How Biofuels Policies Boosted Grain Staple Prices: A Counterfactual Analysis

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Abstract

We empirically address the implications of biofuels policy regarding major grains, to the subsequent evolution of the markets for calories from the three major grains, maize, wheat and rice. The implied market variables, namely, market price, consumption, and stocks, using a structurally estimated model combined with data on current and projected demand shifts, replicate the levels and dynamics of actual market behaviors, including the price rise before and during the 2007-2008 world food price crisis and the price dip at the breakout of the latest financial crisis. Counterfactual market variables constructed by removing mandates and their effects on production suggest that the biofuels mandate is the main driving force of the increase in price levels.

Key words: commodity price, biofuels, dynamic programing, food security, mandates, numerical simulation

1 Introduction

In 2005 Congress passed legislation, supported by a rare coalition of environmentalists and farmers, to employ a series of rising mandates, along with an ethanol subsidy and a tariff on imported ethanol, to increase domestic production of corn ethanol. Ethanol was seen as a domestic substitute for imported gasoline that generated no net atmospheric carbon when used as a fuel. The use of mandates to implement biofuels policy was copied in nations in the European Union and in other countries. In 2007 new United States legislation expanded the mandates and extended them to "second-generation" biofuels. The results have been more controversial than supporters might have anticipated.

Grain prices jumped in 2007/08 and farmer's wealth has subsequently soared. However environmentalists subsequently dismayed to learn that apparently simple supporting calculations had ignored the fact that corn plants used for biofuels displaced corn plants used for food or feed; if output of the latter were to be replaced in full, either yields must rise or land area must increase. Further, though scientific evidence on the effects of such induced land expansion was not conclusive, they might well induce release of large amounts of carbon into the atmosphere as greenhouse gases. Output expansion to cover food and feed demands proved costly on the margin, so grain prices rose, raising farmers' incomes and land values. The larger relative burden

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on poor food consumers was a frequently cited cause of riots and even changes of governments in the "Arab Spring."

The role of biofuels in raising food prices is currently hotly disputed in the struggle over maintenance of current biofuels mandates and expansion of ethanol blending shares allowed for unmodified vehicles. The lack of resolution of this issue reflects the lack of a well-grounded empirical model of evolving biofuels prices. Since grains are storable and subject to harvest shocks, an appropriate empirical model should confront the nonlinearities inherent in models with storage demands having non-negativity constraints. Most papers on this topic are not fully dynamic, and tend to rely on calibration rather than econometric estimation, although there are prominent exceptions including Roberts and Schlenker (2013). The literature seems to agree that biofuels caused less than one third of the price rises in the years to 2010, a conclusion indicating an implicit assumption of a linear relationship between biofuels mandates and price increases.

In this paper we empirically address the implications of biofuels policy regarding major grains, to the subsequent evolution of the markets for calories from the three major grains, maize, wheat and rice. (Although oil-seeds including soy and rapeseed, as well as Palm oil are also used in bio-diesel production, especially in Europe, we ignore them here.) We use a dynamic stochastic model in the tradition of Gustafson (1958), and an empirical strategy based on the maximum likelihood procedure as in Cafiero et al. (2014). We extend the methodology to take account of the implications of obvious trends in prices for intertemporal storage arbitrage. We also recognize the existence of essential stocks and the necessity to furnish sufficient grain to satisfy augmentation of such stocks in a trending model with increasing population. To simply the model, we take advantage of stylized empirical regularities in time series of global crop yields, land use and population.

This very simple model is estimated on price data as in Deaton and Laroque (1992, 1995, 1996), using quantities for calibration and for reproduction of yield disturbances and land area expansion in out-of-sample simulation. The estimated model can replicate key features of price behavior closely. Remarkably, it can also closely reproduce the out-of-sample evolution of stocks and production, given initial values observed at the end of the estimation interval in 2004 and actual yield disturbances after 2004.

We use a counterfactual analysis based on the estimated model, with no increase in per capita grain biofuels after 2004, to evaluate the effects of global pre-announced mandated biofuels expansion after 2005. The results demonstrate the influence of grain biofuels expansion on grain calorie price levels and price spikes through the 2010 crop year.

2 The Model

We consider the market for calories furnished by the three major grains: corn, rice, and wheat. We transform grain quantities into caloric equivalents ("calories") and then aggregate them in an index, following the general approach of Roberts and Schlenker (2010, 2013), who consider an index including soybeans. Price of calories is determined by a stationary function of consumption per capita. The form of this inverse demand function is specified as log linear, $F(C) \equiv e^{a-bC}$, where C denotes consumption per capita, and a and $b > 0$ are constants.

