**Do not cite or reproduce without permission from the authors**

# Revisiting Quality-Adjusted Price and Quantity Indices of Pesticides


Richard F. Nehring,

Charlie Hallahan

Jorge Fernandez-Cornejo

Sun Ling Wang

Seth Wechsler

Jarrett Hart

Roberto Mosheim

**Economic Research Service, USDA**



*Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2015 AAEA & WAEA Joint Annual Meeting, San Francisco, CA July 26-28, 2015*


The views expressed are those of the authors and do not necessarily represent the views or policies of the U.S. Department. of Agriculture

## Abstract

This study extends previous research, which calculated quality-adjusted price and quantity indices for the pesticides applied to corn, soybeans, cotton, and sorghum using hedonic methods (Fernandez-Cornejo and Jans, 1995). We extend the analysis through 2008 and make several econometric improvements. The analysis proceeds as follows: First, Zivot-Andrews tests are used to determine whether there are structural breaks in the data generating process. Next, we use hedonic regressions to control for pesticide quality characteristics including potency, toxicity, and persistence across active ingredients. Finally, the regression results are used to obtain preliminary estimates of the quality-adjusted price and quantity indices.

*Key Words:* hedonic estimation, pesticide quality, corn, soybeans, cotton, sorghum

**Revisiting Quality-Adjusted Price and Quantity Indices for Pesticides**

## Introduction

Agricultural producers use pesticides (herbicides, insecticides, fungicides, and other pesticides) on millions of crop acres, primarily to prevent or manage weeds, insects and pathogens. Over the course of the last 50 years, public concerns about the adverse human health and environmental effects of pesticides have led to increasingly restrictive regulations. Nonetheless, expenditures on the pesticides used in agriculture grew by approximately 400% (in real terms) from 1960 and 2008. Over this time period, changes in pesticide use were influenced by changes in: economic factors, pest pressures, environmental and weather conditions, crop acreage, production practices, access to land-grant extension personnel and crop consultants, technological innovations, and environmental and health regulations (Fernandez-Cornejo et al.2014). The purpose of this analysis is to identify trends in farmers' pesticide use by accounting for changes in the characteristics of the active ingredients applied.

Pesticides are typically sold as mixtures of active chemical ingredients (a.i.) and inert materials. Hundreds of a.i., with different potencies and toxicities, have been used over the course of the study period. Moreover, new active ingredients (more effective and less harmful to human health and the environment) are frequently introduced, while others are banned or voluntarily canceled by their manufacturers (Fernandez-Cornejo and Jans, 1995). Thus, there is an inherent heterogeneity in the composition of pesticides. This implies that aggregate measures of pesticide use (such as pounds of a.i. applied) do not accurately reflect changes in pesticide use. Quality-adjusted price and quantity indices depict the impacts of technological change and provide insight into how pesticide use has changed over time.

**Methodology**

This study employs the hedonic approach developed in Fernandez-Cornejo and Jans (1995) to compute quality-adjusted indices of pesticide prices and quantities. It is implicitly assumed that the prices of pesticide products reflect the quality characteristics of the active ingredients that they contain. By exploring how changes in these characteristics affect pesticide prices, it is possible estimate shadow prices for quality characteristics such as potency, toxicity, and environmental persistence.

This approach is not novel. Waugh (1928) used hedonic methods to explore how changes in characteristics affected vegetable prices. Court (1939) examined whether increases in automobile prices were primarily due to improvements in quality or the consolidation of market power. Griliches (1958) and Rayner and Lingard (1971) used hedonics to determine the implicit value of fertilizer characteristics. Chow (1967), Griliches (1961), and Triplett (1977, 1989) estimated quality-adjusted price indices for computers, automobiles, and refrigerators. Palmquist (1989) used hedonics to analyze agricultural land values.

These analyses specified the hedonic function using a variety of functional forms. In this study, we employ a generalized linear form. More specifically, the dependent variable and the continuous independent variables are adjusted using Box-Cox transformations.

Three variables control for changes is pesticide quality: application rates, chronic toxicity scores, and soil half-lives. Application rates (in pounds of a.i. per acre) serve as a proxy for the potency, or effectiveness, of active ingredients.[1] Chronic scores reflect the human health hazards associated with pesticide consumption (Kellog et al, 2002).[2] We measure environmental

[1] Application rates are inversely related to pesticide potency
[2] The lower the index, the lower the environmental risk posed by the chemical.

persistence using an indicator variable equal to one for active ingredients with half-lives greater than or equal to 60 days.

