The Effect of Government Policy on Flue-Cured Tobacco Yields

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and

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Abstract

Statistical analysis using rainfall and time trends accounts for county average flue-cured tobacco yields in North Carolina from 1940 to 1987. A change in the annual yield growth path occurred in 1965. The data are consistent with the hypothesis that the switch from acreage allotments to poundage quotas for flue-cured tobacco beginning in 1965 caused a decline in both yield levels and rates of annual yield increase. Both declines are fully consistent with changed relevant incentives facing growers and researchers.

Key words: *Nicotiana tabacum* L., Technical change, Tobacco policy, Average annual yield increase

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INTRODUCTION

Between 1940 and 1987 North Carolina average per-hectare yields of flue-cured tobacco (*Nicotiana tabacum* L.) grew at an average rate of 1.9 percent per year (Figure 1). Percentage changes in yields were markedly higher through 1964 (averaging a gain of 3.8 percent per year) relative to the rates of increase after 1964 (0.8 percent). By contrast, the yields of other North Carolina commodities, for example, that of corn (Figure 1) did not exhibit this distinct decline. One possible explanation for the decline in tobacco yield increase lies in the economic response to a change in government policy, specifically the change from acreage allotments to poundage controls in 1965. An alternative explanation for the decline is a natural slowdown in the development and adoption of new yield-increasing technical advances, which occurred independently of the program change. In addition, yield increases may have been further slowed by the introduction in 1964 of the Minimum Standards Program for new varieties of flue-cured tobacco (1). Identifying the underlying process causing changes in the rate at which annual yields grow is important for the accurate prediction both of future growth and of production levels given changes in federal tobacco policy.

This paper uses statistical methods to test which explanation is consistent with historical county-level yield data. The data support the hypothesis that the switch from acreage allotments to poundage quotas for flue-cured tobacco beginning in 1965 caused a decline in both yield levels and the rate of increase of annual yields over time. Both declines are fully consistent with changed economic incentives facing growers and researchers.

MATERIALS & METHODS

Economic Reasoning

The federal tobacco program has undergone many changes since 1940, as concisely described in Grise and Griffin (4). This paper concentrates on one specific change. Prior to 1965, the federal tobacco program controlled market supplies by restricting the amount of land planted to tobacco both nationally and within individual counties. Growers could alter the scale of their tobacco enterprises by buying, leasing, and selling acreage allotments. Prior to 1962, the acreage allotments were attached to particular farms, making the transfer of allotments equivalent to the transfer of property. In 1965, the program adopted the present system of direct supply control (through poundage quotas) that restricts the amount of marketings both nationally and by producers within a county. Since the program change, growers have been able to alter the scale of their enterprises by buying, leasing, or selling pounds of quota, in addition to acreage. After 1985, the quotas have been attached to particular farms. This describes the essential elements of the policy change that affected annual yields.

Restricting the total amount of land available for production would increase the per-unit cost of land relative to the per-unit cost of other inputs. A higher price for tobacco land would give growers the incentive to increase production by using land more intensively by applying greater amounts of non-land inputs per hectare, thus increasing yields. Growers could increase yields through either the adoption of new technologies or the greater application of existing inputs, such as fertilizer, labor, pesticides, and machinery. Moving from restrictions on total land use to restrictions on the total amount of tobacco that can be sold would reduce the price of land relative to non-land inputs. The altered incentives facing growers would induce greater use of land and less of non-land resources. Furthermore, tobacco researchers and plant breeders would respond to the decreased demand for yield-increasing technical advances and would give relatively greater attention to leaf quality and disease resistance (1).

An alternative explanation for the decline in the growth rates of annual yield is that the potential gains from the continued adoption of previous major innovations were exhausted, and that no new major advances came on line. Traditionally, one represents increases in annual per-hectare yield, in response to the introduction of a technical advance, as following an S-shaped adoption curve (2, 3, 6). Diffusion of the advance across producers (and thus the increase in yields) first begins slowly, then proceeds rapidly, and finally slows as the advance reaches all potential adopters. At any point in time, minor technical innovations may shift the diffusion curve upward, but without continued major advances, one expects to observe declining growth rates in aggregate yields as diffusion slows. The exhaustion of previous innovations in tobacco production and a slowdown in the rate of discovery of new innovations would lead to a decline in the rate of increase in yields.