Production data suggest that per capita production of calories follows a linear trend, possibly with a structural break in the early 1980's (see Figure 1). Accordingly, we assume that per capita production at time t, h_t, is perturbed by an *i.i.d.* shock and has a deterministic linear trend, possibly subject to structural breaks. More specifically, $h_t = \alpha t + \omega_t$, where α is a positive constant that may depend on the time interval, and the distribution of ω_t is *i.i.d.* (any additive constant term in h_t can be interpreted as a scaling factor for prices, with no effect on the dynamics of the endogenous variables).

There is no storage cost apart from a constant interest rate $r > 0$. Z_t and C_t are per capita available supply and consumption at time t, respectively. Assume per capita inventories $(Z_t - C_t)$ are non-negative.

Necessary conditions for profit maximization are:

$$F(C_t) = \max\left[F(Z_t), \frac{1}{1+r} E_t F(C_{t+1})\right], \tag{1}$$

$$\text{s.t.} \qquad \begin{aligned} Z_{t+1} &\equiv \frac{1}{1+n}(Z_t - C_t) + h_{t+1},\ \forall\, t \in N, \\ (Z_t - C_t) &\geq 0,\ \forall\, t \in N \end{aligned}$$

where E_t denotes the expected value conditional on the information at time t, and n is the population growth rate.

Define c_t and z_t as the non-trending counterparts of C_t and Z_t :

$$c_t \equiv C_t - \alpha t \text{ and } z_t \equiv Z_t - \alpha t. \tag{2}$$

To simplify the notation, define $\lambda \equiv e^{-b\alpha}$. Using 2, equation 1 implies:

$$e^{-bc_t} = \max\left[e^{-bz_t}, \frac{\lambda}{1+r} E_t e^{-bc_{t+1}}\right].$$

Assume $\dfrac{\lambda}{1+r} < 1$,to ensure the existence of a stationary rational expectations equilibrium p :

$$p(z_t) = \max\left[e^{-bz_t}, \frac{\lambda}{1+r} E_t p(z_{t+1})\right], \text{ where } z_{t+1} = \frac{1}{1+n}(z_t - c_t) + \omega_{t+1}. \tag{3}$$

Standard arguments imply that p is non-negative, continuous, strictly decreasing, and that the following complementary inequalities hold:

$$\begin{aligned} p(z) &= F(z), \quad \text{for} \quad z \leq F^{-1}(p^*), \\ p(z) &> F(z), \quad \text{for} \quad z > F^{-1}(p^*), \end{aligned}$$

where $p^* \equiv \left(\dfrac{\lambda}{1+r}\right) Ep(\omega) \in R$.

Define the latent de-trended price by $p_t \equiv e^{-bc_t} = p(z_t)$. Using 2, we can relate the de-trended price p_t to the observed price P_t :

$$P_t = F(C_t) = F(\alpha t + c_t) = e^a \lambda^t p_t. \tag{4}$$

3 Econometric Procedure

The econometric estimation proceeds in 2 stages. We first estimate the trend parameter λ using least squares, based on 4expressed in natural logarithms. For prices from a storage model with trend, Bobenrieth et al. (2014) prove super-consistency in probability of this estimator.[1]

If the trend in per capita calorie production has a breakpoint, then the implied trend in calorie prices has a breakpoint. We assume any break point in trend is unanticipated. Application of the supremum tests of Andrews (1993) to the calorie price series suggests there is a breakpoint in the trend parameter λ, in 1982/83. Accordingly, we split the sample in two segments.[2] Given the estimated values for λ in each segment, we then use the Maximum Likelihood (ML) procedure proposed by Cafiero et al. (2014) to estimate the parameters b and r of the stationary storage model described in 3, using the de-trended prices p_t implied by the estimated value of λ and the average population growth rates, in each time interval.[3]

We assume a normal distribution for the *i.i.d.* harvest shocks ω_t. In order to estimate an identified model we set the mean and standard deviation of the unobserved harvest shocks at 0 and 1, respectively, in accordance with Proposition 1 of Deaton and Laroque (1996, p.906).

The ML estimator is based on the mapping from ω_t to de-trended prices p_t, conditional on the previous price p_{t-1}.[4]

$$\begin{aligned} p_t = p(z_t) &= p\left(\frac{1}{1+n}(z_{t-1} - c_{t-1}) + \omega_t\right) \\ &= p\left(\frac{1}{1+n}\left(p^{-1}(p_{t-1}) - F^{-1}(p_{t-1})\right) + \omega_t\right) \end{aligned}$$

Given a slope parameter b, a discount rate r, and a sample of positive prices p_t, $t = 0, 1, \cdots, T$, the likelihood function is:

$$L(\theta|p_0, \cdots, p_T) = \prod_{t=1}^{T} \phi(\omega_t)|J_t| = \prod_{t=1}^{T} \phi\left[p^{-1}(p_t) - \frac{1}{1+n}(p^{-1}(p_{t-1}) - F^{-1}(p_{t-1}))\right]|J_t| \quad (5)$$

where ϕ is the density of ω_t, and $J_t = \frac{dp^{-1}}{dp_t}(p_t)$ is the Jacobian of the mapping $p_t \mapsto \omega_t$. The monotonicity of p implies that the Jacobian J_t exists almost everywhere.

