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Environmental Regulation: The Welfare Cost of BOD Limitations in the Palm Oil Industry

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ABSTRAK

Industri minyak kelapa sawit ialah salah satu penyumbang utama ekonomi Malaysia. Sungguh pun ia telah mencapai kejayaan di peringkat antarabangsa, perkembangan industri ini mengakibatkan masalah kemerosotan alam sekitar dalam negara. Industri ini telah dikenal pasti sebagai industri berasaskan pertanian yang paling mencemarkan, dan oleh itu peraturan alam sekitar untuk mengawal pengeluaran buangannya telah dikuatkuasakan. Impak peraturan ini ke atas kebajikan pencemar, pengguna dan pemilik sumber yang diukur oleh lebihan ekonomi dinilai dengan menggunakan model pasaran bersepadu tegak. Hasil kajian ini menyokong hipotesis mengenai arah kesan peraturan itu tetapi kesannya adalah kecil bagi pengeluar minyak kelapa sawit mentah yang dikenakan peraturan secara langsung. Malah, kesannya diagihkan kepada pengeluar minyak kelapa sawit bertapis dan pembekal bahan mentah.

ABSTRACT

The Malaysian palm oil industry is one the chief contributor to the nation's economy. Despite all the successes the palm oil industry has achieved in the international arena, domestic problems arising from the rapid development of the industry has had serious consequences on the natural environment. It has been singled out as the most polluting agro-based industry and thus, environmental regulation governing its effluent discharge in processing has been enforced. The impacts of this regulation on the welfare of the polluter, the consumer and the resource owner in terms of changes in economic surpluses are evaluated using a vertically integrated market model. Results support the hypotheses about the direction of the effects of this regulation, but these effects have been rather small for the crude palm oil producers who are directly

regulated. The impacts are passed on to refiners and the suppliers of raw materials.

INTRODUCTION

Malaysia's agricultural base was broadened by the expansion of oil palm cultivation since the early 1960s. The intent was to reduce reliance on exports of rubber. Palm oil output expanded rapidly and has accounted for about 40% of the increase in agricultural output during the last decade. Expanding palm oil production had had serious consequences on the environment. Since 1977, Malaysia has imposed progressively more stringent effluent regulations on crude palm oil processors. This paper analyzes the producer welfare effects of those regulations in a vertical market structure based on the following justification. First, Malaysia is one of the few trade-dependent industrializing nations to move decisively against pollution in a key export industry. The economic consequences are instructive for other industrializing nations which have been more reluctant, fearing serious economic losses. Second, the theoretical and empirical models highlight the analytical treatment of both multiple product production processes and a multiple sector industry, with regulations imposed on an intermediate sector. Finally, the application of dual models to derive demand and supply functions facilitates estimation of theoretically consistent functional forms.

EFFLUENT PRODUCTION AND ENVIRONMENTAL REGULATIONS

Crude palm oil (CPO) is extracted from the mesocarp of the oil palm fruits which are harvested in bunches, generally termed fresh fruit bunches (FFB). In separate mills, oil is also extracted from the kernel of the fruit, viz. kernel oil. Palm oil, kernel and wastes are produced in almost constant proportions in palm oil mills. There are three main waste streams that combine in the overall waste discharge in the processing of FFB, (1) sterilizer condensate, which contains oil, dirt and soil amounting to about 0.9 tonne per tonne of oil produced; (2) hydrocyclone waste from kernel processing amounting to about 0.1

– 0.2 tonne per tonne of oil produced; and (3) separator sludge amounting to about 1.5 tonnes per tonne of oil produced. The total palm oil mill effluent (POME) jointly produced is about 2.5 tonnes per tonne of oil.

The palm oil processing industry discharges various water pollutants, most notably biological oxygen-demanding (BOD) organic wastes. The effluents cause serious depletion of dissolved oxygen and kill fish, prawns and crabs which are important sources of jobs and nutrition. The unsightly and smelly oil palm sludges accumulate on riverbanks and in ditches, if not checked. By 1982, the palm oil processing industry was responsible for about 63% of Malaysia's total water pollution load (Table 1). More public complaints about water pollution were directed at the palm oil industry than any other industrial source (Table 2).

At present, most systems for the treatment and disposal of POME use chemical coagulation and precipitation followed by some forms of waste disposal. The systems in actual operation are capable of removing 99% of the Biochemical Oxygen Demand (BOD), 98% of Chemical Oxygen Demand (COD), 88% of total solids, 95% of suspended and volatile solids, 99.7% of oil and grease and 75% of total nitrogen.

TABLES 1. Domestic and Industrial Pollution Load Generated, 1982

Water Pollution Source (m'/day)	Total Effluent Discharge (tonnes/day)	%	BOD Generated	%
Household				
Domestic sewage and sullage	210,500	26.0	715	25.5
Industrial				
Palm oil mills	70,500	8.7	1,760	62.7
Rubber factories	116,000	14.3	208	7.4
Other manufacturing industries	412,000	51.0	124	4.4
Industrial subtotal	598,000	74.0	2,092	74.5
Total	809,000	100.0	2,807	100.0

Source: Malaysia Department of Environment, Environmental Quality Report, 1982.

