**CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY**

**CALIFORNIA AIR RESOURCES BOARD**

# DECLARATION OF THOMAS L. DARLINGTON

I, Thomas L. Darlington, declare as follows:

1. I am an engineer with training and expertise in lifecycle emissions analysis, the use of models to estimate lifecycle emissions and to attribute emissions to the production, distribution and use of various fuels, and use of regulations to control mobile-source emissions. My areas of expertise also include land-use change ("LUC") modeling and the application of econometric models to attributional and consequential lifecycle emissions analysis. Following my graduation from the University of Michigan in 1979, I served for eight years as a Project Manager at the United States Environmental Protection Agency's Motor Vehicle Emissions and Fuels Laboratory in Ann Arbor, Michigan. Thereafter I worked at Detroit Diesel Corporation and General Motors Corporation, and as the Director of Mobile Source Programs at Systems Application International. I am the President of Air Improvement Resource ("AIR"), a company formed in 1994 to provide mobile source emission modeling to government and industry. A copy of my CV is attached to this Declaration as Attachment A.

2. I have participated on behalf of renewable fuels producers in the public consultation and rulemaking processes at the California Air Resources Board ("ARB" or "the Board") to consider, adopt and revise the low-carbon fuel standard ("LCFS") regulation since 2008. I testified at the Board's February 2015 hearing concerning proposed amendments to the LCFS regulation. I am fully familiar with the models released by CARB to establish and implement the LCFS regulation, including the versions of the Global Trade Analysis Project ("GTAP") modeling systems used by CARB or proposed for use by the CARB staff as part of the current and proposed LCFS regulation.

3. I make this Declaration based upon my personal knowledge, my training and expertise, and my familiarity with the subjects that I address here. This Declaration is divided into four parts: (1) Access to the Database Used by ARB Consultant David Rocke, (2) Proposed Modification 18 in the 15-Day Notice, (3) Differences between the December and June versions of CA-GREET and (4) Memoranda from ARB's External Scientific Reviewers.

## *A. Access to the Database Used by ARB Consultant David Rocke*

4. ARB's LUC emission factor for corn starch ethanol in the revised LCFS regulation is 19.8 grams of carbon dioxide equivalent emissions per megajoule of energy ("g/MJ"). That is 12.2 g/MJ lower than the 30 g/MJ used in the current LCFS rule. The CARB staff has declined to consider and to propose a different and lower LUC emission factor for corn starch ethanol, in reliance on an analysis of crop price-yield values by David Rocke, an ARB consultant. ARB used Dr. Rocke's work for ARB in selecting price-yield values in its analysis of LUC values for all ethanol feedstocks; that analysis was in turn used in the proposed new LCFS regulation that is now under consideration by the Board. As soon as it learned of the project assigned to Dr. Rocke by

ARB, in the fall of 2014, AIR requested the data used by Dr. Rocke. As explained below, although ARB staff agreed to provide to the public the data used by Dr. Rocke, but the data were never provided by ARB to me or other members of the public; the lack of timely access to that data has prevented effective public participation in the current LCFS rulemaking.

5. The ARB analysis applied in the proposed regulation in reliance on the data used by Dr. Rocke and on Dr. Rocke's analysis employs five price-yield values: 0.05, 0.10, 0.175, 0.25, and 0.35. The average of these 5 values is 0.19. Those values are used in ARB's version of the GTAP model, originally developed at Purdue University. The Purdue recommended value is 0.25. CARB's Expert Working Group for the LCFS regulation also recommended 0.25. ARB sponsored research indicated that there was little or no price-yield response (i.e., 0.0). AIR recommended that ARB should drop the lower price yield values (0.05 and 0.10) because the research supporting these lower values was developed over the very short term (1-3 years of price and yield data), and the GTAP model is a longer-term model (5-10 years). [1] ARB utilizes an 11.59 billion gallon per year shock of corn ethanol in its corn ethanol modeling, clearly illustrating that ARB is exercising the model with a medium-term shock, and not a short-term shock. Thus, ARB's use of short term price yield responses with the medium or longer term GTAP model is clearly inconsistent.

6. In the Initial Statement of Reasons ("ISOR") for the new LCFS regulation, ARB references a recent analysis by Dr. Rocke in support of using lower price-yield responses. [2] The Rocke analysis utilized one set of data from a 2012 dissertation by Juan Francisco Rosas Perez. [3] That dissertation indicated that the price-yield response was in the region of 0.29, very close to the Purdue default value. Dr. Rocke obtained the data from the dissertation, conducted his own statistical analysis, and concluded that the data did not support the 0.29 price yield value.

7. Because of the differences between these two analyses (Perez and Rocke), which stakeholders clearly must understand fully, AIR requested from ARB staff the data that Dr. Rocke used for his analysis. While staff said they were trying to get the data for AIR, the data was never supplied by staff. Therefore, AIR was unable to replicate Dr. Rocke's analysis of the Perez data. There is insufficient information in Dr. Rocke's available written work to reject the Perez analysis. (Dr. Rocke's rebuttal is only three pages in length.). In addition, this is only one of two sources (according to Rocke) that were used to support the 0.25 price-yield value, Rocke did not attempt to critique the other source. Thus, because ARB never supplied Rocke's database, AIR was not able to replicate Rocke's sketchy analysis, and Rocke only critiqued one source. To my knowledge no other person or organization has been able further to understand or replicate this portion of the analysis used in the current regulatory proposal. Based on the standards for transparency and public participation that I have observed in other regulatory proceedings, ARB should not rely on the Rocke analysis for its use of low price-yield values, and should therefore eliminate the lowest two values (0.05 and 0.10). The impacts of eliminating the lowest two price-yield values on corn

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[1] "Discussion of the Yield Price Elasticity of GTAP", Taheripour and Tyner, Purdue University, April 2014. (See Attachment B.)

[2] "Statistical issues Related to the Low-Carbon Fuel Standard", October 31, 2014. (See Attachment C.)

[3] "Essays on the Environmental Effects of Agricultural Production", Dissertation, Perez, Juan Francisco Rosas, Iowa State University. (Copyright material, not included in public filing.)

ethanol LUC emissions are shown in Table 1 below. Without both 0.05 and 0.10, the LUC value is 15.53 gCO2e/MJ instead of 19.84. CARB's choice of the higher emissions factor creates an inefficient bias against the use of corn starch ethanol, by overstating the LUC emissions attributed to the use of corn starch ethanol.

**Table 1. Impact of the Low Price-Yield Values**

| Average of ARB Scenarios | Average price-yield | LUC (gCO2e/MJ) |
|---|---|---|
| All (ARB value) | 0.19 | 19.84 |
| w/o 0.05, 0.1 price-yield | 0.26 | 15.53 |

### *B. Proposed Modification 18 in the 15-Day Notice*

8. Proposed Modification 18 in the June 4, 2015, 15-day notice discusses recertification of the approximately 270 existing fuel pathways. Staff is proposing a system for prioritizing that work and eliminating potentially unrealistic deadlines in various parts of the existing proposal. Staff proposes to review and approve fuel pathway applications in batches based on fuel type, so that providers of the same fuel compete on equal terms, obtaining the new carbon intensity score at the same time. The proposed prioritization of fuel types would be: ethanol, followed by biodiesel, renewable diesel, compressed natural gas, liquefied natural gas, and finally all others. This prioritization makes sense, but the record submitting requirements of the recertification process are unnecessary burdensome for ethanol plants.