In implementing the ML procedure, the first step is to find the price function p that solves the storage model. We approximate the equilibrium price function with a cubic spline. The search for p follows an iterative procedure based on 3. To solve for the price function p, we approximate the distribution of the harvests using a Gaussian Quadrature with nodes $\{\omega_s\}_{s=1}^{10}$ and weights $\{\pi_s\}_{s=1}^{10}$.

The j-th iteration is:

[1] Their proof uses Theorem 2 of Andrews (1988, p. 461) of a weak law of large numbers for uniformly integrable triangular arrays which are $L1$-mixingales.

[2] We exclude 1983/84 from the data, due to the possibility that 1983/84 was a transition period. Therefore the second segment starts in 1984/85.

[3] Cafiero et al. (2014) prove that while their ML estimator imposes no additional assumptions on the model, it has small sample properties significantly superior to those of the Pseudo Maximum Likelihood estimator of Deaton and Laroque (1995, 1996).

[4] To simplify the notation we write a single price function p, though there is a price function for each sub-sample of detrended prices.

$$p^{\mathrm{sp}}_{\langle j+1\rangle}(z) = \max\left\{e^{-bz_t}, \left(\frac{\lambda}{1+r}\right)\sum_{s=1}^{10}\pi_s p^{\mathrm{sp}}_{\langle j\rangle}\left(\omega_s + \frac{1}{1+n}\left(z - F^{-1}\left(p^{\mathrm{sp}}_{\langle j\rangle}(z)\right)\right)\right)\right\} \tag{6}$$

The first iteration uses a guess $p^{\mathrm{sp}}_{\langle 1\rangle}$ on the right hand side of 6. Conditional on $p^{\mathrm{sp}}_{\langle 1\rangle}$, we evaluate $p^{\mathrm{sp}}_{\langle 2\rangle}$ on an equally spaced grid of 1000 points between the minimum harvest shock and 50. Iterations continue until the maximum difference between $p^{\mathrm{sp}}_{\langle j+1\rangle}$ and $p^{\mathrm{sp}}_{\langle j\rangle}$ evaluated at each grid point is within a given small tolerance. We first use a grid-search routine to locate a candidate maximum, and then use a gradient based constrained maximization algorithm to search for a maximum in the neighborhood of the candidate.

4 Estimation

4.1 Data for ML Estimation

In what follows "global" data exclude China, even though it accounts for a substantial portions of grain production and consumption. Unfortunately Chinese data in the sample, especially grain stocks, proved highly unreliable and indeed were heavily revised. Fortunately, although it has recently been very active in soybean trade, China has operated as nearly autarkic in grain markets, as illustrated in Figure 2 . Henceforth "global" and "world" refer to the world less China.

We use the December monthly average price for Corn (US), no. 2, yellow, f.o.b. US Gulf ports as the corn price for the marketing year that contains this month (i.e., the 1960 December monthly average price is used as the 1990/91 marketing year price). Similarly, we use the December monthly average price for Wheat (US), no. 1, hard red winter, as the wheat price for the corresponding marketing year, and use November monthly average price for Rice (Thailand), 5% broken, f.o.b. Bangkok as the price for the corresponding marketing year. These nominal monthly average prices for the three grains are obtained from the World Bank Commodity Price Data (The Pink Sheet).[5] We deflate the price constructed as above for the marketing year $n/(n+1)$ by the index of manufactures unit value (MUV) for the calendar year n in each marketing year. The MUV index is also obtained from the World Bank, Development Prospects Group website.[6] The value for the population growth rate, n, in each segment of the estimation sample equals the average world less China population growth rate in the corresponding segment. The Population data is from the United Nations World Population Prospects: the 2010 revision.

The price index of grain calories is the weighted average of the individual price of calories contents in three major grains, maize, rice and wheat. The weight is the proportion of calorie content in the world less China production of each grain in the aggregated calorie content in the aggregate world less China productions of the three grains.[7] The world and China quantity data used to generate the weight are obtained from the PS&D Online database of the United State Department of Agriculture (USDA).[8] The conversion units from weight to calorie for each grain are obtained from the USDA National Nutrient Database of Standard Reference.[9]

[5] http://go.worldbank.org/4ROCCIEQ50

[6] http://go.worldbank.org/SZXEODLF60

[7] Note that the weighting index constructed in this way is ad hoc. The PS&D Online database is marketing-year based and it aggregates quantity variables from major producing countries to obtain the world-level quantity. However, the marketing year for the three major grains are not identical from each other and across regions, whereas the timing of the monthly price used to represent a market year price is fixed. Therefore, there is a concern that whether the weight constructed in this way accurately represents the shares of the three grains in the world grains calorie market during a period when the monthly price is representative. Nevertheless, there is no obvious, convenient way to construct a better index of grains calorie.

