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An Econometric Analysis of Coca Eradication Policy in Colombia

ROCIO MORENO-SANCHEZ, DAVID S. KRAYBILL and STANLEY R. THOMPSON *
The Ohio State University, Columbus, USA

Summary. — We estimate an econometric model of coca production in Colombia. Our results indicate that coca eradication is an ineffective means of supply control as farmers compensate by cultivating the crop more extensively. The evidence further suggests that incentives to produce legal substitute crops may have greater supply-reducing potential than eradication.

Key words — war on drugs, Colombia, coca production, coca eradication, drug control policy

1. INTRODUCTION

For more than two decades, politicians, policy analysts, and journalists have focused much attention on the production of coca in South America. Coca (*erythroxylum coca*) is the main input in the manufacture of cocaine hydrochloride, an addictive, psychostimulant drug whose use is illegal today in most countries. The United States is the largest consumer of cocaine and a major source of funding for coca eradication programs in Colombia, the leading producer. These programs are controversial because of high costs, unintended environmental and health consequences, and lack of clear evidence regarding their effectiveness.

Statistical testing of the effectiveness of programs to control cocaine supply has not been conducted previously, presumably because of the shortness of the available time series on production and control activities. Sufficient data are now available on Colombian coca production to enable credible hypothesis testing regarding the effects of governmental coca supply-control programs.

2. THE POLICY SETTING

Cocaine is produced in four stages: cultivation of the coca plant and harvesting of the leaf, extraction of coca paste, transformation of the paste into cocaine base, and conversion of the base into cocaine (Riley, 1993). In the past, small-holding producers who grew coca sold the dried leaf after harvest. In recent years, some smallholders have undertaken value-added activities in which they transform their own coca leaves into coca paste.

Colombia, Peru, and Bolivia are host to more than 98% of the global land area planted in coca. In 2000, over 210,000 ha of coca were cultivated in these three countries (UNDCP, 2001). But, the coca production shares among the three countries shifted dramatically over 1986–2000. During this period, the Colombian share increased from 12% to 75%, while the shares of the other two countries decreased from 75% to 18% for Peru and from 13% to 8% for Bolivia (UNDCP, 1999, 2001). Global supply during the same period has remained almost constant with estimates of the growth ranging from −7.7% to 5.8% (UNDCP, 1999, 2001).

By 2001, an estimated 163,000 ha were planted in coca in Colombia, primarily in three departments, the largest political division in the country's system of governance (CGR, 2001). Putumayo, Guaviare, and Caqueta departments produce approximately 68% of Colombian coca leaf (DNE, 2000). These isolated

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regions of the country have long received little funding from the Colombian national government for infrastructure, technical assistance, education, and health services. As a result, the range of feasible legal economic activities is limited. In 1998, the index of poverty, measured in terms of unsatisfied basic needs (housing, health services, education, and infrastructure) for rural areas was estimated at 72% in Caqueta and 100% in Putumayo and Guaviare (DNP, 2002).

A number of reasons have been advanced for why coca acreage has increased in Colombia despite the intensification of counternarcotic policies. Cocaine traffickers appear willing to increase the farm gate price to compensate farmers for policy-induced increases in production risk. They are able to do this because, though coca is the primary ingredient in the production of cocaine, the farm gate price is a small fraction of the retail price of cocaine in the consuming countries. Doubling or tripling the farm gate price can occur with a barely perceptible influence on the retail price in North America and Europe. Other reasons for the increase in coca supply in Colombia despite supply-control policies complement this hypothesis: low national and international prices for coffee and other legal crops, rising poverty rates in rural areas of Colombia, the virtual abandonment of some regions by the national government, inequality in land distribution, and the presence of left-wing guerillas and right-wing paramilitaries. Guerrilla and paramilitary groups, which profit from the drug trade, control the main coca-producing regions, and civil unrest has undoubtedly contributed to the expansion of coca acreage in Colombia (UNDCP, 2000).

The factors promoting coca production have not been overcome effectively by the "war on drugs" waged by governments in the coca-producing and cocaine-consuming countries. During the past decade, large amounts of money have been spent on coca eradication, crop substitution, and interdiction (interception) of cocaine supply. In Colombia, the area eradicated annually increased from 459 ha in 1991 to 72,379 ha in 2001 (CGR, 2001; DNE, 2000; UNDCP, 2001). Approximately US$113 million was spent on aerial spraying of coca in Colombia during 1994–2000. In 2000, the US government approved a two-year budget of US$860 million in support of Plan Colombia, the main objective of which is to reduce drug production and trafficking. Of the US$860 million allocated to Colombia, US$642 million was designated specifically for efforts to reduce the supply of illegal crops. As a complement, US$440 million were approved for related activities in surrounding countries.

