Technical Report for the ICCT: Empirical Evidence on Crop Yield Elasticities

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1 Introduction

This technical note addresses an important empirical issue in the study of bio-fuels and indirect land use. Incremental crops used by the bio-fuel industry are provided by some combination of decreased demand and increased production. That increased production, in turn, results from some combination of increased yields and increased land use. Because of the potentially large carbon costs of increased agricultural land use, the "indirect land use change" (ILUC) from bio-fuels has been the subject of increasing study and policy concern, beginning with the pioneering study of Searchinger, Heimlich, Houghton, Dong, Elobeid, Fabiosa, Tokgoz, Hayes, and Yu (2008). If higher prices drive higher crops yields, the amount of indirect land use associated with bio-fuel production will be reduced. In general, indirect land use change will be larger the larger the land-price elasticity and the lower the yield-price elasticity. This leads to an important policy interest in the yield-price elasticity of crop production.

Our report provides direct empirical evidence on crop yield-price (and land-price) elasticities. These are critically important quantities in any attempt to simulate the effect of the massive bio-fuel policies that are presently implemented and/or under consideration around the world. The present report has a tight empirical focus and should be read in the context of Berry's earlier report to CARB, the California Air Resources Board (Berry 2011).

We use an instrumental variables empirical approach that builds closely on the work of Roberts and Schlenker (2010) and Roberts and Schlenker (2009), who propose the use of *last year*'s yield shock as an instrument that effectively shifts the demand for new production while being uncorrelated with the current year's supply shock. We estimate yield-price elasticities using an updated and improved version of their dataset and making use of a broader set of instrumental variables that potentially account for serially correlated unobserved shocks to yields. Our estimates of yield-price elasticities are close to zero. This is consistent with existing literature that finds low yield-price elasticities (see the literature review in Berry (2011), referring particularly to that report's Table 1 and Figure 1.) However, as compared to most of the prior literature, our improved approach allows for somewhat more precise and credible yield-elasticity estimates.

Our research firmly indicates that yield elasticities for US crops are close to zero. However, note that these are *net* yield elasticities. When output prices rise there are two opposing effects. First, yields on existing land might rise. Second, new land is called into production and this land could have different yield characteristics as compared to previously farmed land. Our empirical "net yield" elasticity estimates combine both effects. A finding of near-zero net yield elasticities is consistent with, for example, a world that features [i] a clearly positive yield elasticity that applies to existing farm land, together with [ii] a substantial farm land-use price elasticity and [iii] incremental farm land that is less productive than existing land. The increased yield on existing land could be offset by the lower yield on "new land."

While we don't have an estimate for a price-yield elasticity, we have estimates for the area-price elasticity. Given an estimate for the productivity of marginal land, we can then back out an implied yield-price elasticity for non-marginal land. For example, suppose that the ratio of the productivity of marginal land to the productivity of existing land is 0.66. In this case, our preferred estimates imply a yield-price elasticity for non-marginal land that is no higher than roughly 0.1.

As with any empirical results, there is uncertainty in our estimates due to sampling error. Additional research and better data would always be valuable. However, policy-makers often need guidance as to the best point estimate of policy-relevant parameters and we believe that our estimates have a stronger foundation than many earlier estimates used in policy analysis (again, see (Berry 2011).)

We begin with US data, first providing an overview of US aggregate data and then a much more detailed analysis of a panel dataset on US states over time. The overview shows that observed US yields are very well explained by a very smooth (nearly linear) "technology" time trend together with a parsimonious observed set of weather variables. There is very little variance left to be explained by prices. The panel results show, that for a variety of empirical approaches, the estimated *net* yield-price elasticities are not statistically different from zero. On the other hand, we find a highly significant area-price elasticity of 0.25-0.3. Assuming that the new marginal land has a productivity of two thirds of the land that is in production, the yield-price elasticity can be no larger than 0.1.

We also provide results on fertilizer use; these results are consistent with our near zero findings for yield elasticities. We finish with a discussion of empirical results on yield and land elasticities for four main crops (maize, soybeans, wheat and rice) across all major producing countries. Unlike our US data, we do not have detailed weather data for these results and we put somewhat less weight on the exact point estimates from these results. However, these crop-by-country results broadly support the finding of net yield-elasticities that are close to zero.

One intriguing finding from the crop-by-country analysis is a marginally statistically significant positive yield elasticity for soybeans in Brazil, which is combined with a much larger and highly statistically significant land-use elasticity. There are also some statistically significant *negative* net yield elasticities for wheat and rice in China. Both the positive and negative yield results are interesting and deserve further study, but they could simply be the kind statistical artifacts that would be expected to occasionally occur when a large number of specifications are run on modestly sized datasets. They do point to the value of obtaining better data (for example, on weather, yields and land-use within sub-regions of large countries.)

2 US Data and Empirical Approach

We would like estimates of the world-wide yield elasticity of crops. However, US data is of considerably higher quality than world-level datasets and much of the debate about yield elasticities takes place in the context of US data. It is true that US agricultural practices are quite different from agriculture in poorer countries. However, it is difficult to know how third-world elasticities will compare to US elasticities.[1]

There is little controversy that yields are highly influenced by both slow-moving technical change and by short-run weather. Technical change is typically proxied by a time trend. Because our data runs over many decades, we would like this trend to be modeled in a flexible way, allowing for the possibility that technical change is more or less rapid during some sub-sets of the data. In all our results, we pay use flexible time trends and pay attention to the sensitivity of our results to how the time trend is modeled.

Weather obviously has a huge effect on annual yields, but obtaining a parsimonious measure of "good" or "bad" weather requires some care. For the US, Roberts and Schlenker (2009) develop a parsimonious set of state-level variables that are highly correlated with corn and soy yields. Yields are increasing in temperature approximately linearly up to a threshold, above which they sharply decline. This piecewise linear growth is best captured by the concept of degree days (see Section 5.1 for a definition). These unusually good weather controls allow us to more precisely isolate the effect of price on yields.

We begin with a graphical analysis of US aggregate data and then turn to more detailed statistical results on a panel dataset of US crop-producing states over time.

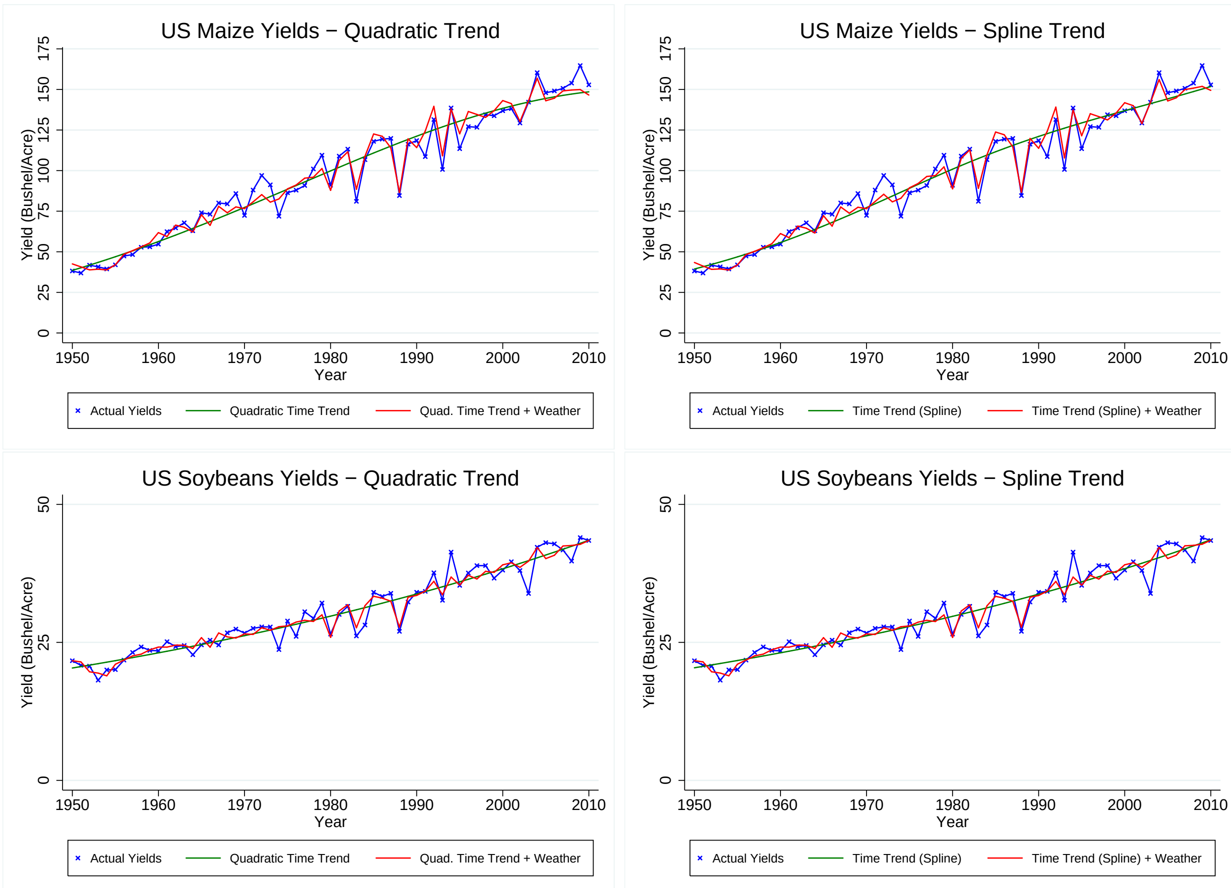
2.1 Aggregate US Data on Yield, Weather and Price

Data on aggregate US yields are displayed in Figure 1.[2] Each panel of Figure 1 plots three lines. The blue "Actual Yield" lines are the actual US yield data averaged over the entire country for either corn or soybeans. The green lines are a simple smooth quadratic or spline time trend fit to that data. The estimated yield trends are remarkably close to linear, which is consistent with steady technological progress that changes very little with changes

[1] On one hand, third world farmers are likely far away from the technological frontier and so there are probably greater potential yield gains. On the other hand, there is much evidence that third-world farmers do not and/or cannot make economically efficient use of inputs like fertilizer. This may greatly limit any price-responsive behavior of third-world farmers. On both points see Duflo, Kremer, and Robinson (2008) and related literature.