Indicator variables (D) are assumed to capture annual impacts which are unrelated to active ingredient quality. Thus the general functional form of the model is:

(1) $$B(P_0) = \sum_{n=1}^{N} \alpha_n B_n(X_n) + \sum_{m=1}^{M} \gamma_m T_m + \beta D + \varepsilon$$

such that:

(2) $$B_i(\theta_i) = \begin{cases} \frac{\theta_i{}^{\lambda_i - 1}}{\lambda_i} \; if \; \lambda_i \neq 0 \\ \ln \theta_i \; if \; \lambda_i = 0 \end{cases}$$

where $B_i(\theta_i)$ represents the Box-Cox transformation, $X$ is a vector of quality characteristics, $P_0$ reflects prices, $T_m$ are year time dummy variables, $D$ is the proxy for environmental persistence, $\{\alpha_n, \beta, \gamma_m\}$ are unknown parameters, and ε is a stochastic disturbance.

Pesticides have different market shares. Consequently, weights are calculated using data on expenditures, and weighted least squares is used to estimate Equation 1.

The quality adjusted price index is estimated from the parameter estimates of the year dummies ($T_m$). The base year (1960) is normalized to 100. Total annual expenditures are divided by the quality adjusted prices to obtain the index of quality adjusted quantities.

Fernandez-Cornejo and Jans (1995) used a series of Chow tests to check the stability of the hedonic coefficients (Chow, 1960). An important limitation of this approach is that the break date must be specified before the test is conducted. As Hansen (2001) points out, the test results can be “uninformative” because the true break date has not been tested, or “misleading” because the test indicates a break when none exists. Therefore, we employ break tests that 1) determine the break point endogenously, and 2) allow the unit root to have both stochastic and deterministic components. Specifically, we use the structural break test developed by Zivot and Andrews

(1992). This is a sequential test which utilizes the full sample and employs a dummy variable to test for each possible break date. The break date is selected where the test statistic from an augmented Dickey–Fuller test of the unit root is smallest (Dickey and Fuller, 1979). This ensures that the break data is chosen such that the evidence is least favorable for the unit root null hypothesis.[3]

**Data**

The dataset contains state level information for two hundred fifty-five of the active ingredients applied to corn, cotton, sorghum, and soybeans in the continental United States from 1960 to 2008. This data reflects more than 90% of the total pesticide expenditures on each of the four crops for each state and during each year in the study period. Table 1 provides information about twenty of the most commonly used active ingredients, which account for more than 80% of pesticide expenditure during the study period. Fernandez-Cornejo et al. (2014) provides a detailed description of the data used in this analysis.

Figures 1 illustrates how the quality characteristics of the pesticides being analyzed changed over time. There are several obvious trends. For instance, application rates decreased over the course of the study period. In part this is due to technological improvements (the commercial introduction of new, increasingly potent chemicals). However, it is also due to the commercial introduction of genetically engineered seeds.

Despite increases in potency, the average toxicity of pesticides decreased over time. In part, this is due to restrictions on more toxic products such as DDT, toxaphene used in cotton and

[3] The Zivot-Andrews test is carried out as follows. For each candidate for a break in the intercept, trend, or both, a test statistic for the null hypothesis of a unit root is calculated allowing for the given break. The break point providing the strongest evidence against the null hypothesis is selected and compared against the various p-values provided by Elliott and Mueller at levels of 10%, 5%, and 1%. The decision to accept or not accept the null hypothesis of a unit root is based on this comparison."

Aldrin applied to corn. However, it is also due to increases in the use of relatively benign products like carbaryl and chloropyrifos, and pyrethroids.

Average soil half-lives decreased sharply during the 1970's due to regulatory restrictions, but increased during the 1980's and 1990's due to increases in the use of metolachlor and pendimethalin. Soil half-lives decreased rapidly subsequent to the introduction of HT seeds (in 1996), as farmers increased glyphosate usage.

**Hedonic Regression Results**

Two structural breaks were identified using the Zivot-Andrews tests: 1978 and 1998. Consequently, the study period is partitioned into three time periods: 1960-1978, 1978-1998, and 1998-2008.[4] The first of these periods encompasses the establishment of the EPA (in 1970). During this time period, very toxic pesticides (such as DDT and Aldrin) were in use, but increasingly restricted. The second period is dominated by the use of traditional pesticides like chlorpyrifos, methyl parathion, metolachlor, pendimethalin, atrazine and 2,4-D. The third period follows the commercial introduction of genetically modified seeds and the ensuing increase in glyphosate usage and a reduction in the use of other herbicides.