9. The relevant sections of the recordkeeping requirements for recertification in the proposed regulation order are shown below. Plants are to submit

*Invoices and receipts for all forms of energy consumed in the fuel production process, all fuel sales, all feedstock purchases, and all co-products sold. Invoices shall be submitted in electronic form. Each set of invoices shall be accompanied by a spreadsheet summarizing the invoices. Every invoice submitted shall appear as a record in the summary. Each record shall, at a minimum, specify in a separate column the period covered by the purchase, the quantity of energy purchased during that period, the invoice amount, and any special information that applies to that record (the special information column need not be populated for every record). For each form of energy consumed, the two-year total and average consumption shall be reported in the spreadsheet. These two-year totals and averages shall be used to calculate the per-million-Btu and per-megajoule energy consumption inputs used to calculate the life cycle CI of the fuel pathway.*

*a. Period Covered. The period covered shall be the most recent two-year period of relatively typical operation.*

*b. Production Processes Covered. The invoices submitted under this provision shall cover the energy consumed in all unit operations devoted to feedstock handling and pre-processing; fuel production; co-product handling and processing; waste handling, processing, and treatment; the handling, processing and use of chemicals, enzymes, and organisms; the generation of process energy, including the generation, handling and* *processing of combustion fuels; and all plant monitoring and control systems. If the fuel produced or any by-products or co-products receive additional processing after they leave site, such as additional distiller's grains drying or fuel distillation, invoices covering the energy consumed for those processes must also be submitted. If the fuel production facility is co-located with one or more unrelated facilities, and energy consumption invoices are not separately available for the fuel production process, the applicant shall obtain a third-party energy audit sufficient to establish the long-term, typical energy consumption patterns of the fuel production facility.*

*3. In lieu of receipts or invoices for fuel sales, feedstock purchases, or co-product sales, the applicant may seek Executive Officer approval to submit audit reports prepared by independent, third-party auditors that document fuel sales, feedstock purchases, or co-product sales.*

Ethanol production plants can have dozens of invoices for feedstock every week from many different suppliers. It would not be unusual for plants to have 3000-5000 invoices, DDG sales receipts, ethanol sales receipts, and other information requested by CARB. All of this information would require not only scanning but also significant redacting of key information to protect business relationships. I believe this is unnecessarily burdensome, nor do I believe CARB staff will be able to adequately review all of this information for 270 biofuel plants in the time required. Therefore, I request staff to revise these requirements. I recommend that the requirements be revised to require only summary information of key plant inputs and outputs (feedstock used, natural gas and electricity used, ethanol produced, DDG produced, etc.) on a monthly basis. This would be far more manageable by plants, and would not need as much redacting. The information could be verified by staff through on-site auditing if necessary.

I note that ARB allows applicants to seek Executive Officer approval to submit audit reports prepared by independent, third-party auditors that document fuel sales, feedstock purchases, or co-product sales. I recommend that ARB allow 3$^{rd}$ party audits to be performed using generally accepted auditing standards which would allow for a sampling approach, and would not need to involve every transaction unless there was a significant deficiency in the sampled data.

### *C. Differences between the December and June versions of CA-GREET*

10. The June version of the CA-GREET model differs from the version of the CA-GREET model provide with the ISOR. CA-GREET includes a feature for selecting the presence of, and percentage of, mechanized harvesting of sugarcane. Users may select whether mechanized harvesting is used, and if so, in what percentage of feedstock used by a cane ethanol plant. In both the December (ISOR) and June versions of CA-GREET, when mechanized harvesting is selected, the model reduces emissions from cane straw burning. If 100% mechanized harvesting is selected, the model eliminates emissions from straw burning. Of course, a producer claiming that credit, referred to in the model as the "mechanized harvesting credit," must attest to and demonstrate the use of mechanized harvesting

11. Unlike the December version of CA-GREET, the new, June versions of CA-GREET awards a producer a mechanized harvesting credit even if a user does not specify, and is not thereby

requited to attest to, mechanized harvesting. Thus, even if a producer's percent of mechanized harvesting is 0%, the newly proposed regulation still awards a mechanized harvesting credit of 100%. Whether by design or error, a Brazilian sugarcane ethanol plant that had no mechanized harvesting would be assumed to have the same emissions as a plant with 100% mechanized harvesting.

***D. Memoranda from ARB's external scientific reviewers.***

12. In one of the memoranda attached to a May 2015 letter concerning the work of various external scientific reviewers retained by CARB, Dr. Clarens states as follows:

> *As written, the report states that the source must be directly consumed in the production process. But this is ambiguous in certain contexts such as those fuels that produce co-products. For example, if a corn feedstock were used to make ethanol and the stover were also used to make fuel (but was not consumed in the same production process) would that not trigger a switch from Tier 1 to Tier 2? It seems like it should but as written it might not. Clarifying this language is key for groups seeking to obtain co-product credit through the CA-LCFS.*

Despite my familiarity with the models to which Dr. Clarens is apparently referring, I am unable to determine whether Dr. Clarens believes stover is a coproduct of the corn feedstock or is a separate feedstock. Stover is not a coproduct of corn ethanol, clearly it is not. To the extent that Dr. Clarens recognizes that stover is a feedstock, I am unable to understand why or how he relates that fact to the impact of coproducts in relation to "trigger[ing] a switch from Tier 1 to Tier 2." In addition, I am unable to understand the point of confusion that Dr. Clarens perceives that would important to clarify for producers whose pathways include coproduct credits, even though I prepare pathway applications for some of those producers and am familiar with the newly proposed changes for registration and certification of ethanol pathways. I also note that Dr. Clarens appears not to know the LUC emissions factor that has been proposed for corn starch ethanol: he believes it to be 30 g/MJ, based on his memorandum. In my opinion, Dr. Clarens's memorandum demonstrates insufficient knowledge of the scientific portions of the proposed regulation to be given credibility in the scientific community as a reviewer of the LUC and CA-GREET portions of the proposed rule.

13. In the memorandum from Dr. Matthews that is attached to the May 5 letter, Dr. Matthews comments on the potential interaction between GHG emissions and emissions of volatile organic compounds and carbon monoxide. Those who work in the fields of GHG regulation and of criteria or related pollutant regulation consider such potential interactions to be minor, compared with the limitations on the effectiveness of GHG emissions regulations that do not address net emissions impact, or "leakage." The phenomenon of "fuel shuffling" -- in whch fuels that are not sold for use in California are still produced for sale elsewhere, regardless of the LCFS regulation -- is well recognized, but is not discussed in Dr. Matthews' memorandum.

14. In the draft memorandum from Dr. McCarl attached to the May 5 letter, Dr. McCarl states as follows:

> *In GTAP I believe that there also are increases in emissions from intensification (more irrigation or fertilization) so that the characterization of it only in terms of indirect land use change is not accurate.*

Dr. McCarl's belief about the contents of GTAP is not correct. There are no increases in emissions in GTAP attributed to intensification. Fertilization rates, for example are addressed in CA-GREET and not in GTAP, for purposes of ARB's lifecycle emissions analysis and standard-setting. I believe this error in Dr. McCarl's memorandum would be identified by anyone familiar with the relevant portions of the scientific basis of the proposed regulation. Although I believe Dr. McCarl to possess expertise in LUC modeling, the draft memorandum attributed to him does not demonstrate a level of familiarity with the scientific portions of the LCFS regulation on which he appears to be opining that can be considered to give the draft memorandum's opinion on those portions of the regulation credibility in the scientific community.

I declare under penalty of perjury under the laws of the State of California that the foregoing is true and correct.

Executed this 18th day of June, 2015 in Holland, Michigan.