TABLE 2. Sources of Water Pollution Complaints, 1978 – 84

	1978 – 80	1981 – 84
	(percent)	
A. Regulations Under Environmental Quality Act (E.Q.A.), 1974		
I Palm Oil Regulation:		
1. Palm oil mills	28.3	20.5
II Rubber Regulation:		
2. Rubber mills	19.9	13.7
III Sewage and Industries Regulation:		
3. Animal husbandry	6.6	9.2
4. Other Agro Industries	5.3	6.1
5. Manufacturing Industries	15.5	22.1
6. Sewage	2.2	5.2
B. Non – E.Q.A regulations		
7. Mining and Land Development	12.4	12.0
8. Solid Waste	4.9	5.6
9. Others	4.9	5.6

Source : Malaysia Department of Environment, Environmental Quality Report 1982 – 84.

Abatement regulations, established in 1977, allowed one year for the mills to install treatment facilities and then enforced four stages of allowable discharge limits. The mills were required to reduce the effluent components, using BOD as a parameter, from 20,000 mg/l to 5,000 mg/l in 1978, 2,000 mg/l in 1979, 1,000 mg/l in 1980 and 500 mg/l by 1981. These BOD limits were further reduced to 250 mg/l in 1982, 100 mg/l in 1983, and 50 mg/l in 1986 (Table 3).

An interesting feature of the palm oil mill effluent regulations is the levy of effluent fees. The regulations leave firms the option of discharging POME onto land subject to a fee of $50 per 1,000 tonnes. Or, the effluent may be treated and discharged into watercourses subject to the BOD concentration standard and fees. Dischargers were required to pay $100 per metric tonne for BOD discharges exceeding the scheduled legal standard and $10 per metric ton of BOD for loads equal to or less than the standard. Each discharger also paid a $100 annual license fee. During the first year the regulation was effective, implementation was relaxed but a large number of mills opted to pay high effluent fees rather than implement the then available technology, which was capable of achieving only intermediate standards.

TABLE 3. Regulatory Standards for Palm Oil Mill Effluent[a]

Parameter Effective July 1:	1978	1979	1980	1981	1982	1983	1986
Biochemical Oxygen Demand (BOD) 3-day @ 30°C	5,000	2,000	1,000	500	250	100	50
Chemical Oxygen Demand	10,000	4,000	2,000	1,000	–	–	–
Total Solids	4,000	2,500	2,000	1,500	–	–	–
Suspended Solids	1,200	800	600	400	400	400	400
Oil & Grease	150	100	75	50	50	50	50
Ammoniacal Nitrogen	25	15	15	10	150[b]	150[b]	100[b]
Organic Nitrogen	200	100	75	50	300[b]	200[b]	200[b]
pH	←----------		5.0 – 9.0		----------→		5.0
Temperature, °C	←----------			45			----------→

[a] All parameters in mg/l except pH and temperature.
[b] Value of filtered sample.

Source : Department of Environment, Malaysia, 1983; PORIM, 1986.

MODEL DESCRIPTION

THE INDUSTRY

Malaysian palm oil industry consists of three sectors: the production of FFB involving the planting and cultivation of oil palms, the processing of the FFBs into CPO, and the subsequent processing of CPO into refined palm oil (RPO), virtually all of which is exported.

About half (49.5) of the acreage devoted to oil palms is in technologically-advanced estates owned by private individuals, groups of private individuals, and state governments in 1989. Smallholdings make up the other 50.5% (Table 4). Smallholdings have been assisted by government land development schemes and agricultural programmes and generally are not as productive as the estates but are fast becoming increasingly important.

The mills producing CPO from FFBs are either integrated into the estates or are centrally sited in the development schemes among

TABLE 4. Area Under Major Crops, Malaysia 1965–89 ('000 Hectares)

	1965	1970	1975	1980	1985	1989
Oil Palm	97.0	261.2	641.8	1023.3	1431.9	1887.6
Estates	84.2	193.4	389.8	545.5	786.5	935.3
Small-holdings	12.8	67.8	252.0	477.8	645.4	952.3
Rubber	2043.7	2019.4	1991.6	2004.6	1944.2	1856.8
Estates	788.5	677.0	583.4	512.5	431.2	369.2
Small-holdings	1255.2	1342.4	1408.2	1492.1	1513.0	1487.6
Cocoa	..	4.0	9.8	123.9	303.9	423.2
Estates	..	2.1	2.9	52.8	160.7	180.2
Small-holdings	..	1.9	6.9	71.1	143.2	243.0
Cocount	196.0	210.0	230.0	250.0	327.6	331.0
Estates	26.0	22.0	17.0	20.0	28.6	26.8
Small-holdings	170.0	188.0	213.0	230.0	299.0	304.2

Sources: Department of Statistics, Malaysia: Oil palm, cocoa, coconut and tea statistics handbook, various issues;
Department of Statistics, Malaysia: Economic Time Series, 1986.

smallholders. At the end of 1990, there were 261 mills in operation producing CPO with a total capacity 9,695 tonnes FFB/hour and an average installed capacity of 37 tonnes FFB/hour. Since the 1970's, the Government has encouraged domestic palm oil refining through the introduction of a variable export duty on CPO and duty exemptions on processed palm oils. More refined oils receive greater exemptions. As a result, 97% of Malaysia's palm oil was exported in processed form in 1985 whereas in 1974 palm oil was exported entirely as crude. The refining sector has thrived, and as of 1990, 53 refineries were in operation.