Regression results can be found in Table 2. Generally, our model appears to fit the data well. Adjusted R-squared values range from 0.71 to 0.93. Notice that farmers appear to have been less concerned with (or less aware of) human health risks in period 1, but reasonably sensitive to these risks in periods 1 and 2. Similarly, farmers appear to have accepted pesticides with longer half lives in period 1, but were willing to pay a premium for less persistent chemicals in periods 2 and 3. Not surprisingly, more potent pesticides tend to be more valuable than

[4] It is likely that there would be different (or additional break dates) if the dataset contained different crops.

relatively ineffective ones. Though not reported, the parameter estimates for the year fixed effects are positive and significant throughout the study period.

Figure 2 presents the preliminary estimates of the quality-adjusted price index. Because of improvements in pesticide quality (improved pest control effectiveness or lower application rates), adjusted pesticide prices (constant quality) increase less quickly than unadjusted ones. Intuitively, this is because the unadjusted (actual) prices reflect technological improvements, while the quality adjusted ones do not. Similarly, quality-adjusted quantities are higher than unadjusted quantities because farmers would have had to use more pesticides if pesticide quality had remained constant instead of improving (Fernandez-Cornejo and Jans, 1995).

Figure 3 presents the preliminary estimates of the quality-adjusted quantity index. As expected, quality-adjusted quantities are greater than unadjusted ones. Notice that there were nearly twice as many quality adjusted as non-quality adjusted pounds applied in 2008.

**Concluding Comment**

Using hedonic methods, we are able to disentangle improvements in quality (technological change) from other factors that impact pesticide prices and usage. In doing so, we provide insight into how pesticide use has changed over time. The pounds of active ingredients applied by US farmers tripled over the course of the study period (1960-2008). However, this statistic understates the extent to which farmers have benefited from technological change. Our preliminary results suggest that if pesticide quality had remained constant instead of improving, farmers would have had to use in 2008 about six times the amount used in 1960.

**References**

Clemente, J., A. Montanes, and M. Reyes. 1998. Testing for a Unit Root in Variables with a Double Change in the Mean. Economics Letters 59: 175–182.

Chow, G. “Technological Change and the Demand for Computers.” *Amer. Econ. Rev*. 57(1967): 1117-30.

Court, A.T. “Hedonic Price Indices with Automotive Examples.” *The Dynamic of Automotive Demand*. New York: General Motors Corp., 1939.

Dickey, D. A., and Fuller, W. A. (1979), "Distribution of the Estimators for Autoregressive Time Series With a Unit Root," Journal of the American Statistical Association, 74, 427-431.

Doanes Marketing Research, Inc. *Doanes Major Crop Pesticide Study*. St. Louis, MO, various issues, 1986-2006.

Environmental Protection Agency (EPA), Office of Pesticide Programs. *Specific Chemical Fact Sheets* (accessed online at: http://www.epa.gov/pesticides/factsheets/chemical_fs.htm).

Farm Chemicals Handbook 2006. Willoughby OH: Meister Publishing Company, 2006.

Fawcett, R.S. “Two Decades of Atrazine Yield Benefits Research.” Triazine Network, 2006.

Elliot, G., and U.K. Mu¨ ller. 2006. Efficient Tests for General Persistent Time Variation in Regression Coefficients. Review of Economic Studies 73 (4): 907–940.

ExToxNet. (Extension Toxicology Network). Information on herbicide attributes. Oregon State University, Corvalis. Available at http://extoxnet.orst.edu. [retrieved July 2007]

Fernandez-Cornejo, J., & Caswell, M. (2006, April). *The first decade of genetically engineered crops in the United States* (Economic Information Bulletin EIB-11). Washington, DC: U.S. Department of Agriculture, Economic Research Service.

Fernandez-Cornejo, J., and S. Jans. “Quality-Adjusted Price and Quantity Indices for Pesticides.” *American Journal of Agricultural Economics* 77-3(1995): 645-59.