Thomas L. Darlington

Attachment A

**Thomas L. Darlington**
President, Air Improvement Resource Inc.

## Profile

Thomas L. Darlington is President of Air Improvement Resource, a company formed in 1994 specializing in mobile source emission modeling. He is an internationally recognized expert in mobile source emissions modeling, lifecycle analysis, and land use modeling.

## Professional Experience

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|---|---|
| 1994-Present | President, Air Improvement Resource |
| 1993-1994 | Director, Mobile Source Programs, Systems Application International |
| 1989-1994 | Senior Engineer, General Motors Corporation, Environmental Activities |
| 1988-1989 | Senior Project Engineer, Detroit Diesel Corporation |
| 1979-1988 | Project Manager, U.S. EPA, Ann Arbor, Michigan |

## Recent Major Projects

- Developed Life Cycle reports and complete applications for 8 plants for the California Low Carbon Fuel Standard; six are currently registered, two plants are pending. Five plants were corn ethanol plants, one is sorghum and two are cellulose.
- Participated in and provided written comments on ARB’s three 2014 iLUC workshops
- With Purdue and Don O’Connor, conducted study of iLUC emissions of rapeseed and other oilseeds in 2013 utilizing an updated version of GTAP
- Reviewed EPA’s palm oil iLUC emissions in 2013
- Submitted comments on ARB’s new GREET2.0 model
- Reviewed CARB’s land use emissions for soybean biodiesel
- Reviewed the land use impacts of the RFS2 from EPA, including the notice of Proposed Rule, Regulatory Impact Analysis, and approximately one hundred documents in the rulemaking docket.
- Completed a land use study for Renewable Fuels Association and reviewed California Air Resource Board’s Initial Statement of Reasons for the Low Carbon Fuel Standard
- Represented three stakeholders in the recent development of the ARB Predictive Model for reformulated gasoline in California (Alliance of Automobile Manufacturers, Renewable Fuels Association and Western States Petroleum Association)
- Represented two stakeholders in EPA’s development of the MOVES on-highway emissions model (Alliance of Automobile Manufacturers and Engine Manufacturers Association)



Attachment "A"

- Developed the effects of ethanol permeation on on-highway and off-highway mobile sources in California and other states for the American Petroleum Institute
- Studied gasoline and diesel fuel options for Southeast Michigan (for SEMCOG, API and Alliance of Automobile Manufacturers)

## Recent Publications

"Study of Transportation Fuel Life Cycle Analysis: Review of Economic Models Use to Assess Land Use Effects", CRC-E-88-3, July 2014.

"Land Use Change Greenhouse Gas Emissions of European Biofuel Policies Utilizing the Global Trade Analysis Project Model", Darlington, Kahlbaum, O'Connor, and Mueller, August 30, 2013.

"A Comparison of Corn Ethanol Lifecycle Analyses: California Low Carbon Fuels Standard (LCFS) Versus Renewable Fuels Standard (RFS2)", June 14, 2010. Renewable Fuels Association and Nebraska Corn Board. This study compared and contrasted the corn ethanol lifecycle analyses performed by both CARB (as a part of the LCFS) and the EPA (as a part of RFS2).

"Review of EPA's RFS2 Lifecycle Emissions Analysis for Corn Ethanol", September 25, 2009. Conducted for Renewable Fuels Association. This study reviewed EPA's land use GHG emissions assessment for corn ethanol, including the FASOM and FAPRI models and Winrock land-use types converted and emission factors by ecosystem type. The study made many recommendations for improving the land-use and emissions modeling.

"Review of CARB's Low Carbon Fuel Standard Proposal", April 15, 2009. Conducted for Renewable Fuels Association. This study reviewed CARB's analysis of land use emissions using GTAP6 and CARB's overall lifecycle emissions for corn ethanol. This study made many recommendations for improving the land use and lifecycle emissions of corn ethanol.

"Emission Benefits of a National Clean Gasoline", August 2008. Conducted for the Alliance of Automobile Manufacturers. This study evaluated the nationwide criteria pollutant emission reductions of a national clean gasoline standard.

"Land Use Effects of Corn-Based Ethanol", February 25, 2009. Conducted for Renewable Fuels Association. This study evaluates possible land use changes and GHG emissions associated with these land use changes as a result of the renewable fuel standard mandated 15 billion gallons of corn ethanol required by calendar year 2015. The study utilized projections of land use in the US and rest of world performed by Informa Economics, LLC, as well as newer estimates of the land use credits of co-products produced by ethanol plants to evaluate possible land use changes.

"On-Road NOx Emission Rates From 1994-2003 Heavy-Duty Trucks", SAE2008-01-1299, conducted for the Engine Manufacturers Association. This study examined manufacturers consent decree emissions data to determine on-road NOx emission rates, and deterioration in emissions from heavy-duty vehicles. (Peer reviewed publication)

"Evaluation of California Greenhouse Gas Standards and Federal Energy Independence and Security Act - Part 2: CO2 and GHG Impacts", SAE2008-01-1853, conducted for the Alliance of Automobile Manufacturers. This paper evaluated the comparison of greenhouse gases from cars and light trucks in the US under both the Federal and California GHG policies. (Peer reviewed publication)

"Effectiveness of the California Light Duty Vehicle Regulations as Compared to Federal Regulations", June 15, 2007. Conducted with NERA Economic Consulting and Sierra Research for The Alliance of Automobile Manufacturers. This study compares the emission benefits of the California and Federal light duty vehicle regulations for HC, CO, NOx, PM, SOx, and Toxics taking into account the difference in emission standards, new vehicle costs and its effect on fleet turnover, new vehicle fuel economy and its effect on vehicle miles traveled, and other factors. Both the EPA MOBILE6 and ARB EMFAC on-road emissions models were used to estimate changes in emissions inventories.

"The Case for a Dual Tech 4 Model Within the California Predictive Model", May 20, 2007. Conducted with ICF International and Transportation Fuels Consulting for the Renewable Fuels Association (RFA). This study developed separate emissions vs fuel property models for lower and higher Tech 4 (1986-1995) vehicles, and showed that utilizing this alternative Predictive Model would result in a higher compliance margin for fuels containing higher volumes of ethanol. It was thought that this could lead to higher ethanol concentrations in the state, but even if the dual model is not used, it is a better representation of the 2015 inventory than the ARB single model.

"Updated Final Report, Effects of Gasoline Ethanol Blends on Permeation Emissions Contribution to VOC Inventory From On-Road and Off-Road Sources, Inclusion of E-65 Phase 3 Data and Other Updates", June 20, 2007. Conducted for the American Petroleum Institute. This report updates the earlier March 3, 2005 report for API utilizing data collected by CRC and others since of the time of the earlier report.

Final Report, Development of Technical Information for a Regional Fuels Strategy, February 28, 2006. Conducted for the Lake Air Directors Consortium (LADCO). This report provided guidance to the LADCO states (Midwestern states) concerning how to model different types of fuel control programs (in particular) using EPA mobile source models, and how to set up the baseline input files so that results are consistent between the different states.

"Emission Reductions from Changes to Gasoline and Diesel Specifications and Diesel Engine Retrofits in the Southeast Michigan Area", February 23, 2005. Conducted for the Southeast Michigan Council of Governments (SEMCOG), the Alliance of Automobile Manufacturers, and the American Petroleum Institute. This study examined the on-road and off-road emission benefits of many different possible gasoline and diesel fuel specifications that the state could adopt to help meet the 8-hour ozone standards. This study formed the basis for the state's move to lower RVP summer gasoline.

