Research and Advertising Decisions in an Open Economy: the Case of Colombian Milds Coffee

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Research and advertising investment both offer the potential to increase producer surplus. A model is developed that includes applied research and generic advertising with the aim of measuring marginal and optimal returns from each. While applicable to specific firm behavior, the model is applied to data from the world coffee market, with particular focus on Kenyan and Colombian producer groups.

Both research and advertising present the potential to increase producer welfare. Firms or producer groups may invest in research to reduce costs of production or increase output, thus shifting out the supply curve.[1] Alternatively, firms may advertise in order to sell at higher quantities, prices, or both. These benefits are recognized by many agricultural producer groups, for example, who impose levies on their members to cover costs of applied research and generic advertising.

In evaluating these alternatives, firms decide where investment money is most effectively spent — in advertising, research, both, or neither. Using coffee producers as examples, the objective of this study is to provide firms or producer groups with a framework to evaluate resource allocation with respect to supply- and demand-shifting strategies. This objective is approached by, first, a brief discussion of the literature pertaining to measuring returns to research and advertising. Optimal investment rules for applied research and commodity advertising are then derived and applied to a coffee trade model. Using data from Colombia and Kenya, results provide an empirical illustration of potential gains from the alternative investments. The paper concludes with implications of results for export promotion policy in the two cases investigated.

Investment in Research and Advertising

Two similar but largely separate streams in the economic literature have examined returns to investment in research and advertising (exceptions that examine both are Wohlgenant; Chyc and Goddard; Goddard, Griffith and Quilkey). On conceptual grounds or for practical purposes, these studies tend to assume that research and advertising appear as separate arguments in their respective production and utility functions and thus serve to shift supply and demand curves. The elasticities of demand and supply partly determine the changes in economic surplus resulting from such supply- and demand-shifting policies. The more inelastic the demand, the more producers gain from outward shifts in demand, and the less they gain from outward shifts in supply. The type of shift has also been shown to be important. For example, the more divergent the supply shift with respect to the price axis, the less producers gain (Lindner and Jarrett).

A common approach to measuring returns to research is the "economic surplus" or "index number" approach, which is based on benefit-cost and welfare analysis.[2] First used by Schultz, it considers the outward shift in supply caused by

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[1] Research can also be used to develop new products or improve quality, but this type of research is not addressed directly in this study.

[2] A second common method, known as the "production function" approach, views research as inducing an upward shift in the production function, and estimates the marginal productivity of research using econometric methods. Reviews of both approaches (and others) are found in Norton and Davis; Prentice and Brinkman; and Alston, Norton, and Pardey.

per unit cost-reducing research. Returns to research are expressed in terms of the resulting changes in economic surplus, translated into benefit-cost ratios or internal rates-of-return. Empirical studies have indicated widespread underinvestment in research (surveys appear in Ruttan; Echeverría). Few studies have examined optimal expenditure in research. Shumway reviews several optimization models designed specifically for research (he cites none applied to agricultural research). Knutson and Tweeten use a dynamic model that derives optimal rates of growth in agricultural production research.

Returns to advertising are generally measured with the change in economic surplus that results from the outward shift in the demand curve. The change in consumer surplus from advertising that alters a consumer's tastes and preferences has been the subject of much debate in the literature (Dixit and Norman) since traditional welfare analysis assumes constant tastes. On the producer surplus side — the focus of this paper — the picture is relatively clear; producers gain from advertising-induced increases in either price or quantity. Empirical returns to advertising studies typically examine marginal returns from advertising (Forker and Ward), which are expressed in rates of return, benefit-cost ratios, or in effects on consumption or revenues. Optimal advertising expenditure studies are less common (exceptions are Nerlove and Waugh; Dorfman and Steiner; Goddard and Conboy; Chyc and Goddard).

Optimal Research and Advertising Rules

A firm, industry association, or country may need to allocate limited funds between research and advertising investment. Optimal allocation will depend on a variety of factors, including functional form of the investment model, cost specification, market power, market structure, financing sources, discount factors, and alternative investments (Goddard, Griffith, and Quilkey). In a simple case, with research and advertising costs considered quasi-fixed (i.e. not indexed to output), the problem for the decision-maker is to maximize net producer returns:

$$\text{(1)} \quad maximize\ PS = P \cdot Q - \int MCdQ - RES - ADV$$

where *PS* is producer surplus and *MC* is marginal cost. Supply is a function of research, $Q_s=f(P,RES)$, and demand is a function of advertising, $Q_d=g(P,ADV)$. Solution of this problem gives optimal investment levels in research and advertising.