[2] We generally model log yields as a function of time trends and weather. The graphs display the results from a log-model that is transferred back to a linear scale for easier display.

Figure 1: US Maize and Soybean Yields



Notes: Figure displays actual yields (blue), a time trend (green) as well as yield predictions (red) from a model using the same weather variables as in Table 1 and Table 2. The top row displays the results for maize, the bottom for soybeans. The left column uses a quadratic time trend, while the right column uses restricted cubic splines with 3 knots.

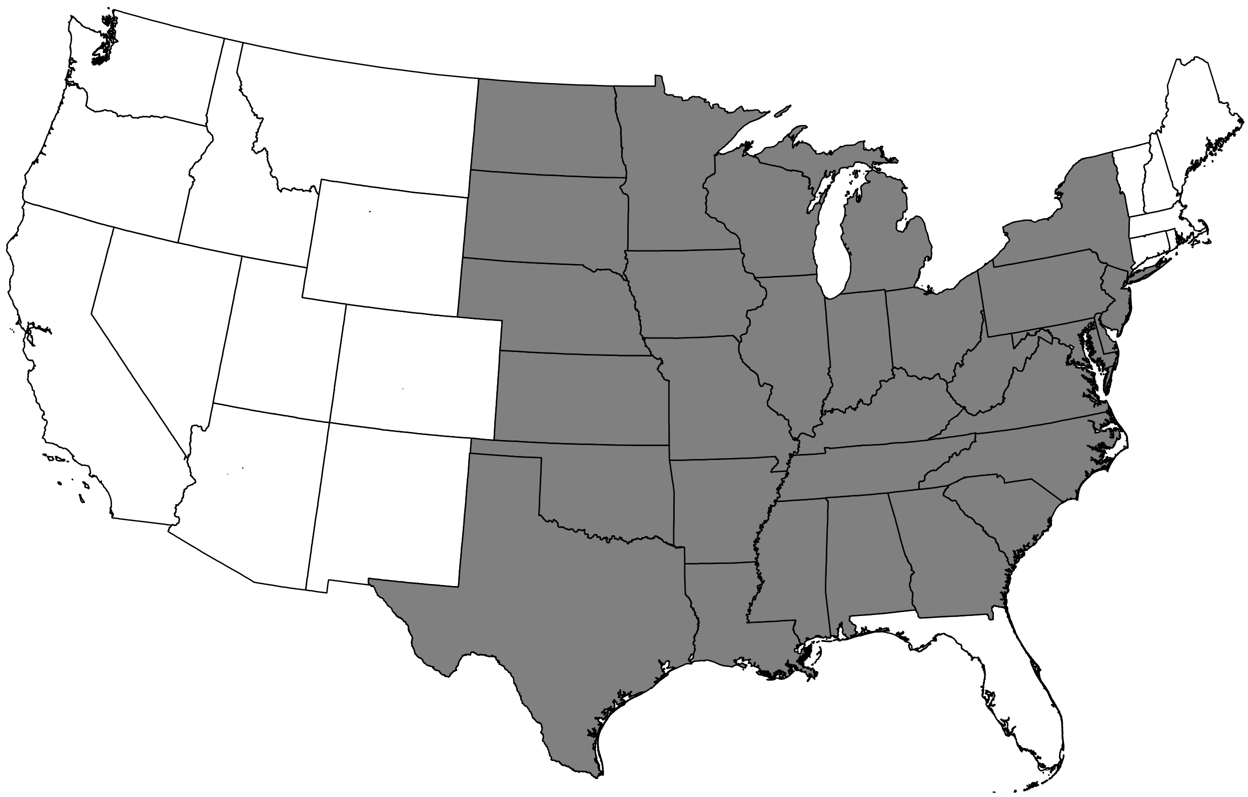
in medium-run market conditions (whereas price and land-use trends, not displayed, show much more variability over the same time period.)

The red lines in Figure 1 are the predicted values of yields from a regression of yields (in levels) on both the time trend variables and US weather variables that are inspired by Roberts and Schlenker (2009). The figures show a remarkable fit of the trend plus weather data to actual yields, for both maize and corn. Note that there is very little remaining variance for price to "explain." This is consistent with traditional agricultural economics models that treat yields as functions of technology (measured by a time trend) and idiosyncratic weather. This is also consistent with agronomic evidence (discussed in Berry (2011)) that the marginal product of fertilizer, in the US, is very small (or even zero) at observed levels of use.

2.2 US State-Level Panel Data

For more detailed statistical analysis, we now turn to a state-level panel dataset. The crop-producing states used in the analysis are shown in Figure 2. Looking at each of the 30 states across the time period 1961-2009 (up to 49 years) gives us more than 1400 observations, as opposed to the annual data that has one observations per year.[3]

Figure 2: States in Analysis



Notes: Figure displays the states used in the state-level analysis in grey.

To obtain correct estimates of yield elasticities, Berry (2011) discusses the need for "instruments" that separately and exogenously shift supply and demand. (See, for example, the standard undergraduate textbook treatment in Stock and Watson (2006).) In keeping with standard econometric practice, to look at the "causal effect" of price on the supply side, we need an "instrumental variable" that moves demand without directly affecting supply. It is important that the instrument not be correlated with any unobserved determinants of supply and that it do a good job of predicting changes in price. Intuitively, such a variable shifts demand while supply is held, on average, constant. This allows us to "trace out" the

[3]The maximum number of observations is 30*49=1470. Since some states do not grow all crops in a given year, especially at the beginning of the analysis, the number is slightly lower.

supply relationships.

Current-year weather is the classic supply-side instrument used in the identification of demand: weather shifts supply while having little or no effect on demand. Roberts and Schlenker (2010) propose the use of *last year*'s yield shock (that is mostly due to weather) as an instrument that effectively shifts the demand for new production while being uncorrelated with the current year's unobserved supply shock. The argument is that better than expected yields last year are at lest partially placed into inventories that are held over to this year. Crop inventories are an excellent demand-side substitute for newly produced crops. By this argument, last year's weather-induced yield shock should be a good instrument that moves this year's demand curve while being uncorrelated with the supply shock.

In our first results (columns (1a) and (1b) in Tables 1 and 2), we use last year's observed US weather as our "instrumental variable" that shifts demand but not current-year yields.[4] US weather, in crop-producing states, is likely to be highly uncorrelated over time and thus should be uncorrelated with any serially time-correlated yield shocks. Weather is not observed at the time of planting and so does not effect input and land-use decisions at the time of planting. This makes observed US weather it a potentially good instrument.

On the other hand, world prices are shifted by world aggregate weather events, and there is a question about how well lagged US weather predicts current-year futures prices. Since the US at present produces around 40% of global corn and soybeans production, US shocks alone should have some explanatory power. This is partly an empirical question and we find below that lagged US weather does a reasonably good job of predicting current prices. However, world aggregate weather shocks likely predict prices even better and so we also use three "yield residual" measures of the aggregate weather shock. One of these is the original Roberts and Schlenker instrument, while the other two are designed to address the problem of serially correlated yield shocks.

Table 1 and Table 2 present the results for corn and soybeans, respectively. Columns vary by the time trends as well as the instrument for price. All regressions use instrumented futures prices from the Chicago Board of trade at the average time of planting, i.e., prices can vary by state as the planting dates vary by state.

This data improves on the existing aggregate data by including weather and "time-of-planting" variables that vary by location. This more precise control of the aggregate weather shock allows for potentially more precise measure of the price effect.

Note that while we have greatly increased the number of observed yields, the variance in price is still mostly annual (with some small additional variation due to differences in planting time.) In the regression results, standard errors are clustered by state and year, so as to account for important correlated unobservables and so as to not exaggerate the effect of the increased number of observations in the panel data, as opposed to the US aggregate data.

The two tables give four sets of instruments (indicated by 1-4) as well as two different time trends (indicated by a and b). The time trends are as follows: Columns (a) use a quadratic time trend, while columns (b) use restricted cubic splines with 3 knots.

[4]The construction of US weather is further outlined in the appendix.