"Examination of Temperature and RVP Effects on CO Emissions in EPA's Certification Database, Final Report", CRC Project No. E-74a, April 11, 2005. Conducted for the Coordinating Research Council. This study compared CO vs temperature results from the MOBILE6 model to the certification data, and recommended further testing, which is being conducted by the CRC at this time.

"Effects of Gasoline Ethanol Blends on Permeation Emissions Contribution to VOC Inventory From On-Road and Off-Road Sources" March 3, 2005. Conducted for the American Petroleum Institute (API). Using data from the CRC-E-65 program, and data collected by the California EPA and Federal EPA, this study estimated the impacts of ethanol use on increasing permeation VOC emissions from on-road vehicles, off-road equipment and vehicles, and from portable containers. Emission inventory estimates were made for a number of geographical areas including the state of California, and results showed that the permeation effect increases anthropogenic VOC inventories by 2-4%.

Review of EPA Report "A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions", February 11, 2003. Conducted for the American Petroleum Institute. This study critically examined the methods that EPA used to develop the impacts of biodiesel fuels on HC, CO, NOx, and PM emissions.

"Well-To Wheels Analysis of Advanced Fuel/Vehicle Systems – A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions", May 2005. Conducted for General Motors Corporation, with Argonne National Labs. This study examined many different well to wheels pathways for various fuels, and their impacts on GHG and criteria pollutant emissions.

"Potential Delaware Air Emission Impacts of Switching From MTBE to Ethanol in the Reformulated Gasoline Program", May 26, 2005. Conducted for Lyondell Chemical Company. This study examined the HC, CO, and NOx impacts of switching from MTBE to ethanol.

"Potential Massachusetts Air Emission Impacts of Switching From MTBE to Ethanol in the Reformulated Gasoline Program" June 17, 2005. Conducted for Lyondell Chemical Company. This study is similar to the Delaware study above.

"Potential Maryland Air Emission Impacts of a Ban on MTBE in the Reformulated Gasoline Program", October 18, 2005. Conducted for Lyondell Chemical Company. This study is similar to the Delaware study above.

"MOBILE6.2C with Ethanol Permeation and Ethanol NOx Effects", February 8, 2005. Conducted for Health Canada. This study modified the MOBILE6.2C model for ethanol permeation VOC and ethanol NOx effects.

## Education

B. Sc., (Materials and Metallurgical Engineering), University of Michigan, Ann Arbor, 1979
Post Graduate Courses (Business Administration), University of Michigan, Ann Arbor, 1982

Attachment B

# Discussion of the Yield Price Elasticity in GTAP

Farzad Taheripour and Wallace E. Tyner
Purdue University

At the March 11, 2014 CARB meeting, there was considerable interest in the yield to price elasticity parameter in GTAP. There also seemed to be a good bit of confusion on what it does and does not do. The purpose of this note is to provide an explanation of the role of this parameter in GTAP, explain why it is there, and to explain other reasons why yields can change in GTAP.

First, the basic idea behind the parameter is that over the medium to long term (the time horizon of GTAP), one would expect the agricultural sector to respond to increases in net returns to crops with appropriate investments in improving yields of crops with growing returns. This investment is certainly not limited to on-farm investment. In fact, a major portion of it may occur off-farm. It could include investments by seed companies to produce higher yielding seeds, investments in chemical companies to produce better herbicides/pesticides, investments by farm equipment companies to produce more efficient machinery for cultivation and harvest, investments by farmers to improve drainage and other soil properties, and other productivity enhancing investments. In other words, this parameter attempts to capture responses throughout the agricultural sector to higher returns in given crops.

The yield to price elasticity does not measure changes over one crop year. In fact, any estimate done over one year would be totally inappropriate for GTAP and should be excluded from consideration in determining appropriate values for the parameter.

What is the precise definition of the yield to price elasticity (YDEL)? YDEL is the percentage change in intensive yield over the percentage changes in relative price of a crop over input prices. In other words it is the intensive yield change with respect to change in variable returns to a crop. If the YDEL value is 0.25, and the change in variable returns of a crop is 10%, then the change in intensive yield would be 2.5%. It is very important to emphasize that the parameter YDEL only governs changes in intensive yield due the changes in net return. Other factors can affect crop yields as well.

How else can yields change in GTAP? Yields are affected by changes on the intensive and extensive margins. As noted in Hertel et al. (2010), there are two important sources which affect the extensive margin of yields. The first source is due to shifting among crops. For example, shifting from corn-soybean rotation to corn-corn rotation could affect yield. The second source of change in extensive yield is due to land conversion from forest or pasture to cropland. In the first case, if there is a corn ethanol shock applied to the model, more corn will be demanded, and there likely will be both crop switching and land cover changes to accommodate the higher demand for corn. With crop switching, there will be more acres of corn and fewer acres of other lower yielding crops. Thus, when one calculates the weighted average yields after the shock, the average likely would be higher. For example, consider typical corn, soybean, and wheat yields of 4.5, 1.2, and 1.7 tons/ac respectively. If the post shock crop mix has more corn acreage, the post shock

Attachment "B"

weighted average yields can be higher even if YDEL were zero. That is simply because corn has a higher mass yield per acre.

Yields can also change when more or less productive acres come into corn from other uses. Crop switching can result in higher or lower productivity. However, land cover changes from pasture or forest typically tends to reduce yields because new land could be lower productivity. The productivity of converted land is affected by the ETA parameter.

Since GTAP is a CGE model, yields can also be influenced by a myriad of other changes such as changes in relative price of variable inputs. The bottom line is that while yields can be and are affected by many factors working in GTAP, the YDEL parameter is only designed to capture the incentive to invest over the medium term in crops with increasing returns.

It is not correct to divide the weighted average of percentage changes in crop yields by the weighted average of percent changes in crop prices as was done in the CARB presentation. This calculation incorporates area changes as well as yield changes. One must take into account percentage changes in variable costs of production as well. The calculated value from the CARB presentation of 0.39 for yield to price elasticity for US for the corn ethanol expansion is meaningless because it includes many factors. If we follow the CARB approach and calculate the same measure for Brazil due to the US corn ethanol shock, we get a yield to price elasticity of -0.16 for Brazil, which obviously does not make sense. Furthermore, CARB has ignored the fact that the yield to price ratio only cover the percentage change in intensive yield not total yield. In their calculations, percentage changes in total yield instead of intensive yield were used.

Attachment C

**Statistical Issues Related to the Low-Carbon Fuel Standard**
**Submitted by**
**David M. Rocke, PhD**
**October 31, 2014**
**Under contract 13-405 (2014)**

## Analysis of Simulations for ILUC

Two separate simulation methodologies were employed by CARB to help determine factors to which Indirect Land Use Change (iLUC) is sensitive. The iLUC impact of biofuels relates to the unintended increase of carbon emissions due to land-use changes around the world induced by the expansion of croplands for production of biofuels such as ethanol in response to the increased global demand for these fuels. If more biofuels are needed, in general the price of the feedstock would rise compared to other uses of the land. This in turn may result in forests or other uncropped land being converted to agricultural use. Because natural lands, such as rainforests and grasslands, store carbon in their soil and in biomass as plants grow each year, clearance of wilderness for new farms translates to a net increase in greenhouse gas emissions. Due to this change in the carbon stock of the soil and the biomass, indirect land use change has consequences in the greenhouse-gas emissions balance of a biofuel.