If growers (and others) did respond to the change in the tobacco program, one would expect to see a discrete change in the path of yields beginning in 1965. This discrete change would comprise two components and two corresponding testable hypotheses. First, less incentive to generate and adopt yield-increasing innovations would lead to a kinked flattening in the upward path of expected yields over time. Second, growers would substitute land for non-land inputs, and this would lead to an observed drop in the level of tobacco yields in 1965 (accounting for random effects, such as weather). If growers did not respond to the change in the tobacco program, then expected rates of annual yield increase would follow a smooth time path.

Methodology

We first present a general model of yield change, then turn to a discussion of the data used to test the competing hypotheses. A time index, t, represents the influence of innovation and adoption on the increase in yields, and appropriate restrictions on estimated coefficients associated with time serve to represent various hypotheses regarding technical change. A sufficiently flexible function of time, G(t), allows for the possibility of a stable regime of technical change with varying rates of yield increase throughout the period of estimation. The statistical test for a non-stable regime of technical change, implying an economic response to the altered tobacco policy, against the null hypothesis of a stable regime, is a test of whether the estimated coefficients defining G(t) are equal before and after the implementation of poundage quotas.

Consider the following algebraic representation of county-level flue-cured tobacco yields,

$$Y_{tc} = \alpha_c + \beta \cdot W_{tc} + G(t) + u_{tc} \qquad [1]$$

where Y_{tc} represents a given county's average yield in time t; α_c a county-specific shifter, invariant of time; W_{tc} county-specific weather variables; G(t) technical change as a function of time; and u_{tc} a county-specific, mean-zero error term accounting for unmodeled effects. Initially, for flexibility take G(t) to be a fourth degree polynomial in time (t = 1 at 1940): $G(t) = a \cdot t + b \cdot t^2 + c \cdot t^3 + d \cdot t^4$. Under the null hypothesis of no structural shift in utilized tobacco technology in 1965, all of the estimated coefficients associated with G(t) would remain constant over the sample period.

We chose county-level data as the most appropriate available. State-level data limits the number of observations and the ability to account for variations in growing conditions across regions, such as weather and soil types. Data generated on experimental plots are inappropriate for testing changes in growers' decisions because of the likely divergence of researchers' and growers' production objectives. County-level average yields and rainfall data were obtained for five counties representing the three different growing belts in North Carolina. The yield data (Table 1) were obtained from the North Carolina Department of Agriculture (7). The inclusion of relevant weather variables in the regression increases the efficiency with which one estimates the technology parameters of the yield equation. The present analysis uses county-specific monthly rainfall levels in May, June, and July (Table 2). The yield equation allows a response to rainfall at a decreasing rate. A quadratic function adequately represents this relationship. Data were obtained from North Carolina's Hydrologic Information Storage and Retrieval System for the weather stations in Raleigh (NCSU), Fayetteville, Lumberton (6 NW), Smithfield, and Greensboro (WSO AP),

One yield equation of the form given by expression [1] exists for each of the five counties. We restrict the parameters associated with weather and technical change to be the same for all counties. An intercept shifter, α_c, incorporates county-specific differences in average yields. To account for possible contemporaneous correlations between the error terms u_{tc}, parameter estimation requires the use of seemingly unrelated regression (SUR) (5, pp.466-80). To test a hypothesis regarding a restriction on the parameters of G(t) requires two regressions: one imposing the null hypothesis of a set of restrictions, the other not imposing the restrictions. A χ^2 statistic, which equals twice the difference between the log-likelihood values from the SURs of the unrestricted and restricted models, provides a test of the null hypothesis (5, p.216). The degrees of freedom of the χ^2 test equals the number of restrictions under the null hypothesis.

RESULTS

Allowing the coefficients of G(t) and the intercept term to change in 1965 provides a test of whether there is a discernable shift in the technology regime (5, pp. 800-06). We accomplish this by defining a dummy variable, D_t, which equals zero prior to 1965 and unity for years 1965 to 1987. The function G(t) is given by

$$G(t) = K \cdot D_t + (a + a' \cdot D_t) \cdot t + (b + b' \cdot D_t) \cdot t^2 + (c + c' \cdot D_t) \cdot t^3 + (d + d' \cdot D_t) \cdot t^4 \quad [2]$$

The parameter K represents a common shift in the intercept for each county equation. Under the null hypothesis of no change in technological regime -- i.e., that the observed slowdown in annual yield increases is consistent with a stable technology regime -- all the coefficients associated with the dummy variable in expression [2] (K, a', b', c', and d') equal zero. This is the *restricted* model. The parameter estimates and associated statistics from this regression are given in the second column of Table 3. The alternative hypothesis that allows for a technical regime change in 1965 yields the parameter estimates in column one of Table 3. This is the *unrestricted* model. The estimated coefficients on the rainfall variables are of expected signs and of reasonable magnitudes. From the unrestricted regression estimates in column one of Table 3, additional rainfall decreases yields for rainfall amounts beyond 94.6 mm for May, 97.4 mm for June, and 203.4 mm for July.