Table 1: Regression of Log Corn Yields and Area Planted on Instrumented Price

Variable	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)	(4a)	(4b)
Panel A: Regressing Log Yields on Instrumented Price								
Instrumented Log Price	0.055	0.044	-0.007	-0.012	0.014	0.011	0.031	0.041
	(0.125)	(0.175)	(0.064)	(0.074)	(0.065)	(0.073)	(0.120)	(0.127)
Heat (100 Degree Days)	-0.593***	-0.595***	-0.595***	-0.598***	-0.595***	-0.597***	-0.594***	-0.595***
	(0.077)	(0.083)	(0.077)	(0.084)	(0.077)	(0.084)	(0.077)	(0.083)
Mod. Temp (1000 Degree Days)	0.050	0.047	0.037	0.035	0.041	0.040	0.045	0.046
	(0.191)	(0.211)	(0.185)	(0.201)	(0.185)	(0.200)	(0.187)	(0.202)
Precipitation (m)	0.202	0.203	0.191	0.194	0.195	0.198	0.198	0.203
	(0.531)	(0.565)	(0.531)	(0.567)	(0.531)	(0.567)	(0.533)	(0.568)
Precipitation Squared	-0.410	-0.411	-0.392	-0.395	-0.398	-0.402	-0.403	-0.410
	(0.395)	(0.411)	(0.392)	(0.410)	(0.392)	(0.411)	(0.397)	(0.415)
R^2	0.7569	0.7578	0.7584	0.7590	0.7582	0.7588	0.7578	0.7579
Observations	1439	1439	1439	1439	1439	1439	1439	1439
Panel B: First Stage - Regressing Log Price on Instruments								
Lag Shock			-0.782***	-0.779***	-0.784***	-0.779***	-0.694**	-0.704*
			(0.151)	(0.224)	(0.135)	(0.197)	(0.261)	(0.378)
Lag US Heat (100 Degree Days)	0.491**	0.476						
	(0.211)	(0.326)						
Lag US Mod. Temp (1000 DDays)	0.069	0.087						
	(0.410)	(0.643)						
Lag US Precipitation (m)	1.410	1.533						
	(2.231)	(3.379)						
Lag US Precipitation Squared	-0.494	-0.609						
	(2.008)	(3.044)						
Heat (100 Degree Days)	0.010	0.004	-0.020	-0.024	-0.052	-0.056	-0.016	-0.020
	(0.085)	(0.098)	(0.086)	(0.094)	(0.074)	(0.078)	(0.088)	(0.099)
Mod. Temp (1000 Degree Days)	-0.209	-0.203	-0.237	-0.232	-0.233	-0.229	-0.229	-0.225
	(0.210)	(0.300)	(0.179)	(0.242)	(0.173)	(0.235)	(0.197)	(0.275)
Precipitation (m)	0.220	0.226	0.232	0.239	0.200	0.206	0.041	0.056
	(0.613)	(0.687)	(0.489)	(0.544)	(0.491)	(0.539)	(0.556)	(0.616)
Precipitation Squared	0.010	0.005	-0.066	-0.074	-0.018	-0.026	0.115	0.099
	(0.452)	(0.484)	(0.364)	(0.403)	(0.363)	(0.397)	(0.408)	(0.444)
R^2	0.7521	0.7517	0.7757	0.7754	0.7845	0.7838	0.7453	0.7458
Observations	1439	1439	1439	1439	1439	1439	1439	1439
F-stat on Inst.	4.13	1.72	26.97	12.12	33.86	15.57	7.07	3.47
p-value on F	.009064	.1727	.0000148	.001599	2.62e-06	.0004629	.0126	.07255
Panel C: Regressing Log Area Planted on Instrumented Price								
Instrumented Log Price	0.252***	0.257**	0.298***	0.301***	0.230***	0.230***	0.293**	0.284**
	(0.098)	(0.107)	(0.067)	(0.081)	(0.087)	(0.073)	(0.144)	(0.138)
R^2	0.0254	0.0245	0.0223	0.0215	0.0264	0.0256	0.0227	0.0228
Observations	1439	1439	1439	1439	1439	1439	1439	1439
Time Trend	Quad.	3 knots	Quad.	3 knots	Quad.	3 knots	Quad.	3 knots

Notes: Table regresses state-level log corn yields (and area planted) on time trends, weather variables for the state, and instrumented prices. Columns (a) us quadratic time trends, columns (b) use restricted cubic splines in time with 3 knots. The futures price at the time of planting (varies by state) is instrumented with different variables. Columns (1) use the production-weighted lagged average weather in the US. Columns (2) use world caloric shocks summed over all countries and the four commodity crops: maize, rice, soybeans, and wheat. Columns (3) are similar to columns (2), but only use caloric shocks of the other three crops. Columns (4) use lagged residuals from a regression of yields on area (as well as lagged area) as well as output and input (oil) prices for each country and crop in the world. Significance levels: *** 0.01; ** 0.05; and * 0.1.

Columns (1a)-(1b) instrument futures price at the time of planting on lagged weather outcomes in the United States for *the same crop*. If there was excessive heat in the previous year as measured by the variable Lag US Heat (which is bad for crops), future prices generally go up. Appendix 5.2 outlines how the weather variables were constructed. Using observed weather as an instrument has the advantage that it is clearly exogenous and US weather is unlikely to exhibit any important serial correlation. The disadvantage is that prices respond not only to US weather, but to world weather. Unfortunately, we do not (as of yet) have good weather data for the rest of the world.

Columns (2a)-(2b) instrument futures price at the time of planting on lagged world caloric shocks. These regressions use new extended data from the Foreign Agricultural Service of the United States Department of Agriculture, but follow the same methodology of Roberts-Schlenker, i.e., yield shocks for each of the four staple crops (maize, rice, soybeans, wheat) and each country (not just the big ones) are fit and then aggregated based on the caloric production along a trend line for the crop. Countries and their production shares are given

Table 2: Regression of Log Soybean Yields and Area Planted on Instrumented Price

Variable	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)	(4a)	(4b)
Panel A: Regressing Log Yields on Instrumented Price								
Instrumented Log Price	0.008	0.006	0.021	0.019	-0.010	-0.011	0.149	0.147
	(0.066)	(0.083)	(0.089)	(0.101)	(0.088)	(0.101)	(0.112)	(0.121)
Heat (100 Degree Days)	-0.582***	-0.583***	-0.582***	-0.583***	-0.582***	-0.583***	-0.584***	-0.584***
	(0.042)	(0.052)	(0.042)	(0.052)	(0.042)	(0.052)	(0.043)	(0.053)
Mod. Temp (1000 Degree Days)	0.368***	0.367***	0.368***	0.367***	0.368***	0.367***	0.365***	0.364***
	(0.119)	(0.131)	(0.120)	(0.131)	(0.119)	(0.131)	(0.130)	(0.139)
Precipitation (m)	1.356***	1.355***	1.359***	1.358***	1.351***	1.351***	1.391***	1.389***
	(0.382)	(0.408)	(0.376)	(0.406)	(0.373)	(0.404)	(0.395)	(0.422)
Precipitation Squared	-0.981***	-0.980***	-0.986***	-0.986***	-0.974***	-0.974***	-1.037***	-1.034***
	(0.249)	(0.272)	(0.241)	(0.270)	(0.238)	(0.268)	(0.252)	(0.280)
R^2	0.6504	0.6505	0.6502	0.6502	0.6501	0.6502	0.6279	0.6284
Observations	1291	1291	1291	1291	1291	1291	1291	1291
Panel B: First Stage - Regressing Log Price on Instruments								
Lag Shock			-0.699***	-0.691***	-0.744***	-0.739***	-0.809***	-0.833**
			(0.178)	(0.222)	(0.174)	(0.219)	(0.251)	(0.304)
Lag US Heat (100 Degree Days)	-0.054	-0.062						
	(0.269)	(0.340)						
Lag US Mod. Temp (1000 DDays)	1.223***	1.207**						
	(0.423)	(0.581)						
Lag US Precipitation (m)	-2.579	-2.456						
	(2.441)	(3.170)						
Lag US Precipitation Squared	2.621	2.496						
	(2.011)	(2.610)						
Heat (100 Degree Days)	0.064	0.058	0.041	0.034	0.026	0.019	0.053	0.045
	(0.061)	(0.083)	(0.058)	(0.079)	(0.056)	(0.075)	(0.064)	(0.085)
Mod. Temp (1000 Degree Days)	0.046	0.047	-0.009	-0.011	0.003	0.002	0.011	0.009
	(0.274)	(0.318)	(0.248)	(0.278)	(0.245)	(0.275)	(0.270)	(0.302)
Precipitation (m)	0.255	0.248	0.047	0.050	0.097	0.102	-0.015	-0.001
	(0.532)	(0.655)	(0.548)	(0.614)	(0.533)	(0.601)	(0.605)	(0.670)
Precipitation Squared	0.093	0.093	0.119	0.109	0.088	0.077	0.195	0.175
	(0.415)	(0.514)	(0.428)	(0.487)	(0.419)	(0.479)	(0.456)	(0.512)
R^2	0.7427	0.7428	0.7150	0.7189	0.7193	0.7234	0.6989	0.7046
Observations	1291	1291	1291	1291	1291	1291	1291	1291
F-stat on Inst.	4.69	2.29	15.40	9.67	18.27	11.40	10.43	7.50
p-value on F	.004828	.08349	.0004914	.004174	.0001892	.002109	.003073	.01044
Panel C: Regressing Log Area Planted on Instrumented Price								
Instrumented Log Price	0.312***	0.292**	0.338**	0.333***	0.307*	0.310**	0.329**	0.357**
	(0.112)	(0.129)	(0.151)	(0.106)	(0.161)	(0.121)	(0.139)	(0.147)
R^2	0.2897	0.2869	0.2897	0.2869	0.2897	0.2870	0.2897	0.2866
Observations	1291	1291	1291	1291	1291	1291	1291	1291
Time Trend	Quad.	3 knots	Quad.	3 knots	Quad.	3 knots	Quad.	3 knots

Notes: Table regresses state-level log soybean yields (and area planted) on time trends, weather variables for the state, and instrumented prices. Columns (a) us quadratic time trends, columns (b) use restricted cubic splines in time with 3 knots. The futures price at the time of planting (varies by state) is instrumented with different variables. Columns (1) use the production-weighted lagged average weather in the US. Columns (2) use world caloric shocks summed over all countries and the four commodity crops: maize, rice, soybeans, and wheat. Columns (3) are similar to columns (2), but only use caloric shocks of the other three crops. Columns (4) use lagged residuals from a regression of yields on area (as well as lagged area) as well as output and input (oil) prices for each country and crop in the world. Significance levels: *** 0.01; ** 0.05; and * 0.1.

in Appendix 5.3, while the methodology is further described in Appendix5.4.[5] The average log caloric shock is divided by the fraction of a years production that is currently stored, i.e., shocks are presumed to have a larger effect if storage levels are low. This method for measuring "lagged weather" creates an instrument that is strongly correlated with the current-year prices, but it is not valid if there are serially correlated shocks to yields.

Columns (3a)-(3b) instrument futures price at the beginning of planting on lagged world caloric shocks just like columns (2a)-(2b), with one exception: Caloric shocks are derived from the other three crops, e.g., the maize regression uses only lagged shocks for rice, soybeans, and wheat. In case there was a technological break-through, yield shocks might be auto-correlated. Using only shocks from other crops circumvents this problem if technological innovations are not correlated between crops, as seems relatively reasonable.