The model allows for joint production technology in the CPO industry where the effluent joint product is undesirable and subject to effluent charges and environmental quality standards. The other joint product is palm kernels, which are sold to kernel oil mills.

The price and quantity of CPO are determined through the intersection of CPO demand and supply relations. RPO supply and CPO demand are derived from the dual specification of profit maximisation in RPO production. CPO supply and the demand for FFB are based on dual costminimising decisions of CPO producers. Theoretically consistent estimating equations are developed and presented in Appendix I. In the short run, FFB is not substitutable and thus the demand is proportional to the quantity of CPO produced. The CPO mills offer FFB prices based on the prices of CPO and palm kernels and on the extraction rates of FFB. The supply of FFB is to a large extent determined by biological factors. Thus, FFB supply are highly price inelastic in the short run. For the individual grower, ripe bunches are harvested every 9 – 14 days. Bunches and loose fruits are collected and taken to a mill for processing.

THEORETICAL FRAMEWORK

Using producers' surplus concepts in vertically related markets, the welfare changes due to environmental regulation in the production of CPO are evaluated for the producers of RPO, CPO and FFB, taking account of the interactions in the respective markets. We consider that palm oil mills install pollution abatement equipment. Operation of that equipment increases the private cost of production. The price of CPO is competitive in the world market and with an export duty imposed, the domestic price of CPO is determined competitively by the domestic demand and supply functions so that an insignificant amount of CPO is exported.

When pollution control is imposed, the supply curve for CPO shifts upwards from $S^o(r^o; BOD^o)$ to $S'(r^o; BOD')$. Since individual producers do not perceive that their actions affect prices, the shift of the CPO supply curve from $S^o(\cdot)$ to $S'(\cdot)$ results in decreases in CPO production and in demand for FFB from $D^o_x(p^o; BOD^o)$ to $D^o_x(p^o; BOD')$ at that level of CPO price p^o (Fig. 1). But, at the industry level, the CPO price increases from p^o to p' to meet the demand for CPO.

In the RPO market, producers are price takers, in which case the RPO price is determined in the world market. Due to the highly competitive nature of world vegetable oils market, demand for RPO is highly elastic, if not perfectly elastic. Changes in RPO supply have little or no effect on the price of RPO. Thus, an increase in CPO price means more costly production of RPO which causes a decrease in the quantity demanded for CPO from q^o to q' along the derived demand curve $D^o_d(p^o_{rpo})$ in Fig. 1. This is also obtained by equating the value of

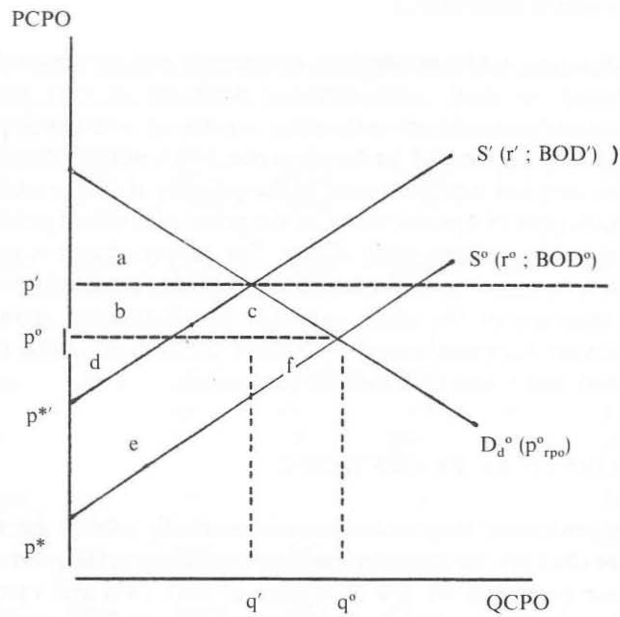

FIGURE 1. Welfare Change for CPO Prodcers

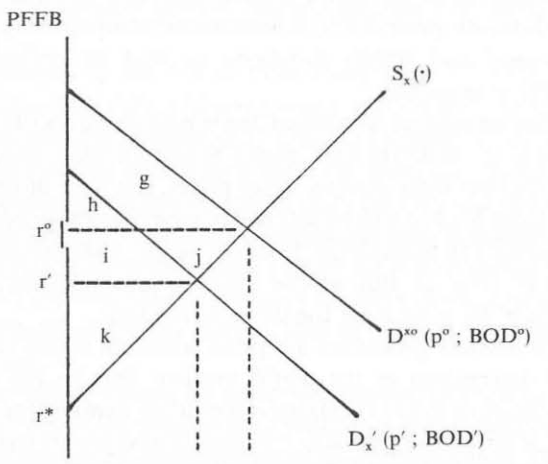

FIGURE 2. Welfare Change for FFB Suppliers

marginal product, as shown by the derived demand curve for CPO, with the input cost, in this case the price of CPO. The new equalibria are achieved in the CPO and FFB markets with an increase in CPO price from p^o to p' and a reduction in FFB price from r^o to r'. The corresponding quantity levels are q^o and x' in the respective markets.