Critics of the US-sponsored Plan Colombia point out four problems with the drug control policies currently in effect in Colombia. First, they argue that the hardware, training, and technical support provided by the United States for drug-control purposes contribute to growing militarization of the Colombian state and Colombian society. In recent years, paramilitary and guerilla groups have been involved in the drug trade and have attempted to exert control in coca-producing regions. Many observers have alleged abuses by all sides in this conflict, and there is potential for weapons intended by the United States for drug control to exacerbate breaches of human rights (Wilson, 2002). Second, observers point to negative environmental consequences of aerial fumigation of coca using the herbicide, glyphostate (Forero, 2002). Cropdusters sometimes miss their target and the plume from aerial spraying can drift up to a half mile from the intended site, damaging food crops and threatening the health of local residents. In addition, environmentalists express concern that eradication efforts may lead to the displacement of coca production to tropical rainforests and to steeply sloped hillsides. Third, politicians and civic leaders in the neighboring countries of Ecuador and Venezuela express concern that the reduction of coca production in Colombia may cause production to move across the border, bringing to these countries the violence that surrounds the drug business in Colombia (The Economist, 2001). Fourth, coca production in Colombia has continued to rise despite efforts to eradicate the crop, according to statistics from the United Nations and other sources (UNDCP, 2001). Critics contend that this is evidence that eradication is a failed approach to drug control.

While the drug business has an undisputably significant impact on political and social processes in Colombia, there is a great deal of misunderstanding about the relative importance of drugs in the Colombian economy. Contrary to the widespread belief that the economy depends largely on the illegal drug trade, Steiner (1998) showed that drug revenues represent a small percentage of national income. Using official data and his own computations, he found that income from the drug trade represents approximately 3% of Colombia's gross domestic product (GDP) and 25% of its exports.

3. PREVIOUS RESEARCH

The body of economic research examining the market for illegal drugs is small. Demand studies have focused on factors affecting the consumption of illegal drugs by various population groups, the impact of consumption on worker performance, the effect of illegal drug use on labor market outcomes, substitution or complementarity among various illegal drugs, consumer expenditures on illegal drugs, the effect of drug-control spending on illegal drug use, and the effects of decriminalization of illegal-drug possession on prices and consumption (Chaloupka, Grossman, & Tauras, 1998; Desimone, 1998; Grossman & Chaloupka, 1998; MacDonald & Pudney, 2000; Saffer & Chaloupka, 1998).

Most of the supply studies of illegal drugs focus on the effectiveness of drug control policies. Fowler (1990) analyzed the effects of drug interdiction expenditures on illegal drug use. Gibson and Godoy (1993) analyzed alternatives to coca production in Bolivia using a computable general equilibrium model of the national economy. Riley (1993) assessed the impact of eradication, interdiction, and economic development strategies in Bolivia, Colombia, and Peru using a dynamic economic model of the cocaine industry and source-country drug-control policies. He concluded that these policies could disrupt production for only short periods. Whynes (1991) used a simple game-theoretic approach to examine the feasibility of various supply-side policy options including taxation of coca production, crop substitution, eradication, and purchase of production by the government. He concluded that supply policies are ineffective as a means of drug control.

Kennedy, Reuter, and Riley (1993), using a model of cocaine production in Bolivia, Colombia, and Peru, analyzed the determinants of the volume of cocaine trade, and simulated the effects of crop substitution, eradication, and other policies on cocaine production. One of the main conclusions was that strategies that seize and destroy even as much as 70% of cocaine production will have little impact on the market if cocaine traffickers can increase gross production to compensate for some percentage of the product being destroyed. The reason is that the increased cost of the higher gross production is low relative to the retail price of cocaine. They also conclude that crop substitution has a negligible impact on the world cocaine market because traffickers can easily offer producers financial incentives that exceed the producer profit from most crop substitution programs.

Rydell and Everingham (1994) examined the cost-effectiveness of both supply and demand control programs including source-country control, interdiction, domestic enforcement, and treatment of heavy users. They concluded that cutting back on supply control and expanding treatment of heavy users would make cocaine control policy more cost-effective.