To measure aggregate weather shocks in the face of other (unobserved to us) yield shocks

[5]The baseline model use caloric conversion rates between crops that are derived by setting the average price per calory to be the same in 1961-2010. In a sensitivity check (available upon request) we use the conversion ratios of Williamson and Williamson (1942) and obtain comparable results.

that are correlated across *both* time and crops, we make use of new method (part of an ongoing research agenda) that uses proxy variables to control for unobserved correlated supply and demand shocks. The method is similar to the proxy production function estimation method introduced in the classic paper of Olley and Pakes (1996). In this method, we supplement the time trend in the Roberts and Schlenker (2010) paper with four additional variables that are intended to proxy for the effects of serially correlated demand and supply shocks. These are the log futures price, the log of harvested area, lagged log area and oil prices.[6]. This last shifts the price of inputs like fertilizer. Columns (4a)-(4b) make use of the this new lagged "weather" (yield-residual) instrument, which ought to be considered still somewhat experimental.

None of the estimated net yield-price elasticity coefficients are statistically significantly different from zero in Panel A. In some cases, the coefficients are sufficiently precisely estimated to statistically reject a net yield elasticity as high as 0.25.

In discussing the results, it is important to look at the F-statistics of the first-stage regressions in Panel B, which indicate whether the instruments are "strong enough" to produce reliable results. We begin with the corn yield results, ignoring the "experimental" columns (4a)-(4b) for now. The "p values" for the F-test (found at' at the bottom of the table), which we hope to be quite small, are particularly encouraging for columns (2a) and (3a). The results in (2a) might be biased by serially correlated yield shocks, so the results in (3a) would be preferred. This result shows a slightly *negative* point-estimate of the net yield-price elasticity, which is reasonable if newly farmed land is sufficiently less productive than existing land.

Recall that the numbers in Panel A reflect *net* yield-price elasticities, as they are averaged over the growing area in a county, which itself might change as prices changes. Panel C examines this directly: it is the same regression as Panel A with a different dependent variable: log area planted instead of log yield. Note that we find a highly significant area-price elasticity of 0.25-0.3. These are own-crop elasticities and one might reasonably wonder if total crop elasticity would be substantially lower, as some of the own-crop elasticity could reflect cross-crop substitution. Table (4), discussed more below, looks at the total crop land elasticity across various countries and finds very similar US land elasticities, in the range of 0.27.

The crop-land elasticity estimates allow us to derive an implied on the direct yield-price elasticity for existing land because the (i) net yield elasticity is function of the (ii) direct yield-price elasticity; the (iii) area-yield elasticity; and (iv) the yield reduction on new marginal land. If we assume various values for (iv), we can solve for (ii). For example, if the area-price elasticity is 0.25 and the yields are roughly two-thirds on the new marginal land, the direct yield-price elasticity is 0.08. If yields on marginal land are higher, or if the crop-yield elasticity is lower, the direct yield-price elasticity will be lower.

Turning next to the soybean table, we note that the pattern of F-statistics across columns is similar to the results for corn. In columns (1)-(3), the point estimates of the yield elastic-

[6] We use the average price of the Western Texas Intermediate oil averaged over the growing season March-August

ities are all very small in absolute value.

Turning finally to the more experimental results in columns (4a)-(4b), for both corn and soy, we see that the F-stats in the first-stage regressions are slightly better than for columns (1), but worse than in columns (2) or (3). This may be because on one hand a measurement of "world weather" is better than using just US weather, but on the other hand outside of the US we have access only to a limited amount of time-series data and the coefficients on the proxy variables in the original country-specific yield equations may, in at least some cases, be somewhat badly estimated.

For both corn and soy, the experimental column (4) estimates are not statistically significantly different from zero. In the case of corn, the point estimates are smaller as compared to column 1(a), but the in case of soybeans, we see the only point estimates (across all tables) that exceed 0.1. However, the average of our soybean yield-price elasticity estimates across the first row of table 2 is still quite small and there seems to be no reason, for either corn or soy, to privilege our most experimental estimates.

3 Fertilizer and Crop Prices

One plausible mechanism for a substantial yield-price elasticity is that farmers make greater use of productive inputs in response to a price increase. Fertilizer is frequently suggested as an input that will respond to price (however, again see Berry (2011) for possible counter-arguments.) While this effect could be offset by the lower productivity of new land, there is still an interesting question of whether fertilizer in fact varies systematically with price.

Table (3) shows instrumental variable regressions of fertilizer use per area on instrumented price. The Foreign Agricultural Service does not report fertilizer use, and we hence rely on data from the FAO but pair it with the same yield shocks from the previous section. FAO reports total fertilizer use up until 2002 when reporting stopped and our data set hence spans 42 years: 1961-2002. These data are not crop-specific, but crop prices are highly correlated and hence fertilizer use should change for crops synchronously. We regress log fertilizer use per area (the log of the ration of total fertilizer use to the sum of the growing area for the four crops) on instrumented prices.

Columns (1a) and (1b) use world caloric shocks - analogous to columns (2a) and (2b) in Tables 1 and 2 above. Since we are looking at individual countries in Panels B-F, we add a second specification where we use the lagged caloric shocks from all other countries in columns (2a) and (2b). For example, the regression for the United States uses only caloric shocks from all other countries than the United States. Note how the F-stat decreases significantly, which is not surprising as the United States produce 23% of global caloric production from the four commodities.

The resulting coefficient estimates have unstable signs and are never positive and significantly different from zero. While we do not want to over-emphasize these preliminary results, this finding is again consistent with yields that do not vary with price.

Table 3: Fertilizer Use as Function of Commodity Price

	(1a)	(1b)	(2a)	(2b)	(1a)	(1b)	(2a)	(2b)
	Panel A: World				**Panel B: United States**			
Instrumented Log Price	-0.048	-0.090			-0.109	-0.117	0.192	0.216
	(0.078)	(0.076)			(0.146)	(0.155)	(0.255)	(0.277)
R^2	0.9794	0.9817			0.5298	0.4991	0.3152	0.2589
Observations	42	42			42	42	42	42
F-stat on Inst.	16.69	16.12			16.69	16.12	6.45	6.05
p-value on F	2.2e-04	2.7e-04			2.2e-04	2.7e-04	.0153	.0185
	Panel C: Brazil				**Panel D: China**			
Instrumented Log Price	0.056	0.002	0.036	-0.016	-0.023	-0.079	0.202	0.213
	(0.350)	(0.357)	(0.351)	(0.358)	(0.212)	(0.223)	(0.327)	(0.347)
R^2	0.8978	0.8995	0.8968	0.8986	0.9821	0.9814	0.9779	0.9757
Observations	42	42	42	42	42	42	42	42
F-stat on Inst.	16.69	16.12	16.78	16.28	16.69	16.12	7.19	7.27
p-value on F	2.2e-04	2.7e-04	2.1e-04	2.5e-04	2.2e-04	2.7e-04	.0108	.0104
	Panel E: India				**Panel F: Thailand**			
Instrumented Log Price	-0.241	-0.296	-0.401**	-0.481**	-0.663**	-0.686*	-0.661**	-0.684*
	(0.165)	(0.193)	(0.198)	(0.233)	(0.336)	(0.364)	(0.334)	(0.361)
R^2	0.9866	0.9827	0.9858	0.9813	0.9622	0.9581	0.9622	0.9581
Observations	42	42	42	42	42	42	42	42
F-stat on Inst.	16.69	16.12	11.17	10.82	16.69	16.12	17.02	16.47
p-value on F	2.2e-04	2.7e-04	.0019	.0022	2.2e-04	2.7e-04	1.9e-04	2.4e-04
Time Trend	Quad.	3 knots	Quad.	3 knots	Quad.	3 knots	Quad.	3 knots

Notes: Table regresses the log of total fertilizer use for all crops per total growing area on instrumented prices as well as time trends. Columns (a) use quadratic time trends, columns (b) use restricted cubic splines in time with 3 knots. The futures price as traded at the end of the previous year is instrumented with different variables. Columns (1) use world caloric shocks summed over all countries and the four commodity crops: maize, rice, soybeans, and wheat. Columns (2) is similar to columns (2), but only countries except for the country in question are used (e.g., columns (2a) and (2b) in Panel B - United States - adds shocks of all four commodities for all countries *besides* the United States).

4 World Regional Results

In this section, we use Roberts and Schlenker (2010) style lagged yield-residual instruments to consider yield-price and area-price elasticities for a variety of crops and countries around the world.

Looking at Tables (4) through (8), notice that there is first a table that considers all crops aggregated together followed by a table for each of four crops: maize, soy, wheat and rice. Within each table, there is a panel of results for each of the large producing countries. Yield and area elasticities are presented for a combination of instruments and time trend specifications. In the crop specific tables, columns (2a)-(2b) use an instrument that is robust to serial correlation in unobserved own-crop yield factors and so they may be preferred. The aggregate crop results use only the original Robert-Schlenker instrument. We have not as of yet considered a version of the "experimental" proxy method that was presented for the US panel data.

As compared to our US results, the absence of high-quality weather data leads us to place less emphasis on the results of this section. As opposed to our previous state-level panel data, the datasets in this section are pure time-series. We can summarize the time-series world / regional / crop results of Tables 4 through 8 as follows. First, the broad pattern of very little evidence of large positive yield-price elasticities continues to hold. There are some interesting possible exceptions: some positive yield elasticity results for Brazil and some negative elasticities for China. Second, we note that the time-series results for corn and soybeans in the United States are quite comparable to our previous state-level panel analysis: we find a significant area-price elasticity, but not a significant net yield-price elasticity. Third, in addition to the fairly large area elasticities in the US (also found for some other exporting crop / country combinations), we see very large estimated land elasticities for Brazilian soybeans.

We now turn to a brief discussion of each of the tables of this section.

Table (4) considers crops aggregated by caloric content, with Panel A first considering aggregation to the World level. The Panel A results point to a net yield elasticity that is precisely estimated at a value of almost exactly zero (just slightly negative.) The World area elasticity is about 0.09 and again quite precisely estimated. As in Roberts and Schlenker (2010), this suggests an overall supply elasticity of a little less than 0.1, with the entirety of price-induced supply coming from increased area. The remaining panels look at aggregate crops in major producing countries. In the US, yield and area elasticities are similar to those previously reported from the US panel data. Estimated Brazilian yield elasticities are somewhat large but imprecisely estimated, while estimated Brazilian area elasticities are somewhat higher than in the US and statistically significantly different from zero. China shows statistically significant *negative* yield elasticities, while Thailand has an estimated aggregate crop-land elasticity that is similar to the US.