[8] http://apps.fas.usda.gov/psdonline/psdQuery.aspx

[9] http://ndb.nal.usda.gov/

Figure 3 shows the deflated price index for grain calories. Since 2004/05, actual use of grain for biofuels production began to grow rapidly, which seems to be reflected in the price sample. To be consistent with trends in per capita production, the first segment is 1966/67 - 1982/83 and the segment is 1984/85 - 2003/04. We assume the two segments have identical per capita demand functions for grain calories.

4.2 Estimates and Model Fitness

The estimates are reported in table 1. From the table, both decay factors are significantly smaller than 1, with that for the second segment closer to one. This is consistent with the observation that productivity increased at a faster rate in the first segment. Figure 4 shows the estimated trends for the two segments of the estimation sample.

Figure 5 shows the estimated equilibrium function of detrended prices for the two segments of the estimation sample. The figure shows that the per capita total demand functions estimated for the two segments have similar shapes but have somewhat different storage demands. Assuming a constant per capita consumption demand and constant real interest rate, the two segments in the estimation sample differ in two aspects, the rate of productivity change and the rate of population growth. The rate of productivity change is higher in the first segment, discouraging storage in the first segment because future supply is expected grow faster. However, the population grows faster in the first segment too, which encourages storage per capita.

By comparing variables implied in the estimated model with actual data, we can check validity of the model for explaining market behavior in the estimation sample.[10] As in construction of the price index for world grain calories, the actual quantity data - per capita grains calorie production, consumption and stocks - are constructed from the weight data from the PS&D Online database of the USDA, using conversion units from weight to calorie for each grain given in the National Nutrient database of the USDA.[11]

Part of measured stocks consists of minimal "pipeline" stocks essential for the operation of the market. Our specification of log-linear inverse consumption demand ensures that there is no trend in the ratio of essential stocks to trending per capita consumption. Unfortunately this ratio is unobservable. We choose the ratio such that the lowest level in model stocks and actual stocks data are the same. The result ratio is 5%.

The comparison is shown in figure 6. The dynamics in the actual variables are well captured by the model variables. The comparison illustrates the superior ability of the model to explain market behavior during the estimation sample period.

5 Simulation Analysis

5.1 Data for Simulation Analysis

Historical and baseline projections of grain calories use for biofuels production In the following simulation analysis, we consider global corn and wheat use for biofuels production in the United States, European Union, and elsewhere. The historical use data are obtained from the USDA Feed Grain Database and the FAO OECD Agricultural Outlook. Specifically, the USDA Feed Grain Database provides the marketing year based corn use for fuels in the US. The FAO OECD Agricultural Outlook provides marketing year based coarse grain and wheat

[10]Since ML estimation of the model assumes a standard normal distribution for the production shock, to make this comparison, it is necessary to rescale variables in estimated model to match actual quantity data.

[11]The world consumption data in the PS&D online database excludes small net importing countries such as Barbados. Therefore, the production, consumption, import and stocks data conform to the accounting formula, production - consumption + import = change in stocks, up to a small error. We force the variables to conform to the balance formula by subtracting an amount that equals to the small error from the production data.

use for biofuels for the world and a set of countries including China and the OECD members.[12]

Since our model is forward-looking, expected future demand increases are necessary inputs. It is difficult if not impossible to obtain data on exactly what expectations the market forms of the future demand shifts. Nevertheless, official long-term projections of grain use for biofuels, once apparently heeded by the market, may be used as proxies for its expectations. The USDA Agricultural Baseline Projection announced in February each year contains a 10-year projection for US corn use for fuels. The top left chart of figure 7 plots the per capita US corn use for fuels calculated using the USDA baseline projections, weight-to-calorie conversion rates, and world population. The first data point in each projection is always the actual per capita US corn use for fuels in the baseline year. The remaining ten points in each projection are the projected use for future years, conditional on information available in the initial year.

We construct the baseline projections for the world less US corn use for fuels, and for the world wheat use for fuels. Specifically, given the actual data of world less US corn use for biofuels and world wheat use for biofuels in the OECD Agricultural Outlook data set, we assume that the market expects the amount of use to grow linearly to the 2022 predicted level. And then we extract the first 10 year (excluding the baseline year) in the sequence as the baseline projection. The top right chart of figure 7 presents these baseline projections measured in per capita terms. The consolidation of the two baseline projections by year for all baseline years forms the baseline projection for world grain calories use for biofuels production.