Fernandez-Cornejo, J., C. Hallahan, R. Nehring, S. Wechsler, and A. Grube. 2012. “Conservation Tillage, Herbicide Use, and Genetically Engineered Corps in the U.S.A.: The Case of Soybeans,” *AgBioForum* 15(3): 231-241.

Fernandez-Cornejo, J., R. Nehring, C. Osteen, S. Wechsler, A. Martin, and A. Vialou. *Pesticide Use in U.S. Agriculture, 21 Selected Crops,* 1960-2008. EIB-124. May 2014.

Griliches, Z. “The Demand for Fertilizer: An Economic Interpretation of a Technical Change.” *J. Farm. Econ.* 40(August 1958): 591-606.

___. “Hedonic Price Indices for Automobiles: An Economic Analysis of Quality Change.” *The Price Statistics of the Federal Government.* General Series No. 73. New York: Columbia University Press for the National Bureau of Economic Research, 1961.

___. “Notes on the Measurement of Price and Quantity Indexes.” *Models of Income Distribution,* vol. 28. New York: National Bureau of Economic Research, 1964.

Hansen, B.E. 2001. The New Econometrics of Structural Change: Dating Breaks in U.S. Labor Productivity. *Journal of Economic Perspectives* 15 (4): 117–128.

Kellogg, R., R. Nehring, A. Grube, D.W. Goss, and S. Plotkin. 2002. “Environmental Indicators of Pesticide Leaching and Runoff from Farm Fields,” *Agricultural Productivity: Measurement and Sources of Growth.* V. Eldon Ball and G. Norton (eds.). Boston: Kluwer Academic Publishers.

Palmquist, R.B. “Land as a Differentiated Factor of Production: A Hedonic Model and its Implications for Welfare Measurement.” *Land Econ.* 65(February 1989): 23-28.

Rayner, A.G., and J. Lingard. “Fertilizer Prices and Quality Change: Construction of Fertilizer Prices and Quantity Indices for Great Britain, 1956/57 to 1968/69.” *J. Agr. Econ.* 22(May 1971): 149-62.

Teekens, R., and J. Koerts. “Some Implications of the Log Transformation of Multiplicative Models.” *Econometrica* 40: 796-819.

Triplett, J.E. “Price and Technological Change in a Capital Good: A Survey of Research on Computers.” *Technology and Capital Formation*. D.L. Jorgenson and R. Landau, eds. Cambridge MA: MIT Press, 1989.

Triplett, J.E., and R.J. McDonald. “Assessing the Quality Error in Output Measures: The Case of Refrigerators.” *Rev. Income and Wealth* 23(June 1977): 137-56.

U.S. Department of Agriculture, Economic Research Service. *Agricultural Resource Marketing Study*. Washington DC, various issues, 1996-2006.

U.S. Department of Agriculture, National Agricultural Statistics Service. *Agricultural Statistics: 1989, 1994, 2007*. Washington DC, 2007, 1994, 1989.

___. *Agricultural Chemical Usage: 1986-2006 Field Crops Summary*. Washington DC, various issues, 1987-2007.

___. *Agricultural Prices: 1986-2006 Summary*. Washington DC, various issues, 1987-2007.

Waugh, F.V. “Quality Factors Influencing Vegetable Prices.” *J. Farm Econ.* 10(April 1928):185-96.

Zivot, E., and D.W.K. Andrews. 1992. Further Evidence on the Great Crash, the Oil-Price Shock, and the Unit-Root Hypothesis. Journal of Business and Economic Statistics 10 (3): 251–270. Applied Economic Perspectives and Policy 450

**Tables**

Table 1. Top 20 Active Ingredients Included (use in corn, cotton, sorghum, and soybean production)