Statewide predicted yields over the sample from the two regressions are found by replacing the rainfall variables by their means in each county and averaging the county-level predictions. The two series of predicted yields as well as actual yields for the five-county averages are shown in Figure 2. The log-likelihood values for the regressions are given at the bottom of each column in Table 3. The calculated χ^2 test statistic for testing the null hypothesis of no regime change is 29.3 which is well beyond the 0.01 critical value of 15.09 with five degrees of freedom. Therefore, we reject the null hypothesis of no response to the change in the tobacco program.

One may more accurately characterize the nature of the structural change by testing various restrictions on the path of annual yield increase after 1964. There are three more specific hypotheses regarding the change in yield trends: 1) that growers continued using the same 1964 technology base and resource levels, with only the adoption rate of new technologies changing, that is, there was no immediate effect on per-hectare input use; 2) growers immediately altered their per-hectare use of inputs, but the development and incorporation of yield-increasing innovations did not change; and 3) that growers immediately altered their production practices, specifically substituting land for non-land inputs, and that the adoption of yield-increasing innovations was slowed.

If the first hypothesis is correct, then the post-1964 trend curve would pass through the expected 1964 yield level (where $t = 25$). This hypothesis can be tested by restricting the parameters associated with the dummy variables in equation [2] in the following manner:

$$K + a' \cdot 25 + b' \cdot 25^2 + c' \cdot 25^3 + d' \cdot 25^4 = 0 \ .$$

This hypothesis implies no restrictions regarding the rate of annual yield increase after 1964. The calculated χ^2 statistic for testing this structure is 15.54, which is well beyond the 0.01 critical value of 6.64 with one degree of freedom. The rejection of this hypothesis regarding technical change is evidence that yield levels fell due to the program change.

If the second hypothesis is correct, then the post-1964 trend curve would be identical to the preceding trend curve except for an intercept shift. This hypothesis can be tested by restricting the parameters associated with dummy variables in equation [2] in the following manner:

$$a' = b' = c' = d' = 0 \ .$$

This hypothesis implies no restrictions regarding the level of expected yields in 1965. The calculated χ^2 statistic for testing this structure is 15.8, which is beyond the 0.01 critical level of 13.28 with four degrees of freedom. The rejection of both of these first two hypotheses is evidence supporting the third, that both annual yield levels and rates of increase declined after the implementation of poundage controls in 1965.

Although a fourth-degree polynomial provides flexibility in describing historical yield trends, it may be an inappropriate model to predict the future time path of yield increases based on the data after 1964. A polynomial of a high degree may overfit the data in the sense that it offers no statistically significant improvement over a polynomial of lower degree in describing historical trends. The danger of overfitting the data is, that if the trend is actually a function of time of a lower-degree, then out-of-sample predictions of yields based on a higher-degree polynomial may be highly inaccurate. For example, from inspection of Figure 2, it is unlikely that there is a long-term downward trend in yields beginning in 1984 as is implied by the unrestricted (regime-change) model. It is likely that the apparent downturn during this period is due to random effects.

A more parsimonious model is that expected yields grew quadratically until 1964 and linearly afterwards. The restrictions imposed by this hypothesis are $(c = c' = d = d' = 0)$, and $(b + b' = 0)$. Parameter estimates from the regression imposing these five restrictions are presented in column three of Table 3. In this case, one cannot reject this hypothesis against the alternative hypothesis of the unrestricted fourth degree polynomial model. The calculated χ^2 statistic associated with this restricted model is 6.36, which is well below the 0.05 critical value of 11.07 with five degrees of freedom. Figure 3 presents actual and expected yields for this final model of technical regime change.

DISCUSSION

The statistical evidence supports the hypothesis that the change to poundage quotas in 1965 altered the adoption of yield-increasing technical advances, and in particular that the rate of yield increase slowed due to the change. Prior to the program change expected yields grew at an increasing rate; after the change, yields grew linearly over time. Furthermore, the evidence also implies that in the first year of its introduction the poundage quota program decreased yield levels.

There are two related influences explaining the decline in rates of increase in annual yields after 1965: that growers had less incentive to adopt yield-increasing technologies after 1964, and that fewer yield-increasing innovations were available from plant breeding and other research activities.