The producers' surplus associated with the supply of CPO without pollution control and with FFB price fixed at r^o as measured by the area left of the supply curve and below price is d + e + f in Fig. 1. This area is precisely the area behind the derived demand for FFB or equivalently g + h in Fig. 2. With the shifts in the supply curves due to pollution control $S'(\cdot)$ the producers' surplus is b + d in Fig. 1 (equivalent to h + i in Fig. 2).

Thus, the net change in CPO producers' surplus is b − (e + f) [= (b + d) − (d + e + f)]. This is equivalent to (i − g) [= (h + i) − (g + h)] in Fig. 2. These measures may be obtained by integration of the appropriate functions, for example,

$$d + e + f = \int_{p*}^{p_o} S^o(\cdot)\, dp = 1/2\,(p^o - p^*).$$

$$b + d = \int_{p*'}^{p_o} S'(\cdot)\, dp = 1/2\,(p' - p^{*\prime}).$$

Hence,

$$b - (e + f) = \left\{ \int_{p*'}^{p_o} S'(\cdot)\, dp - \int_{p*}^{p_o} S^o(\cdot)\, dp \right\}$$

$$= 1/2\,\{(p' - p^{*\prime})\cdot q' - (p^o - p^*)\cdot q^o\}.$$

Since there are no substitutes for FFB and a fixed coefficient is assumed in the production of CPO, the demand for FFB by CPO producers depends upon the quantity of CPO produced which in turn depends upon the prices of CPO, palm kernel and the costs of CPO production. Given the highly competitive structure of the CPO industry, the demand for FFB in its price-quantity space is downward sloping as shown in Fig. 2. Hence, at any given levels of CPO and palm kernel prices p^o, more FFB is demanded as FFB price decreases, i.e. a movement along the demand curve $D_r^o(\cdot)$ without pollution control.

The FFB producers' surplus without pollution control in the CPO market, i.e., at CPO price p^o, is i + j + k associated with the demand curve $D_x^o(\cdot)$, as shown in Fig. 2. This may be obtained by integrating the FFB supply function as follows:

$$i + j + k = \int_{r*}^{r_o} S_x \, dr = 1/2(r^o - r^*)\cdot \hat{x}^o$$

With pollution control in CPO market that results in an increase in CPO price and the resulting demand for FFB $D_x^o(\cdot)$, FFB producers' surplus is k, where

$$k = \int_{r*}^{r_o} S_x \, dr = 1/2\,(r' - r^*)\cdot x'.$$

Thus, the net change in FFB producers surplus after taking account of environmental policy and changes in CPO price is

$$-(i + j) = [k - (i + j + k)], \text{ i.e.,}$$

$$-(i + j) = \int_{r*}^{r_o} S_x \, dr - \int_{r*}^{r_o} S_x \, dr$$

$$= 1/2\,\{(r' - r^*)\cdot x' - (r' - r^*)\cdot x^o\}.$$

The total change in welfare of CPO and FFB producers may be obtained by summing the welfare effects over the two individual producers, given the adjustments in RPO, CPO and FFB markets. Collecting these effects over both industries as reflected in the FFB market, yields the net change of − (g + j) [= (i − g) − (i + j)].

In our description of welfare effects, the significance of area i in Fig. 2 is noted. For CPO producers, the loss of welfare is obviously less than area g by an area i. For FFB producers, the welfare loss is area j plus area i. Thus, area i is the transfer of welfare from FFB to CPO producers through lower FFB price.

DATA

Annual data is desirable for the study. However, as environmental regulation in the palm oil industry in Malaysia began only in 1978, the number of observations in relation to the number of parameters estimated is limited for any flexible functional forms. Thus, monthly data beginning in 1982 through 1986 are used here. At the firm level, 5 years is a short time to consider changes in the input mix. Since capital equipment are durables, it is unreasonable to expect substantial changes in the input mix over five years. At the industry level, however, new firms may enter and some older firms may shift to new technology. These characteristics allow for long-run analysis of the industry's production technology. The data were obtained mainly from the Malaysian Palm Oil Registration and Licensing Authority (PORLA), Department of Statistics, and Department of Environment (DOE).

To minimise multicollinearity in nominal prices due to inflation, prices of intermediate and refined products are deflated by the producer price index, 1980 = 100. The implicit prices of capital services are computed based on the implied equality between the value of capital investment and the discounted value of its services following Griliches and Jorgenson (1966) and Christensen and Jorgenson (1969). The prices of an aggregated CPO/palm kernel are weighted by the shares of the total value of production derived from each product.

RESULTS OF ESTIMATION

PARAMETER ESTIMATES

Parameter estimates of the structural model are presented in Table 5. Using these estimates, the elasticities of demand for and supply of CPO and FFB are computed for the years of key regulation changes, i.e. 1982 – 86 for which the welfare effects are evaluated. The quantity of RPO supplied depends positively on the price of RPO. However, this relationship is statistically insignificant. More significant are the past quantity of production, past RPO price and current CPO price. Other input prices, such as the wage rate and the price of capital, are not significant in influencing the quantity of RPO production.

For the sake of argument, say that the coefficient on current RPO price is plausible. The RPO supply elasticity derived from this estimate is a low 0.844 at the sample means of price and quantity.

