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Food subsidies and market interdependence: the case of the Moroccan soft wheat subsidy

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ABSTRACT

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Among the several propositions advanced to explain the rising cost of subsidizing soft wheat production and consumption in Morocco are the indirect effects emanating from related markets, namely the hard wheat and barley markets. A three-sector supply–demand model, described in this paper, was used to estimate the direct and indirect (induced) effects on government cost of changes in the soft wheat subsidy. The results show that virtually all the indirect effects come from the soft wheat market itself. The indirect effects emanating from the related markets are negligible.

1. INTRODUCTION

When subsidized commodity markets are interrelated in production and consumption, a price change, because of a change in either consumer or producer subsidy in one market, will have both price and quantity effects in the other market. An important task for economic analysis is to explain and quantify the process by which production and consumption respond in these interrelated markets. The task is important for two reasons. First, the quantities supplied and demanded in a given market will almost certainly change when prices are distorted through government subsidies, resulting in further changes in the cost of the subsidy (the direct effect). Second, since prices and quantities of related commodities will also be affected, further changes in government costs will be engendered by the intermarket rebound-

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ing of price changes (indirect or induced effects) (Tolley et al., 1981; Gardner, 1987).

The purpose of this paper is to estimate the direct and indirect (induced) effects on government cost of changes in the soft wheat subsidy in Morocco. The study is motivated by the proposition that unanticipated effects of the Moroccan soft wheat program, namely lower producer response and increased government subsidy expenditures, are the reactions in interrelated markets (Tuluy and Salinger, 1989). Specifically, since soft wheat, hard wheat and barley are substitutes in both production and consumption, the consumer subsidy for soft wheat may increase the quantity demanded of soft wheat and depress the prices of the other two commodities. The consequences are twofold. First, there is less incentive for producers to increase the supply of hard wheat and barley and, for a given level of demand, their prices remain higher relative to the subsidized price of soft wheat. Second, with less overall cereal production, the cost of the soft wheat program is exacerbated by increased imports.

The plan for the paper is as follows. The next section contains a description of the operational features of the soft wheat commodity program in Morocco. The analytical method is described in the third section. The data and results are described, respectively in the fourth and fifth sections. The final section contains conclusions and a description of the limitations of the analysis.

2. MOROCCO'S SOFT WHEAT POLICY

Morocco's soft wheat policy involves the regulation of price at all stages of production, processing and distribution (for a historical analysis of Moroccan soft wheat policy, including its colonial roots, see Swearingen, 1987). This involves controls affecting the activities of five principal agents: producers, licensed traders, millers, wholesalers and bakers, and retailers (Laraki, 1989). Producers sell the grain to licensed traders at a 'support price'. Licensed traders, who may also purchase grain from the world market, sell the grain (domestic and imported) to millers at a subsidized price. The difference between the subsidized price plus margin and the support price is reimbursed to the licensed traders by the government. When the support price is above the world price, the difference between the two prices minus margin is reimbursed to the government by the licensed traders, and vice-versa if the support price is below the world price.

Millers process the wheat purchased from the licensed traders and sell the flour to wholesalers and bakers at a fixed price. The difference between the subsidized price at which millers purchase the grain from licensed traders

plus a fixed margin and the fixed price is reimbursed to the millers by the government. Wholesalers and bakers are in turn required to sell to retailers at a price equal to the official price paid to the millers plus a fixed margin. Finally, retailers sell the flour to consumers at a fixed price equal to the wholesale price plus a fixed retail margin. Unlike the millers and licensed traders, wholesalers and retailers are not reimbursed by the government should their marketing costs exceed their respective fixed margins.

It should be noted, however, that not all the domestically produced soft wheat flows through official government channels. Only about 18% of the soft wheat production is traded through official marketing channels (Laraki, 1989). The rest is either consumed at the farm level or sold at free market prices. The implication is that the benefits of the support price, which has been consistently above the free market price, accrue to only a small portion of farmers. More importantly, the relatively smaller amounts of grain flowing through official channels may explain the heavy reliance on imports to satisfy the needs of the urban population (for an extensive discussion on this issue, see Byerlee, 1987).