In the following analysis, we do not assume that the sum by year of the two baseline projections above are necessarily the market expectations of future demand increases. Instead, we assume that whether the market expectations can be approximated by the constructed long-term projections of a given baseline year depends on whether in a simulation scenario the market has begun to recognize the future rapid growth in biofuels demand in that baseline. Before futures prices indicate that the market recognizes the future rapid growth in demand, we assume that the market expects the current per capita use to be maintained.

Yield and harvested area of grain calories Figure 9 presents the world average yield of grain calories divided by world population from 1984/85 to 2010/11. The horizontal straight line in the figure represents the time average of the series. In the figure, we do not observe any obvious structural change or time trend in the series within the sample period. Accordingly, it seems reasonable to assume that yield per capita has a constant mean over time.

Note that per capita production always equals the product of harvested area and yield per capita. In general we assume that the per capita production exhibits a linear time trend in the estimation sample. The assumption that yield per capita has a constant mean implies that there is a linear trend in harvested area and the trend differs from the linear trend in per capita production only by a scalar. Figure 9b plots the implied trend in harvested area together with the aggregate harvested area of the three grains.

From the figure, it seems clear that there was production expansion via increased land use for 2007/08 and beyond. However it is also very clear that before recognition of the implications of a new biofuels regime, there was a substantial expansion of harvested area in 2004/05 and 2005/06. Prices and available supplies indicate that existing substantial use of corn ethanol for gasoline oxygenation (counted here as part of consumption demand) was matched at current price levels by the output of this increased harvested area. Hence later harvested area expansion in response to the expanded profile of biofuels mandates is measured from the 2005/06 land base.

5.2 Reconstruction Analysis

Market equilibrium under expected structural change Let the inverse per capita consumption demand in period t be $F_t(c) = e^{a_t - b_t \cdot c}$. Let the profile of expected period s inverse

[12]Since we are working with the world less China market, we have subtracted China use of those grains for fuels from world use. For convenience, in the following context, world means world less China.

per capita consumption demand as of period t be $F_t^s(c) = e^{a_t^s - b_t^s \cdot c}$. For parallel demand shifts, if the period s parallel demand shifts expected as of period t is m_t^s, then

$$a_t^s = a_t + m_t^s \cdot b_t,\ b_t^s = b_t,\ \text{or}\ F_t^s(c) = e^{a_t + b_t \cdot m_t^s - b_t \cdot c}.$$

On the production side, let the per capita harvest shock in period t be ω_t and the expected period s per capita harvest shock as of period t be ω_t^s. Let Φ_t^s denote the distribution function of ω_t^s.

By the Euler equation under the profiles $\{m_t^s\}_s$ and $\{\Phi_t^s\}_s$, the period s equilibrium function f_t^s as of period t satisfies

$$f_t^s(z) = \max\left\{F_t^s(z), \frac{\lambda}{1+r} E_t^s\left[f_t^{s+1}\left(\frac{1}{1+n}\left(z - (F_t^s)^{-1}(f_t^s(z))\right) + \omega_t^{s+1}\right)\right]\right\},$$

where E_t^s is the period s conditional expectation operator as of period t.

For each period t, we first solve the stationary equilibrium price function (inverse demand for consumption plus storage) at the far end of each profile of biofuel mandates,assuming it represents a perceived long run equilibrium per capita, then solving backwards for all f_t^s, $t \leq s$, using the Euler equation above given projection profiles $\{\Phi_t^s\}_{s \geq t}$ and $\{m_t^s\}_{s \geq t}$. The projection profiles update each period. The function solved in initial year t, f_t^t, is the realized equilibrium in period t while f_t^s, $s > t$ exists in expectation. We replicate the procedure for a different time, say for $t+1$, to solve f_{t+1}^{t+11}, ..., f_{t+1}^{t+3}, f_t^{t+2} and f_{t+1}^{t+1}, given projection profiles $\left\{m_{t+1}^s\right\}_{s \geq t+1}$ and $\left\{\Phi_{t+1}^s\right\}_{s \geq t+1}$. Again, f_{t+1}^{t+1} is the realized equilibrium in period $t+1$ while f_{t+1}^s, $s > t$ is part of an expectation profile of mandated biofuel use.

Specifying expected demand shifts We have constructed baseline projections for grain calories use for fuels as shown in figure 7. If the market agents form their beliefs about future demand shifts based on or consistent with information including official long-term projections of crops used for biofuels, then those projections can be used as proxies for the market projections, once futures prices indicate that the the market has recognized the significance of the future fast growth in biofuel demands. In the following analysis, in order to be consistent with evidence in the futures market and implementation of the U.S. ethanol mandates, we assume that the market began in 2006/07 to recognize the rapid growth in biofuels demand and formed expectations based on the long-term projections shown in figure 7 and continued to do so using the corresponding baseline projections. For 2005/06, we assume instead that the market expected the per capita current use to be maintained in the future.