Since CPO is an input in the production of RPO, the quantity of CPO demanded depends on the relative prices of CPO and RPO as well

TABLE 5. Estimates of Structural Equations

1. Three-stage Least Squares

RPO Supply Equation

$$S_t = 200.44^{*} - 30880.00\, P_t^{-1/2} + 2.71^{**}\, p_t^{1/2} \cdot P_t^{-1/2}$$
(105.42) (24294.00) (1.05)

$$+ 853.24\, W_t^{1/2} \cdot P_t^{-1/2} + 2045.00\, K_t^{1/2} \cdot P_t^{-1/2} + 0.70^{**}\, S_{t-1}$$
(1077.40) (1979.70) (0.08)

$$+ 0.5^{*}\, P_{t-1}$$
(0.01)

$R^2 = 0.6970$, D.W. = 1.9409

CPO Demand Equation

$$d_t = -2.11 - 541.00^{*}\, p_t^{-1/2} + 2.71^{**}\, P_t^{1/2} \cdot p_t^{-1/2}$$
(1.36) (305.97) (1.05)

$$+ 21.97\, W_t^{1/2} \cdot p_t^{-1/2} + 40.61\, K_t^{1/2} \cdot p_t^{-1/2} - 0.62^{**}\, d_{t-1}$$
(14.54) (24.40) (0.07)

$$+ 0.01\, P_{t-1}$$
(0.02)

$R^2 = 0.7779$, D.W. = 1.9592

CPO Supply Equation

$$s_t = -7.86 + 0.01\, p_{t-1} + 0.02\, p_t + 0.03\, s_{t-1} - 0.18\, w_t$$
(48.70) (0.01) (0.03) (0.02) (0.18)

$$- 0.57\, k_t + 0.41^{**}\, \mathrm{POME}_t - 0.03\, \mathrm{BOD}_t - 0.03\, r_t^{1/2} \cdot k_t^{1/2}$$
(0.42) (0.01) (0.02) (0.42)

$$+ 0.03\, r_t^{1/2} \cdot w_t^{1/2} + 0.35\, w_t^{1/2} \cdot k_t^{1/2}$$
(0.24) (0.48)

$R^2 = 0.9915$, D.W. = 0.8317

FFB Demand Equation

$$q_t = 243.17^{**} + 0.10\, \mathrm{BOD}_t - 0.74^{**}\, r_t - 0.08\, q_{t-1}$$
(72.81) (0.09) (0.20) (0.04)

$$- 0.03\, k_t^{1/2} \cdot r_t^{-1/2} + 0.03\, w_t^{1/2} \cdot r_t^{-1/2} + 4.06^{**}\, s_t$$
(0.42) (0.24) (0.16)

$R^2 = 0.9733$, D.W. = 1.1040

System $R^2 = 0.9970$

Chi-square = 330.83 with 25 d.f., $\text{Chi-square}_{0.05} = 37.6525$

Breusch-Pagan LM test for diagonal covariance matrix:

Chi-square = 57.716 with 6 d.f., $\text{Chi-square}_{0.05} = 12.5916$.

continued next page

Table 5 (*Continued*)

2. Two-stage Least Squares

FFB Supply Equation

$$Q_t = 2345.8 - 2.44^{**} r_{t-1} + 1.77^{*} r_{t-2} + 0.24 r_{t-2}$$
$$(2977.10) \quad (0.80) \quad (0.83) \quad (0.63)$$
$$+ 1.04^{**} Q^t_{-1} - 0.43^{**} Q_{t-2} - 1.49\, l - 19.36\, \text{RAIN}$$
$$(0.11) \quad (0.09) \quad (6.06) \quad (25.28)$$
$$-0.002\, \text{AC} + 178.76\, T$$
$$(0.002) \quad (231.21)$$
$$R^2 = 0.8482,\ D.W. = 2.2715$$

Chi-square = 113.13 with 10 d.f., $\text{Chi-square}_{0.05}$ = 18.3070

Note :

* significant at 0.05 level;
** significant at 0.01 level;
S is quantity of RPO output, ('000 tonnes);
d is quantity of CPO consumed domestically, ('000 tonnes);
s is quantity of CPO produced ('000 tonnes);
q is quantity of FFB demanded by palm oil mills ('000 tonnes);
Q is quantity of FFB produced ('000 tonnes);
P is domestic price of RPO (M$/tonne);
p is domestic price of CPO, (M$/tonne);
r is domestic price of FFB (M$/tonne);
W is average monthly wage rate in refineries (M$);
w is average monthly wage rate in palm oil mills (M$);
l is average monthly wage rate in the plantation sector (M$);
K is price of capital in refineries (M$);
k is price of capital in palm oil mills (M$);
POME is quantity of effluent produced ('000 tonnes);
BOD is BOD concentration discharged (mg/l);
AC is mature acreage of oil palm ('000 hectares);
RAIN is rainf all (cm);
T is a time index.

as the relative prices of other inputs. The estimated coefficient on the relative prices of RPO and CPO implies that an increase of M$1 increases the quantity of CPO demanded by 2,714 tonnes. This estimate is significant at the 0.01 level. The past quantity of CPO demanded also is significant at the 0.01 level. Based on the reported estimates and sample means, the price elasticity of demand for CPO is a low − 0.502.