In contrast to soft wheat, hard wheat and barley are little affected by government pricing policy. Although minimum support prices are in effect for hard wheat and barley, free market prices have been consistently above the minimum prices. Therefore, for all intents and purposes, the markets for hard wheat and barley can be considered free of government control.

Figure 1 summarizes the major features of the pricing support system for soft wheat. Schedules C and S in Fig. 1A represent, respectively, producer's demand for home consumption and total supply. Here, we abstract from sales in the free market and assume Q_C to represent on-farm consumption;

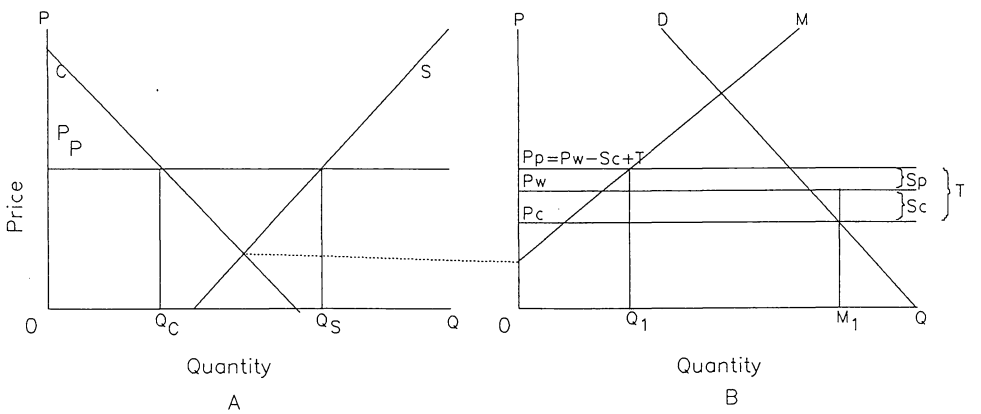

Fig. 1. Model of the Moroccan soft wheat subsidy program.

Q_S denotes total production. The difference between S and C is M (the market supply) the function for which is drawn in Fig. 1B. The market (non-farm) demand curve is represented by schedule D, also in Fig. 1B.

Producers are guaranteed the support price P_P, at which they supply the market with quantity Q_1 ($Q_S - Q_C$ in Fig. 1B). Assuming a perfectly elastic world supply of soft wheat to the Moroccan market, the world price is P_W. Consumer prices are fixed at P_C and the quantity demanded is M_1. Since only Q_1 is forthcoming from the domestic market, the difference $M_1 - Q_1$ is met through imports. Relative to the world price, consumers receive subsidy S_C, i.e. $P_W - P_C$, and producers receive subsidy S_P, i.e. $P_P - P_W$. The total domestic subsidy is $T = S_C + S_P$, and the total unit cost to the government is the sum of S_C per unit of OM_1 plus S_P per unit of OQ_1.

Data for the 1983/84 crop year (Morocco Min. Agric., 1986) are used to illustrate the government's costs from the soft wheat subsidy program. The import price, P_W, including landing costs, was 143.90 dirhams (1 DH = US$0.10) per quintal (1 q = 100 kg), the price support for soft wheat P_P was DH 150.00 per q, and the subsidized consumer price P_C was DH 86.24 per q of soft wheat flour in grain equivalent (the conversion ratio from flour to grain is 0.77). The quantity marketed through official channels, Q_1, was approximately 3 068 000 q (37% of total production). Imports were 20 607 000 q. With a fixed handling and processing margin of DH 22.45 per q (imported and domestically produced), the total financial cost per q of flour (in wheat equivalent) was DH 172.45 for domestic wheat and DH 166.35 for imported wheat. With a guaranteed price of DH 86.24 to consumers, the government paid a consumer subsidy S_C of DH 80.11 per q soft wheat and a producer subsidy S_P of DH 6.09 per q of domestic wheat, with a total subsidy T of DH 86.20. In wheat flour equivalent, total government subsidy costs were about DH 2.5 billion.

The DH 2.5 billion dirhams cost represent approximately 10% of current government expenditures and two-thirds of total food subsidy program costs (other subsidized commodities include sugar and edible oils). The 1983 subsidy cost was 500% greater than the average expenditures on soft wheat subsidies in the 1970's. Laraki (1989, p. 19) reports that the financial burden on the government is such that millers are never fully reimbursed for their milling costs and are, in fact, financing part of the soft wheat program.

