of total area committed to groundnuts, I take 1150 thousand hectares.\(^5\) Thus the total crop ($\hat{G}_i$) to be expected in any year having the rainfall of the $i$th year, $i = 1919–1980$, and a relative price that had been set at 1.40 would be

$$\hat{G}_i = 1150 \hat{y}_r. \quad (10)$$

The proportion of the groundnut crop that is available for processing depends on a number of factors, including the quantity peasants desire to hold over as seed, to consume themselves and to smuggle from Senegal to neighbouring countries. There is very little information on the choices made by producers between supplying the crop to Senegalese processing mills and withholding it. I make an approximate correction to account for the amount that is not marketed by defining the predicted marketed crop ($\hat{G}_m$) as\(^6\)

$$\hat{G}_m = \hat{G}_i - 210 \quad \text{if } \hat{G}_i \leq 1050 \quad (11a)$$

$$\hat{G}_m = \hat{G}_i - 210 - 0.33(\hat{G}_i - 1050) \quad \text{if } \hat{G}_i > 1050. \quad (11b)$$

Additional variation in the $\hat{G}_m$ series could be introduced either at the stage of (10) or (11).

Finally, this methodology, based on the model of the last section, requires that the availability of groundnuts is uncorrelated from year to year. This assumption of independence does seem to be valid for Senegal.\(^7\)

Peasants are paid for a kg of unshelled groundnuts, containing 0.76 kg of shelled groundnuts and 0.24 kg of shells. The 0.24 kg of shells have an opportunity cost estimated at 5 FCFA.\(^8\) The value of a kg of unshelled groundnuts, $P_{un}$, is therefore 0.76 times the world price per kg of shelled groundnuts plus the value of the 0.24 kg of shells. (The CFA franc used by Senegal is fixed at 50 to the French franc.)

On average, one kg of unshelled groundnuts yields 0.34 kg of unrefined oil and 0.42 kg of cake (CPSP, pp. 182–187). There is some variation in these coefficients with a slight tendency for good harvests to be accompanied by relatively higher oil yields, but this factor will be neglected in the following analysis. If the world price of unrefined oil is $p_1$ and the world price of cake is $p_2$ per kg, then the world value of the products produced from a kg of unshelled groundnuts is

$$p_0 = 0.34p_1 + 0.42p_2. \quad (12)$$
In 1981, the new Société Electrique et Industrielle du Baol (SEIB) plant had total fixed costs (exclusive of taxes) of 3295 million FCFA attributed to its facility that can process 200,000 tonnes of unshelled groundnuts into cake and unrefined oil (CPSP, p. 79). An estimate of fixed cost per kg of unshelled groundnuts, \( r \), is 3295/200 = 16·5 FCFA per kg. Variable costs, \( v \), exclusive of taxes and the costs of unshelled groundnuts, are estimated at 0·9 FCFA per kg of unshelled groundnuts (CPSP, p. 107).

The world prices in the formulae of Section 2 are expected or average prices rather than the actual prices prevailing in any year. An opinion on these expected prices requires a model of the world groundnut and millet markets. Such models are beyond the scope of this paper. To illustrate how conclusions on processing capacity and pricing can be derived from the framework of Section 2, I assume that the expected price per kg in 1981 FCFA of oil is 260 FCFA, of cake is 50 FCFA, of shelled groundnuts is 110 FCFA and of millet is 50 FCFA. These prices are close to those prevailing in 1981 and to forecasts in 1981 prices by such organizations as the World Bank. But prices have typically fluctuated by 20% above or below, and in the exceptional year of 1974 were almost twice these values. The CIF prices at European ports must be corrected for transportation costs from Senegal to indicate a net value to Senegalese producers. Total transportation costs are taken as 19·5 FCFA per kg.10

Using these prices gives

\[
p_0 - v - p_G - r = (109·5 - 19·5) - 0·9 - (83·6 + 5 - 19·5) - 16·5 = 3·5 > 0. \quad (13)
\]

Referring back to the discussion following equation (6), a positive value indicates that it is profitable to invest in some groundnut processing.