The quantity of CPO supplied and the production of POME as a joint output are significantly affected by past quantity supplied, the capital service price and BOD limitations. Wage rates and the current CPO price are not significant in influencing the supply of CPO. However, assuming that the CPO price coefficient is plausible, a M$1 increase in the price of CPO increases the quantity of CPO and palm kernels supplied by only 21 tonnes, *ceteris paribus*. An increase of M$1 in the capital service price decreases the quantity of CPO supplied by 570 tonnes. POME is highly correlated with CPO output. Our estimates imply that a tonne of CPO is accompanied by 2.40 tonnes of POME. Increases in BOD limitations increase the cost of CPO production and would decrease the quantity of CPO supplied *ceteris paribus* by 28 tonnes per mg/l reduction in BOD.

The cross-price terms, when applied to a given set of input prices, yield Allen partial elasticities of substitution between the respective inputs in production. These terms are found to be insignificant at the 0.05 level in our estimation. This outcome implies that during our sample period, FFB processors used inputs in fixed proportion.

The quantity of FFB demanded depends significantly on the current FFB price and the quantity of CPO produced. An increase of M$1.00 in FFB price *ceteris paribus* decreases the quantity of FFB demanded by 735 tonnes using our estimates. At the mean quantities and prices, the price elasticity of demand for FFB is -0.079. An increase of 1,000 tonnes of CPO produced increases the demand for FFB by 4,064 tonnes, for an extraction rate of 24.6% for CPO and palm kernels in composite.

The ratio of the capital service price to the price of FFB captures substitutability between capital and the quantity of FFB used. Similarly, the ratio of the wage rate to the price of FFB captures substitutability between labor and the quantity of FFB used in CPO production. The statistical insignificance of the coefficients on these variables implies that, over the sample period of 5 years, the technology employed FFB, labor, and capital in fixed proportions.

Factors that significantly affect the quantity of FFB supplied are past prices and quantities. The current quantity of FFB supplied is negatively related to the FFB price in the last period, but positively related for longer lags. This indicates that FFB growers may not have any flexibility at the margin to shift harvesting from one month to the next, even when current prices are low due to the non-storability of FFB. The positive price effects with longer lags suggest some flexibility to shift emphasis among crops and alter the mix of variable inputs in response to price movements. These, together with the mixed effects of past quantities, reflect two forces. One is that contractual supply arrangements are often made in advance. The other is seasonality in the productivity of oil palms.

Harvesting wages, rainfall, stock of mature acreage and time which reflect changes in technology, do not significantly influence the supply of FFB even though the directions of influence obtained are as expected.

WELFARE EVALUATION

To evaluate the welfare effects of Malaysia's environmental policies for palm oil effluents, the changes in economic surpluses are quantified for RPO, CPO and FFB producers and the values are summarized in Table 6 for the 1982, 1983, and 1986 changes in effluent standards (refer to Table 3). RPO and CPO prices were generally modest in 1982, high in 1983, and generally low in 1986.

The monthly gain/loss of quasi-rent is evaluated using the results of our estimation and the actual average monthly quantity and price of CPO during the year. The changes are evaluated sequentially accounting for earlier regulations when calculating the effects of later standards. Cumulative effects are evaluated based on sample period mean prices and quantities, the associated elasticities, and the change in regulatory standards from 1982 to 1986. Welfare effects on individual sectors are discussed in the following sections.

RPO Producers The economic surplus change for RPO producers equals the change in the area under the input (CPO) demand curve and above the equilibrium price level. From our estimation results, the price elasticity of demand for CPO at the 1986 values of price and quantity is -0.076.

With the equilibrium price and quantity of CPO determined by the intersection of demand for and supply of CPO, the losses in RPO producers' surplus associated with increases in price and decreases in quantity are about M\$86,800/mo. in 1982, M\$74,200/mo. in 1983 and M\$109,800/mo. in 1986 (M\$1.00 $\approx$ US\$0.40). These losses vary depending on the demand elasticity and the extent of the CPO supply shift. In 1983 for example, quantity was low and the losses to RPO producers were lowest. Conversely, the welfare losses to RPO producers were highest when the actual quantity of CPO consumed was highest, as shown in Table 5. These losses, when computed for the reduction of BOD levels required by regulation, represent about 1.9 – 8.37% of the monthly average gross revenue of RPO production.

CPO Producers The estimated supply of and demand for CPO are both highly inelastic. However, the losses in producers' surplus due to regulation are small relative to the values of production: only 0.79% of the total monthly value of CPO production in 1982, 1.66% in 1983 and 1.12% in 1986. Relative to the total values of RPO, CPO and FFB production, the losses to CPO producers represent only 0.001% in 1982, 0.05% in 1983 and 0.007% in 1986.

FFB Producers The price of FFB follows closely the price of CPO. However, FFB price may not necessarily increase when CPO production costs rise due to environmental control. Increasing stringency of CPO pollution control *ceteris paribus* increases the costs of production, increases the CPO price, and decreases the quantity of CPO supplied at equilibrium. Thus, associated with the leftward shift in the supply function for CPO due to pollution control is a leftward shift in the demand for FFB.

As shown in Table 6, environmental regulations imposed on CPO producers cost FFB producers more in lost economic surpluses than any other sector. The incremental losses were 9.11% to 29.30% of the respective values of FFB production. In relation to the values of production for the industry, the losses to FFB producers represent 0.027% to 0.046%.