In what follows, the major features of the soft wheat program described above are incorporated in a soft wheat supply–demand model. Two supply–demand models for hard wheat and barley are also formulated. The aim is to derive algebraic formulas decomposing the change in government costs of the soft wheat program into direct and induced changes. The basic methodology is an extension of Tolley et al.'s two-sector model to a three-sector model.

3. ANALYTICAL MODEL

The basic behavioral equations for the supply–demand model of the three commodities and the government cost of the soft wheat program are as follows:

- Supply

$$Q_F = S_F(P_P^F, P_H, P_B) \tag{1}$$

$$Q_H = S_H(P_F^P, P_H, P_B) \tag{2}$$

$$Q_B = S_B(P_F^P, P_H, P_B) \tag{3}$$

- Demand

$$Q_F + I_F = D_F(P_C^F, P_H, P_B) \tag{4}$$

$$Q_H = D_H(P_C^F, P_H, P_B) \tag{5}$$

$$Q_B = D_B(P_C^F, P_H, P_B) \tag{6}$$

$$P_P^F = P_W - S_C + T \tag{7}$$

$$P_C^F = P_W - S_C \tag{8}$$

- Government cost

$$TQ_F + S_C I_F \tag{9}$$

where Q_j, for $j = F, H, B$, are respectively the domestic output of soft wheat, hard wheat and barley. Supply of each crop is a function of its own (producer) price and the producer prices of substitutes. In the case of soft wheat, the own producer price P_P^F is the support price, which is equal to the difference between the world price P_W, and the consumer subsidy S_C plus the total subsidy T (equation 7). The producer and consumer prices for hard wheat and barley are P_H and P_B, respectively. Consumer demand for each commodity (equations 4–6) is a function of own (consumer) price and the price of substitutes. In the case of the subsidized soft market, imports I_F are added to consumption of domestic wheat. The own consumer price P_C^F is equal to the difference between the world price P_W and the consumer subsidy S_C (8). Finally, government cost (equation 9) is defined as the sum of the subsidy payments (consumer and producer) on domestically produced wheat and the consumer subsidy payments on important wheat.

To examine how the system changes in response to a change in one of the two policy instruments (T, S_C), first take the total differential of equations

(1) through (6) after making the necessary substitution using equations (7) and (8). The result, in matrix form, is as follows:

$$\begin{bmatrix} 1 & 0 & 0 & 0 & -S_{FH} & -S_{FB} \\ 0 & 1 & 0 & 0 & -S_{HH} & -S_{HB} \\ 0 & 0 & 1 & 0 & -S_{BH} & -S_{BB} \\ 1 & 0 & 0 & 1 & -D_{FH} & -D_{FB} \\ 0 & 1 & 0 & 0 & -D_{HH} & -D_{HB} \\ 0 & 0 & 1 & 0 & -D_{BH} & -D_{BB} \end{bmatrix} \begin{bmatrix} dQ_F \\ dQ_H \\ dQ_B \\ dI_F \\ dP_H \\ dP_B \end{bmatrix} = \begin{bmatrix} S_{FF} \\ S_{HF} \\ S_{BF} \\ D_{FF} \\ D_{HF} \\ D_{BF} \end{bmatrix} dP_W$$

$$+ \begin{bmatrix} -S_{FF} \\ -S_{HF} \\ -S_{BF} \\ -D_{FF} \\ -D_{HF} \\ -D_{BF} \end{bmatrix} dS_C + \begin{bmatrix} S_{FF} \\ S_{HF} \\ S_{BF} \\ 0 \\ 0 \\ 0 \end{bmatrix} dT \tag{10}$$

The elements S_{ij} and D_{ij}, for $i = j =$ F, H, B, are respectively the partial derivatives of the ith quantity supplied and demanded with respect to the jth price. Since there is a wedge between the producer and the consumer price of soft wheat, the supply and demand functions are differentiated with respect to the supply and demand price of wheat, respectively. Note that a change in the total domestic subsidy T, holding the consmer subsidy S_C constant, implies a change in the producer support price. On the other hand, a change in the consumer subsidy, holding the total domestic subsidy constant, implies a change in both consumer and producer prices.