Both sets of simulations are based on the Global Trade Analysis Project (GTAP) database and the Agro-ecological Zone Emission Factor (AEZ-EF) Model. One method was to use varying specific values of some parameters as sensitivity analysis. For example, this could consist of YDEL, the price elasticity of yield, ETL1, the elasticity of transformation between forest, cropland, and pasture, ETL2, the elasticity of transformation among crops, PAEL_US, the yield elasticity for cropland/pasture in the US, and PAEL_Brazil, yield elasticity for cropland/pasture in Brazil. The other simulation method used the Monte Carlo methodology in which values for a large number of parameters were chosen at random repeatedly.

In order to determine the most influential factors, we conducted a statistical analysis of the iLUC factor for corn ethanol in terms of the input variables in a simulation with 600 variables and 3,000 trials. This was done using stepwise regression, but since all the parameters were chosen independently in the Monte Carlo (except CDGC and CDGS, which were highly correlated), the coefficient estimates were almost orthogonal, so the results of a single analysis of the 600 variable model would have been very similar, except for CDGC and CDGS. Table 1 gives the results of this analysis. The most influential factors in terms of contribution to the sum of squares were YDEL, the price elasticity of yield, the ESBV parameters, the elasticity of substitution between primary input factors in production, ETA, the elasticity of effective hectares with respect to harvested area, and ETL1, the elasticity of transformation among crops.



Attachment "C"

Table 1. Statistical Analysis of Corn Ethanol ILUC Factor in a Monte Carlo Simulation

Response: ilucFactor

| | Df | Sum Sq | Mean Sq | F value | Pr(>F) | |
|---|---|---|---|---|---|---|
| ESBV.11.0. | 1 | 68324 | 68324 | 4989.7281 | < 2.2e-16 | *** |
| YDEL | 1 | 65612 | 65612 | 4791.7008 | < 2.2e-16 | *** |
| ETA | 1 | 37960 | 37960 | 2772.2342 | < 2.2e-16 | *** |
| ESBV.13.0. | 1 | 17097 | 17097 | 1248.6237 | < 2.2e-16 | *** |
| ETL1 | 1 | 13970 | 13970 | 1020.2320 | < 2.2e-16 | *** |
| CDGC | 1 | 13886 | 13886 | 1014.0667 | < 2.2e-16 | *** |
| croplandPastureEmissionRatio | 1 | 7214 | 7214 | 526.8437 | < 2.2e-16 | *** |
| ESBV.12.0. | 1 | 4978 | 4978 | 363.5544 | < 2.2e-16 | *** |
| N2O_N_EF | 1 | 2975 | 2975 | 217.2690 | < 2.2e-16 | *** |
| PAEL.3.0. | 1 | 2268 | 2268 | 165.6035 | < 2.2e-16 | *** |
| pastureSoil_C.0.1. | 1 | 2089 | 2089 | 152.5737 | < 2.2e-16 | *** |
| croplandSoil_C | 1 | 2034 | 2034 | 148.5450 | < 2.2e-16 | *** |
| youngStandAglb | 1 | 1471 | 1471 | 107.4001 | < 2.2e-16 | *** |
| SUBP.0.18. | 1 | 1356 | 1356 | 98.9945 | < 2.2e-16 | *** |
| EFED | 1 | 946 | 946 | 69.0674 | < 2.2e-16 | *** |
| SUBP.0.1. | 1 | 874 | 874 | 63.8461 | 1.934e-15 | *** |
| totalTree_C.0.4. | 1 | 890 | 890 | 64.9935 | 1.094e-15 | *** |
| croplandLandUseFactor.5.0. | 1 | 752 | 752 | 54.9003 | 1.661e-13 | *** |
| PAEL.1.0. | 1 | 694 | 694 | 50.7027 | 1.354e-12 | *** |
| SUBP.0.2. | 1 | 644 | 644 | 47.0584 | 8.416e-12 | *** |
| totalTree_C.0.1. | 1 | 627 | 627 | 45.8145 | 1.572e-11 | *** |
| carbonNitrogenRatio | 1 | 639 | 639 | 46.6822 | 1.016e-11 | *** |
| SUBP.0.3. | 1 | 562 | 562 | 41.0261 | 1.751e-10 | *** |
| deadwoodByLatitude_C.3.1. | 1 | 525 | 525 | 38.3264 | 6.844e-10 | *** |
| croplandLandUseFactor.10.0. | 1 | 488 | 488 | 35.6556 | 2.646e-09 | *** |
| deadwoodByRegion_C.4.1. | 1 | 515 | 515 | 37.5940 | 9.912e-10 | *** |
| deadwoodByRegion_C.1.1. | 1 | 473 | 473 | 34.5168 | 4.715e-09 | *** |
| totalTree_C.0.2. | 1 | 385 | 385 | 28.1390 | 1.215e-07 | *** |
| forestSoil_C.0.18. | 1 | 383 | 383 | 27.9501 | 1.339e-07 | *** |
| forestSoil_C.0.4. | 1 | 367 | 367 | 26.8051 | 2.407e-07 | *** |
| oldStandAglb | 1 | 313 | 313 | 22.8335 | 1.856e-06 | *** |
| pastureSubsoilLossFraction | 1 | 323 | 323 | 23.5576 | 1.277e-06 | *** |
| totalTree_C.0.18. | 1 | 253 | 253 | 18.4775 | 1.777e-05 | *** |
| croplandLandUseFactor.6.0. | 1 | 246 | 246 | 17.9905 | 2.291e-05 | *** |
| forestLitter_C.10.1. | 1 | 218 | 218 | 15.9474 | 6.677e-05 | *** |
| pastureAgb.6.0. | 1 | 211 | 211 | 15.4370 | 8.732e-05 | *** |
| understory_C | 1 | 202 | 202 | 14.7871 | 0.0001230 | *** |
| GWP_N2O | 1 | 177 | 177 | 12.9423 | 0.0003267 | *** |
| pastureSoil_C.0.19. | 1 | 175 | 175 | 12.8020 | 0.0003520 | *** |
| ETL2 | 1 | 171 | 171 | 12.4815 | 0.0004175 | *** |
| EPSR | 1 | 170 | 170 | 12.3870 | 0.0004391 | *** |
| foregoneGrowthRate | 1 | 152 | 152 | 11.1033 | 0.0008727 | *** |
| croplandLandUseFactor.4.0. | 1 | 149 | 149 | 10.8470 | 0.0010016 | ** |
| ESBM.4.0. | 1 | 143 | 143 | 10.4288 | 0.0012547 | ** |
| ESBM.2.0. | 1 | 124 | 124 | 9.0317 | 0.0026764 | ** |
| ESBV.25.0. | 1 | 119 | 119 | 8.7089 | 0.0031924 | ** |
| pastureSoil_C.0.12. | 1 | 115 | 115 | 8.4070 | 0.0037663 | ** |
| pastureSoil_C.0.3. | 1 | 117 | 117 | 8.5596 | 0.0034642 | ** |
| ESBV.30.0. | 1 | 105 | 105 | 7.6970 | 0.0055672 | ** |
| forestLitter_C.15.1. | 1 | 108 | 108 | 7.8711 | 0.0050571 | ** |
| ELEN.9.0. | 1 | 102 | 102 | 7.4502 | 0.0063818 | ** |