Nerlove and Waugh derive the conditions for optimal advertising under perfect competition by totally differentiating with respect to ADV (i.e. supply is allowed to adjust to the higher prices). The optimal advertising rule for the producer in a competitive market is:

$$\text{(2)} \quad \frac{\eta_{Q,ADV}^{ADV}}{\eta_{Q,P}^{S} - \eta_{Q,P}^{D}} = \frac{ADV}{P \cdot Q}$$

which says that, at the optimum, the ratio of advertising to total sales will be greater the more effective is advertising and the more inelastic is supply or demand.

A similar approach can be applied to develop an optimal research rule, the derivation of which is contained in Appendix 1. The optimal research rule for the producer in a competitive market is:

$$\text{(3)} \quad \frac{\eta_{Q,RES}^{RES}}{\eta_{Q,P}^{D} - \eta_{Q,P}^{S}} - \frac{\partial C}{\partial RES}\frac{RES}{P \cdot Q} = \frac{RES}{P \cdot Q}$$

which says that the ratio of research to total sales will be lower the more research depresses price, and the higher the cost-reducing effect of that research. Thus it reflects the trade-off between greater quantity and lower price created by research when demand is downward sloping.

A Coffee Trade Model

The optimal rules developed above are now included in empirical analysis. The examples used here are Colombian and Kenyan producer groups, who are monopsonistic within their respective countries and act as firms — maximizing the net benefits of coffee sales on the world market.

The empirical problem is a critical one for many countries and poor farmers. Coffee ranks as one of the most important export commodities in developing countries, where virtually all coffee is grown. World production has increased steadily despite multilateral efforts to curb output. Demand is stagnant in industrialized countries, which account for nine-tenths of consumption. These factors have contributed to declining real prices which recently reached their lowest levels in three decades. At a time when export earnings are desperately needed to service large external debts and to cope with structural adjustment programs, developing countries and donor organizations are faced with the problem of choosing policies and programs to increase the profitability of coffee production. A variety of options have been considered, including crop diversification, increased value-added production, international commodity (quota) agreements, and liberalized exchange rate regimes, but all have generally met with limited success.

This points to the possible gains from research and advertising. Coffee research centers are found in many producing countries, and are credited with major improvements in yields and pest control. Promotion of consumer demand through advertising has also been proposed, either generically (in conjunction with other countries) or independently, by promoting the product of a particular country. Colombia, for example, independently mounted its "Juan Valdez" advertising campaign that has enhanced consumer recognition and preference for its product.

For illustrative purposes, we first consider a simple trade model with two supplying countries (Colombia and Other Producers) and two importing countries (the United States and Other Consumers). A simplifying assumption made is that all coffee is exported. Stocks from coffee producing countries tend to be quite large (at times higher than annual production levels), so these are explicitly modelled. Stocks in importing countries are smaller and are ignored. Coffee is assumed to be a heterogeneous product by country of origin.

Table 1 summarizes the four-region trade model. Producer prices, consumer prices, supplies, demands, inventories, exports, and imports are denoted PP, P, S, D, I, X, and M, respectively. Supplies are functions of producer price and research expenditure, RES. Regional demands, Dij, are demand in region i for a good produced in region j, and appear as a function of consumer prices and Colombian advertising, ADV_1 (Other Producers are assumed not to advertise). Demand for inventories is a function of producer prices, carry-over stocks, and current period production. Consumer prices are explained by producer prices through price-linkage equations. The model is closed with identities that equate the sum of imports to the sum of exports which in turn equate to production net of inventory changes. The model solves for four market-clearing prices.