The direct and induced effects on government cost of a change in T with S_C constant, and of a change in S_C with T held constant, are respectively given by the following expressions:

$$\begin{aligned} \frac{dG}{dT}\frac{T}{G} &= K_1 \frac{T}{P_P^F}\varepsilon_{FF} + K_1 \frac{T}{P_P^F}\varepsilon_{FH}\frac{H}{D} + K_1 \frac{T}{P_P^F}\varepsilon_{FB}\frac{B}{D} \\ &\quad - K_2 \frac{T}{P_P^F}\varepsilon_{FF} - K_2 \frac{T}{P_P^F}\varepsilon_{FH}\frac{H}{D} - K_2 \frac{T}{P_P^F}\varepsilon_{FB}\frac{B}{D} \\ &\quad + K_3 \frac{T}{P_P^F}\eta_{FH}\frac{H}{D} + K_3 \frac{T}{P_P^F}\eta_{FB}\frac{B}{D} + \frac{TQ_F}{G} \end{aligned} \tag{11}$$

and

$$\frac{dG}{dS_C}\frac{S_C}{G} = -K_1\frac{S_C}{P_P^F}\varepsilon_{FF} + K_1\varepsilon_{FH}\frac{H_1}{D} + K_1\varepsilon_{FB}\frac{B_1}{D} + K_2\frac{S_C}{P_P^F}\varepsilon_{FF} - K_2\varepsilon_{FH}\frac{H_1}{D} - K_2\frac{S_C}{P_P^F}\varepsilon_{FB}\frac{B_1}{D} - K_3\frac{S_C}{P_C^F}\eta_{FF} + K_3\eta_{FH}\frac{H_1}{D} + K_3\eta_{FB}\frac{B_1}{D} + \frac{S_C I_F}{G} \tag{12}$$

where $K_1 = TQ_F/G$, $K_2 = S_C Q_F/G$, and $K_3 = S_C(Q_F + I_F)/G$. The η_{ij}'s and the ϵ_{ij}'s are respectively the price elasticities of demand and supply of commodity i with respect to the jth price, for $i = j = $ F, H, B. The definitions of D, H, H_1, B, and B_1 are in the appendix along with the necessary manipulations to derive equations (11) and (12). The economic interpretation of each component on the right hand side of equations (11) and (12) is given in the first column of Table 1.

4. DATA AND ASSUMPTIONS

Calculation of the direct and indirect effects of government cost of a change in the total domestic subsidy T (as given by equation 11), or a change in the consumer subsidy (as given by equation 12), requires that certain data and parameters be specified. For the purpose of this analysis, we use the 1983–1984 production year data (see Section 2 and Table 2). Estimates of the own- and cross-price elasticities of demand for the three commodities are from a cross-sectional study based on a 1984–1985 household consumption survey (Laraki, 1989). Since own- and cross-price elasticities of marketed supply are unavailable, we use the price elasticities of total supply from Tuluy and Salinger (1989). The parameters and data are summarized in Table 2.

5. RESULTS

Estimates of the direct and induced effects on government costs, using information in Table 2, are found in Table 1. Figures 2 and 3 (not drawn to scale) provide a graphic explanation of the results.

A doubling of the total domestic subsidy from T to T' raises the producer from P_P to P_P' (Fig. 2). This has a direct effect on government costs of 13.8% (Table 1) (area *abde* in Fig. 2). However, since the marketed production forthcoming at the increased support level is Q_2, cost to the government increases by only 5.45%, or area *ijbc* in Fig. 2. The increase in marketed supply from Q_1 to Q_2 reduces imports by $Q_2 - Q_1$, thus gener-

TABLE 1

Direct and induced effects on the cost of the Moroccan soft wheat program of changes in the soft wheat subsidy