| Common Name | Trade Name | Type | Chemical Class | Firm Registrant | Origin | Share[/1] | Share[/2] |
|---|---|---|---|---|---|---|---|
| Atrazine | Aatrex | H | Triazine | Ciba-Geigy | 1959 | 19.2% | 19.3% |
| Alachlor | Axiom | H | Amide | Monsanto | 1967 | 10.0% | 2.1% |
| Glyphosate | Roundup | H | Phosphorus | Monsanto | 1972 | 8.1% | 25.1% |
| Metolachlor | Dual | H | Amide | Ciba-Geigy | 1974 | 7.6% | 11.0% |
| Trifluralin | Treflan | H | Dinitroaniline | Elanco | 1959 | 4.9% | 2.9% |
| Butylate | Genate, Sutan | H | Thiocarbamate | Zeneca | 1965 | 3.9% | 0.1% |
| Cyanazine | Bladex | H | Triazine | DuPont | 1968 | 3.7% | 1.5% |
| Toxaphene | Hels-Mate | I | Organo-chlorine | None | 1940s | 3.6% | 0.0% |
| Acetochlor | Guardian | H | Chloro-acetamide | Monsanto | 1995 | 2.9% | 8.8% |
| Methyl Parathion | Metafos | I | Organo-phosphate | Drexel | 1940s | 2.8% | 0.4% |
| 2, 4-D | Plantgard | H | Phenoxy compound | Rhone-Poulenc | 1940s | 2.6% | 1.8% |
| Pendimethalin | Prowl | H | Nitroaniline | American Cyanamid | 1972 | 2.2% | 3.3% |
| EPTC | Eptam | H | Carbamate | Stauffer | 1959 | 2.0% | 0.7% |
| DDT | Anofex | I | Organo-chlorine | None | 1940s | 1.8% | 0.0% |
| Propachlor | Ramrod | H | Chloro-acetanilide | Monsanto | 1965 | 1.5% | 0.1% |
| Terbufos | Counter | I | Organo-phosphate | American Cyanamid | 1973 | 1.4% | 0.8% |
| Carbofuran | Furadan | I | Carbamate | FMC | 1969 | 1.2% | 0.2% |
| Chloramben | Amiben | H | Benzoic acid compund | None | 1958 | 1.1% | <0.01% |
| Aldrin | Aldrin | I | Organo-chlorine | None | 1940s | 1.1% | 0.0% |
| MSMA | Weed-Hoe | H | Organoarsenic | Drexel | 1940s | 1.0% | 0.6% |

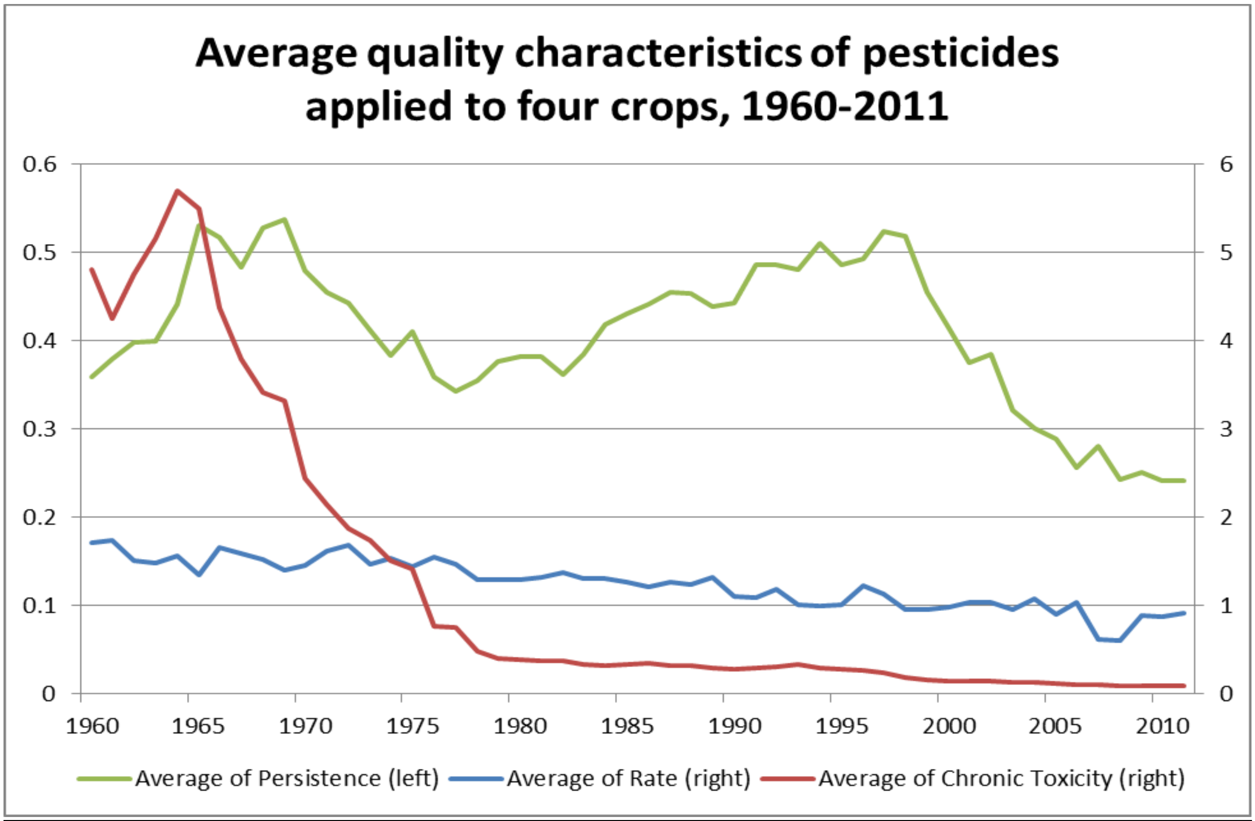
Source: Farm Chemical Handbook, EXTONET. [/1] Share in total pesticide expenditures from 1960 to 2008; [/2] Share in total pesticide expenditures from 1996 to 2008