The second influence is also consistent with the adoption in 1964 of the Minimum Standards Program (MSP) for new varieties of flue-cured tobacco (1). The MSP, however, does not explain the immediate decline in 1965 in rates of annual yield increase, because of inherent time lags in the adoption of innovations. The MSP could have contributed to the decline in the rate of yield increases, but the results here demonstrating a sudden decline in yields in 1965 indicate that producers altered their production methods immediately in response to altered incentives. Future research will seek to determine the effect of the MSP and changes in federal policy on the production of new variety characteristics.

This analysis has two broad implications. First, analyses that seek to anticipate future yield increases should also anticipate the policy environment in which those increases will take place. Second, there appears to be a large potential for an increase in yields if and when such increases become profitable.

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Table 1. County-level per-hectare yields (kg/ha)

	Yields (kg/ha)				
Year	Wake	Cumberland	Robeson	Johnston	Guilford
1940	1135.392	940.3687	1265.407	1285.582	1054.692
1941	960.5435	847.3406	1180.224	1012.101	1005.376
1942	1179.104	1175.741	1395.422	1193.674	1055.813
1943	904.5025	907.8649	1060.297	914.5898	1021.068
1944	1176.862	1067.021	1375.247	1299.031	1192.553
1945	1238.507	1165.654	1229.541	1302.394	1281.098
1946	1292.306	1188.070	1344.985	1405.509	1292.306
1947	1295.669	1140.996	1299.031	1416.718	1102.888
1948	1385.335	1220.574	1509.746	1492.933	1293.427
1949	1208.245	1232.903	1492.933	1459.309	1155.566
1950	1506.383	1347.227	1569.149	1682.352	1426.805
1951	1483.967	1365.160	1606.136	1656.573	1191.433
1952	1329.294	1228.420	1517.591	1448.101	1171.258
1953	1231.782	1444.738	1603.895	1514.229	1080.471
1954	1231.782	1395.422	1479.484	1503.021	1307.998
1955	1429.047	1738.393	1854.959	1764.172	1497.417
1956	1886.342	1719.339	1941.262	1930.054	1692.440
1957	1464.913	1687.956	1821.334	1705.889	1547.854
1958	1813.488	1843.750	1949.108	2044.377	1696.923
1959	1575.874	1590.445	2011.873	1634.157	1570.270
1960	2017.478	1899.791	2241.642	2258.454	1838.146
1961	2070.156	2064.552	2273.025	2301.045	1826.938
1962	2214.742	2233.796	2519.605	2308.891	1889.704
1963	2092.573	2205.776	2379.503	2312.253	1999.544
1964	2573.405	2390.711	2586.855	2613.754	2419.852
1965	1960.316	1842.630	2257.333	2085.848	1876.254
1966	2095.935	1995.061	1922.208	2247.246	1810.126
1967	2028.686	2135.164	2505.035	2419.852	2159.822
1968	1972.645	2034.290	2202.413	2185.601	1810.126
1969	2039.894	1854.959	2039.894	2241.642	1955.832
1970	2303.287	2258.454	2381.744	2493.826	1995.061
1971	2364.932	2409.765	2488.222	2505.035	2123.956
1972	2308.891	2376.140	2398.557	2336.912	1882.979
1973	2275.266	2364.932	2477.014	2561.076	2079.123
1974	2174.393	2208.017	2297.683	2381.744	1860.563
1975	2112.747	2269.662	2432.181	2605.909	1647.607
1976	2123.956	2432.181	2437.785	2314.495	1950.228
1977	2112.747	2067.915	2123.956	2247.246	1961.437
1978	2325.703	2179.997	2432.181	2364.932	2123.956
1979	2101.539	2364.932	2505.035	2140.768	1950.228
1980	2280.871	2303.287	2325.703	2482.618	1860.563
1981	2381.744	2409.765	2521.847	2460.202	2364.932
1982	2297.683	2465.806	2477.014	2482.618	2179.997
1983	2219.225	2342.516	2308.891	2342.516	2202.413
1984	2488.222	2477.014	2404.161	2538.659	2387.348
1985	2594.700	2432.181	2448.994	2706.782	2482.618
1986	2376.140	2320.099	2264.058	2376.140	2505.035
1987	2297.683	2465.806	2269.662	2477.014	2208.017