Effect	Percent change in cost of the soft wheat program from a 1% change in:			
	Subsidy on domestic wheat production		Soft wheat import subsidy	
	formula	value	formula	value
Change in soft wheat subsidy costs due to				
(1) Changes in soft wheat production due to changes in producer price of soft wheat	$K_1 \frac{T}{P_P^F} \varepsilon_{FF}$	0.054751	$-K_1 \frac{S_C}{P_P^F} \varepsilon_{FF}$	−0.054751
(2) Changes in soft wheat production due to changes in producer price of hard wheat	$K_1 \frac{T}{P_P^F} \varepsilon_{FH} \frac{H}{D}$	0	$K_1 \varepsilon_{FH} \frac{H_1}{D}$	−0.000191
(3) Changes in soft wheat production due to changes in producer price of barley	$K_1 \frac{T}{P_P^F} \varepsilon_{FB} \frac{B}{D}$	0	$K_1 \varepsilon_{FB} \frac{B_1}{D}$	−0.000107
(4) Existing level of soft wheat production	$\frac{TQ_F}{G}$	0.138079	–	–

Change in soft wheat import subsidy costs due to				
(5) Changes in soft wheat production due to changes in producer price of soft wheat	$-K_2\frac{T}{P_P^F}\varepsilon_{FF}$	−0.050883	$K_2\frac{S_C}{P_P^F}\varepsilon_{FF}$	0.050883
(6) Changes in soft wheat production due to changes in producer price of hard wheat	$-K_2\frac{T}{P_P^F}\varepsilon_{FH}\frac{H}{D}$	0	$-K_2\varepsilon_{FH}\frac{H_1}{D}$	0.000177
(7) Changes in soft wheat production due to changes in producer price of barley	$-K_2\frac{T}{P_P^F}\varepsilon_{FB}\frac{B}{D}$	0	$-K_2\frac{S_C}{P_P^F}\varepsilon_{FB}\frac{B_1}{D}$	−0.000057
(8) Changes in soft wheat consumption due to changes in consumer price of Soft wheat	–	–	$-K_3\frac{S_C}{P_C^F}\eta_{FF}$	0.373847
(9) Changes in soft wheat consumption due to changes in consumer price of hard wheat	$K_3\frac{T}{P_P^F}\eta_{FH}\frac{H}{D}$	0	$K_3\eta_{FH}\frac{H_1}{D}$	−0.000957
(10) Changes in soft wheat consumption due to changes in consumer price of barley	$K_3\frac{T}{P_P^F}\eta_{FB}\frac{B}{D}$	0	$K_3\eta_{FB}\frac{B_1}{D}$	−0.00307
(11) Existing levels of soft wheat important	–	0	$\frac{S_C I_F}{G}$	0.861921

TABLE 2

Data and parameters used for the analysis

Item	Value
(K_1) [a]	0.14
(K_2) [b]	0.13
(K_3) [c]	0.99
$\left(\frac{T}{P_P^F}\right)$ [d]	0.57
$\left(\frac{S_C}{P_P^F}\right)$	0.53
Own price elasticity of demand (supply) of soft wheat, $\eta_{FF}(\varepsilon_{FF})$	−0.700 (0.69)
Own price elasticity of demand (supply) of hard wheat, $\eta_{FF}(\varepsilon_{HH})$	−0.575 (0.52)
Own price elasticity of demand (supply) of barley, $\eta_{BB}(\varepsilon_{BB})$	−0.796 (0.78)
Cross-price elasticity of demand (supply) of soft wheat with respect to hard wheat, $\eta_{FH}(\varepsilon_{FH})$	0.056 (−0.08)
Cross-price elasticity of demand (supply) of soft wheat with respect to barley wheat, $\eta_{FB}(\varepsilon_{FB})$	0.020 (−0.05)
Cross-price elasticity of demand (supply) of hard wheat with respect to soft wheat, $\eta_{HF}(\varepsilon_{HF})$	0.032 (0.00)
Cross-price elasticity of demand (supply) of hard wheat with respect to barley, $\eta_{HB}(\varepsilon_{HB})$	0.017 (−0.10)
Cross-price elasticity of demand (supply) of barley with respect to soft wheat, $\eta_{BF}(\varepsilon_{BF})$	0.042 (0.00)
Cross-price elasticity of demand (supply) of barley with respect to hard wheat, $\eta_{BH}(\varepsilon_{BH})$	0.062 (0.00)

[a] $K_1 = TQ_F/G$, where T (per q consumer and producer subsidy) = DH 86.20; Q_F (domestic wheat marketed supply) = 3 068 000 q; and G (total government subsidy costs, equation 9) = DH 2.5 billion.