Table 2. Hedonic Regressions Results by Pesticide Class

| | Pesticide | Variables | | | |
|---|---|---|---|---|---|
| | All | Rate | Chronic Toxicity | Persistence | Adj R-Sq |
| Period | 1960-1977 | -0.35403*** | 0.00478*** | 0.17934*** | 0.6859 |
| | 1978-1998 | -0.75398*** | -0.02063*** | -0.10674*** | 0.9418 |
| | 1998-2008 | -0.97395*** | -0.00831*** | -0.13924*** | 0.9744 |

***: 1% significance, **: 5% significance, *: 10% significance

**Figure 1**


Average quality characteristics of pesticides applied to four crops, 1960-2011
0.6
0.5
0.4
0.3
0.2
0.1
0
6
5
4
3
2
1
0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Average of Persistence (left)
Average of Rate (right)
Average of Chronic Toxicity (right)

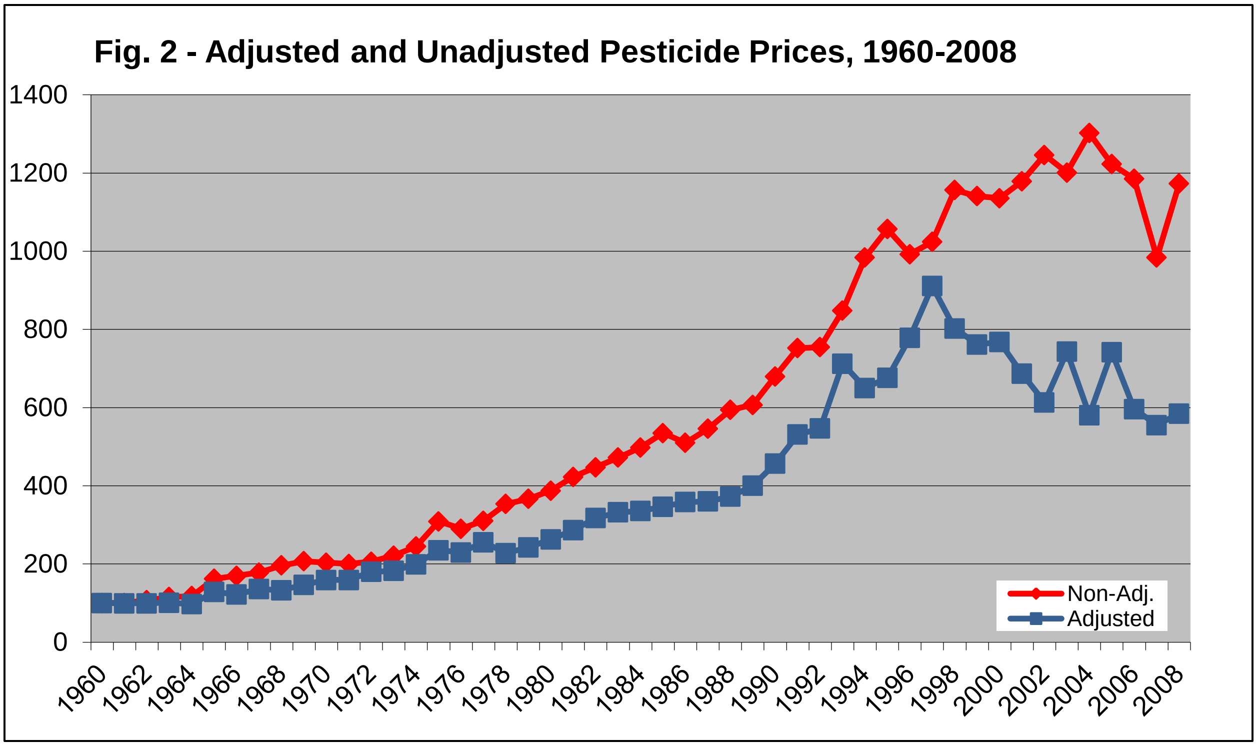


Fig. 2 - Adjusted and Unadjusted Pesticide Prices, 1960-2008
0
200
400
600
800
1000
1200
1400
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
Non-Adj.
Adjusted

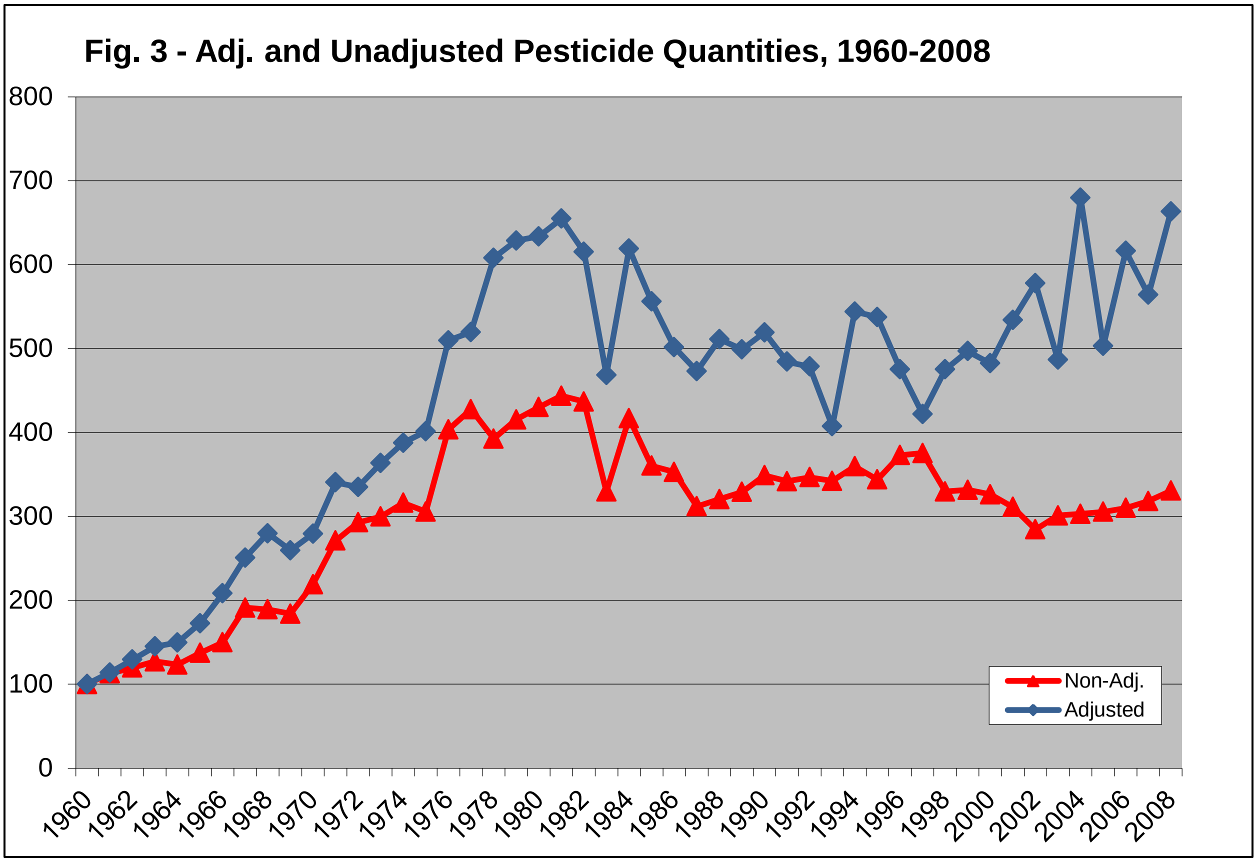


Fig. 3 - Adj. and Unadjusted Pesticide Quantities, 1960-2008
800
700
600
500
400
300
200
100
0
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
Non-Adj.
Adjusted