Table 2. Monthly rainfall (cm) by county

	Wake			Cumberland			Robeson			Johnston			Guilford		
Year	M	JN	JY	M	JY	JL	M	JN	JY	M	JN	JY	M	JN	JY
1940	8.9	4.6	6.4	9.1	8.9	8.9	7.6	4.9	11.0	6.6	9.6	11.3	15.2	7.6	15.4
1941	5.3	8.6	27.6	2.2	18.2	18.7	3.2	18.6	22.6	2.1	17.0	23.0	3.6	13.3	11.7
1942	8.5	11.0	8.0	7.1	11.7	11.6	7.9	12.4	13.0	8.9	11.2	11.2	12.0	10.7	10.8
1943	4.7	22.2	16.4	7.2	7.6	33.9	8.1	18.7	24.5	8.2	23.6	2.5	7.3	14.5	11.2
1944	3.9	4.2	13.5	9.9	3.7	12.3	6.5	5.8	34.7	5.5	5.5	15.3	4.8	3.2	16.8
1945	8.8	2.9	21.0	3.6	11.8	14.1	14.5	22.3	18.4	6.4	10.0	19.8	13.0	3.9	8.9
1946	14.4	13.0	28.0	20.9	6.0	18.6	13.3	6.2	26.2	17.6	7.7	11.7	12.5	5.2	19.9
1947	5.4	11.9	14.7	5.3	5.0	11.5	11.5	4.3	24.5	5.9	7.1	19.1	4.7	5.7	8.5
1948	8.2	5.8	14.9	11.8	10.9	9.8	12.9	11.8	7.4	7.3	8.3	9.3	11.3	10.7	5.6
1949	19.0	14.2	11.6	12.2	18.4	6.3	14.2	16.3	7.1	15.3	24.2	9.5	7.8	4.8	18.1
1950	12.5	18.4	15.1	11.4	12.2	22.0	11.7	11.8	28.5	12.5	14.1	18.1	13.7	12.8	13.0
1951	4.7	8.5	17.2	4.4	17.0	10.8	2.8	12.1	6.8	4.1	11.0	13.1	1.1	20.2	6.1
1952	6.0	3.6	14.6	5.0	12.4	11.0	3.2	11.2	9.6	4.2	5.4	4.5	8.1	3.5	17.2
1953	5.5	10.6	1.0	11.5	9.6	8.3	9.7	14.7	4.8	12.4	18.5	3.1	2.3	20.1	2.5
1954	1.9	10.0	7.9	9.2	7.9	10.4	5.4	2.1	11.3	11.3	6.0	18.6	6.6	6.8	8.8
1955	7.4	3.6	14.4	9.9	13.8	22.4	7.0	5.3	9.2	6.7	7.0	17.3	6.3	4.7	7.7
1956	7.0	11.6	20.2	6.2	5.8	11.1	6.1	10.6	15.7	13.4	4.9	14.3	10.6	6.8	12.0
1957	21.9	12.7	6.4	9.4	18.6	11.0	9.6	13.1	10.1	10.3	12.6	4.5	5.0	13.5	5.4
1958	18.4	14.5	14.6	16.9	17.6	5.4	7.6	21.4	7.4	12.5	5.4	12.8	7.6	9.4	13.4
1959	7.2	8.9	18.2	11.6	12.6	28.9	3.5	7.3	22.2	8.7	6.2	32.7	7.8	6.3	24.9
1960	9.0	2.9	17.9	10.1	7.0	22.5	6.4	15.9	18.5	11.4	4.7	31.3	11.9	2.4	10.8
1961	11.0	10.3	6.6	13.4	10.8	8.9	12.6	16.3	13.3	14.9	12.4	10.9	15.8	8.4	
1962	4.2	14.9	20.8	6.3	15.3	9.5	5.4	19.7	9.6	6.0	17.9	19.7	5.5	18.0	7.4
1963	13.9	4.9	18.7	12.4	10.0	20.4	13.5	9.2	10.5	11.0	4.9	6.0	7.4	9.0	8.9
1964	4.3	9.5	7.1	4.8	15.0	17.9	4.3	12.8	20.1	4.3	5.2	15.7	1.4	7.8	16.8
1965	12.3	20.2	26.8	4.5	23.7	25.1	9.5	16.8	19.0	8.8	16.7	34.0	2.5	20.3	23.0
1966	16.7	6.7	2.5	12.5	5.2	7.0	21.2	8.9	11.7	17.8	7.9	7.8	10.5	10.3	5.1
1967	12.3	14.4	10.8	9.5	10.8	23.2	6.9	13.4	21.6	8.5	12.9	23.6	10.2	5.4	7.9
1968	10.6	4.3	11.9	4.4	6.6	14.9	2.2	8.2	15.8	7.1	9.2	8.2	9.9	4.1	6.6
1969	7.2	9.6	12.2	9.6	23.9	15.5	8.5	31.1	12.4	4.5	24.4	16.9	8.0	19.9	10.4
1970	6.9	7.0	14.5	3.0	11.3	16.5	3.2	6.6	20.6	3.0	4.0	25.3	7.0	9.1	6.5
1971	14.3	3.9	13.9	7.3	4.0	11.5	11.6	12.2	12.5	7.3	5.5	21.5	13.6	7.6	9.8
1972	11.3	11.9	13.7	9.8	6.8	18.7	8.9	11.7	13.8	15.8	8.5	12.0	15.8	16.2	6.4
1973	10.6	18.5	8.4	8.5	13.5	8.4	8.6	11.5	13.2	11.9	12.7	9.2	14.5	12.4	13.5
1974	18.3	7.8	4.6	12.8	10.8	23.0	20.1	12.9	14.6	15.8	7.2	9.3	14.4	6.9	4.3
1975	6.5	4.4	28.3	9.4	5.1	23.0	15.3	10.6	28.0	5.1	5.7	19.6	15.8	4.3	31.3
1976	15.5	13.8	5.2	17.1	8.9	6.0	11.8	13.3	8.8	14.2	10.4	3.2	7.5	9.9	4.7
1977	10.0	5.3	1.1	11.0	10.2	3.7	21.6	10.6	3.2	10.3	6.5	10.3	1.8	3.9	3.9
1978	10.0	9.3	8.7	9.4	14.5	14.5	14.9	18.0	15.0	7.0	8.8	11.5	12.9	9.4	23.4
1979	16.4	8.2	15.7	9.0	8.3	12.6	9.8	11.2	14.4	15.9	13.2	8.1	11.3	6.9	10.9
1980	6.8	12.2	6.8	4.5	15.6	6.7	16.5	9.0	6.4	5.6	6.6	3.4	8.2	8.7	6.8
1981	6.3	7.3	9.0	10.3	4.8	15.7	15.0	7.7	23.4	22.3	11.0	16.2	7.1	7.4	22.8
1982	8.5	18.2	9.4	9.7	11.1	12.5	8.4	12.7	18.5	4.3	23.7	17.2	21.2	18.5	8.8
1983	11.3	9.5	4.2	1.6	13.5	5.6	5.8	8.4	11.9	11.8	8.8	5.4	10.5	13.1	7.1
1984	20.2	12.1	20.5	12.8	5.8	22.6	9.6	10.4	16.3	23.3	8.6	21.5	14.8	7.9	32.3
1985	8.0	7.1	13.4	10.1	9.8	18.9	6.7	16.1	22.2	4.8	7.4	22.2	11.0	5.7	10.9
1986	7.9	5.3	11.0	6.3	3.6	13.6	6.0	6.9	8.3	7.8	5.3	11.2	2.8	2.8	8.1
1987	3.9	5.5	4.1	4.7	4.8	4.8	2.3	13.9	6.5	9.4	3.9	5.1	6.3	3.0	14.7