[b] $K_2 = S_C Q_F/G$, where S_C (per q consumer subsidy) = DH 80.11.

[c] $K_1 = S_C(Q_F + I_F)/G$, where I_F (soft wheat imports) = 20 607 000 q.

[d] P_P^F (support price) = DH 150.00 per q.

Note: the conversion ratio from flour to grain is 0.77.

ating a 5.08% reduction in the import subsidy or area *ghji*, The total effect on government cost of a doubling of the domestic subsidy is 14.19%. The remainder of the indirect effects are all zero since the estimated cross elasticities of supply of hard wheat and barley with respect to the price of soft wheat are zero (see Table 2).

A change in the consumer subsidy S_C, affecting supply and demand in the soft wheat and related markets, generates several indirect effects. A doubling of the consumer subsidy lowers the consumer price of soft wheat from v to w, and lowers the producer price from P_P to P_P' (Fig. 3). The direct effect is an increase in the import subsidy cost of 86.19 percent, or area *mqrn* in Fig.

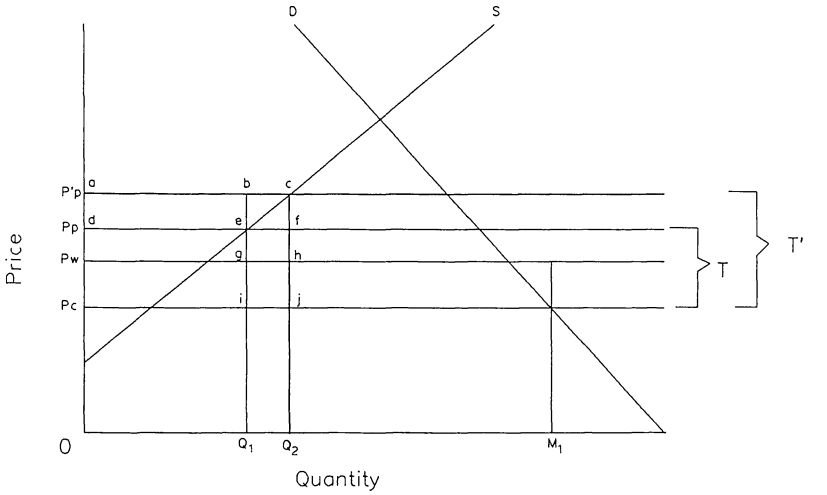

Fig. 2. Graphic illustration of the effects on government cost of a change in the total subsidy (T).

3. The increase is compounded by three indirect effects: the movement along the demand curve for soft wheat (distance *nt*) caused by the consumer price decrease, and the shift in the demand curve, as well as the supply curve of soft wheat as a result of price changes caused by the shift in consumer demand for the other two commodities.

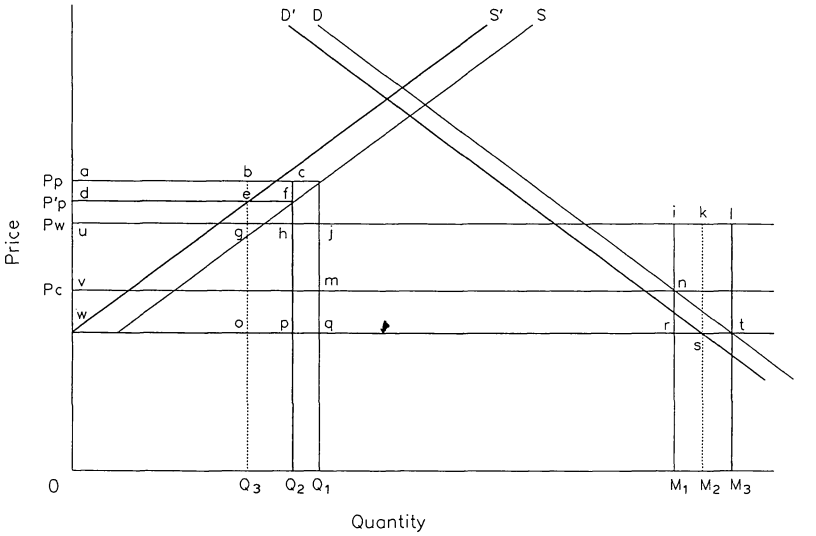

Fig. 3. Graphic illustration of the effect on government cost of a change in the consumer subsidy.