Turning to crop-specific results, in Table 5, we see that maize yield-elasticity estimates are statistically significantly different from zero in no country, whereas land area elasticities are highly significant for the US and China, although not for other countries.

Table (6) considers country-specific elasticities for soybeans. The only highly statistically significant results are for land area elasticities in Brazil, China and Argentina. The estimated soy-land elasticities in Brazil and Argentina are extremely high, while the somewhat negative soy-land elasticities in China are somewhat odd (and might indicate cross-crop competition in the face of prices that are correlated across crops.) Point estimates of net yield elasticities are fairly high in Brazil (over 0.2) and are marginally statistically significant. These yield results, together with area elasticities that are over 4 times as high, suggest that further research on Brazilian soybeans would be desirable. However, the very marginal statistical significance of the current yield result makes it hard to draw any firm conclusions as to whether soybean yield elasticities in Brazil are actually particularly high. One possibility to be explored is that, in the case of Brazilian soybeans, the apparently large quantity of "new land" attracted by high prices is of higher than average productivity, driving up average yields. This could be because land in Amazonian Brazil is often cultivated because it is close to transportation rather than because it is necessary the most productive land in the country. For the purpose of carbon accounting, it would also be very important to know what kind of land is being drawn into soy production and whether high yields are sustainable over a long period of time.

In Tables (7) and (8), covering wheat and rice respectively, the only statistically significant yield elasticity estimates involve China and are *negative*. The statistical significance of the negative yield-price elasticity for Chinese wheat and rice are not consistent across (column) specifications and might be a statistical artifact. Alternatively, "new land" in China may be relatively unproductive, at least in the case of wheat and rice. US wheat-land elasticities are highly significantly positive, as are Thai rice-land elasticities. Note that Thailand is a major rice exporter.

Overall, the land-elasticity results are roughly consistent with the idea that land-elasticities are high in countries that are important exporters of a particular crop, but closer to zero for other crop / country combinations.

Table 4: Regression of Log Yields and Log Total Growing Area on Instrumented Price

	Explaining Log Yield		**Explaining Log Area**	
Variable	(1a)	(1b)	(1a)	(1b)
		Panel A: World		
Instrumented Log Price	-0.010	-0.013	0.091***	0.089***
	(0.027)	(0.027)	(0.027)	(0.027)
R^2	0.9943	0.9944	0.9580	0.9564
Observations	50	50	50	50
F-stat on Inst.	12.82	12.69	12.82	12.69
p-value on F	8.2e-04	8.7e-04	8.2e-04	8.7e-04
		Panel B: United States		
Instrumented Log Price	-0.033	-0.033	0.272***	0.267***
	(0.091)	(0.091)	(0.084)	(0.090)
R^2	0.9153	0.9151	0.8736	0.8569
Observations	50	50	50	50
F-stat on Inst.	12.82	12.69	12.82	12.69
p-value on F	8.2e-04	8.7e-04	8.2e-04	8.7e-04
		Panel C: Brazil		
Instrumented Log Price	0.152	0.155	0.397***	0.388***
	(0.103)	(0.103)	(0.126)	(0.125)
R^2	0.9654	0.9653	0.9364	0.9377
Observations	50	50	50	50
F-stat on Inst.	12.82	12.69	12.82	12.69
p-value on F	8.2e-04	8.7e-04	8.2e-04	8.7e-04
		Panel D: China		
Instrumented Log Price	-0.127**	-0.135**	0.043	0.040
	(0.065)	(0.063)	(0.055)	(0.056)
R^2	0.9817	0.9831	0.7672	0.7523
Observations	50	50	50	50
F-stat on Inst.	12.82	12.69	12.82	12.69
p-value on F	8.2e-04	8.7e-04	8.2e-04	8.7e-04
		Panel E: Thailand		
Instrumented Log Price	-0.031	-0.027	0.245***	0.238***
	(0.062)	(0.060)	(0.081)	(0.077)
R^2	0.9274	0.9302	0.9066	0.9152
Observations	50	50	50	50
F-stat on Inst.	12.82	12.69	12.82	12.69
p-value on F	8.2e-04	8.7e-04	8.2e-04	8.7e-04
Time Trend	Quad.	3 knots	Quad.	3 knots

Notes: Table regresses country-level log yields and log growing area on time trends and instrumented prices. Production of the four commodities is aggregated by converting them all into calories. Columns (a) use quadratic time trends, columns (b) use restricted cubic splines in time with 3 knots. All columns use world caloric shocks summed over all countries and the four commodity crops: maize, rice, soybeans, and wheat. Significance levels: *** 0.01; ** 0.05; and * 0.1.

Table 5: Regression of Log Maize Yields and Log Growing Area on Instrumented Price

Variable	**Explaining Log Yield** (1a)	(1b)	(2a)	(2b)	**Explaining Log Area** (1a)	(1b)	(2a)	(2b)
				Panel A: United States				
Instrumented Log Price	0.005	0.004	0.004	0.004	0.262***	0.261***	0.238***	0.238***
	(0.120)	(0.121)	(0.115)	(0.116)	(0.083)	(0.084)	(0.079)	(0.079)
R^2	0.8844	0.8839	0.8844	0.8840	0.7126	0.7114	0.7185	0.7174
Observations	50	50	50	50	50	50	50	50
F-stat on Inst.	12.82	12.69	14.51	14.19	12.82	12.69	14.51	14.19
p-value on F	8.2e-04	8.7e-04	4.1e-04	4.7e-04	8.2e-04	8.7e-04	4.1e-04	4.7e-04
				Panel B: China				
Instrumented Log Price	-0.042	-0.051	-0.101	-0.105	0.149**	0.151**	0.171***	0.173***
	(0.091)	(0.087)	(0.091)	(0.087)	(0.062)	(0.062)	(0.060)	(0.060)
R^2	0.9741	0.9768	0.9716	0.9747	0.9508	0.9515	0.9499	0.9506
Observations	50	50	50	50	50	50	50	50
F-stat on Inst.	12.82	12.69	14.51	14.19	12.82	12.69	14.51	14.19
p-value on F	8.2e-04	8.7e-04	4.1e-04	4.7e-04	8.2e-04	8.7e-04	4.1e-04	4.7e-04
				Panel C: Brazil				
Instrumented Log Price	0.091	0.095	0.070	0.074	-0.008	-0.012	-0.008	-0.012
	(0.092)	(0.091)	(0.087)	(0.086)	(0.085)	(0.084)	(0.081)	(0.080)
R^2	0.9616	0.9627	0.9621	0.9632	0.8468	0.8508	0.8467	0.8507
Observations	49	49	49	49	49	49	49	49
F-stat on Inst.	12.59	12.47	14.22	14.10	12.59	12.47	14.22	14.10
p-value on F	9.2e-04	9.7e-04	4.7e-04	5.0e-04	9.2e-04	9.7e-04	4.7e-04	5.0e-04
				Panel D: Former USSR				
Instrumented Log Price	0.059	0.062	0.055	0.063	-0.310	-0.325	-0.226	-0.273
	(0.194)	(0.195)	(0.224)	(0.225)	(0.320)	(0.335)	(0.358)	(0.379)
R^2	0.5894	0.5861	0.5906	0.5857	0.5585	0.5175	0.5906	0.5385
Observations	26	26	26	26	26	26	26	26
F-stat on Inst.	9.36	9.41	6.28	6.36	9.36	9.41	6.28	6.36
p-value on F	.0057	.0056	.0201	.0194	.0057	.0056	.0201	.0194
				Panel E: Mexico				
Instrumented Log Price	-0.044	-0.042	-0.103	-0.102	0.158	0.162	0.160	0.168
	(0.106)	(0.106)	(0.098)	(0.099)	(0.130)	(0.131)	(0.124)	(0.125)
R^2	0.9627	0.9626	0.9650	0.9650	-0.0214	-0.0285	-0.0235	-0.0355
Observations	50	50	50	50	50	50	50	50
F-stat on Inst.	12.82	12.69	14.51	14.19	12.82	12.69	14.51	14.19
p-value on F	8.2e-04	8.7e-04	4.1e-04	4.7e-04	8.2e-04	8.7e-04	4.1e-04	4.7e-04
Time Trend	Quad.	3 knots	Quad.	3 knots	Quad.	3 knots	Quad.	3 knots

Notes: Table regresses country-level log yields and log growing area on time trends and instrumented prices. Columns (a) use quadratic time trends, columns (b) use restricted cubic splines in time with 3 knots. The futures price as traded at the end of the previus year is instrumented with different variables. Columns (1) use world caloric shocks summed over all countries and the four commodity crops: maize, rice, soybeans, and wheat. Columns (2) is similar to columns (2), but only use caloric shocks of the other three crops. Significance levels: *** 0.01; ** 0.05; and * 0.1.