Abbreviations; M - May rainfall; JN - June rainfall; JY - July rainfall

Table 3. Regression estimates of county-level yield equation

Variable[1]	Unrestricted Model. Regime change.	Restricted Model. No regime change.	Final Model. Regime change.
M	0.87112 (0.60929)[2]	0.37604 (0.64273)	0.81226 (0.60740)
M^2	-0.0051889 (0.0025742)*	-0.0033442 (0.0026982)	-0.0049980 (0.0025794)
JN	0.76662 (0.56467)	0.69221 (0.59508)	0.70727 (0.56183)
JN^2	-0.0044881 (0.0021097)*	-0.0044817 (0.0022163)*	-0.0044051 (0.0020971)*
JY	1.3854 (0.40664)*	1.4584 (0.43072)*	1.4353 (0.40823)*
JY^2	-0.0038407 (0.0011448)*	-0.0039951 (0.0011994)*	-0.0040189 (0.0011473)*
T	42.423 (54.097)	-25.699 (24.662)	1.3963 (9.8748)
T^2	-1.6846 (8.2488)	6.9238 (2.0197)*	1.9686 (0.36888)*
T^3	0.073627 (0.47243)	-0.22743 (0.061694)*	0.0
T^4	0.00068825 (0.0090176)	0.0022218 (0.00062526)*	0.0
D	-40021. (22774.)	0.0	598.81 (115.34)*
D•T	4461.0 (2556.0)	0.0	13.761 (10.218)
$D{\bullet}T^2$	-181.28 (106.45)	0.0	-1.9686 (0.36888)*
$D{\bullet}T^3$	3.1981 (1.9909)	0.0	0.0
$D{\bullet}T^4$	-0.022359 (0.01586)	0.0	0.0
County-specific constants:			
Wake	822.94 (120.10)	952.04 (110.61)	924.25 (82.140)
Cumberland	817.72 (121.23)	947.04 (111.17)	919.38 (83.604)
Robeson	979.99 (121.64)	1109.5 (117.98)	1082.2 (84.443)
Johnston	983.45 (120.08)	1112.4 (109.93)	1085.1 (82.385)
Guilford	702.59 (119.62)	831.24 (109.19)	803.68 (81.194)
Likelehood value	-1464.04	-1478.68	-1467.22