The indirect effect from moving along the demand curve for soft wheat would have been 37.38% or area *iltr* had the quantity imported been M_3. However, because of the shift in the soft wheat demand curve itself, only M_2 is imported. The cost of the import subsidy declines by 0.13% (0.096% owing to the shift in the demand of soft wheat triggered by the change in the consumer price of hard wheat, plus 0.031% triggered by the change in the consumer price of barley), or area *klts*.

The supply-side indirect effects on government import subsidy costs of a doubling of the consumer subsidy are as follows. The reduction in the producer price from P_P to P'_P results in a decrease in the quantity of soft wheat marketed from Q_1 to Q_2 (moving along schedule S), generating a 5.09% additional import subsidy cost (area *hjqp*). Moreover, the leftward shift of the supply schedule from S to S' further reduces the quantity marketed to Q_3, adding 0.012% (0.0177–0.057) to cost. The total direct and indirect effects of doubling the consumer subsidy on the import subsidy costs are 128%.

On the production side, the direct impact before the supply shift is a 5.47% reduction in producer subsidy, or area *acfd*, reducing the producer subsidy by an additional 0.03% (0.0191 + 0.0107). The aggregate impact on cost (including consumers and producers) is 123%, of which 86% constitutes the direct effect, and 37% the indirect effect. In terms of 1983–1984 expenditures of DH 2.5 billion, the indirect effects translate to approximately DH 1 billion.

6. CONCLUSIONS

Among the several propositions advanced to explain the rising cost of the soft wheat program in Morocco is the problem of related markets. Since soft wheat, hard wheat and barley substitute in both production and consumption, a change in the soft wheat producer and/or consumer subsidy will almost certainly trigger a change in the quantities supplied and demanded of soft wheat as well as in the quantities supplied and demanded in the markets for the competing crops. The changes in costs of government subsidies for soft wheat engendered by the intermarket rebounding of price changes following a change in producer and/or consumer subsidy come from two sources: a direct source from the soft wheat market itself and an indirect source from the related markets.

Using a three-commodity (soft wheat, hard wheat, and barley) supply–demand model, this study attempts to decompose the changes in the cost of the soft wheat subsidy into direct and indirect effects emanating from market dependence among the three commodities. Based on the given data and assumed parameters, virtually all indirect effects emanate from the soft

wheat market itself. Therefore, we tentatively conclude that the problem of related markets is not a major factor in explaining the rising expenditures on the soft wheat subsidy in Morocco.

The model and its applications naturally have limitations. Since the model considers only the systematic components of supply and demand model-based changes cannot be expected to exactly match the actual changes. In reality, Morocco's periodic devastating droughts force the government to turn to international markets to fill the food-grain gap which, during years of rising world wheat prices, exacerbates subsidy costs. Nonetheless, it is hoped that the approach and results described in this paper will heighten interest in solving the problem of subsidizing soft wheat, a commodity with immense social and political importance in Morocco as well as in other cereal-deficit countries.

MATHEMATICAL APPENDIX

Derivation of equation (11). First differentiate (9) with respect to T and convert the derivatives into elasticities. This yields:

$$\frac{dG}{dT}\frac{T}{G} = \frac{TQ_F}{G}\frac{dQ_F}{dT}\frac{T}{Q_F} + \frac{S_C I_F}{G}\frac{dI_F}{dT}\frac{T}{I_F} + \frac{TQ_F}{G} \tag{A.1}$$

where (using equation 1)

$$\frac{dQ_F}{dT}\frac{T}{Q_F} = \frac{T}{P_P^F}\varepsilon_{FF} + \varepsilon_{FH}\frac{dP_H}{dT}\frac{T}{P_H} + \varepsilon_{FB}\frac{dP_B}{dT}\frac{T}{P_B} \tag{A.2}$$

and (using equation 4)

$$\frac{dI_F}{dT}\frac{T}{I_F} = -\frac{Q_F}{I_F}\frac{dQ_F}{dT}\frac{T}{Q_F} + \eta_{FH}\frac{(Q_F + I_F)}{I_F}\frac{dP_H}{dT}\frac{T}{P_H} + \eta_{FB}\frac{(Q_F + I_F)}{I_F}\frac{dP_B}{dT}\frac{T}{P_B} \tag{A.3}$$