Implications of use of distillers' grains as feed As a byproduct of biofuels production, distillers' grains are used as feed for livestock. We assume the maximum effects of distiller grains from mandated increases in corn biofuels on world food prices to obtain a lower bound for the reconstructed market prices. Specifically, we assume 16 pounds of dried distillers' grains solubles (DDGS) per 56 pound bushel of corn grain. Further we assume that the market average of 89% of the cornprice indicates its relative value as feed.[13] Thus the equivalent of 28% of corn returns to the corn market as feed. FInally we conservatively ignore any effects of biodiesel biofuels on the demand for DDGS.

Specifying expected production expansions Finally, we specify the baseline projections of future production distributions. The data indicate that expansion in per capita production after 2005/06 was achieved through expanding land use as the yield per capita did not exhibit any shift in trend. Therefore, it seems reasonable to express the projected per capita production distribution in the form of an expansion ratio from the previous trend in harvested area.

[13] http://farmdocdaily.illinois.edu/2013/07/understanding-pricing-distillers-grain.html

However, since the effect of a few percent expansion has very limited effect on variance of per capita production, in actual simulation exercises we consider only the main effect of land expansion, that is, the mean shift.[14] As in constructing the projections of grain calories use for fuels, it is difficult if not impossible to know exactly what expectations the market has formed of production shifts. To be consistent with futures market evidence, we assume in 2005/06, production had already fully adjusted to the growth in biofuels demand up to these two years and the market in these two years did not expect anyper capita bioethanol production expansion in the future. In contrast, we assume in 2006/07 and beyond the market expected a mean future harvest arean in excess of the 2005/06 benchmark level by the average of 2007/08 - 2010/11 additional harvest area.

Solved equilibrium price functions Treating 2004/05 and 2005/06 as the baseline, we can solve the equilibrium of the stationary counterpart model using the procedure described and the projections constructed above. Figure 8 presents the solved market equilibrium for each year during the analysis period under the specified scenario. We can see that as the demand for biofuels increase over time, the demand functions gradually shift outward from the 2005/06 baseline. Since the storage model was estimated using data before 2004/05, we re-normalized the quantity variables to account for the increase in production and consumption er capita to the 2005/06 benchmark level.

Reconstructing market variables Reconstruction of the market prices from 2004/05 to 2010/11 (i.e., out-of-sample prediction) uses the estimated model, actual and projected demands shifts, the projected harvest shock distribution change, and the per capita yield and harvested area data, iteratively. Recall that 2003/04 price is the last observation in the estimation sample. Then, we first calculate the per capita normalized storage in 2003/04 by plugging the detrended price data in 2003/04 into the estimated baseline equilibrium policy function. Adding the result (with an adjustment due to population growth) and the normalized per capita production in 2004/05 gives us the detrended and normalized per capita availability in 2004/05. The reconstructed price in 2004/05 is then the value of the solved 2004/05 equilibrium function of detrended price at the detrended and normalized 2004/05 per capita availability. Since the reconstructed 2004/05 price maps to a detrended and normalized per capita storage through the solved 2004/05 inverse equilibrium function of detrended price, repeating the above procedure reconstructs the price in 2006/07. By continuing doing so, we can reconstruct the market prices, consumptions and stocks for the entire counterfactual analysis sample. Finally, we normalize the 2004/05 reconstructed to actual 2004/05 price level to correct for possible effects of estimation biases on levels of generated prices. In the reconstruction, we continue to assume the opportunity cost of capital is 2% and the proportion of essential stocks to consumption trend is 5%. As before, we scale variables implied in the model so that we can compare model implications with observed market behavior at similar magnitudes.

[14] Suppose land use is projected to expand from its trend level by a rate A in period s as of period $s-1$, the projected per capita production in period s becomes

$$(1+A)\,LandTrend_s\frac{Yield_s}{N_s}.$$

Since per capita production has a linear trend, we can rewrite the last expression as

$$\begin{aligned}(1+A)\left(\sigma\left(\alpha s+\omega_s\right)+\mu\right) &= \sigma\left(\alpha s+(1+A)\,\omega_s+\left(A\alpha s+A\frac{\mu}{\sigma}\right)\right)+\mu \\ &\equiv \sigma\left(\alpha s+(1+A)\,\omega_s+\delta\right)+\mu,\end{aligned}$$

where ω_s is distributed as the harvest shock in the stationary counterpart model. Thus, land expansion is equivalent to shifting and rescaling the harvest shock in the stationary counterpart model. Assume A and δ are projected to stay constant over time. Then future harvest shock in the stationary counterpart model becomes $(1+A)\,\omega+\delta$. Since μ and σ are known from calibrating quantity data, it suffices to know the projected A to obtain projected per capita production distribution for future periods. Since A is small, the main effect is δ.