Cumulative Welfare Impacts At the mean price and output quantity levels, the cumulative losses of all changes from 1982 to 1986 were M$115.9 million/mo. for FFB producers, M$18.2 million/mo. for RPO producers, and M$3.5 million/mo. for CPO producers. These translate to reductions of 44%, 4.7% and 1.2% relative to the mean monthly values of production for FFB, RPO and CPO producers respectively.

The small impact on the CPO sector are due to the inelasticity of demand for crude palm oil and the highly inelastic supply of FFB.

TABLE 6. Welfare Effects of Reducing a Unit of BOD

Producer Welfare Effects by Sectors[a]					
Year	BOD Standards (mg/l)[b]	RPO	CPO	FFB	Total
1982	250	−86.805 (0.033%) [8.37%]	−7.087 (0.003%) [0.79%]	−244.166 (0.117%) [29.30%]	−338.058 (0.049%) [12.21%]
1983	150	−74.197 (0.025%) [2.51%]	−38.047 (0.017%) [1.66%]	−203.510 (0.09%) [9.15%]	−315.754 (0.042%) [4.22%%]
1986	50	−109.816 (0.038%) [1.90%]	−44.301 (0.022%) [1.12%]	−299.902 (0.182%) [9.11%]	−454.019 (0.070%) [3.48%%]
Cumulative Effect of Changes from pre-1982 to post-1986[c]		−18,230.4 (0.011%) [4.7%]	−3,163.1 (0.003%) [1.2%]	−115,945.7 (0.098%) [44%]	−137,339.2 (0.037%) [14.8%%]

[a] Unbracket numbers are M$'000/mo./unit reduction in BOD from the previous standard. Numbers in () are percentage of total values of production for one unit BOD reduction. Numbers in [ ] are percentage of total values of production for specified units of BOD reduction.

[b] The baseline for 1982 and the cumulative change is the previous standard of 500 mg/l. The 1982 standard is the baseline for the change in 1983, etc.

[c] Change evaluated at sample mean prices and output quantities.

CONCLUSION

Pollution regulations generally have the effect of raising production costs, and hence product prices. Many nations, especially industrializing nations, fear regulations will result in a loss of international competitiveness for exporting firms. This can have an effect on the individual export industries as well as the country's trade balance. However, the export (RPO) sector for Malaysia's palm oil lost only 5% of the value of output as a result of environmental regulations from 1982 to 1986 that reduced the allowable BOD discharges by 90%. The CPO sector lost even less-only about 1% of the value of production. Thus, despite the highly competitive nature of the world oils market and Malaysia's RPO and CPO industries, environmental regulations do not appear to have been particularly onerous to the processors.

The really significant losses apparently have been concentrated in the FFB growing sector. There, over 40% of the value of production has been lost and the impacts are undoubtedly felt by smallholders and plantation owners as well. These findings serve notice that environmental protection may significantly change the distribution of returns to trade. Producers of primary inputs are especially vulnerable.

Appendix I

THEORETICAL DERIVATION OF OUTPUT SUPPLY AND INPUT DEMAND FUNCTIONS

For Malaysian crude and refined palm oil, the Leontief technology is an appropriate but rather restrictive *ex post* characterisation of short run production decisions. The essential inputs (FFB in CPO production and CPO in RPO production) are not substitutable in the short run, when plants and technology are fixed, and only marginal changes in the input/output ratios are possible in the long run. A Generalised Leontief production specification used here allows for arbitrary sets of factor substitution possibilities. Diewert (1974) has shown that the Generalised Leontief production function can reveal Allen-Uzawa elasticities of substitution or shadow elasticities of substitution for a specified set of inputs and input prices. Using the Generalised Leontief profit and cost functions, supply and input demand equations are linear in parameters, thus facilitating econometric estimation. The hypothesis of a Leontief technology with no factor substitution is testable in the Generalised Leontief specification.

Let $g(y) = y$, an aggregate output. The Generalised Leontief profit function is given by

$$\Pi(P, p) = a_o + a_y P_y^{1/2} + \sum_{i=1}^{n} a_i p_i^{1/2} + a_{yy} P_y + \sum_{i=1}^{n} a_{yi} P_y^{1/2} \cdot p_i^{1/2} + \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} p_i^{1/2} \cdot p_j^{1/2} \quad (1)$$

where P_y and p_i are prices of output and inputs respectively.

By Hotelling's lemma, differentiating the profit function with respect to an aggregate output price P_y gives the supply function

$$y = \partial\Pi/\partial P_y = 1/2\, a_y\, P_y^{1/2} + a_{yy} + \sum_{i=1}^{n} a_{yi} (p_i/P_y)^{1/2} \quad (2)$$

Input demand functions are obtained by differentiating the profit function with respect to the input prices:

$$x_i = \partial\Pi/\partial p_i = 1/2\ a_i\ p_i^{1/2} + a_{yi}\ (P_i/p_i)^{1/2} + \sum_{j=1}^{n} a_{ij}\ (p_j/p_i)^{1/2} \quad , \quad i, j = 1, \dots, n \tag{3}$$

The profit-maximising approach is applied to RPO since RPO prices are determined in the world market. For CPO, howeverr prices are influenced by producers' aggregate output decisions. While individual producers have little control over the aggregate supply of CPO, they will strive to minimise the costs of any level of output. Their decision problem then is one of finding the cost-minimising way to produce any particular level of output.