Table 6: Regression of Log Soybean Yields and Log Growing Area on Instrumented Price

	Explaining Log Yield				**Explaining Log Area**			
Variable	(1a)	(1b)	(2a)	(2b)	(1a)	(1b)	(2a)	(2b)
					Panel A: United States			
Instrumented Log Price	-0.002	-0.003	-0.040	-0.041	0.196*	0.204*	0.187*	0.201*
	(0.091)	(0.091)	(0.091)	(0.092)	(0.107)	(0.110)	(0.109)	(0.113)
R^2	0.8462	0.8464	0.8508	0.8510	0.8396	0.8301	0.8392	0.8301
Observations	46	46	46	46	46	46	46	46
F-stat on Inst.	12.58	12.42	12.05	11.79	12.58	12.42	12.05	11.79
p-value on F	9.7e-04	.001	.0012	.0014	9.7e-04	.001	.0012	.0014
					Panel B: Brazil			
Instrumented Log Price	0.222	0.226*	0.269*	0.275*	1.153***	1.210***	1.143***	1.230***
	(0.135)	(0.137)	(0.144)	(0.146)	(0.319)	(0.350)	(0.328)	(0.363)
R^2	0.8862	0.8845	0.8790	0.8765	0.9380	0.9262	0.9383	0.9255
Observations	45	45	45	45	45	45	45	45
F-stat on Inst.	12.29	12.10	11.42	11.14	12.29	12.10	11.42	11.14
p-value on F	.0011	.0012	.0016	.0018	.0011	.0012	.0016	.0018
					Panel C: China			
Instrumented Log Price	-0.150	-0.146	-0.146	-0.138	-0.179**	-0.184**	-0.189**	-0.199**
	(0.102)	(0.103)	(0.104)	(0.105)	(0.076)	(0.078)	(0.078)	(0.080)
R^2	0.8944	0.8928	0.8944	0.8928	0.6440	0.6328	0.6410	0.6270
Observations	46	46	46	46	46	46	46	46
F-stat on Inst.	12.58	12.42	12.05	11.79	12.58	12.42	12.05	11.79
p-value on F	9.7e-04	.001	.0012	.0014	9.7e-04	.001	.0012	.0014
					Panel D: Argentina			
Instrumented Log Price	0.075	0.087	0.096	0.114	1.268***	1.369***	1.170***	1.331***
	(0.174)	(0.177)	(0.179)	(0.183)	(0.391)	(0.398)	(0.401)	(0.409)
R^2	0.7800	0.7772	0.7800	0.7766	0.9795	0.9791	0.9796	0.9793
Observations	45	45	45	45	45	45	45	45
F-stat on Inst.	12.29	12.10	11.42	11.14	12.29	12.10	11.42	11.14
p-value on F	.0011	.0012	.0016	.0018	.0011	.0012	.0016	.0018
					Panel E: India			
Instrumented Log Price	0.358	0.381	0.419	0.450	0.182	0.357*	0.133	0.348*
	(0.254)	(0.263)	(0.276)	(0.290)	(0.192)	(0.187)	(0.208)	(0.199)
R^2	0.3978	0.3902	0.3616	0.3471	0.9935	0.9942	0.9932	0.9942
Observations	41	41	41	41	41	41	41	41
F-stat on Inst.	12.06	11.37	10.47	9.71	12.06	11.37	10.47	9.71
p-value on F	.0013	.0018	.0026	.0035	.0013	.0018	.0026	.0035
Time Trend	Quad.	3 knots	Quad.	3 knots	Quad.	3 knots	Quad.	3 knots

Notes: Table regresses country-level log yields and log growing area on time trends and instrumented prices. Columns (a) us quadratic time trends, columns (b) use restricted cubic splines in time with 3 knots. The futures price as traded at the end of the previous year is instrumented with different variables. Columns (1) use world caloric shocks summed over all countries and the four commodity crops: maize, rice, soybeans, and wheat. Columns (2) is similar to columns (2), but only use caloric shocks of the other three crops. Significance levels: *** 0.01; ** 0.05; and * 0.1.

Table 7: Regression of Log Wheat Yields and Log Growing Area on Instrumented Price

	Explaining Log Yield				**Explaining Log Area**			
Variable	(1a)	(1b)	(2a)	(2b)	(1a)	(1b)	(2a)	(2b)
					Panel A:Former USSR			
Instrumented Log Price	-0.188	-0.192	-0.320	-0.346	0.135*	0.139*	0.022	0.019
	(0.243)	(0.238)	(0.215)	(0.213)	(0.081)	(0.084)	(0.062)	(0.066)
R^2	0.6185	0.6334	0.6231	0.6375	0.7938	0.7768	0.8472	0.8309
Observations	26	26	26	26	26	26	26	26
F-stat on Inst.	9.36	9.41	13.33	12.93	9.36	9.41	13.33	12.93
p-value on F	.0057	.0056	.0014	.0016	.0057	.0056	.0014	.0016
					Panel B: China			
Instrumented Log Price	-0.115	-0.126	-0.233**	-0.254**	-0.047	-0.054	-0.008	-0.021
	(0.108)	(0.105)	(0.117)	(0.115)	(0.075)	(0.071)	(0.066)	(0.063)
R^2	0.9801	0.9815	0.9731	0.9740	0.6591	0.6953	0.6884	0.7203
Observations	50	50	50	50	50	50	50	50
F-stat on Inst.	12.82	12.69	15.61	15.52	12.82	12.69	15.61	15.52
p-value on F	8.2e-04	8.7e-04	2.7e-04	2.8e-04	8.2e-04	8.7e-04	2.7e-04	2.8e-04
					Panel C: United States			
Instrumented Log Price	-0.066	-0.068	-0.061	-0.065	0.365***	0.357***	0.352***	0.335***
	(0.088)	(0.088)	(0.081)	(0.081)	(0.096)	(0.095)	(0.089)	(0.087)
R^2	0.8528	0.8533	0.8538	0.8540	0.7604	0.7672	0.7625	0.7708
Observations	50	50	50	50	50	50	50	50
F-stat on Inst.	12.82	12.69	15.61	15.52	12.82	12.69	15.61	15.52
p-value on F	8.2e-04	8.7e-04	2.7e-04	2.8e-04	8.2e-04	8.7e-04	2.7e-04	2.8e-04
					Panel D: India			
Instrumented Log Price	-0.113	-0.119	-0.062	-0.074	0.010	0.004	0.072	0.060
	(0.081)	(0.081)	(0.075)	(0.075)	(0.072)	(0.071)	(0.063)	(0.062)
R^2	0.9771	0.9774	0.9769	0.9772	0.9486	0.9506	0.9542	0.9555
Observations	50	50	50	50	50	50	50	50
F-stat on Inst.	12.82	12.69	15.61	15.52	12.82	12.69	15.61	15.52
p-value on F	8.2e-04	8.7e-04	2.7e-04	2.8e-04	8.2e-04	8.7e-04	2.7e-04	2.8e-04
					Panel E: Canada			
Instrumented Log Price	0.240	0.241	-0.109	-0.109	-0.038	-0.048	-0.195	-0.212
	(0.203)	(0.204)	(0.193)	(0.193)	(0.218)	(0.212)	(0.205)	(0.200)
R^2	0.5883	0.5853	0.5686	0.5678	0.2045	0.2454	0.1808	0.2186
Observations	50	50	50	50	50	50	50	50
F-stat on Inst.	12.82	12.69	15.61	15.52	12.82	12.69	15.61	15.52
p-value on F	8.2e-04	8.7e-04	2.7e-04	2.8e-04	8.2e-04	8.7e-04	2.7e-04	2.8e-04
Time Trend	Quad.	3 knots	Quad.	3 knots	Quad.	3 knots	Quad.	3 knots

Notes: Table regresses country-level log yields and log growing area on time trends and instrumented prices. Columns (a) use quadratic time trends, columns (b) use restricted cubic splines in time with 3 knots. The futures price as traded at the end of the previous year is instrumented with different variables. Columns (1) use world caloric shocks summed over all countries and the four commodity crops: maize, rice, soybeans, and wheat. Columns (2) is similar to columns (2), but only use caloric shocks of the other three crops. Significance levels: *** 0.01; ** 0.05; and * 0.1.

Table 8: Regression of Log Rice Yields and Log Growing Area on Instrumented Price

	Explaining Log Yield				**Explaining Log Area**			
Variable	(1a)	(1b)	(2a)	(2b)	(1a)	(1b)	(2a)	(2b)
					Panel A: China			
Instrumented Log Price	-0.165**	-0.171**	0.021	0.001	0.094*	0.090	-0.026	-0.040
	(0.071)	(0.069)	(0.157)	(0.149)	(0.055)	(0.058)	(0.157)	(0.163)
R^2	0.9717	0.9735	0.9700	0.9723	0.7216	0.6927	0.5099	0.4615
Observations	50	50	50	50	50	50	50	50
F-stat on Inst.	12.82	12.69	2.28	2.30	12.82	12.69	2.28	2.30
p-value on F	8.2e-04	8.7e-04	.1382	.1363	8.2e-04	8.7e-04	.1382	.1363
					Panel B: India			
Instrumented Log Price	-0.020	-0.021	0.140	0.136	0.034	0.033	0.080	0.076
	(0.093)	(0.093)	(0.246)	(0.243)	(0.032)	(0.032)	(0.079)	(0.079)
R^2	0.9372	0.9376	0.9058	0.9069	0.8899	0.8877	0.8515	0.8524
Observations	50	50	50	50	50	50	50	50
F-stat on Inst.	12.82	12.69	2.28	2.30	12.82	12.69	2.28	2.30
p-value on F	8.2e-04	8.7e-04	.1382	.1363	8.2e-04	8.7e-04	.1382	.1363
					Panel C: Indonesia			
Instrumented Log Price	0.003	-0.006	0.178	0.158	-0.051	-0.052	-0.002	-0.008
	(0.085)	(0.076)	(0.212)	(0.191)	(0.036)	(0.036)	(0.080)	(0.080)
R^2	0.9491	0.9597	0.9311	0.9438	0.9769	0.9764	0.9750	0.9748
Observations	50	50	50	50	50	50	50	50
F-stat on Inst.	12.82	12.69	2.28	2.30	12.82	12.69	2.28	2.30
p-value on F	8.2e-04	8.7e-04	.1382	.1363	8.2e-04	8.7e-04	.1382	.1363
					Panel D: Bangladesh			
Instrumented Log Price	0.005	0.009	0.084	0.098	0.038	0.038	-0.014	-0.015
	(0.059)	(0.060)	(0.150)	(0.153)	(0.045)	(0.045)	(0.105)	(0.104)
R^2	0.9788	0.9782	0.9702	0.9685	0.7367	0.7363	0.6927	0.6915
Observations	50	50	50	50	50	50	50	50
F-stat on Inst.	12.82	12.69	2.28	2.30	12.82	12.69	2.28	2.30
p-value on F	8.2e-04	8.7e-04	.1382	.1363	8.2e-04	8.7e-04	.1382	.1363
					Panel E: Thailand			
Instrumented Log Price	-0.038	-0.035	0.095	0.102	0.250***	0.245***	0.337	0.324
	(0.059)	(0.058)	(0.164)	(0.163)	(0.080)	(0.078)	(0.207)	(0.199)
R^2	0.9255	0.9273	0.8755	0.8751	0.8874	0.8919	0.8366	0.8469
Observations	50	50	50	50	50	50	50	50
F-stat on Inst.	12.82	12.69	2.28	2.30	12.82	12.69	2.28	2.30
p-value on F	8.2e-04	8.7e-04	.1382	.1363	8.2e-04	8.7e-04	.1382	.1363
Time Trend	Quad.	3 knots	Quad.	3 knots	Quad.	3 knots	Quad.	3 knots

Notes: Table regresses country-level log yields and log growing area on time trends and instrumented prices. Columns (a) us quadratic time trends, columns (b) use restricted cubic splines in time with 3 knots. The futures price as traded at the end of the previous year is instrumented with different variables. Columns (1) use world caloric shocks summed over all countries and the four commodity crops: maize, rice, soybeans, and wheat. Columns (2) is similar to columns (2), but only use caloric shocks of the other three crops. Significance levels: *** 0.01; ** 0.05; and * 0.1.