Using the preceding information and assumptions, I can now proceed to a set of calculations useful in evaluating Senegalese capacity and pricing decisions. Equation (13) corresponds to a rearrangement of several of the terms of equation (6) which implies that, at an optimum:

\[
F(K/\phi) = \frac{p_0 - v - p_G - r}{p_0 - v - p_G} = 0·175. \quad (14)
\]

This condition states that the probability of excess capacity \([F(K/\phi)]\) should equal the right-hand side. Given the previous assumptions, the probability of any particular quantity of groundnuts being available to the oil mills can be calculated as follows: order the \(\hat{G}_{m_j}\) of equation (11) so that \(j = 1\) is the lowest \(\hat{G}_{m_j}\) etc. Denote this series in ascending order as \(\hat{G}_{m_j}\). The probability of a \(\hat{G}_m\) less than any \(\hat{G}_{m_j}\) is simply \(j/62\) since there are 62 \(\hat{G}_{m_j}\)'s. The value of the \(\hat{G}_{m_j}\) are plotted in Figure 2 along the horizontal axis, and the vertical axis gives the probability that a \(\hat{G}_m\) less than the corresponding \(\hat{G}_{m_j}\) would occur. Connecting these points by line segments and using the broken line to interpolate between points allows the calculation of the capacity corresponding to any given probability of excess capacity.11 For instance, a probability of excess capacity of 0·175 (on the vertical axis) corresponds to a capacity of approximately 700,000 tonnes (on the horizontal). This falls short of the actual installed capacity in 1981 of 900,000 tonnes. The actual capacity has a probability of approximately 0·9 of yielding a situation of excess capacity. Other things equal, this actual capacity could only be justified by a higher value of the right-hand side of (14).

A second important question is, given existing capacity, are current prices correct and how should they be altered? If the economy were at the optimum, relative prices
(\(\rho\)) should be given by

\[
\rho = \frac{(p_0 - v)w + (p_0)(1 - w)}{p_M}.
\] (15)

All the values for the variables on the right-hand side have already been discussed except for \(w\). As defined above, \(w\) equals the proportion of the average value of the \(\hat{G}_{mj}\) attributed to levels of \(\hat{G}_m\) below the given capacity. That is, \(w\), for any value of \(\hat{G}_{mj}\), is given by:

\[
w = \frac{\sum_{k=1}^{l} \hat{G}_{mk}/62}{\sum_{k=1}^{l} \hat{G}_{mk}/62}.
\] (16)

The values of \(w_j\) corresponding to each \(\hat{G}_{mj}\) are plotted on the vertical axis of Figure 3. For a capacity of 900,000 tonnes, the implied value of \(w_j\) is approximately 0.89. Thus the price per kg of unshelled nuts relative to the price per kg of millet that should be offered peasants, given the values of all other variables yielding equation (13), is

\[
\rho = \frac{(109.5 - 0.9 - 19.5) 0.89 + (83.6 + 5 - 19.5) 0.11}{50} = 1.74.
\] (17)

These values compare with the official prices for the 1981-1982 agricultural season of 70 FCFA for groundnuts and 50 FCFA per tonne of millet, yielding a relative price of 1.40. Thus prices in Senegal are not consistent with an optimum, given capacity and the assumptions about expected world prices.

The results of the two calculations undertaken in connection with (14) and (15) can be interpreted using Figure 1. Since actual capacity of 900,000 exceeds 700,000 tonnes, corresponding to an \(F(K/\phi) = 0.175\), the current \(\phi\), \(K\) combination lies above the \(KK\) line. Because the actual relative price (1.40) is below the \(\rho\) calculated from (17) using the known, current capacity of 900,000, the current \(\phi\), \(K\) combination must also lie above the \(GM\) curve. Thus the current \(\phi\), \(K\) combination is in zone 4. But zone 4 contains three sub-regions. In III, 4 both \(\phi\) and \(K\) are too low relative to their optimal values \(\phi^*\) and \(K^*\), and groundnut prices and capacity should be increased. In IV, 4 capacity should be lowered and groundnut prices increased. Finally, in I, 4 both \(\phi\) and \(K\) are too high; groundnut prices should be lowered. This last sub-region can be ruled out, however, since the optimum \(\rho\) cannot fall below its value if \(w = 0, 1.40\). But current relative prices are 1.40, and thus groundnut prices and \(\phi\) must be raised.

Note that as \(\phi\) increases relative to \(K\) \(\rho\) of equation (17) falls. For instance, for a \(K\) of 700,000 tonnes, Figure 3 gives a \(w\) of approximately 0.13. Whether the increase in prices will raise \(\phi\), and shift the curve in Figure 2 sufficiently to justify an increase in \(K\), rather than a decrease as would be recommended based only on inspection of (14) is an open question; it depends on how responsive \(\phi\) is to an increase in prices. Given the discrepancy between the 700,000 tonnes indicated by (14) and the 900,000 tonnes of current capacity relative to the discrepancy between the actual relative price of 1.40 and the 1.74 calculated from (17), such an outcome is conceivable as can be checked by changing 1.4 to 1.74 in equations (9)-(11) and footnote 5. On the assumption that \(K^* < 900,000\), however, \(K\) is not currently a choice variable and the optimal price given \(K = 900,000\) can be calculated from (15) by recognizing that \(w\) is a function of \(\rho\) via its effect on the position of the curve in Figure 3.