| | | | | | | |
|---|---|---|---|---|---|---|
| ELEN.26.0. | 1 | 103 | 103 | 7.5010 | 0.0062047 | ** |
| cropCarbonAnnualizationFactor | 1 | 87 | 87 | 6.3746 | 0.0116303 | * |
| ELEG.19.0. | 1 | 88 | 88 | 6.4184 | 0.0113473 | * |
| pastureSubsoil_C.0.1. | 1 | 86 | 86 | 6.2890 | 0.0122040 | * |
| forestLitter_C.13.1. | 1 | 86 | 86 | 6.2485 | 0.0124856 | * |
| ELNC.16.0. | 1 | 83 | 83 | 6.0512 | 0.0139554 | * |
| ESBM.46.0. | 1 | 76 | 76 | 5.5190 | 0.0188785 | * |
| forestLitter_C.9.1. | 1 | 72 | 72 | 5.2607 | 0.0218848 | * |
| SUBP.0.13. | 1 | 76 | 76 | 5.5662 | 0.0183778 | * |
| pastureSoil_C.0.8. | 1 | 72 | 72 | 5.2931 | 0.0214824 | * |
| ELEN.2.0. | 1 | 71 | 71 | 5.1593 | 0.0231958 | * |
| totalTree_C.0.6. | 1 | 65 | 65 | 4.7814 | 0.0288496 | * |
| ESBV.2.0. | 1 | 68 | 68 | 4.9825 | 0.0256817 | * |
| ELEG.3.0. | 1 | 65 | 65 | 4.7447 | 0.0294704 | * |
| ELKE.10.0. | 1 | 68 | 68 | 4.9421 | 0.0262881 | * |
| deforestedFraction.11.0. | 1 | 64 | 64 | 4.6579 | 0.0309946 | * |
| ELNE.7.0. | 1 | 63 | 63 | 4.6191 | 0.0317009 | * |
| croplandLandUseFactor.15.0. | 1 | 64 | 64 | 4.6402 | 0.0313146 | * |
| forestRootShootRatio | 1 | 63 | 63 | 4.5786 | 0.0324578 | * |
| deadwoodByRegion_C.18.1. | 1 | 59 | 59 | 4.2837 | 0.0385692 | * |
| deforestedFraction.8.0. | 1 | 59 | 59 | 4.2987 | 0.0382306 | * |
| ELKE.37.0. | 1 | 57 | 57 | 4.1496 | 0.0417355 | * |
| pastureSubsoil_C.0.3. | 1 | 57 | 57 | 4.1742 | 0.0411345 | * |
| ELEN.29.0. | 1 | 57 | 57 | 4.1843 | 0.0408909 | * |
| pastureSoil_C.0.18. | 1 | 58 | 58 | 4.2081 | 0.0403236 | * |
| deforestedFraction.13.0. | 1 | 55 | 55 | 4.0201 | 0.0450553 | * |
| hwpFraction.9.0. | 1 | 52 | 52 | 3.7859 | 0.0517839 | . |
| forestLandUseFactor.11.0. | 1 | 52 | 52 | 3.7882 | 0.0517122 | . |
| forestSoil_C.0.13. | 1 | 52 | 52 | 3.7649 | 0.0524376 | . |
| ELNE.22.0. | 1 | 48 | 48 | 3.4933 | 0.0617215 | . |
| totalTree_C.0.12. | 1 | 51 | 51 | 3.7565 | 0.0527010 | . |
| ESBM.41.0. | 1 | 49 | 49 | 3.5807 | 0.0585568 | . |
| ELHL | 1 | 48 | 48 | 3.5264 | 0.0605018 | . |
| croplandLandUseFactor.3.0. | 1 | 47 | 47 | 3.4426 | 0.0636396 | . |
| forestLitter_C.17.1. | 1 | 46 | 46 | 3.3286 | 0.0681885 | . |
| ELNC.13.0. | 1 | 45 | 45 | 3.2580 | 0.0711825 | . |
| ELNE.4.0. | 1 | 43 | 43 | 3.1227 | 0.0773172 | . |
| ESBV.1.0. | 1 | 44 | 44 | 3.1827 | 0.0745296 | . |
| ELNC.19.0. | 1 | 43 | 43 | 3.1486 | 0.0760975 | . |
| forestSoil_C.0.11. | 1 | 42 | 42 | 3.0762 | 0.0795527 | . |
| SUBP.0.4. | 1 | 44 | 44 | 3.1855 | 0.0743993 | . |
| ELEG.2.0. | 1 | 42 | 42 | 3.0802 | 0.0793588 | . |
| PAEL.11.0. | 1 | 41 | 41 | 3.0253 | 0.0820827 | . |
| ELNC.5.0. | 1 | 41 | 41 | 2.9984 | 0.0834557 | . |
| forestBurningEF | 1 | 41 | 41 | 2.9782 | 0.0844994 | . |
| ELKE.15.0. | 1 | 42 | 42 | 3.0370 | 0.0814919 | . |
| pastureSubsoil_C.0.8. | 1 | 39 | 39 | 2.8725 | 0.0902161 | . |
| ESBM.16.0. | 1 | 39 | 39 | 2.8535 | 0.0912852 | . |
| croplandLandUseFactor.1.0. | 1 | 42 | 42 | 3.0817 | 0.0792853 | . |
| ELKE.1.0. | 1 | 39 | 39 | 2.8257 | 0.0928772 | . |
| deforestedFraction.7.0. | 1 | 37 | 37 | 2.7211 | 0.0991387 | . |
| ELVL | 1 | 37 | 37 | 2.7172 | 0.0993831 | . |
| forestSubsoil_C.0.8. | 1 | 39 | 39 | 2.8846 | 0.0895377 | . |
| forestSubsoil_C.0.18. | 1 | 37 | 37 | 2.7202 | 0.0991942 | . |
| ELNE.24.0. | 1 | 39 | 39 | 2.8418 | 0.0919521 | . |
| ELEN.4.0. | 1 | 40 | 40 | 2.9344 | 0.0868207 | . |
| ELNE.6.0. | 1 | 37 | 37 | 2.7386 | 0.0980619 | . |

| | | | | | |
|---|---|---|---|---|---|
| forestSoilLossFraction | 1 | 35 | 35 | 2.5360 | 0.1113837 |
| forestLandUseFactor.3.0. | 1 | 36 | 36 | 2.6196 | 0.1056590 |
| ELEG.7.0. | 1 | 33 | 33 | 2.3757 | 0.1233479 |
| ELKE.36.0. | 1 | 32 | 32 | 2.3144 | 0.1282875 |
| ESBM.33.0. | 1 | 36 | 36 | 2.6437 | 0.1040686 |
| ELNC.26.0. | 1 | 35 | 35 | 2.5444 | 0.1107993 |
| ELEN.6.0. | 1 | 36 | 36 | 2.5966 | 0.1072009 |
| ELNE.34.0. | 1 | 32 | 32 | 2.3068 | 0.1289195 |
| PAEL.6.0. | 1 | 32 | 32 | 2.3672 | 0.1240167 |
| ESBV.28.0. | 1 | 32 | 32 | 2.3410 | 0.1261183 |
| pastureAgb.10.0. | 1 | 37 | 37 | 2.6804 | 0.1017002 |
| ELNE.16.0. | 1 | 33 | 33 | 2.3810 | 0.1229333 |
| forestSubsoil_C.0.14. | 1 | 31 | 31 | 2.2673 | 0.1322385 |
| pastureSoil_C.0.16. | 1 | 33 | 33 | 2.3782 | 0.1231485 |
| ELHB | 1 | 33 | 33 | 2.3743 | 0.1234546 |
| ELNC.1.0. | 1 | 33 | 33 | 2.3922 | 0.1220537 |
| ELKE.18.0. | 1 | 35 | 35 | 2.5512 | 0.1103183 |
| ELNC.17.0. | 1 | 30 | 30 | 2.1732 | 0.1405476 |
| ESBV.19.0. | 1 | 31 | 31 | 2.2578 | 0.1330512 |
| ELEN.31.0. | 1 | 33 | 33 | 2.4252 | 0.1195113 |
| pastureAgb.12.0. | 1 | 30 | 30 | 2.1670 | 0.1411076 |
| ELKE.34.0. | 1 | 33 | 33 | 2.4155 | 0.1202515 |
| ELNE.33.0. | 1 | 32 | 32 | 2.3370 | 0.1264439 |
| ELNE.32.0. | 1 | 32 | 32 | 2.3271 | 0.1272524 |
| ESBM.22.0. | 1 | 32 | 32 | 2.3090 | 0.1287354 |
| ELKE.41.0. | 1 | 30 | 30 | 2.2042 | 0.1377488 |
| SUBP.0.5. | 1 | 34 | 34 | 2.4534 | 0.1173836 |
| ELNC.2.0. | 1 | 31 | 31 | 2.2766 | 0.1314507 |
| ELNE.14.0. | 1 | 28 | 28 | 2.0659 | 0.1507380 |
| ELEN.7.0. | 1 | 28 | 28 | 2.0718 | 0.1501589 |
| forestSubsoil_C.0.11. | 1 | 31 | 31 | 2.2497 | 0.1337495 |
| ELNE.18.0. | 1 | 31 | 31 | 2.2353 | 0.1350028 |
| ELNE.17.0. | 1 | 27 | 27 | 1.9797 | 0.1595262 |
| ELNC.14.0. | 1 | 29 | 29 | 2.1052 | 0.1469068 |
| deforestedFraction.1.0. | 1 | 29 | 29 | 2.0978 | 0.1476215 |
| ELEG.11.0. | 1 | 28 | 28 | 2.0785 | 0.1494954 |
| ESBM.21.0. | 1 | 28 | 28 | 2.0808 | 0.1492744 |
| Residuals | 2854 | 39080 | 14 | | |