Other studies have sought to identify specific economic, political, and social conditions that contribute to the emergence of illegal drug production. Morrison (1997) concludes that contributing factors include isolation, economic insecurity in rural areas, and lack of enforcement caused by corruption or insurgency. It is clear that these conditions are prevalent in Colombian coca-producing regions.

Focusing on Colombia, Uribe (2000) estimated the profitability of coca production for peasants in the three largest coca-producing departments. He found that the net income of peasant producers of coca ranged from $US1,629 to $3,895 per year when the cost of family labor is not counted. If family labor is valued at local wage rates, net income is lower and can even be negative depending on the region, ranging from—US$1,485.91 to US$1,792.06.

Based on the existing literature, there is little reason to believe that supply control measures have been effective in reducing the production or trafficking of illegal drugs. No single drug policy instrument appears capable of permanently reducing output due to inherent characteristics of the cocaine industry: the availability of low-cost land and labor, the dearth of alternative income-generating opportunities in politically unstable regions, and the ease of transporting the low-bulk and low-weight final product.

4. ANALYSIS OF COCA CULTIVATION

Most previous studies on the effectiveness of drug supply-control policies have used non-stochastic methods, such as market simulation models. Deterministic methods have been used in these studies primarily because the relatively small number of observations available on drug crop production limit the degrees of freedom available for econometric analysis. Crop estimates are available on only an annual basis. The number of observations increases, however, with each passing year. In this study, we utilize UN data on annual coca cultivation in Colombia over a 14-year period to estimate an econometric model of Colombian coca cultivation. We confront the problem inherent in small-sample econometric analysis by utilizing influence diagnostics (Belsley, Kuh, & Welsch, 1980) to determine the extent to which parameter estimates from our model are influenced by individual observations.

(a) *Data*

Due to the illegality of coca, available data on this crop are scarce. Colombian and international organizations did not collect data on coca production until the mid-1980s.

For our analysis, we obtained data on coca (area cultivated, area eradicated, and prices) from published reports of United Nations Office for Drug Control and Crime Prevention (UNDCP) and from the Colombian narcotics-control agency (Direccion Nacional de Estupefacientes). UNDCP reports are based on annual questionnaires completed by government agencies in the producer countries. Plantain price data were obtained from the Ministry of Agriculture of Colombia and the Food and Agriculture Organization of the United Nations (FAO). Summary statistics on the variables used in this study are presented in Table 1.

(b) *Basic model*

The decision to plant coca is assumed to be influenced by coca prices and alternative production opportunities in a manner similar to decisions regarding other farming activities. The area planted in coca is also assumed to respond to coca eradication policies in Colombia and to the area planted in other major coca-producing countries. Since coca is a perennial crop, we posit that the area planted responds to production conditions in the previous year.

Based on these assumptions, we specify the following econometric model of coca cultivation:

$$H_t = \beta_0 + \beta_1 P_{t-1} + \beta_2 PP_{t-1} + \beta_3 E_{t-1} + \beta_4 O_{t-1} + \varepsilon_t$$

where H is the number of hectares of coca under cultivation in Colombia, P is the farm-gate price of coca, PP is the farm-gate price of plantain, E is the number of hectares of coca eradicated in Colombia, and O is the number of hectares of coca under cultivation in Bolivia and Peru. The error term is assumed to be normally distributed with zero mean and constant variance; that is, $\varepsilon \sim N(0, \sigma^2)$. The subscript t refers to the current year while $t-1$ refers to the previous year. The model was estimated using ordinary least squares (OLS).

It is assumed that coca farmers attempt to maximize profits, subject to various constraints. Own price of coca is hypothesized to have a positive effect on area planted in coca, while the price of plantain, a major crop substitute, is expected to be negatively related to the number of hectares planted in coca. Coca eradication policy, measured in this study as eradicated hectares of coca, increases the production risk faced by farmers. Given the limited alternative economic opportunities in Colombia's coca-growing regions, it is expected that farmers respond to this increased risk by planting additional hectares of coca. Therefore, we hypothesize a positive relationship between cultivated area and eradicated area. Finally, the area planted in coca in other producing countries is hypothesized to be inversely related to the area cultivated in Colombia, as traffickers

Table 1. *Variable definitions and summary statistics (1987–2001)*[a]