[1]Variable definitions: M - May rainfall in mm; JN - June rainfall in mm; JL - July rainfall in mm; T - time index, 1940 = 1; D - dummy variable, D = 0 if T ≤ 25, D = 1 if T >25.

[2]Estimated standard error in parentheses.

*Significant at 5 percent confidence level.

List of Figures

Figure 1

Average annual yield growth rates for corn and tobacco in North Carolina: 1940-1987.

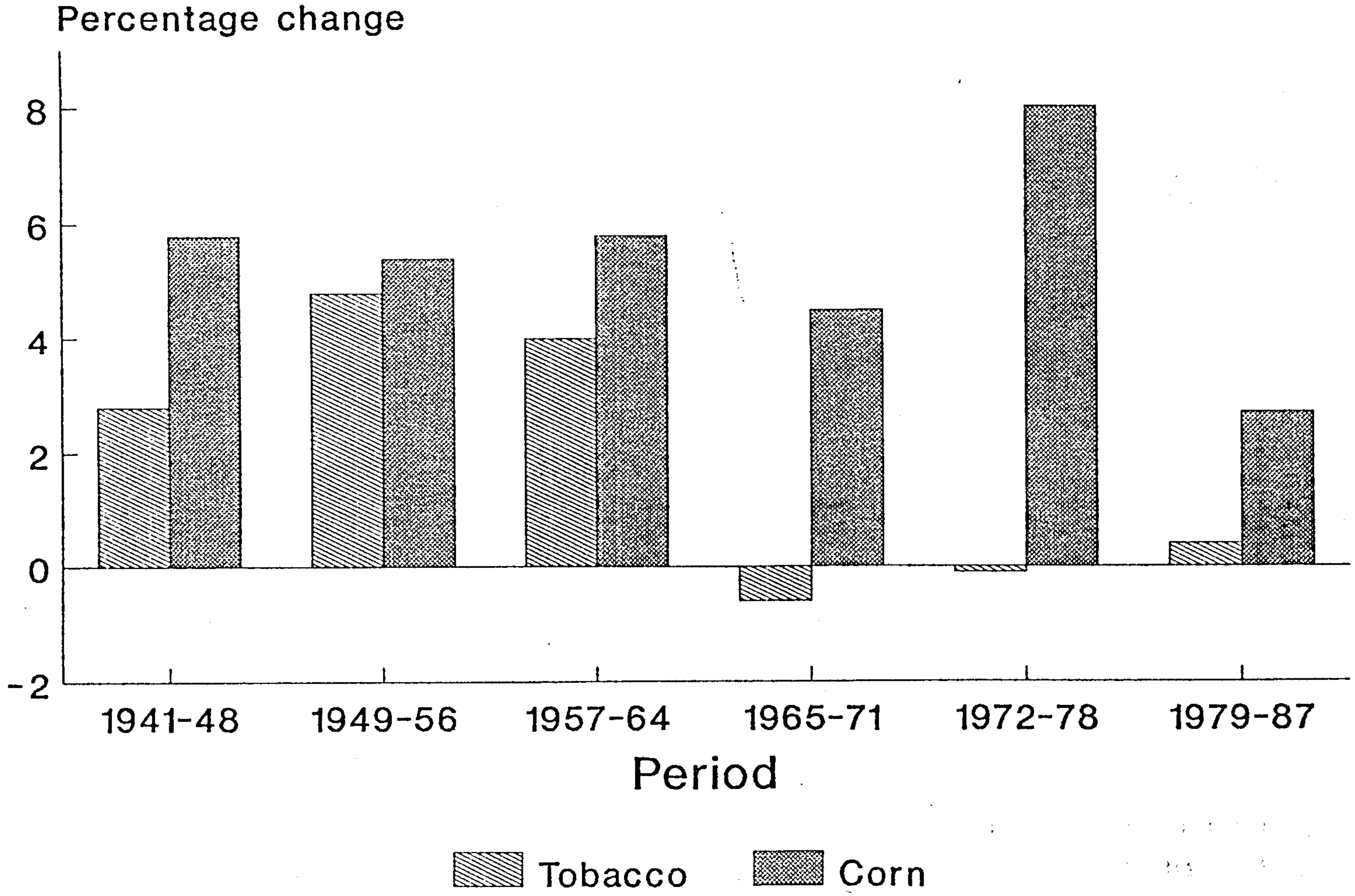

Figure 2

Actual and expected per-hectare flue-cured tobacco yields, five county average, for restricted and unrestricted fourth degree polynomial models.