References

Berry, S. (2011): "Biofuels Policy and the Empirical Inputs to GTAP Models," Discussion paper, California Air Resources Board, http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/010511-berry-rpt.pdf.

Duflo, E., M. Kremer, and J. Robinson (2008): "How High Are Rates of Return to Fertilizer? Evidence from Field Experiments in Kenya," *The American Economic Review*, 98(2), pp. 482–488.

Olley, S. G., and A. Pakes (1996): "The Dynamics of Productivity in the Telecommunications Equipment Industry," *Econometrica*, 64(6), 1263–97.

Roberts, M. J., and W. Schlenker (2009): "World Supply and Demand of Food Commodity Calories," *American Journal of Agricultural Economics*, 91(5), 1235–1242.

——— (2010): "Identifying Supply and Demand Elasticities of Agricultural Commodities: Implications for the US Ethanol Mandate," Working Paper 15921, NBER.

Schlenker, W., and M. J. Roberts (2009): "Nonlinear Temperature Effects Indicate Severe Damages to U.S. Crop Yields under Climate Change," *Proceedings of the National Academy of Sciences of the United States*, 106(37), 15594–15598.

Searchinger, T., R. Heimlich, R. A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, and T.-H. Yu (2008): "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land-Use Change," *Science*, 319(5867), 1238–1240.

Stock, J., and M. Watson (2006): *Introduction to Econometrics*. Addison-Wesley, 2^{nd} edn.

Williamson, L., and P. Williamson (1942): "What We Eat," *Journal of Farm Economics*, 24(3), 698–703.

5 Appendix

5.1 Degree Days

Degree days are a linear transformation of temperature between two boundaries. For example, degree days 10-29°C count how much temperatures are above 10°C for each day of the growing season, with an upper limit of 29°C. For example, all temperatures below 10°C equals 0 degree days 10-29°C; a temperature of 11°C equals 1 degree days 10-29°C; a temperature of 12°C equals 2 degree days 10-29°C; and any temperature of 29°C or higher equals 19 degree days 10-29°C.

5.2 US Weather

US weather is constructed in the following way:

(i) Schlenker and Roberts (2009) construct a detailed weather data sets that construct daily weather measures on a 2.5x2.5 mile grid for the contiguous United States.

(ii) The weather measures where added for the growing season March-August to get total degree days as well as total precipitation for the season.

(iii) A satellite scan revealed how much cropland area was given in each 2.5x2.5 mile grid cell. The weather outcome for a county is simply the area-weighted average of all grid cells whose centroids fall within a county. Note that the cropland-area is overall cropland and not crop-specific.

(iv) Both state and US aggregate weather data are weighted averages of the county data in step (iii). Our models link log yields to weather, i.e., a weather variable has constant *relative* impact on yields. Prices are determined by the overall yield shortfall, and hence having a bad weather event in a high-productivity area will have great impacts on the overall price level than the same bad weather event in a low-productivity area.

   Specifically, we fit state-specific quadratic yields trends (restricted cubic splines with 3 knots) to derive predicted yields in each year. Each county is weighted by it's predicted production, which is the predicted yield times the actual area (a sensitivity check using lagged area or area along a recited trend gave indistinguishable results).

5.3 FAS Data

Table A1 A4 list the countries in the data of the Foreign Agricultural Service (FAS)[7] that on average produce at least 0.1% of world production.[8]

The first three columns of each Table gives the average, minimum and maximum share of world production of the country. The last three columns give the number of observations that were available, as well as the first and last year for which they were available.

The Foreign Agricultural Service gives yields for marketing years, which might differ from calendar years. A marketing year usually starts with the month when a nw harvest becomes available. Since countries in the Northern hemisphere are responsible for a larger share of global production, we chose the end of the calendar year as our cutoff value. Production quantities are assigned to the calendar year if the marketing year starts in February or later and to the previous year if the start in January. For inventory levels we use a linear approximation between the start and end month of the marketing year to derive the inventory level in December.

Table A1: Countries in Foreign Agricultural Data Set with Soybean Yields

	Fraction of World Production			Range of Years		
Country	Avg.	Min	Max	Obs.	Min	Max
United States Of America	54.66%	32.84%	73.41%	47	1964	2010
Brazil	17.28%	1.59%	29.54%	46	1965	2010
China	11.83%	5.70%	27.47%	47	1964	2010
Argentina	8.05%	0.05%	22.00%	46	1965	2010
Peru	2.09%	0.00%	100.00%	48	1963	2010
India	1.89%	0.03%	4.27%	42	1969	2010
Paraguay	1.12%	0.03%	3.04%	46	1965	2010
Canada	1.09%	0.44%	1.85%	47	1964	2010
Indonesia	0.91%	0.27%	1.65%	47	1964	2010
Ussr	0.89%	0.48%	1.61%	23	1964	1986
Italy	0.76%	0.01%	1.69%	10	1981	1990
Mexico	0.41%	0.04%	0.98%	47	1964	2010
Russian Federation	0.36%	0.19%	0.72%	24	1987	2010
Bolivia	0.35%	0.00%	0.93%	42	1969	2010
North Korea	0.32%	0.05%	0.75%	47	1964	2010
South Korea	0.26%	0.04%	0.61%	47	1964	2010
Romania	0.25%	0.01%	0.57%	35	1964	1998
Japan	0.23%	0.07%	0.84%	47	1964	2010
Thailand	0.21%	0.05%	0.65%	46	1965	2010
Ukraine	0.15%	0.01%	0.63%	24	1987	2010
Nigeria	0.13%	0.02%	0.24%	47	1964	2010
Colombia	0.12%	0.02%	0.32%	47	1964	2010
Serbia and Montenegro	0.11%	0.06%	0.19%	16	1990	2005
Rest Of World	0.82%	0.22%	1.57%	47	1964	2010

Notes: Table lists all countries in the Foreign Agricultural Service (FAS) data set that produce at least 0.1 percent of world production. All other countries are lumped together as "Rest Of World".

[7] http://www.fas.usda.gov/psdonline/

[8] Separate yield trends were estimated for each country, but we only report the bigger ones here due to space constraints. The remaining countries were lumped together as "Rest of World".

Table A2: Countries in Foreign Agricultural Data Set with Maize Yields

	Fraction of World Production			Range of Years		
Country	Avg.	Min	Max	Obs.	Min	Max
United States Of America	45.10%	32.90%	58.39%	51	1960	2010
China	17.00%	8.44%	23.55%	51	1960	2010
Brazil	5.71%	3.66%	7.79%	50	1961	2010
Ussr	3.96%	2.11%	8.66%	27	1960	1986
Mexico	3.06%	1.66%	4.40%	51	1960	2010
Yugoslav Sfr	2.65%	1.48%	3.62%	32	1960	1991
Indonesia	2.64%	0.76%	77.82%	51	1959	2010
Romania	2.61%	1.36%	3.72%	39	1960	1998
Argentina	2.53%	1.11%	3.78%	50	1961	2010
South Africa	2.12%	0.65%	3.88%	50	1961	2010
India	2.09%	1.35%	3.02%	51	1960	2010
Hungary	1.57%	0.81%	2.19%	39	1960	1998
Canada	1.23%	0.38%	1.84%	51	1960	2010
Ukraine	1.03%	0.29%	2.35%	24	1987	2010
Serbia and Montenegro	0.95%	0.55%	1.20%	14	1992	2005
Egypt	0.95%	0.78%	1.16%	50	1960	2010
Philippines	0.83%	0.61%	1.23%	51	1960	2010
Czechoslovakia	0.78%	0.10%	18.10%	32	1959	1991
Thailand	0.71%	0.30%	1.23%	51	1960	2010
Nigeria	0.71%	0.32%	1.43%	51	1960	2010
Bulgaria	0.64%	0.18%	1.03%	39	1960	1998
Kenya	0.52%	0.26%	0.78%	51	1960	2010
North Korea	0.50%	0.18%	0.77%	51	1960	2010
Russian Federation	0.48%	0.14%	1.06%	24	1987	2010
Turkey	0.42%	0.28%	0.60%	51	1960	2010
Ethiopia	0.40%	0.23%	0.59%	51	1960	2010
United Republic Of Tanzania	0.40%	0.19%	0.70%	51	1960	2010
Zimbabwe	0.38%	0.07%	0.81%	50	1961	2010
Malawi	0.35%	0.05%	0.52%	50	1961	2010
Croatia	0.34%	0.25%	0.45%	19	1992	2010
Pakistan	0.29%	0.21%	0.48%	51	1960	2010
Nepal	0.27%	0.14%	0.49%	51	1960	2010
Colombia	0.26%	0.15%	0.51%	51	1960	2010
Guatemala	0.24%	0.14%	0.34%	51	1960	2010
Zambia	0.23%	0.09%	0.52%	49	1962	2010
Venezuela	0.22%	0.11%	0.35%	51	1960	2010
Moldova	0.22%	0.05%	0.36%	24	1987	2010
Vietnam	0.20%	0.01%	0.66%	51	1960	2010
Peru	0.20%	0.10%	0.25%	49	1961	2010
Afghanistan	0.17%	0.02%	0.41%	51	1960	2010
Democratic Republic Of The Congo	0.16%	0.10%	0.27%	50	1961	2010
Mozambique	0.15%	0.03%	0.26%	50	1961	2010
Ghana	0.15%	0.05%	0.26%	51	1960	2010
Chile	0.15%	0.06%	0.23%	49	1960	2010
Albania	0.14%	0.03%	4.08%	52	1959	2010
Uganda	0.14%	0.08%	0.26%	51	1960	2010
Cameroon	0.13%	0.08%	0.23%	51	1960	2010
Paraguay	0.13%	0.06%	0.31%	51	1960	2010
El Salvador	0.12%	0.07%	0.16%	51	1960	2010
Bosnia And Herzegovina	0.11%	0.07%	0.18%	19	1992	2010
Honduras	0.11%	0.06%	0.15%	51	1960	2010
Bolivia	0.11%	0.07%	0.15%	51	1960	2010
Angola	0.10%	0.04%	0.22%	49	1962	2010
Benin	0.10%	0.05%	0.18%	51	1960	2010
Rest Of World	1.49%	0.98%	2.35%	51	1960	2010