Variable	Definition	Mean	Median	Maximum	Minimum	Standard deviation
H	Cultivated area in Colombia (ha)	70,969	47,800	160,000	34,000	42,379
P	Farm-gate coca base price in Colombia[b]	898	832	1,721	591	320
E	Eradicated area in Colombia (ha)	19,538	2,925	65,755	230	24,610
PP	Farm-gate price of plantain in Colombia[b]	751	745	968	473	143
O	Cultivated area in Peru and Bolivia (ha)	141,114	158,000	196,300	48,800	45,265

[a] Sample period for *H*: 1988–2001. Sample period for *P*, *E*, *PP* and *O*: 1987–2000.
[b] Prices are in US dollars, base year 2000.

are assumed to quickly seek out new geographic sources of supply when production is reduced in old production areas.

(c) *Model one*

As shown in Table 2, all variables in the coca cultivation model are significant at the 5% level, and the model explains a high proportion of the total variation in Colombian coca cultivation. All parameters have the expected signs. Consistent with our hypotheses, eradication appears to increase rather than reduce hectares planted in coca, and cutbacks in coca production in Bolivia and Peru result in the planting of more hectares of coca in Colombia.

The estimated parameters were used to compute elasticities at mean values of the variables. Coca cultivation is inelastic to own price (0.144), as shown in Table 5. Low area-planted responsiveness to price could be due to the fact that coca is a perennial crop. Once it is planted, the coca bush continues to produce foliage each year with a minimum of maintenance, thus muting the responsiveness of production to price changes. The control that guerilla groups and paramilitaries exert over production and marketing decisions in coca-producing areas in Colombia probably further diminishes the effect of the farm gate price on coca cultivation.

The elasticity of coca cultivation with respect to hectares eradicated in Colombia indicates that producers increase the area cultivated in response to eradication efforts but less than proportionately (0.204). Since coca is generally somewhat more profitable than other crops, producers apparently respond to the production risk imposed through supply control policies by increasing the area planted. Eradication seems to have an effect opposite to the one intended by policymakers.

The crossprice elasticity (−0.345) indicates that coca cultivation decreases in response to increases in plantain price although less than proportionately. The area cultivated in Colombia is elastic (−1.013) with respect to the area cultivated in Bolivia and Peru. This elasticity is not statistically different from 1.0. Changes in the area cultivated in the other major producing countries, whether due to eradication efforts or other factors in those countries, appear to be exactly offset by changes in the area cultivated in Colombia. This result is consistent with the argument of Youngers (2000) and others that coca eradication in the Andean region, while successful in reducing production in the Bolivia and Peru, has not reduced the total supply from the region.

(d) *Model two*

Because the coca bush is typically maintained over a number of years, we estimated an alternative model with a lagged dependent variable to account for plant-stock carryover. Regression results are presented in Table 3. All signs remain the same as in model 1, and all parameter estimates are significant at the 10% level with the exception of area cultivated in Bolivia and Peru. Thus, when the perennial nature of the coca plant is taken into account, the conclusion that eradication is ineffective remains valid.

Long-run elasticities, whose calculation is made possible by lagging the dependent variable, are presented in Table 5. For three of the four independent variables, the short-run elasticities from model 1 lie between the short-run and long-run elasticities of model 2.

Table 2. *Coca cultivation in Colombia, 1988–2001; model with lagged independent variables but no lagged dependent variable*

Variable	Coefficient	Standard error	t-Statistic	Probability
Intercept	142560.2***	13054.9	10.9	0.00
$P(-1)$	11.403**	4.8	2.4	0.04
$E(-1)$	0.742***	0.121	6.2	0.00
$PP(-1)$	−32.6**	12.3	−2.6	0.03
$O(-1)$	−0.509***	0.067	−7.6	0.00
R-squared		0.992		
Adjusted R-squared		0.988		
F-statistic		268.3		
Durbin–Watson statistic		2.2		

** Significant at the 5% level.
*** Significant at the 1% level.

Table 3. *Coca cultivation in Colombia, 1988–2001; model with lagged dependent and independent variables*

Variable	Coefficient	Standard error	t-Statistic	Probability
Intercept	49565.8	32562.6	1.5	0.17
$P(-1)$	10.4**	3.5	3.0	0.02
$E(-1)$	0.577***	0.104	5.6	0.00
$PP(-1)$	−19.9*	10.0	−2.0	0.08
$O(-1)$	−0.148	0.131	−1.1	0.29
$H(-1)$	0.597**	0.200	3.0	0.02
R-squared		0.996		
Adjusted R-squared		0.994		
F-statistic		405.2		
Durbin-h statistic		1.9		

* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

(e) *Model three*

The data on hectares of coca eradicated exhibit a sharp increase in 1998 (see Figure 1). We therefore added a dummy variable included to determine the extent to which this one-year spike in eradication affects the parameter estimates. As show in Table 4, the estimated parameter of the dummy variable is statistically significant at the 1% level. The parameters of the other variables are all significant and the signs remain consistent with our hypotheses. Elasticities for model 3 are presented in Table 5.