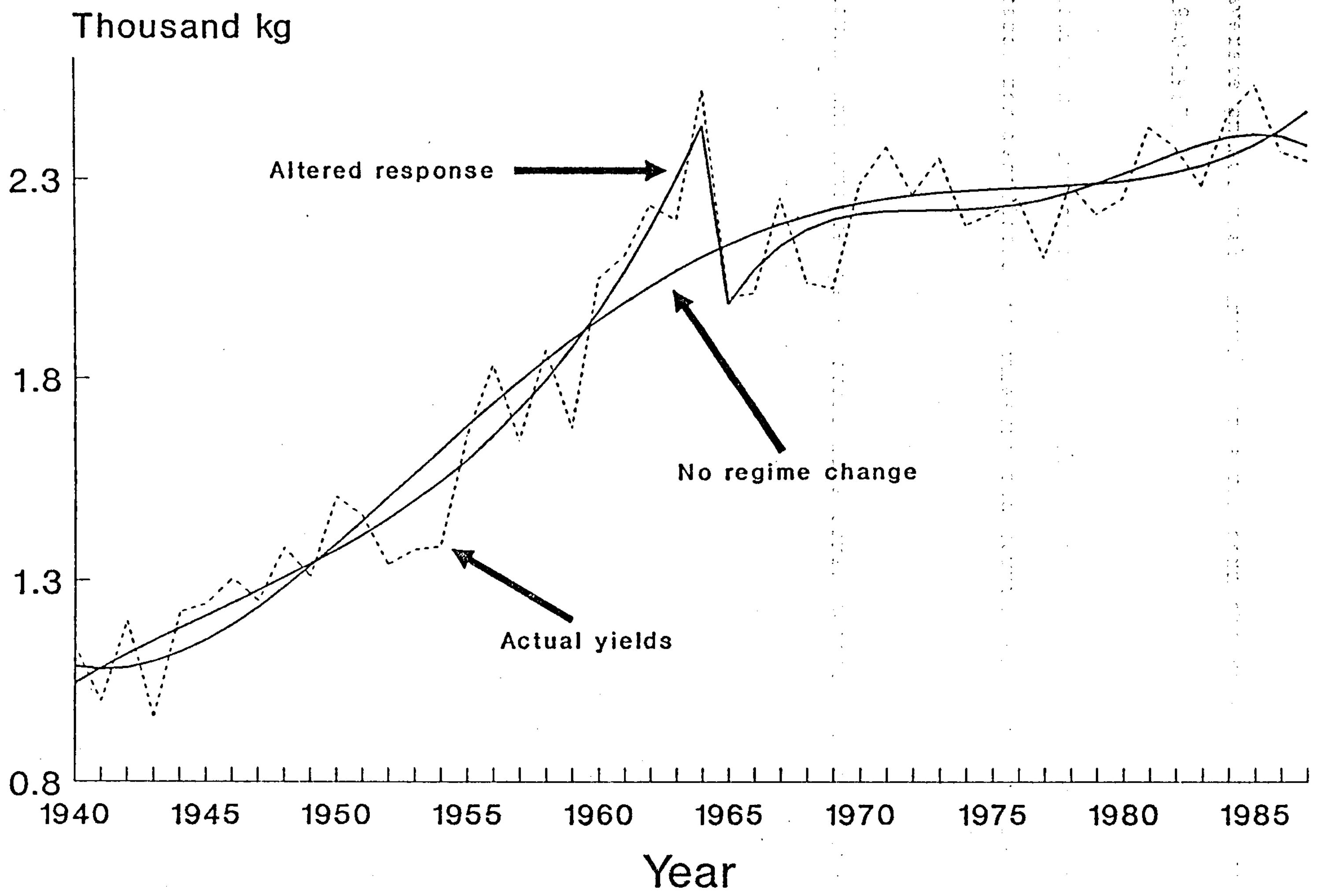

Figure 3

Actual and expected per-hectare flue-cured tobacco yields, five county average, for restricted quadratic model.