Notes: Table lists all countries in the Foreign Agricultural Service (FAS) data set that produce at least 0.1 percent of world production. All other countries are lumped together as “Rest Of World”.

Table A3: Countries in Foreign Agricultural Data Set with Wheat Yields

	Fraction of World Production			Range of Years		
Country	Avg.	Min	Max	Obs.	Min	Max
Ussr	26.54%	15.35%	35.94%	27	1960	1986
China	17.25%	7.71%	24.35%	51	1960	2010
United States Of America	14.52%	10.02%	19.90%	51	1960	2010
India	10.58%	4.01%	16.92%	51	1960	2010
Russian Federation	8.96%	5.54%	11.99%	24	1987	2010
Canada	5.80%	3.46%	10.25%	51	1960	2010
Ukraine	3.85%	0.81%	6.12%	24	1987	2010
Australia	3.84%	2.05%	5.88%	51	1960	2010
Turkey	3.42%	2.56%	4.13%	51	1960	2010
Pakistan	3.09%	1.51%	4.74%	51	1960	2010
Argentina	2.70%	1.74%	5.10%	51	1960	2010
Kazakhstan	2.45%	0.96%	3.85%	24	1987	2010
Iran	1.89%	1.14%	3.23%	51	1960	2010
Romania	1.64%	0.64%	2.79%	39	1960	1998
Poland	1.62%	1.10%	2.16%	39	1960	1998
Yugoslav Sfr	1.55%	1.08%	2.16%	32	1960	1991
Czechoslovakia	1.25%	0.76%	1.71%	32	1960	1991
Hungary	1.24%	0.64%	1.76%	39	1960	1998
Bulgaria	0.99%	0.35%	1.37%	39	1960	1999
Egypt	0.89%	0.43%	1.76%	51	1960	2010
Mexico	0.77%	0.50%	1.06%	51	1960	2010
Afghanistan	0.70%	0.33%	1.23%	51	1960	2010
Uzbekistan	0.70%	0.08%	1.27%	24	1987	2010
Morocco	0.66%	0.23%	1.34%	51	1960	2010
Brazil	0.64%	0.05%	1.45%	51	1960	2010
Syria	0.56%	0.19%	1.11%	51	1960	2010
Serbia and Montenegro	0.51%	0.31%	0.75%	14	1992	2005
South Africa	0.47%	0.21%	0.85%	51	1960	2010
Algeria	0.42%	0.13%	0.83%	51	1960	2010
Iraq	0.37%	0.11%	0.93%	51	1960	2010
Chile	0.36%	0.15%	0.63%	50	1960	2010
Saudi Arabia	0.30%	0.01%	0.90%	51	1960	2010
Ethiopia	0.29%	0.12%	0.59%	51	1960	2010
Azerbaijan	0.24%	0.12%	0.40%	24	1987	2010
Japan	0.23%	0.06%	0.96%	51	1960	2010
Tunisia	0.23%	0.05%	0.41%	51	1960	2010
Moldova	0.19%	0.02%	0.29%	24	1987	2010
Lithuania	0.19%	0.13%	0.26%	12	1987	1998
Kyrgyzstan	0.18%	0.10%	0.30%	24	1987	2010
Turkmenistan	0.18%	0.02%	0.34%	24	1987	2010
Bangladesh	0.18%	0.01%	0.43%	51	1960	2010
Belarus	0.18%	0.05%	0.39%	24	1987	2010
Croatia	0.17%	0.10%	0.23%	19	1992	2010
Nepal	0.16%	0.06%	0.30%	51	1960	2010
Switzerland	0.13%	0.09%	0.21%	51	1960	2010
Uruguay	0.12%	0.03%	0.34%	51	1960	2010
Rest Of World	1.03%	0.75%	1.26%	51	1960	2010

Notes: Table lists all countries in the Foreign Agricultural Service (FAS) data set that produce at least 0.1 percent of world production. All other countries are lumped together as "Rest Of World".

Table A4: Countries in Foreign Agricultural Data Set with Rice Yields

	Fraction of World Production			Range of Years		
Country	Avg.	Min	Max	Obs.	Min	Max
China	34.74%	25.58%	39.71%	51	1960	2010
India	20.59%	16.54%	24.30%	51	1960	2010
Indonesia	7.64%	5.35%	9.02%	51	1960	2010
Bangladesh	5.58%	4.63%	7.39%	51	1960	2010
Thailand	4.15%	3.27%	4.70%	51	1960	2010
Vietnam	4.02%	2.50%	5.73%	51	1960	2010
Japan	3.83%	1.73%	7.81%	51	1960	2010
Myanmar	2.48%	2.12%	3.11%	51	1960	2010
Brazil	2.07%	1.47%	2.87%	50	1960	2010
Philippines	1.85%	1.36%	2.44%	51	1960	2010
South Korea	1.68%	0.96%	2.41%	51	1960	2010
United States Of America	1.52%	1.05%	2.16%	51	1960	2010
Taiwan	1.24%	0.23%	28.92%	52	1959	2010
Nepal	1.11%	0.44%	22.11%	51	1959	2010
Pakistan	1.07%	0.69%	1.55%	51	1960	2010
Egypt	0.74%	0.41%	1.07%	51	1960	2010
Sri Lanka	0.67%	0.29%	9.92%	51	1959	2010
Malaysia	0.64%	0.32%	12.18%	52	1959	2010
Cambodia	0.63%	0.13%	1.17%	51	1960	2010
North Korea	0.59%	0.31%	0.77%	51	1960	2010
Iran	0.53%	0.27%	7.68%	51	1959	2010
Madagascar	0.50%	0.40%	0.69%	51	1960	2010
Colombia	0.42%	0.21%	4.77%	51	1959	2010
Ussr	0.38%	0.06%	0.60%	27	1960	1986
Nigeria	0.32%	0.12%	0.60%	51	1960	2010
Laos	0.28%	0.20%	0.44%	51	1960	2010
Peru	0.22%	0.10%	0.48%	51	1960	2010
Afghanistan	0.16%	0.04%	3.30%	51	1959	2010
Ecuador	0.14%	0.04%	1.29%	51	1959	2010
Australia	0.14%	0.00%	0.29%	50	1961	2010
United Republic Of Tanzania	0.12%	0.03%	1.06%	50	1959	2010
Guinea	0.12%	0.08%	0.23%	51	1960	2010
Russian Federation	0.11%	0.06%	0.22%	24	1987	2010
Argentina	0.11%	0.06%	0.26%	50	1961	2010
Venezuela	0.11%	0.04%	0.76%	51	1959	2010
Dominican Republic	0.11%	0.05%	1.22%	51	1959	2010
Sierra Leone	0.11%	0.03%	0.17%	50	1960	2010
Guyana	0.11%	0.02%	1.98%	52	1959	2010
Uruguay	0.10%	0.02%	0.23%	50	1961	2010
Ivory Coast	0.10%	0.07%	0.15%	50	1960	2010
Rest Of World	1.16%	0.91%	4.80%	52	1959	2010

Notes: Table lists all countries in the Foreign Agricultural Service (FAS) data set that produce at least 0.1 percent of world production. All other countries are lumped together as “Rest Of World”.

5.4 World Shocks - Methodology

We derive world caloric shocks following Roberts and Schlenker (2010). The four staple commodities maize, wheat, rice, and soybeans are responsible for roughly 75% of the calories that we consume as humans.

(i) For each of the four crops and each country we fit a time trend to log yields using restricted cubic splines with 3 knots. Jackknifed yield residuals are obtained by estimating the yield trend while excluding one observation at a time and then taking the log yield residual for that observation from the estimates trend.

(ii) The log yield residuals from part (i) are averaged using production weights. The methodology is analogous to how we averaged weather variables in part (iv) of Appendix 5.2. Production wights are the product of three terms: predicted yields along the time trend (restricted cubic spline with 3 knots); the actual production area; and a conversion ratio that transform production quantities into calories. We derive the conversion ration by requiring that the average price per calorie is the same for all four crops for the years 1961-2010.

(iii) The average log yield residual of step (ii) is then divided by the world caloric inventory level. Intuitively, the same shock will have a leger effect on prices if inventory levels are low.

The caloric price is the average of the futures prices for corn (maize), wheat, and soybeans at the Chicago Board of trade one year before delivery.[9] We use a delivery month of December for corn and wheat, and November for soybeans. Caloric prices are the weighted average of the three prices, where each commodity is weighted by the caloric production as outlined in part (ii) above.

[9]Futures prices for rice only start being traded in the early 1980s and are hence excluded.