---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

**Price Elasticity of Yield (YDEL)**

In view of the importance of YDEL in the analysis, and in view of the conflicting results in the literature on its likely size, the next part of the project undertaken was to analyze one of the data sets upon which these estimates have been based. The data were used in a 2012 dissertation of Juan Francisco Rosas Pérez (also given as Juan Francisco Rosas in a 2014 paper by Rosas, Hayes, and Lence, apparently taken from the dissertation). In these works, the price elasticity of yield was estimated from data on corn (maize) in Iowa for 1960–2004, and was said to be in the range of 0.29. The data set was publicly available so it was used for a re-analysis. The analysis used by Rosas Pérez, was complex, and can be criticized for insufficiently handling autocorrelation in the series. Therefore, a simpler analysis was conducted that should have similar results to the more complex analysis if the latter is not flawed.

The data set used was the one supplied with the Rosas Pérez dissertation, though there is no good data dictionary and the meaning of some of the statistics was less than clear. The most clearly relevant variables were a corn price index series (here called corn.price) and a corn supply index series (corn.supply) and their natural logarithms (lcorn.price and lcorn.supply). There do not seem to be good data on land devoted to corn, or perhaps land at all, since the variable Z4 = Q Land is equal to 1 for all years, so this analysis was aimed at the price elasticity of supply not the price elasticity of yield; this would tend to overestimate the effect of price on supply given that land substitution is often an easier response to greater potential profit from a crop than is attempting to increase yield.

The quantity of interest then would be the ratio of the percentage change in supply to the percentage change in price. Roughly, the percentage change is equal to the actual change on the natural log scale. For example (110 – 100)/100 = 0.10 while log(110) – log(100) = 0.0953, so we will proceed to relate the change on the log scale of supply to the change on the log scale of price.

Without participating in debates about the proper functional form of multi-equation models of the agricultural economy, we can go back to statistical basics using the following principles:

1. All other things being equal, the price elasticity of supply can be estimated by regressing log(supply) on log(price).
2. In regressions with autocorrelated time series, it is important to account for the self-effects of the series being predicted before asking if another series has an effect. This is sometimes called Granger causality analysis.

In fact, both series are autocorrelated in a plausibly autoregressive way, with the ACF function declining slowly and the PACF function dropping of more quickly (see Figures 1 and 2 for the supply series later in the document). As can be seen from the output in Table 2, there is no significant relationship of supply to current or past prices after accounting for last year's supply. In fact, the estimated coefficients are not even positive.

While there may exist alternative explanations of these results with respect to omitted factors, it is hard to find such modeling aspects that provide effects in the direction of reducing the apparent response of supply to price and that themselves could explain a large elasticity that is so hidden. The best interpretation of these results is that

1. The price elasticity of yield implied by the Iowa corn data is likely close to 0 and very unlikely to be as large as 0.10 or 0.20.
2. The results obtained by Rosas Pérez showing an apparently higher elasticity is likely caused by mishandling the autocorrelation in the time series.

As documented in Berry (2011), Berry and Schlenker (2011), and Roberts and Schlenker (2013), much of the literature providing purported estimates of the price elasticity of yield is deeply methodologically flawed. In addition to the problems of endogeneity and autocorrelation that are badly handled, there are other important issues. In Goodwin, Michele Marra, Piggott, and Mueller (2012), for example, 15 years of data are multiplied into 405 data points by considering 27 different districts. But there are still only 15 price values and it is hard to believe that the strong relationships of weather, price, and technology within a given year can be handled by econometric tricks. The analyses, such as those in Roberts and Schlenker (2013), that are methodologically sound all show small to zero price elasticities of yield.

**Table 2. Regression Analysis for Price Elasticity of Supply for Iowa Corn**

```
> anova(lm(lcorn.supply~lcorn.supply1+lcorn.price+lcorn.price1))

Analysis of Variance Table

Response: lcorn.supply
              Df  Sum Sq Mean Sq F value    Pr(>F)
lcorn.supply1  1 1.58085 1.58085 30.5328 2.191e-06 ***
lcorn.price    1 0.00558 0.00558  0.1078    0.7444
lcorn.price1   1 0.01618 0.01618  0.3125    0.5793
Residuals     40 2.07103 0.05178
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> anova(lm(lcorn.supply~lcorn.supply1+lcorn.price+lcorn.price1
           +lcorn.price2))

Analysis of Variance Table

Response: lcorn.supply
              Df  Sum Sq Mean Sq F value    Pr(>F)
lcorn.supply1  1 1.39173 1.39173 26.6904 7.889e-06 ***
lcorn.price    1 0.00466 0.00466  0.0894    0.7666
```

```
lcorn.price1   1 0.01436 0.01436  0.2755    0.6027
lcorn.price2   1 0.07523 0.07523  1.4428    0.2371
Residuals     38 1.98145 0.05214
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> summary(lm(lcorn.supply~lcorn.supply1+lcorn.price+lcorn.price1))

Call:
lm(formula = lcorn.supply ~ lcorn.supply1 + lcorn.price +
lcorn.price1)

Residuals:
     Min       1Q   Median       3Q      Max
-0.64342 -0.11119  0.01966  0.14210  0.52123

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)    0.71117    0.24967   2.848  0.00691 **
lcorn.supply1  0.62929    0.13427   4.687 3.19e-05 ***
lcorn.price   -0.02265    0.23289  -0.097  0.92301
lcorn.price1  -0.12364    0.22116  -0.559  0.57925
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.2275 on 40 degrees of freedom
  (1 observation deleted due to missingness)
Multiple R-squared:  0.4362,    Adjusted R-squared:  0.394
F-statistic: 10.32 on 3 and 40 DF,  p-value: 3.676e-05
```