In order to produce plausible empirical results, the simple trade model is revised to incorporate greater complexity. Complete specification of the expanded model is contained in Appendix 2, and a complete set of estimates is obtainable from the authors. The model is summarized as follows. There are two exporting regions — Kenya and Colombia — which together produce about 97 percent of the high-quality variety known as Colombian Milds. Consumption is small in these countries and is considered exogenous. Supply is specified in partial logarithmic form which imposes a proportionally divergent shift as a result of research, i.e. a shift that is divergent with respect to the Y axis. This imposes the assumption that low and high cost producers have their costs reduced by research in equal proportions. There are four importing regions — the United States, Canada, Germany, and Rest-of-World. Inventory demand is specified for both producers and price-linkage equations are specified for each producer-consumer relationship. All equations include lagged dependent variables to reflect rigidities in technologies and tastes that persist over time. Research expenditure was included in the Kenyan and Colombia supply equations. Colombian ("Juan Valdez") advertising and brand advertising expenditure were included in the Canadian and U.S. models. The demand side was specified in three stages using a linearized version of the Almost Ideal Demand System.

Trade data (in terms of quantities and values) are taken from the United Nations trade data system which uses the Standard International Trade Classification (SITC) #0.711 for green coffee. The available sample period is 1962–1993. Prices used are import unit values derived from the trade data. Population, consumer price indices, exchange rates, and disposable income values are from various years of the IMF's *International Financial Statistics Yearbook*. Production and inventory data for 1960 to 1993 are from the USDA's *World Coffee Situation*. Research expenditure data are from the ISNAR Indicator Series Project: Phase II. Colombia's time series is for 1961–91 and represents expenditure by CENICAFE, the national (and sole) organization for coffee research (Falconi and Pardey 1993). Kenya's time series is from the Coffee Research Foundation (CRF) and covers the same period (Roseboom and Pardey 1993). Advertising expenditure data in Canada for the period 1974–92 are from various years of the *Annual Summary of Advertising Expenditure in Canada* (Media Measurement Services, Inc.). U.S. data for the period 1976–93 are from various years of *Ad $(Dollar) Expenditure* (Leading National Advertisers).

Table 1. A Coffee Trade Model with Product Differentiation.

Region 1 (Colombia)	Region 2 (Other Producers)	Region 3 (United States)	Region 4 (Other Consumers)
$S_1 = f(PP_1, RES_1)$	$S_2 = f(PP_2, RES_2)$	$S_3 = 0$	$S_4 = 0$
		$P_1 = f(PP_1)$	$P_2 = f(PP_2)$
$D_1 = 0$	$D_2 = 0$	$D_{31} = f(P_1, P_2, ADV_1)$	$D_{41} = f(P_1, P_2, ADV_1)$
		$D_{32} = f(P_1, P_2, ADV_1)$	$D_{42} = f(P_1, P_2, ADV_1)$
$I_1 = f(PP_1, S_1, I_1^{t-1})$	$I_2 = f(PP_2, S_2, I_2^{t-1})$		
$X_1 = D_{31}+D_{41}$	$X_2 = D_{32}+D_{42}$	$M_3 = D_{31}+D_{32}$	$M_4 = D_{41}+D_{42}$
$X_1 = S_1-I_1+I_1^{t-1}$	$X_2 = S_2-I_2+I_2^{t-1}$		

Endogenous Variables: Supplies (2), Inventory Demands (2), Prices (4), Demands (4), Imports/Exports (4)

Table 2. Coffee Supply Elasticities by Region.

	Short term elasticity	Short term lag (years)	Long term elasticity	Long term lag (years)
Bacha 1968 (Period 1943–60)				
Latin America	0.28	1	0.52	4
Africa	0.24	1	0.60	4
Maitha 1970 (Period 1946–64)				
Kenya (estates)	0.16	1	0.40	7
Kenya (smallholders)	0.20	1	0.51	7
De Vries 1975 (Period 1947–72)				
Brazil	0.20	1	0.44	7
Colombia	0.03	1	0.18	7
Africa	0.12	1	0.44	7
Asia	0.10	1	0.43	7
Akiyama and Duncan 1982 (Period 1963–79)				
Brazil	0.93	2	1.10	10–13
Colombia	0.68	0–1	0.96	10–13
Indonesia	0.29	0–1	1.05	10–13
Rest of World	0.07	0–1	0.38	10–13
This Study (Period 1969–93)				
Kenya	**insignificant**	**1**	**0.39**	**6–8**
Colombia	**0.13**	**1**	**0.26**	**6–8**

Table 3. Coffee Demand Elasticities by Region.