The results using the \(\hat{y}_i\) series in place of the \(\hat{y}_i\) are not illustrated but can be summarized as: (1) the greater variability in the \(\hat{y}_i\) series leads to a lower probability of underutilization of current capacity (approximately 0.68); (2) a lower weight on \(p_0\)
(approximately 0.61) in comparison to the \( \hat{y} \) results; and (3) optimal capacity given \( F = 0.175 \) of 520,000 instead of 700,000. For very low values of \( F(K/\phi) \) the \( \hat{y} \) series produces lower values for capacity, while for very high values of \( F(K/\phi) \) the \( \hat{y} \) series produces higher values for capacity, illustrating the theoretical ambiguity in movements between different distributions with (approximately) equal means.\(^{12}\)

4. CONCLUSIONS

The evaluation of agro-industrial investments is a frequently encountered problem in poor countries. Differences in the attributes of raw materials imply that different factors must be emphasized in cost-benefit analysis. For many processing investments, however, uncertainty in the supply of the raw material is a crucial factor. The theoretical model of this paper shows how to make decisions about processing capacity and the related problem of input pricing under particular assumptions about: the decision makers' preferences, the sources of uncertainty, the availability of the raw material and the technology of processing.

Calculating the optimal values of these decisions on capacity and prices requires considerable information on the elasticity of supply of groundnuts and a full simultaneous solution of equations (6) and (7). But Section 3 shows how some information on the direction in which to move prices and capacity can be obtained with relatively little effort. Nonetheless, it should be emphasized that the benchmark values for expected world prices, the land planted to groundnuts and the amount of a crop of any given size that is marketed, as well as the costs of processing, are rough and ready. These could be refined, but probably at an expense that is only justified if an actual commitment of funds to processing is contemplated. Perhaps the most crucial simplification is the use of a model in which groundnut availability is intertemporally independent. While a reasonable approximation for Senegal, other situations may not exhibit this property, necessitating more complicated calculations.

APPENDIX A

Notes on theoretical extensions to the model

a. Risk aversion:

Assume that decision making for the agricultural sector can be evaluated by the expected utility of income from all activities including processing. In this case, equation (5) can be modified to

\[
EUY = \int_{0}^{\alpha} U[\theta(p_{0} - v)\phi + p_{MG}(\theta)\Omega - rK]f(\theta)d\theta \\
+ \int_{\alpha}^{\infty} U[(p_{0} - v)K + p_{G}(\theta\phi - K) + p_{MG}(\theta)\Omega - rK]f(\theta)d\theta
\]

(5a)

where \( U(\cdot) \), with \( U' \geq 0, U'' \leq 0 \), is the utility of income.

The condition corresponding to equation (6) is

\[
\frac{\int_{\alpha}^{\infty} U'(\theta)d\theta}{\int_{0}^{\infty} U'(\theta)d\theta} (p_{0} - v - p_{C}) = r.
\]

(6a)
For $U'' > 0$, it is easily shown by partial integration that $\int^\infty_0 U'(\theta)\,d\theta/\int^\infty_0 U'(\theta)\,d\theta < 1 - F$. Hence relative to the risk-neutrality case, $\alpha$ must be lower. Similarly, all increases in risk aversion lower $\alpha$, as can be shown by letting $U^2 = \psi(U^1)$ with $\psi' > 0, \psi'' < 0$ so that $U^2$ embodies greater risk aversion than $U^1$ (Diamond and Stiglitz (1974)).

The weight, $w$, is given by $w = \int^\infty_0 U'\theta f(\theta)\,d\theta/\int^\infty_0 U'\theta f(\theta)\,d\theta$. It is easily shown that $w$ rises with increases in risk aversion for a given $\alpha$. However, because $\alpha$ in fact falls from equation (6a), the impact on $w$ of risk aversion is ambiguous even for $E(U'g)/E(U'\theta)$ constant. Therefore, $\phi$ and $p_F$ can rise or fall, as can $K$. For a given $K$, however, $p_F$ and $\phi$ rise if $E(U'g)/E(U'\theta)$ is constant.