(f) *Serial correlation and heteroskedasticity diagnostics*

Serial correlation, a common problem in the analysis of time-series data, would invalidate the assumptions of the classical linear regression model and make OLS estimates inefficient. We analyzed the residuals of the estimated models to detect the possible presence of serial correlation. Given the error process

$$\varepsilon_t = \rho\varepsilon_{t-1} + \mu_t \quad (t = 1, 2, \ldots),$$

we tested the null hypothesis, $H_0 : \rho = 0$. The Durbin–Watson test, which is appropriate when there is no lagged dependent variable, was used for models 1 and 3. The Durbin-h test, appropriate when there is a lagged dependent, was used for model 2. The test statistics are reported in Tables 2–4. The null hypothesis of zero autocorrelation was not rejected at the 10% level for all three models. In addition, we conducted heteroskedasticity tests developed by White and by Goldfeld and Quandt and rejected the hypothesis of a nonconstant model variance.

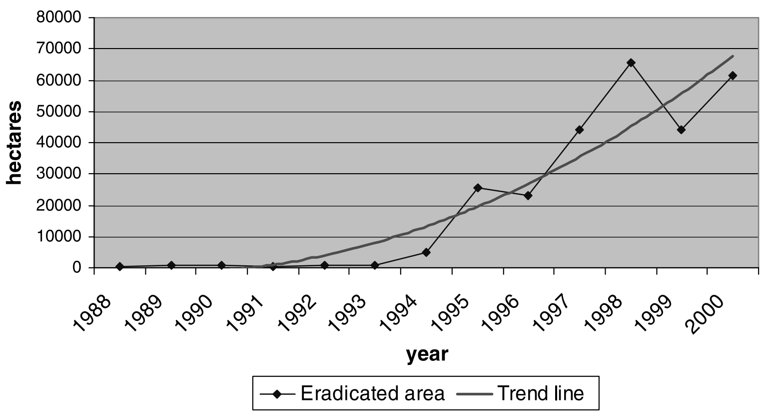

Figure 1. *Hectares of coca eradicated in Colombia, 1988–2001.*

Table 4. *Coca cultivation in Colombia, 1988–2001; model with dummy variable, lagged independent variables but no lagged dependent variable*

Variable	Coefficient	Standard error	t-Statistic	Probability
Intercept	123312.0***	10508.0	11.7	0.00
$P(-1)$	8.7**	3.3	2.6	0.03
$E(-1)$	0.964***	0.105	9.2	0.00
$PP(-1)$	−18.8*	9.3	−2.0	0.08
$O(-1)$	−0.452***	0.049	−9.3	0.00
Dummy	−16181.0***	4757.6	−3.4	0.01
R-squared		0.997		
Adjusted R-squared		0.994		
F-statistic		468.9		
Durbin–Watson statistic		2.2		

* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

Table 5. *Elasticities of area planted in coca for models 1, 2, and 3*

Variable	Model 1	Model 2[a]		Model 3
		Short run	Long run	
P	0.144	0.132	0.328	0.111
E	0.204	0.159	0.395	0.265
PP	−0.345	−0.210	−0.523	−0.198
O	−1.013	−0.294	−0.729	−0.899

[a] Both short-run and long-run elasticities are calculated for model 2, which includes the lagged-dependent variable on the right-hand side of the regression equation.

(g) *Sample-size diagnostics*

Given the limited number of available observations, we utilized an influence diagnostic test to determine the relative effects of each observation on the estimated parameters of the model (Belsley *et al.*, 1980). The DFBETA statistic indicates whether the change in the jth parameter as a consequence of dropping the observation for the ith year is significant (see Appendix A for definition). The hypothesis associated with this test is

$$H_0 : \beta_j^i = \hat{\beta}_j$$
$$H_1 : \beta_j^i \neq \hat{\beta}_j$$

where $\hat{\beta}_j$ is the jth estimated parameter when the whole sample is used, and β_j^i is the jth estimated parameter when the ith observation is dropped. The estimated DFBETA statistic indicates that none of the parameters changes significantly when each observation is dropped one at a time; the exception is the parameter for eradicated area, which changes when the 1999 observation is dropped (see Appendix A). Though the magnitude of the effect of eradicated area on cultivated area changes when this year is omitted, the parameter is still statistically significant and the sign remains positive.