Country or Region	Source	Time Period	Price Elasticity	Income Elasticity
United States	George and King 1971	1955–65	-0.25	0.05
	Timms 1973	1952–65	-0.10	0.24
	de Vries 1975	1948–73	-0.22	0.01
	Goddard and Akiyama 1989	1962–84	-0.13	0.23
	This study	**1974–93**	**-0.20**	**0.15**
Canada	Timms 1973	1952–65	-0.23	0.79
	Akiyama and Varangis 1989	1968–86	-0.13	0.28
	This study	**1974–93**	**-0.15**	**0.19**
Germany	Timms 1973	1952–65	-2.33	0.23
	Akiyama and Varangis 1989	1968–86	-0.17	0.98
	This study	**1963–93**	**-0.11**	**0.37**

Table 4. Demand Elasticities for Kenyan and Colombian Coffee.

	United States		Canada		Germany		ROW	
	Kenya	Colombia	Kenya	Colombia	Kenya	Colombia	Kenya	Colombia
Kenya	-2.05	1.05	-2.19	1.19	-1.41	0.41	-1.02	0.84
	(-4.63)	(2.37)	(-6.54)	(3.56)	(-3.26)	(.95)	(-2.37)	(3.04)
Colombia	0.05	-0.79	0.15	-1.00	0.10	-0.81	0.10	-0.71
	(1.97)	(-33.77)	(3.91)	(-30.23)	(0.93)	(-9.80)	(3.04)	(-3.47)

Note: Figures in parentheses are t-statistics.

Selected Empirical Results

Supply in Kenya and Colombia was shown to be a function of producer price lagged one year and an average of six to eight years. As a perennial crop that matures in five to six years, response to high prices results in increased production about seven years hence, although shorter response (increased crop maintenance) may improve yields much sooner. Supply in both Kenya and Colombia appears to be inelastic, which is consistent with findings from other studies (Table 2). A one percent increase in research was shown to increase production by 0.531 percent (Kenya) and 0.436 percent (Colombia) nine years hence, after which effects decayed at a geometric rate. Both estimates are statistically significant at the 95 percent confidence level. This is likely a supply response to research aimed at multiplying planting materials of new hybrids and disseminating related extension advice to farmers (Nyoro, personal communication). No coffee research elasticities were available for comparison.

Table 3 shows own-price and income elasticities for aggregate coffee demand from this study and others. Results are largely consistent, showing coffee to be price and income inelastic. The multi-stage structure of the demand system was able to produce estimates of coffee demand by country of origin. Own- and cross-price demand elasticities for coffee from Colombia and Kenya appear in Table 4. Demand for these coffees is seen to be much more elastic due to substitution possibilities. However, demand is not perfectly elastic, which is what would be expected if coffees from different countries were perfect substitutes for one another. (This is what the assumption of homogeneous products would suggest.) Demand for Kenyan coffee is more elastic than that from Colombia. Cross-price elasticities suggest that the two countries produce substitutes, although Colombian coffee is more readily substituted for Kenyan than vice-versa. This likely reflects consumer preference for 100% Colombian coffee. Advertising elasticities indicate that a one percent increase in Colombian advertising expenditure in the United States will increase demand for Colombian coffee by 0.004 percent. The corresponding estimate for Canada is 0.009 percent. Both estimates are statistically significant at the 95 percent confidence level. No coffee advertising elasticities were available for comparison.

These supply and demand elasticities may now be combined to compute total export demand elasticity facing Colombia and Kenya. Following Buse, the total export demand elasticity for heterogeneous products is given by:

$$(4)\quad TE_i = PE_i + \sum_{j=1}^{n} \eta_{ij}\left[\frac{-\eta_{ji}}{PE_j - \eta_j^s}\right] for\ i \neq j$$

where η_{ij} and η_{ji} are cross-price elasticities, and η_j^s is the supply elasticity of competitors. PE_i is the partial export demand elasticity for region i which, in this model, is given by:

(5)

$$PE_i = \eta_{USA}\frac{D_i^{USA}}{X_i} + \eta_{CAN}\frac{D_i^{CAN}}{X_i} + \eta_{GER}\frac{D_i^{GER}}{X_i} + \eta_{ROW}\frac{D_i^{ROW}}{X_i} \quad \text{for } i = \text{Kenya, Colombia}$$

which is merely a trade-weighted average of the own-price demand elasticities. The two cross-price elasticities are calculated similarly as trade-weighted aggregates. The term in brackets in (4) thus describes the effect of a one percent change in the price of i's exports on the price of j's exports. If countries i and j produce substitutes (the case here), total demand elasticity will be more inelastic than the partial measure. Total export demand elasticities for Colombia and Kenya are:

$$(6)\quad TE_{col} = -0.735$$

$$(7)\quad TE_{ken} = -1.297$$

Thus Colombia faces inelastic demand for its coffee, and Kenya faces elastic demand. As indicated earlier, this has important consequences for relative returns to research and advertising.

Marginal and optimal returns to research and advertising are now presented. These results are obtained by incorporating parameter estimates from the empirical model into a simulation model. Marginal returns from each investment are obtained by increasing exogenous levels of research and advertising variables by one percent and measuring the change in producer surplus. Changes in producer surplus that occur over the sample period are then discounted and summed. Because of the difficulty of choosing an appropriate opportunity cost of capital, discount rates of five, ten, and fifteen percent are used. These results appear in Table 5.

Simulated results indicate that marginal returns to Kenyan research are quite high — a dollar spent yields a net present value of \$24. In contrast, Colombia experiences heavy losses from investment in research. These results were expected, since a divergent shift in supply — with respect to the Y-axis — must result in producer losses in the presence of inelastic demand (Duncan and Tisdell). Both countries lose from the other's research investment. Results are highly sensitive to the discount rate used. For example, using rates of five and fifteen percent, the benefit-cost ratio for Kenyan research is 45:1 and 1.5:1. Colombian "Juan Valdez" advertising succeeds in increasing price and quantity in the U.S. and Canada. In the U.S. a dollar spent produces \$2.90 of net present value. However, in Canada the return does not cover the increased cost of advertising. Interestingly, Kenya gains from U.S. advertising. This is a result of increased expenditure on coffee in aggregate from this advertising.

Optimal levels of each investment are obtained by incorporating optimal rules into the simulation model and solving. This amounts to putting equations (2) and (3) into the model displayed in Table 1. These results appear in Table 6 for the years in which data were available. Optimal levels for Kenyan research range from a high of 165 and low of 22 times current levels of research expenditure. The highest levels correspond to years when expected prices were highest, and decline after this, a function of declining prices.

Table 5. Marginal Returns to Research and Advertising.

	COLOMBIA				KENYA		
	Change in producer surplus ($US'000) ------discount rate------			Benefit-Cost Ratio	Change in producer surplus ($US'000) ------discount rate------		
Effect of a 1% increase in...	5%	10%	15%		5%	10%	15%
...Colombian Research	-3,376	-1,486	-554	-185.0	-218	-199	-127
...Kenyan Research	-474	-268	-148	24.6	310	168	99
...Colombian Advertising in U.S.	55	44	37	2.9	24	26	20
...Colombian Advertising in Canada	-30	-31	-32	0.9	-1.1	-0.9	-0.8

Note: Benefit-Cost Ratios calculated using 10 percent discount rate.

Table 6. Optimal Research and Advertising.

	Kenyan Research			Colombian Advertising in Canada			Colombian Advertising in U.S.		
Year	Actual	Optimal	Difference*	Actual	Optimal	Difference*	Actual	Optimal	Difference*
1974	23.09	2346	101.63						
1975	23.24	2278	98.05						
1976	26.00	1848	71.09						
1977	28.45	2599	91.36						
1978	31.69	1896	59.85				3.26	6.37	1.96
1979	30.74	1900	61.83				3.54	7.95	2.25
1980	24.46	2532	103.55				3.24	8.78	2.71
1981	23.06	2773	120.27				2.41	8.99	3.72
1982	24.32	1635	67.24				2.88	11.85	4.11
1983	28.34	4680	165.14				2.34	13.32	5.70
1984	35.01	2825	80.70	1.21	0.21	0.17	8.61	10.52	1.22
1985	35.88	2085	58.12	1.32	0.28	0.21	8.16	14.35	1.76
1986	49.53	1654	33.41	1.43	0.23	0.16	7.30	11.47	1.57
1987	49.09	1321	26.91	1.64	0.31	0.19	11.21	15.42	1.38
1988	55.87	1248	22.35	1.85	0.21	0.11	13.45	10.14	0.75
1989	57.16	1221	21.37	1.74	0.23	0.13	14.03	11.23	0.80
1990	56.77	2142	37.74	1.68	0.33	0.20	14.48	15.99	1.10
1991	55.89	1303	23.32	1.90	0.39	0.20	15.21	18.58	1.22
1992				1.19	0.29	0.24	16.82	14.22	0.85
1993				1.21	0.15	0.12	14.37	7.28	0.51
mean	36.5	2128	58.30	1.53	0.36	0.18	8.83	11.65	1.98