b. Tradeoffs between variable and fixed inputs

The design of processing capacity may involve a tradeoff between variable and fixed inputs. Let the quantity of groundnuts that can be processed be $C$,

$$C = C(K, L)$$ (1b)

where $K$ is fixed and costs $r$ per unit while labour, $L$, can be varied after the harvest and costs $v$ per unit actually used. To determine the conditions for an optimum, first consider the situation after $\theta$ is known and only $L$ and exports of groundnuts, $X \geq 0$, are choice variables. The problem is to maximize

$$p_0 C(K, L) - vl + p_G X$$ (2b)

subject to

$$\theta \phi = C + X.$$ (3b)

This problem yields

$$\begin{align*}
(p_0 - p_G)C_L - v = 0 & \text{ if } X > 0 \\
\theta \phi = C(K, L) & \text{ if } X = 0.
\end{align*}$$ (4b) (5b)

Let $\alpha$ be the value of $C(K, L)/\phi$ such that (4b) and (5b) both hold. Then the expected income from the agricultural sector is

$$EY = \int^\alpha_0 (\theta p_0 \phi + p_M g(\theta)\Omega - vL - rK) f(\theta)\,d\theta$$

$$+ \int^\infty_\alpha (p_0 C + p_M (\theta \phi - C) + p_M g(\theta)\Omega - vL - rK) f(\theta)\,d\theta.$$ (6b)

The first-order condition with respect to $K$ is

$$\int^\infty_\alpha (p_0 - p_G) C_K f(\theta)\,d\theta + \int^\alpha_0 vC_K f(\theta)\,d\theta = r.$$ (7b)

The other first-order conditions for $T_G$ and $L_G$ are very similar to equation (7). Information is required on the $C(K, L)$ function to calculate optimal investment in $K$. 


### APPENDIX B

*The data used to produce table 1*

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*Sources:*

Output and area: BCEAO (No. 19, p. 2) and Department of Agriculture worksheets, 000 tonnes and ha.

$R$: CIEH (1976) and Department of Meteorology worksheets.


$P = p_G^d/p_M^d$.

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**NOTES**

1. See Roemer (1979) for a survey of resource-based industrialization and Livingstone and Hazlewood (1979) for an analysis of irrigation capacity with parallels to the treatment of processing capacity in this paper.

2. The present discounted value of expected income is

$$V_0 = \sum_{t=0}^{\infty} \delta^t EY_t$$

(5')
where $\delta$ is the discount rate and $EY_t$ is given by equation (5) with all variables, including $\theta$, subscripted by $t$. If all nonstochastic variables are constant for all $t$, and if the $\theta$'s are identically and independently distributed for all $t$, $K$ will be chosen once-and-for-all and

$$V_0 = \frac{EY_0}{(1-\delta)}.$$

Maximizing the one-period $EY$ of equation (5) is then equivalent to maximizing (5'). If these assumptions are not met, an explicit solution for the model generally will not be possible. For instance, the existence of a storage option implies a fundamental nonlinearity since the stored stock can never be negative (see footnotes 4 and 7 below).

3. Note that even if $p_0$ and $p_C$ are stochastic the formulae are unaltered so long as the symbols $p_0$ and $p_C$ used in the text are interpreted as the means of these prices, and these prices are uncorrelated with $\theta$. This last condition is somewhat stronger than the traditional small-country assumption. A country could be small in the sense of being unable to affect world prices by altering its supply. But it still might be one of many countries subject to a common weather system that induces variations in world supplies sufficient to affect world prices. Formulae incorporating covariances and truncated covariances that parallel (6) and (7) can be derived and implemented as in Section 3. While $p_0$ and $p_C$ might be negatively correlated with $\theta$, $p_0 - p_C$ might be positively correlated with $\theta$ since processing capacity will be relatively scarce in years of good harvest. Correlations between weather in Senegal and prices for groundnuts and groundnut products are, however, not significant, see Gersovitz (forthcoming).

4. Omitted-variables bias would not seem to be a problem because weather is largely unpredictable. In Gersovitz (forthcoming), I reported that regressions of rainfall in June and July ($R_2$) on itself lagged up to five years produced insignificant results. Similar results were obtained for regressions of rainfall in August and September ($R_3$) on itself lagged. Regressions of $R_2$ on $R_1$ in the same year also yielded insignificant results; however, there was some evidence that June–July rainfall to the south of Diourbel could be used to predict August–September rainfall at Diourbel. On long cycles in Sahelian weather, see Nicholson (1979). Most decisions on input quantities are probably made before the weather affecting yields is known. Thus, Gersovitz (forthcoming) suggests that the percentage of total land allocated to groundnuts (rather than to millet) and the use of fertilizer on groundnuts are unrelated to contemporary weather. On the other hand, there may be scope for varying such inputs as harvest-time labour in response to contemporary weather shocks, so that these omitted variables will not be orthogonal.