Setting $dP_W = dS_C = 0$ in (10), and solving simultaneously for dP_H/dT and dP_B/dT, and converting the result to elasticities, gives:

$$\frac{dP_H}{dT}\frac{T}{P_H} = \frac{T}{P_H}\frac{H}{D} \tag{A.4}$$

and

$$\frac{dP_B}{dT}\frac{T}{P_B} = \frac{T}{P_B}\frac{B}{D} \tag{A.5}$$

where

$$H = \varepsilon_{HF}(\eta_{BB} - \varepsilon_{BB}) - \varepsilon_{BF}(\eta_{HB} - \varepsilon_{HB})$$

$$B = \varepsilon_{BF}(\eta_{HH} - \varepsilon_{HH}) - \varepsilon_{HF}(\eta_{BH} - \varepsilon_{BH})$$

and

$$D = (\eta_{BB} - \varepsilon_{BB})(\eta_{HH} - \varepsilon_{HH}) - (\eta_{BH} - \varepsilon_{BH})(\eta_{HB} - \varepsilon_{HB})$$

Substituting (A.2) and (A.3) into (A.1), and making use of (A.4) and (A.5), gives equation (11) in the text.

Derivation of equation (12). First differentiate (9) with respect to S_C and convert the derivatives into elasticities. This yields:

$$\frac{dG}{dS_C}\frac{S_C}{G} = \frac{TQ_F}{G}\frac{dQ_F}{dS_C}\frac{S_C}{Q_F} + \frac{S_C I_F}{G}\frac{dI_F}{dS_C}\frac{S_C}{I_F} + \frac{S_C I_F}{G} \tag{B.1}$$

where (from equation 1):

$$\frac{dQ_F}{dS_C}\frac{S_C}{Q_F} = -\frac{S_C}{P_P^F}\varepsilon_{FF} + \varepsilon_{FH}\frac{dP_H}{dS_C}\frac{S_C}{P_H} + \varepsilon_{FB}\frac{dP_B}{dS_C}\frac{S_C}{P_B} \tag{B.2}$$

and (using equation 4):

$$\frac{dI_F}{dS_C}\frac{S_C}{P_P^F} = -\frac{Q_F}{I_F}\frac{dQ_F}{dS_C}\frac{S_C}{Q_F} + \eta_{FH}\frac{(Q_F + I_F)}{I_F}\frac{dP_H}{S_C}\frac{S_C}{P_H} + \eta_{FB}\frac{(Q_F + I_F)}{I_F}\frac{dP_B}{dS_C}\frac{S_C}{P_B} - \eta_{FF}\frac{Q_F + I_F}{I_F}\frac{S_C}{P_C^F} \tag{B.3}$$

Setting $dP_W = dT = 0$, and solving simultaneously for dP_H/dS_C and dP_B/dS_C from (10), and converting the result to elasticities, gives:

$$\frac{dP_H}{dS_C}\frac{S_C}{P_H} = \frac{H_1}{D} \tag{B.4}$$

and

$$\frac{dP_B}{dS_C}\frac{S_C}{P_B} = \frac{B_1}{D} \tag{B.5}$$

where

$$H_1 = \left(\eta_{HF}\frac{S_C}{P_C^F} - \varepsilon_{HF}\frac{S_C}{P_P^F}\right)(\eta_{BB} - \varepsilon_{BB}) - \left(\eta_{BF}\frac{S_C}{P_C^F} - \varepsilon_{BF}\frac{S_C}{P_P^F}\right)(\eta_{HB} - \varepsilon_{HB})$$

and

$$B_1 = \left(\eta_{BF} \frac{S_C}{P_C^F} - \varepsilon_{BF} \frac{S_C}{P_P^F} \right) (\eta_{HH} - \varepsilon_{HH}) - (\eta_{BH} - \varepsilon_{BH}) \left(\eta_{HF} \frac{S_C}{P_C^F} - \varepsilon_{HF} \frac{S_C}{P_P^F} \right)$$

Substituting (B.3) and (B.2) into (B.1), and making use of (B.4) and (B.5), gives equation (12) in the text.

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