* is ratio of optimal to actual levels. Expenditures expressed in $US millions. Blanks indicate missing data.

An attempt to solve for optimality in the Colombian research case was unsuccessful — likely because the simulation model was attempting to solve for negative values of research, which cannot be logged. Colombia would benefit from increased advertising in the United States. An average of $8.8 million was spent annually on the U.S. campaign. Optimal levels averaged $11.65 million over this period. Again, Colombia appears to be overspending on the advertising directed at Canadians. An average of $1.53 million was spent annually in the decade after 1983; optimal levels averaged only $360,000 per year.

Conclusions

This study examined the returns for pursuing investment policies aimed at shifting supply and demand curves, and applied rules for optimizing such investment in the context of two coffee-producing countries. The hypothesis of coffee as a heterogeneous good by country of origin was accepted. Although it is usually modelled as a homogeneous good, this study has shown that coffees are not perfect substitutes for one another and that a large supplier like Colombia and even a small supplier like Kenya may not increase supply without lowering the export price.

The study has implications for export promotion policy in developing countries. Kenya should increase its expenditure on coffee research. While optimal levels of research indicated here are certainly beyond the financial capability of Kenya (or even that of donors), substantial gains are attainable (although they will not be immediately realized) with marginal changes in the coffee research budget. Since Kenya faces less than perfectly elastic demand, there exists the potential for gains from advertising its product. However, since the nature of such a hypothetical campaign and its own- and cross-advertising effects cannot be known a priori, this study is not able to predict returns to such investment.

The prescription for Colombia is quite different. Research investment does not appear to be profitable since it faces inelastic demand. There are positive but non-optimal returns to generic advertising in the two countries investigated. Colombia appears to be underspending on its advertising in the United States and overspending in Canada. Based on these results, the preferred strategy for Colombia appears to be investment in advertising, but not research. However, some qualifications are required with respect to this prescription. First, Colombia could choose to concentrate on research that enhances the quality of its product. If effective, this would increase the price premium paid for Colombian coffee. However, by further differentiating the product (thus decreasing the demand elasticity), the potential losses from supply-shifting policies increases. Second, a significant portion of Colombia's research effort may be devoted to risk-reducing measures such as pest control or environmental sustainability, which in the long run reduce the possibility of crop losses. It seems reasonable to believe that there are net benefits to such research as insurance against such threats to the industry. Third, both yield-increasing and cost-reducing research shift the supply curve to the right (i.e. both result in per-unit cost reduction), and there may be producer benefits involved in either strategy that this study has failed to capture. Yield-increasing research would allow a coffee farmer to reduce acreage devoted to coffee while maintaining historical yields. Land made available could then be used in other economic pursuits. Similarly, cost-reducing research could free up labor or financial resources that could be diverted to other farm enterprises. Finally, given that Colombia appears to be able to exercise market power in the international coffee market, research may be profitable in conjunction with other policy instruments available to "large" countries, such as supply controls.

This study also has implications for any firm or producer group faced with making a decision between investment in research or advertising. First, the results highlight the critical importance of examining returns to alternative activities when attempting to maximize or optimize returns. Second, advertising response must be defined across markets, and will likely mean that expenditures will be market-specific. Third, knowledge of demand elasticities is critical in undertaking an investment strategy, and therefore the assumption of homogeneous goods may well be a dangerous one. Research will not necessarily produce net benefits if demand is inelastic, and even producers with a small share of the market may be adversely affected by supply increases if their product is sufficiently differentiated.