Result of reconstruction analysis Figure 10 reports the reconstruction results. The figure shows that, although gaps between reconstructed variables and actual data exist, the dynamics of the reconstructed variables, especially the reconstructed price, closely replicate the behavior of actual variables.

The top left chart shows the reconstructed price versus the actual price data. The reconstructed price traces the actual data well: it replicates the peak in 2007/08 as well the dip during the financial crisis. It is important to mention that our simulation scenario assumed that the market began to recognize the rapid future growth in biofuels demand in 2006/07, and accordingly expected a larger an increase inharvested area from the 2005/06 level. In 2006/07, futures prices for corn began to rise dramatically in September. If this is a signal that the market began to recognize the future rapid growth in biofuels demand, then it would be natural that the market expected at the same time a jump in projected harvested area similar to the average observed inthe next several years.

The bottom left chart shows that reconstructed consumption remains slightly lower than actual consumption except for the year 2004/05. In general, the match between reconstructed consumption and actual consumption is quite good. Although the gap is small, it affects the reconstruction in later periods because, as more stocks are rolled over, errors accumulate, as seen in the gap between reconstructed stocks and actual stocks. We cannot avoid accumulating errors in such a dynamic reconstruction, if endogenous variables are not refreshed each year, as would be doneto make a conditional one-year-ahead projection. The general replication quality appears quite satisfactory, given the length of the projection horizon.

In the bottom left chart, we plot reconstructed food consumption. Note that reconstructed food consumption is decreasing, while consumption before 2004/05 is slightly upward trending. The negative effects of biofuels policies on food consumers include slightly lower consumption (likely concentrated on low-income populations) and dramatically higher grain calorie costs.

In sum, in spite of some discrepancies in levels, the reconstructed variables are able to replicate the behavior of the actual market variables under the assumed scenario of expectations updating. Therefore, the simulation result suggests that market behavior after 2005 is strongly influenced by a combination of legislated rapid growth in demand for biofuels, market expectations that constantly underestimated growth in biofuels demand, very modest land area expansion above the 2005 level (given the larg eprice increases) and the forward-looking optimal storage behavior based on those expectations.

5.3 Counterfactual Analysis

Constructing counterfactual productions To perform the counterfactual analysis, we need to construct counterfactual production. We assume that yields and land area in 2004/05 and 2005/06 were jointly appropriate current caloric demands including existing bioethanol production prior to the legislated expansion.

We calculate the shifts in per capita production due to expectation of mandated biofuel demand increase by multiplying the realized yield per capita with the deviation of harvest area from its 2005/06 level. The construction is reasonable if correlation between land expansion and yield per capita is weak; the method presumes that in the short run production expansion is mostly achieved through increasing land use. Country-level data from the PS&D online of the USDA shows that many producing countries expanded their production and have improved yields during the periods of interest. This would have a positive effect on the world average yield. But many countries with yields lower than the world average expanded production as well, tending to reduce global average yields.

The shifts in per capita production calculated in this way are 3.5901 for 2004/05, 3.7694 for 2005/06, 2.6551 for 2006/07, 6.0743 for 2007/08, 7.8709 for 2008/09, 7.0423 for 2009/10 and 6.2617 for 2010/11. We then construct the counterfactual productions by subtracting those shifts from the realized per capita productions. Figure 11 plots the constructed counterfactual productions. Three counterfactual per capita productions are at the original trend.

Calculating counterfactual prices We calculate the counterfactual prices and other counterfactual market variables using an iterative procedure similar to tthat used in the reconstruction analysis. The main difference is that here we use the original estimated equilibrium price function, with no shifts to reflect increased biofuel use after 2005.

Starting with ending stocks data in 2003/04, we calculate the availability in 2004/05 by summing the counterfactual production and the carry over. Then we plug the result availability into the estimated equilibrium price function to obtain the counterfactual price, consumption and ending stocks in 2004/05. Then, with the ending stocks in 2004/05, we iterate the procedure to obtain the counterfactual market variables in 2005/06 and beyond. In the construction, we maintain the assumption that the proportion of essential storage to consumption trend is 5%.

Result of counterfactual analysis We report the result of counterfactual analysis in figure 10. The counterfactual prices are below the actual prices since 2004/05 and the difference between the two are increasing. The counterfactual production stays at a level that is similar to consumption before 2004/05. The widening gap between counterfactual price (consumption) and actual values suggests that biofuels demand increase is the driving force for the price rise in the grain calorie market. The counterfactual stocks are slightly below the actual values while the counterfactual availabilities are considerably lower, reflecting the modest response of harvested area to the large price jumps due to espansion of biofuels use.