**Figure 1. Autocorrelation of Corn Supply in Iowa**

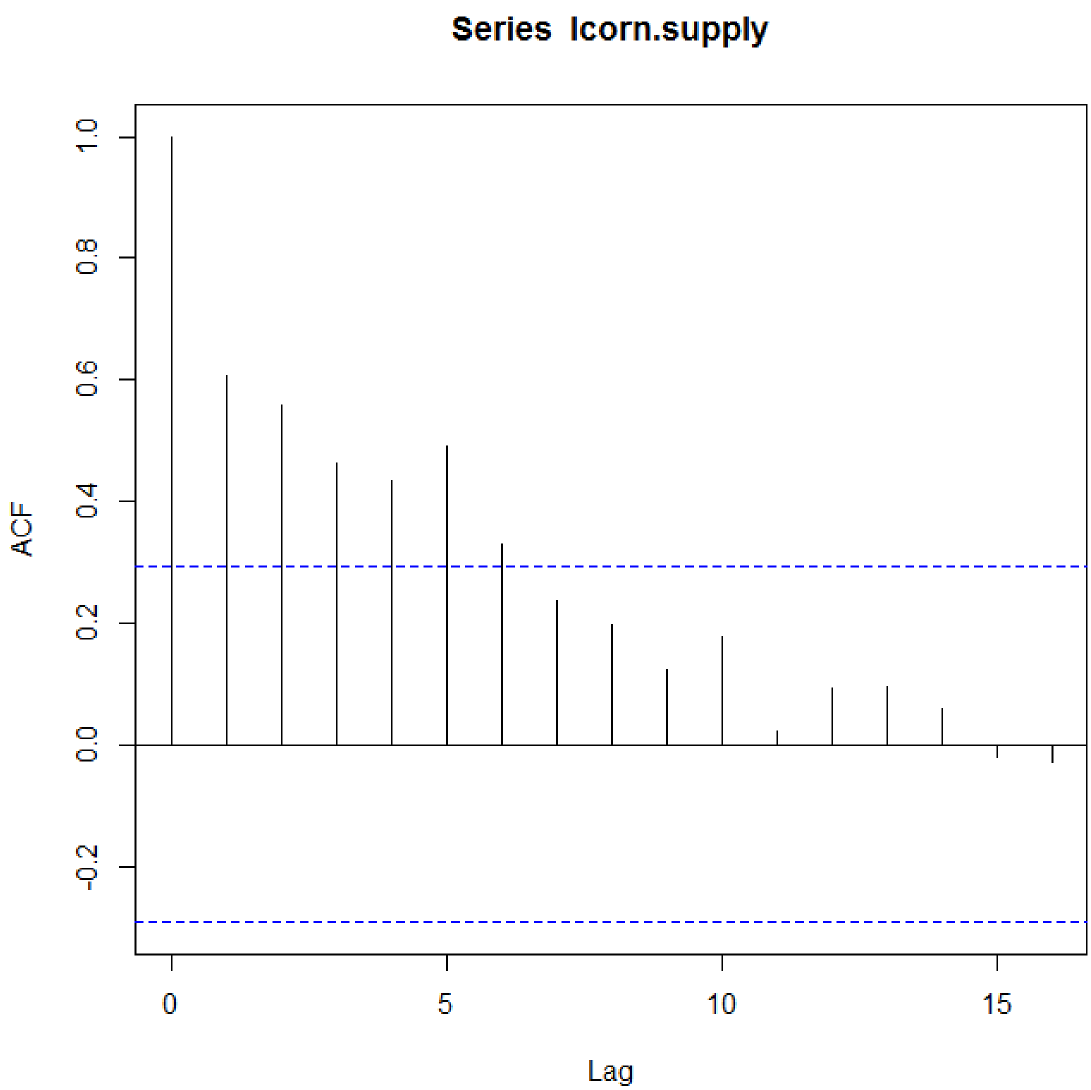
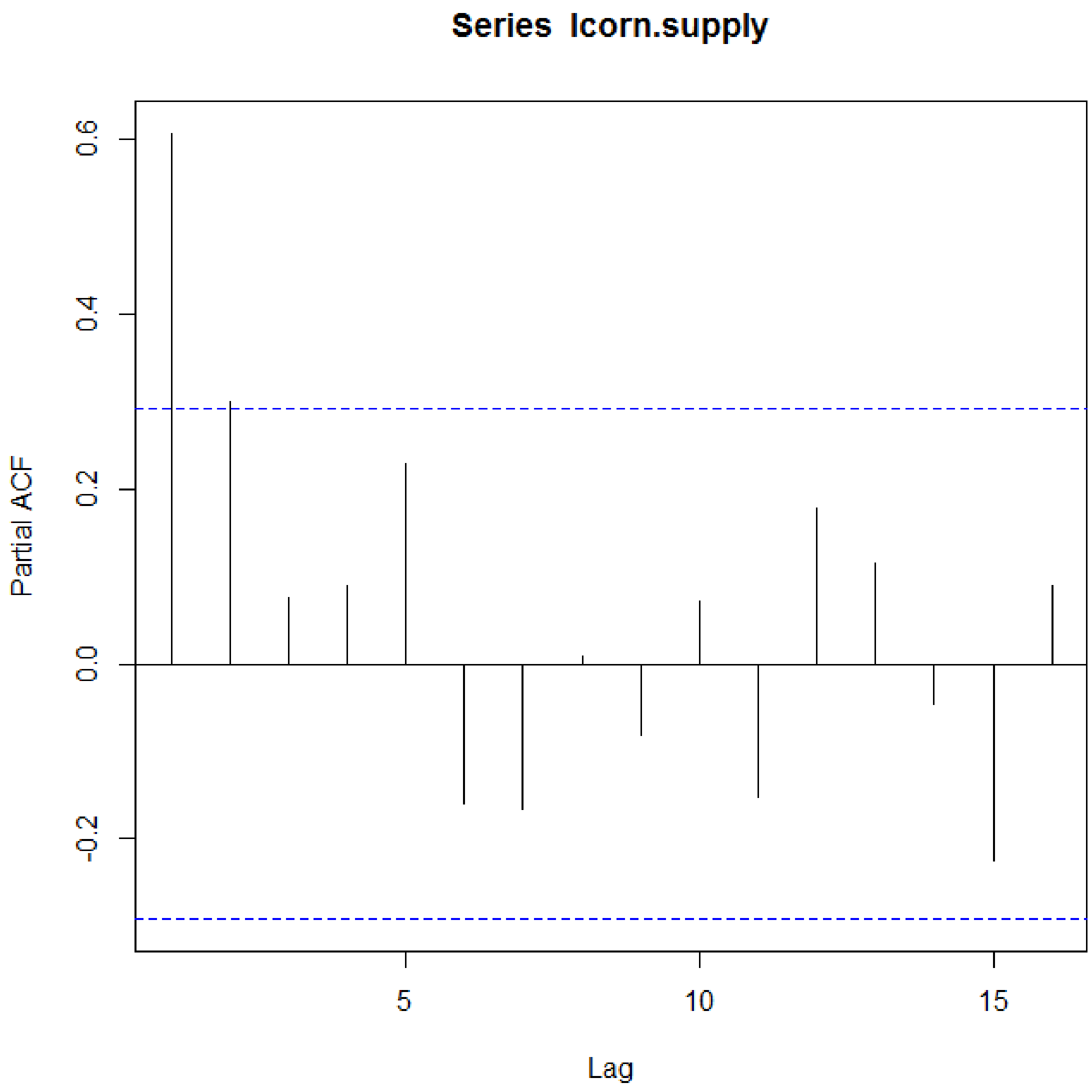


**Figure 2. Partial Autocorrelation of Corn Supply in Iowa**



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