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Appendix 1. Derivation of Optimal Research Rule

Given demand Q_d=*D(P)* and supply Q_s=*S(P,RES)*, and the opportunity to make a fixed research investment that reduces per unit costs of production, the problem for the producer in a competitive market is:

(8) $$\text{maximize } \pi = P \cdot Q - C(Q, RES) - RES$$

Substituting demand and supply into (8) gives:

(9) $$\text{maximize } \pi = P \cdot Q\,(P,\ RES) - C(Q(P, RES),\ RES) - RES$$

Differentiating with respect to research gives:

(10) $$\frac{\partial \pi}{\partial RES} = \frac{\partial P}{\partial Q} \cdot \frac{\partial Q}{\partial RES} Q + \frac{\partial Q}{\partial RES} P + \frac{\partial C}{\partial Q} \cdot \frac{\partial Q}{\partial RES} - \frac{\partial C}{\partial RES} - 1 = 0$$

With marginal cost *(MC)* equal to $\partial C/\partial Q$, factoring out $\partial Q/\partial RES$ gives:

(11) $$\frac{\partial P}{\partial Q} \cdot \frac{\partial Q}{\partial RES} Q + \frac{\partial Q}{\partial RES}\ (P - MC) - \frac{\partial Q}{\partial RES} = 1$$

In perfect competition price equals marginal cost, so (11) reduces to:

(12) $$\frac{\partial P}{\partial Q} \cdot \frac{\partial Q}{\partial RES} Q - \frac{\partial C}{\partial RES} = 1$$

Next, demand and supply equations are totaly differentiated with respect to *RES*.

(13) $$\frac{\partial Q_d}{\partial RES} = \frac{\partial D}{\partial P} \cdot \frac{\partial P}{\partial RES}$$

(14) $$\frac{\partial Q_s}{\partial RES} = \frac{\partial S}{\partial RES} + \frac{\partial S}{\partial P} \cdot \frac{\partial P}{\partial RES}$$

We now determine the effect of research on price. Since Q_d must equal Q_s in market equilibrium,

(15) $$\frac{\partial Q_d}{\partial RES} = \frac{\partial Q_s}{\partial RES}$$

(16) $$\frac{\partial D}{\partial P} \cdot \frac{\partial P}{\partial RES} = \frac{\partial S}{\partial RES} + \frac{\partial S}{\partial P} \cdot \frac{\partial P}{\partial RES}$$

(17) $$\frac{\partial P}{\partial RES} = \frac{\dfrac{\partial S}{\partial RES}}{\dfrac{\partial D}{\partial P} - \dfrac{\partial S}{\partial P}}$$

Substituting (17) into (13) gives:

(18) $$\frac{\partial Q}{\partial RES} = \frac{\dfrac{\partial S}{\partial RES} \cdot \dfrac{\partial D}{\partial P}}{\dfrac{\partial D}{\partial P} - \dfrac{\partial S}{\partial P}}$$

Multiplying both sides by *RES/Q*, we obtain:

$$\textbf{(19)}\quad \frac{\partial Q}{\partial RES}\cdot\frac{RES}{Q}=\frac{\dfrac{\partial S}{\partial RES}\cdot\dfrac{RES}{Q}\cdot\dfrac{\partial D}{\partial P}\cdot\dfrac{P}{Q}}{\dfrac{\partial D}{\partial P}\cdot\dfrac{P}{Q}-\dfrac{\partial S}{\partial P}\cdot\dfrac{P}{Q}}=\frac{\eta^{RES}_{Q,RES}\cdot\eta^{D}_{Q,P}}{\eta^{D}_{Q,P}-\eta^{S}_{Q,P}}$$

Rearranging (12) and multiplying both sides by *RES/PQ* gives:

$$\textbf{(20)}\quad \left(\frac{\partial P}{\partial Q}\cdot\frac{Q}{P}\right)\left(\frac{\partial Q}{\partial RES}\cdot\frac{RES}{P}\right)-\frac{\partial C}{\partial RES}\cdot\frac{RES}{PQ}=\frac{RES}{PQ}$$

Substituting (19) into (20),

$$\textbf{(21)}\quad \frac{\eta^{D}_{P,Q}\cdot\eta^{RES}_{Q,RES}\cdot\eta^{D}_{Q,P}}{\eta^{D}_{Q,P}-\eta^{S}_{Q,P}}-\frac{\partial C}{\partial RES}\cdot\frac{RES}{PQ}=\frac{RES}{PQ}$$