Assuming input-output separability, the Generalised Leontief cost function is given by

$$C(y, p) = g(y) \sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij}\ p_i^{1/2} \cdot p_j^{1/2},\ p_i, p_j \geq 0 \text{ all } i, j, \quad y \geq 0, \tag{4}$$

where $b_{ij} = b_{ji} \geq 0$. The marginal cost of producing y is

$$MC_y = \partial C(y, p_i)/\partial y = g'(y) \sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij}\ p_i^{1/2} \cdot p_j^{1/2} \tag{5}$$

Applying Shepherd's lemma, the conditional factor demands are:

$$x_i(y, p) = \partial C(y, p_i)/\partial p_i = g(y) \sum_{j=1}^{n} b_{ij}\ (p_j)^{1/2}\ (p_i)^{-1/2} \tag{6}$$

for $i, j = 1, \dots, n$, and $p_i > 0$.

In a competitive industry, producers supply an output y to the level where the marginal cost of producing that output is equated to the market price of output P_y, i. e.,

$$P_y = MC_y = g'(y) \sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij}\ p_i^{1/2} \cdot p_j^{1/2}. \tag{7}$$

If $b_{ij} = 0$ for $i \neq j$ and $g(y) = y$, then the system collapses to a Leontief specification and the marginal cost function

$$MC_y^{o} = \partial C(y, p)/\partial y = \sum_{i=1}^{n} b_{ii}\ p_i. \tag{5'}$$

The corresponding conditional n-factor demands are

$$x_i' (p, y) = b_{ii} y. \tag{6'}$$

The inverse supply function is linear in the b_{ij} parameters for both the Leontief and Generalised Leontief cost functions, which is convenient for linear regression estimation. Under appropriate integrability conditions, the systems of demand and supply functions can be solved to obtain the implied production, cost, or profit functions. Our empirical application involves estimating the derived input demand and output supply equations and allows for their interactions in the respective markets through the specification of equilibrium conditions. These are imposed by estimating simultaneously the factor demand and supply and output demand and output supply equations derived above.

MODEL ESTIMATION

The full model consists of three groups of equations. Group I consists of equations for the supply of RPO and the derived demand for CPO. Equations for the supply of CPO, CPO price, FFB price (determined from CPO price), a CPO market clearing identity and derived FFB demand make up group II.

Equations in groups I and II are simultaneously estimated. The FFB supply equation is alone in group III and is estimated separately since FFB producers are price takers and FFB prices are based on the prices of CPO. This equation is used to complete the model of the industry, without which equations in groups I and II are sufficient to provide the welfare measures for the study.

Since insignificant amounts of CPO are exported from Peninsular Malaysia, the market-clearing identity for CPO considers total production of CPO to be equal to the domestic demand for CPO by refiners (QDCPO) and changes in the stock of CPO. The stocks of CPO are treated as residuals and are exogenous in the model since about 95% of CPO is processed into refined forms. Thus, the quantity supplied (QSCPO) is equal to the domestic demand (QDCPO) for CPO less changes in stocks (CHSTCPO):

$$\text{QSCPO} = \text{QDCPO} - \text{CHSTCPO}. \tag{8}$$

As for price identities, the aggregate price of CPO/palm kernel (PACPO) is computed based on the shares of revenues generated from CPO (86%) and palm kernels (14%)

$$\text{PACPO} = 0.86 \text{ PCPO} + 0.14 \text{ PKNL},$$

where PCPO and PKNL are CPO and kernel prices, respectively. Solving for PCPO, we get

$$\text{PCPO} = 1.1628\ \text{PACPO} - 0.1628\ \text{PKNL}. \quad (9)$$

The price of FFB (PFFB) is based on the prices of CPO and palm kernels obtained in the markets. One percent of those prices are deducted for commission. Another 1% of the price of CPO is deducted for losses during processing. Extraction rates are 20% for CPO and 5% for palm kernels. The average costs of processing are deducted from the adjusted output prices prior to setting the price of FFB. Thus, the FFB price relation is known a priori by

$$\text{PFFB} = (0.98)(0.20)\ \text{PCPO} + (0.99)(0.05)\ \text{PKNL} - C$$

or

$$\text{PFFB} = 0.196\ \text{PCPO} + 0.0495\ \text{PKNL} - C \quad (10)$$

where C is the average cost of processing.

The equations in groups I and II contain more than one endogenous variable. In the presence of this simultaneity, three-stage least squares estimates are consistent, asymptotically normally distributed, and asymptotically efficient in the complete system. The 3SLS approach is computationally tractable and avoids placing prior restrictions on the variance-covariance matrix (Dutta 1975).

The FFB supply equation must be handled differently. Using a Nerlovian model of price expectations, all variables in that equation are either exogenous or predetermined in time. Hence, the FFB equation is exactly identified and must be excluded from the 3SLS estimation to prevent singularity of the variance-covariance matrix. Since autocorrelation are suspected as lagged variables are present in the FFB supply equation and the regressors are stochastic, two-stage least squares is used that can improve the asymptotic efficiency of the estimators. An asymptotic test based on Durbin's *h* statistic is carried out to determine the significance of the lagged residuals. In practice, the least squares residuals are regressed on lagged residuals and lags of dependent variables. The significance of lagged residuals are tested using standard least squares procedures. The most popular Durbin-Watson test for first-order autoregressive errors are also tested for each equation and the d statistics are reported in Table 5.

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