5. The average area under groundnuts ($T_G$) for the most recent five years on which I have data (1976–1980) is 1150. It is also approximately the area of multiplying total land under millet and groundnuts ($T$) in 1980 (2140) by the predicted ratio of $T_G/T$ as given by the regression $T_G/T = 0.42 + 0.09p_{C1}$. The sample is 1960–1980, the $t$-statistic on the coefficient of $p_{C1}$ is 2.52, and $\rho = 1.40$ in 1981.

6. I arrived at this formula by visual inspection of a scatter plot of the amount that was not marketed against the marketed crop for the crop years 1963–1979. Data were from BCEAO (various dates).

7. Even when rainfall is intertemporally independent (see footnote 4), there are other reasons why yields may be affected by last year’s weather (see Gersovitz (forthcoming)). I tested for this type of persistence by adding a nonlinear term of the form $\alpha (\gamma_0 R_{t-1}^2 + \gamma_2 R_{t-2}^2)$ to the equation of Table I. The estimated value of $\alpha$ was negative, small in absolute value (–0.031) and insignificant statistically (asymptotic standard error = 0.19). To test for a more general intertemporal dependence in yields as well as allowing for serial correlation in errors, I also estimated the equation $y = (X - \delta X_{t-1})(a + \delta)Y_{t-1} - \alpha \delta Y_{t-2} + \epsilon$ where the $X$ are the variables of the equation in Table I, $\alpha$ is the coefficient on $y_{t-1}$ before the Cochrane–Orcutt transform and $u = \delta u_{t-1} + \epsilon$ is the error in the untransformed equation. Nonlinear estimation of this equation produced estimated values of $\alpha = 0.0158$ and of $\delta = -0.0511$ with asymptotic standard errors of 0.20 and 0.27. The sum of squared errors (SSE) for this equation is 0.3457 while the SSE of the regression corresponding to that of Table I but estimated over the same period as this equation (1949–1980) is 0.3463. Thus $\delta$ and $\delta$ are insignificant either individually or jointly. Persistence effects do not seem important. A variant of the equation in Table I was also estimated with a linear time trend, but it was insignificant. Finally, storage can make the availability of groundnuts to the mills intertemporally dependent, but, as discussed above, storage may not be a viable option for Senegal. See Wright and Williams (1982) on the simulation of markets with storage.

8. Various discussions suggest this approximate value, calculated as follows. A kg of charcoal contains 7800 calories of which 15% can be realized. A kg of groundnut shells contains 4500 calories with an efficiency of 10%. Thus a kg of unshelled groundnuts, which contains 0.24 kg of shells is the equivalent of 0.092 kg of charcoal. The official price for charcoal is 20 FCFA per kg, the black market price is perhaps 50 FCFA and an estimate of the social cost of charcoal including costs of replanting, perhaps as high as 80 FCFA. Hence, an estimate of the range of the value of shells in a kg of unshelled groundnuts is between 1-8 FCFA and 7-4 FCFA per kg.

9. The figure of 3295 is arrived at as 4166 total “fixed” costs (CPSP, p. 110) less 160 (taxes) less 711 (transportation) (CPSP, p. 108). These fixed costs include labour costs of 850 million FCFA (CPSP, p. 108) since the labour force is not adjusted in response to fluctuations in groundnut supply. It is an open question as to how much of these labour costs represent redundant workers (hired under government policy after closing of other mills), how much scope there is for varying labour on an annual basis, and how much of a shadow
wage adjustment should be made for the opportunity cost of the remainder. The fixed cost figure in the text makes no adjustment to labour costs.

10. The estimate of these costs in 1981 for the products from a kg of unshelled groundnuts is approximately 8.5 FCFA exclusive of taxes (CPSP, p. 194). I also take this figure to be an estimate for the costs of exporting 0.76 tonnes of shelled groundnuts. The sorghum price is unadjusted for transportation costs since it is based on the CIF price for U.S. exports in Europe. Various discussions suggest the cost of marketing the unshelled groundnuts from the peasants to the mills is approximately 11 FCFA per kg.

11. An alternative would be to fit a distribution to the $G_{mn}$ and then plot the cumulative distribution. I tried this more complicated approach for both the Beta and the Gamma distributions with similar results.

12. None of these results depends on the different time periods spanned by the $\tilde{y}_i$ and $\tilde{y}_i^*$ series, as was confirmed by taking only those $\tilde{y}_i$ corresponding to 1959–1980. Indeed, the comparisons are strengthened slightly.

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