Since

$$\textbf{(22)}\quad \left(\frac{\partial P}{\partial Q}\frac{Q}{P}\right)^{-1}\cong\frac{\partial Q}{\partial P}\frac{P}{Q}$$

Equation (21) reduces to the optimal research rule:

$$\textbf{(23)}\quad \frac{\eta^{RES}_{Q,RES}}{\eta^{D}_{Q,P}-\eta^{S}_{Q,P}}-\frac{\partial C}{\partial RES}\cdot\frac{RES}{PQ}=\frac{RES}{PQ}$$

Appendix 2. Specification of the Empirical Model

The following summarizes the model in its algebraic formulation with respect to the supply, inventory demand, consumer demand, and identities. Supply and inventory demands were estimated for Kenya and Colombia (Tanzania, which produces about three percent of Colombian Milds, was omitted from the model due to data and estimation problems.) Demand equations were estimated for the United States, Germany, Canada, and Rest-of-World. Price linkage equations relate producer prices in each exporting country to border prices in each of the importing countries. For presentation clarity, variables without a "t" superscript are present period (*t-0*). The subscripts *i* and *j* represent coffee varieties (*Other Milds, Colombian Milds, Unwashed Arabicas, Robustas*). The subscripts *m* and *n* represent coffees from Colombian or Kenya. A full listing of estimated results is available from the authors.

Supply:

(24) $Q = f + g_1 \ln PP^{t-1} + g_2 \ln PP^{t-\gamma} + lQ^{t-1} + k \ln RES^{t-\lambda} + h_1 ICA$

Inventory Demands:

(25) $I = r + sI^{t-1} + tP + uQ + h_2 ICA$

Consumer Demand - 1st stage:

(26) $\ln TEXP = a + c \ln P^* + b \ln Y + d\left((1 - v_{col} w_2) \ln BADV + v_{col} w_2 \ln CADV\right) + tT + e \ln TEXP^{t-1}$

Consumer Demand - 2nd stage:

(27) $w_i = a_i + c_{ij} \ln P_j + e_{ij} \ln X_j^{t-1} + b_i \ln\left(TEXP - P^*\right) + d_{i1} \ln BADV + d_{i2} CADV + t_i T$

Consumer Demand - 3rd stage:

(28) $v_m = a_m + c_{mn} \ln P^n + e_{mn} \ln X_n^{t-1} + b_m \ln\left(t\,exp - P'\right) + d_{m1} \ln BADV + d_{m2} \ln CADV + t_m T$

Price Linkage Equations:

(29) $P = i_1 + i_2 PP$

Identities:

(30) $X = Q - I + I^{t-1} - C$

(31) $X^1 = X^{Guatemala} + X^{CostaRica} + X^{Mexico} + X^{Peru} + X^{Other1}$

(32) $X^2 = X^{col} + X^{ken}$

(33) $X^3 = X^{Brazil} + X^{Ethiopia}$

(34) $X^4 = X^{IvoryCoast} + X^{Zaire} + X^{Uganda} + X^{Indonesia} + X^{Other2}$

where...

Q	Quantity of green coffee harvested.
PP	Real producer price (green coffee equivalent).
RES	Real coffee research expenditure.

γ	Appropriate lag on producer price.
λ	Appropriate lag on research expenditure.
ICA	Dummy variable representing effects of International Coffee Agreements (1 in 1965–71 and 1982–88, 0 in other years).
I	Quantity of green coffee held as stocks by producing country.
p^*	Expenditure-weighted import price of all coffee varieties (the Stone Index).
TEXP	Total expenditure on all coffee.
Y	Real per capita disposable income.
T	A time trend variable.
BADV	Real brand advertising expenditure.
CADV	Real (Colombian) advertising expenditure.
P	Real per unit import value for green coffee.
w	Expenditure share on particular variety of coffee relative to total expenditure on coffee.
X	Export quantities of particular variety of coffee or coffee of a particular exporter using superscripts described above.
P'	Expenditure-weighted price coffee from Colombia and Kenya.
texp	Total expenditure on coffee from Colombia and Kenya.
v	Expenditure share on coffee from Colombia and Kenya relative to total expenditure from these two countries.