In summary, the null hypothesis that the regression coefficients are not sensitive to individual observations is rejected for only one of the estimated betas and for one observation. Since the sensitivity in that one case is small and does not affect the sign of the coefficient, we conclude that our findings regarding the determinants of coca cultivation in Colombia are not unduly influenced by the size of the sample.

5. POLICY IMPLICATIONS AND CONCLUSIONS

Our analysis indicates that the coca eradication policy of the Government of Colombia has not achieved its objective of reducing coca cultivation. Rather, cultivated area has increased as eradication efforts have intensified. Farmers appear to compensate for eradication by cultivating the crop more extensively. This conclusion is robust across the three econometric model specifications used in this paper.

Colombian coca cultivation is positively related to the price of coca in all model specifications. Colombian coca farmers respond to the price of coca just as they would be expected to respond to the price of any crop: when the price rises, if all else is constant, cultivated area increases; when the price falls, cultivated area decreases. But, the price elasticity of coca cultivation is relatively small, implying that policies that affect the price received by coca farmers may have relatively little impact on production.

The finding, based on results of all three models, that the price of a key alternative crop, plantain, is negatively related to coca production suggests that the Colombia government could achieve its narcotic-control objectives more effectively by focusing on policies that increase farmers' net return from producing legal crops. Such policies might include assignment of secure property rights for land, provision of technical assistance and credit, mechanisms to improve marketing conditions for agricultural products, and infrastructure investments. Direct subsidies or lump sum transfers to farmers shifting from coca to other crops should be considered. However, public or private investments in rural areas may not be feasible as long as the civil war in Colombia continues. While crop substitution programs in other countries have not proven to be a panacea as long as adverse socioeconomic and political conditions persist, our analysis suggests that crop substitution is nevertheless more likely to be effective than eradication.

Results from two of the three models support the hypothesis that cutbacks in coca hectares in other Latin American countries have been offset by an increase in coca hectares in Colombia. Our finding of a unitary elasticity of Colombian coca hectares with respect to Bolivian and Peruvian coca suggests that production has moved from one location to another with little change in total regional production. Thus, policies that appear effective at the country level may be ineffective at the regional level. Effective drug supply reduction requires regional coordination among multiple governments and a better understanding of the economic and political conditions that promote drug cultivation.

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APPENDIX A

DFBETA test statistic[a]

Year	Constant	Coca farmgate price	Eradicated area	Plantain price	Area cultivated in Peru and Bolivia
1988	−1.0367	1.4293	0.6696	−0.1403	0.8283
1989	−0.0197	0.0149	0.0967	−0.1230	0.1026
1990	−0.0105	−0.1418	−0.0801	0.1692	−0.0359
1991	0.0086	−0.4692	−0.1469	0.4138	−0.1296
1992	−0.2341	0.2170	0.1978	0.0901	0.0481
1993	0.0723	−0.1392	−0.0560	−0.0210	0.0171
1994	−0.4382	0.0368	0.4366	0.1546	0.2753
1995	−0.0168	−0.3367	0.1211	0.0230	0.0891
1996	−0.2417	−0.1032	0.4615	−0.2636	0.5611
1997	−0.1417	−0.2020	−0.0658	0.4797	−0.1901
1998	−0.0499	−0.0293	0.0652	0.0438	0.0307
1999	2.1740	0.8251	−2.7217*	−1.6503	−1.2511
2000	0.1102	0.0257	−0.0809	−0.0243	−0.1114
2001	0.6329	0.2161	−0.1701	−0.1260	−0.7154

* Indicates significance at 5% level.

[a] $\text{DFBETA}_j^i = \hat{\beta}_j - \beta_j^i = \frac{(X^{\mathrm{T}}X)^{-1}x_i^{\mathrm{T}}\varepsilon_i}{1-h_i}$, where $h_i = (X^{\mathrm{T}}X)^{-1}x_i^{\mathrm{T}}$; X is a matrix; x_i is a row vector.