6 Conclusions

We present a simple stylized model of the market for calories from the three major grains, rice, wheat and corn, and estimate the model using trending price data for the era before biofuels mandates, allowing for population increase and a calibrated ratio of essential stocks to consumption. We assume a real cost of capital of two percent, and recognize average harvested area expansion after 2005/06 due to biofuels. We find that the model replicates out-of-sample price responses after the introduction of biofuel mandates remarkably well. It also implies stock quantities that closely track observed values, even without updating, from 2005/06 to 2010/11. Variations in consumption, which responds very little to policy, are less well tracked. A real interest rate of three percent improves the fit to cmall consumption variations, but fits dramatic price movements less well, and implies a less dominating but still very substantial overall effect on calorie prices.

Our results suggest that biofuels policy was a dominating influence on subsequenbt evolution of price year by year. Had increasing biofuels policies not been introduced, grain prices would likely have continued to fall, and grain calories consumed as food and feed would have been slightly higher, and expenditure on grain calorie consumption would have been far lower.

References

[1] Cafiero, C., Bobenrieth, E. S. A., Bobenrieth, J. R. A., and Wright, B. D. (2014): "Maximum Likelihood Estimation of the Standard Commodity Storage Model. Evidence from Sugar Prices," Working paper, FAO of the UN, Statistics Division, Pontificia Universidad Católica de Chile, Universidad del Bío-Bío, University of California at Berkeley.

[2] Carter, Colin A., Gordon C. Rausser, and Aaron Smith. 2011. "Commodity Booms and Busts." Annual Review of Resource Economics 3: 87–118.

[3] Carter, Colin, Gordon Rausser, and Aaron Smith. 2012. “The Effect of the US Ethanol Mandate on Corn Prices.” Department of Agricultural and Resource Economics, UC Davis. http://agecon.ucdavis.edu /people/faculty/aaronsmith/docs/Carter _Rausser_Smith_Ethanol_Paper_submit.pdf.

[4] Deaton, A., and Laroque, G. (1992): “On the Behaviour of Commodity Prices,” *Review of Economic Studies,* 59(1), 1-23.

[5] Deaton, A., and Laroque, G. (1995): “Estimating a Nonlinear Rational Expectations Model with Unobservable State Variables,” *Journal of Applied Econometrics,* 10, S9-S40.

[6] Deaton, A., and Laroque, G. (1996): “Competitive Storage and Commodity Price Dynamics,” *Journal of Political Economy,* 104(5), 896-923.

[7] Gustafson, R. L. (1958): *Carryover Levels for Grains.* Washington D.C.: United States Department of Agriculture Technical Bulletin 1178.

[8] Roberts, M. J., and Schlenker, W. (2013): "Identifying Supply and Demand Elasticities of Agricultural Commodities: Implications for the US Ethanol Mandate," *American Economic Review*, 103(6): 2265-95.

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

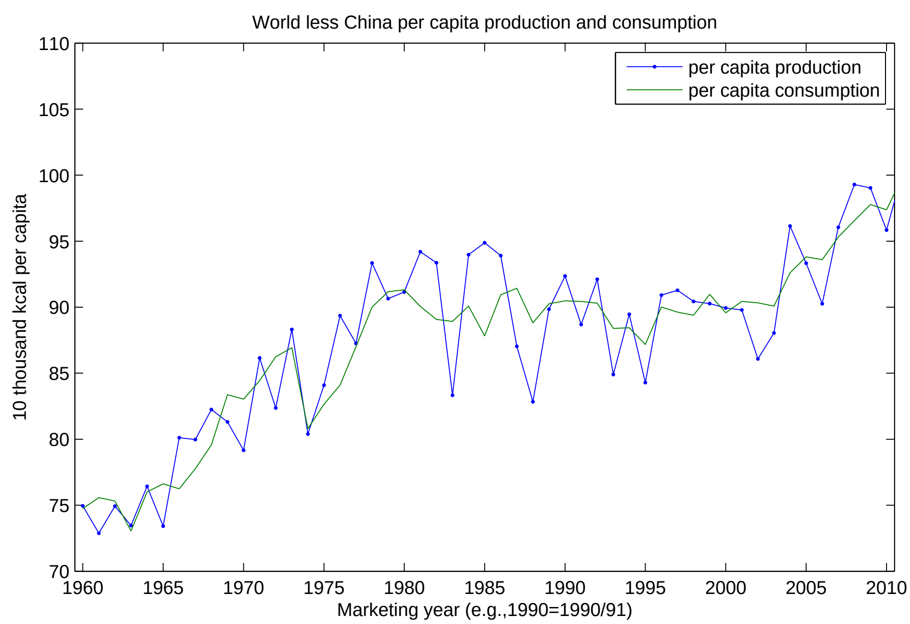
Tables and Figures

Table 1: ML estimates of the world grain calories market

	b	λ 1966/67-1982/83	λ 1984/85-2003/04	p_1^*	p_2^*	F
Estimates	1.3598	0.9760	0.9897	3.2332	3.3305	11.8649
S.E.	(0.0037)	(0.0122)	(0.0048)			

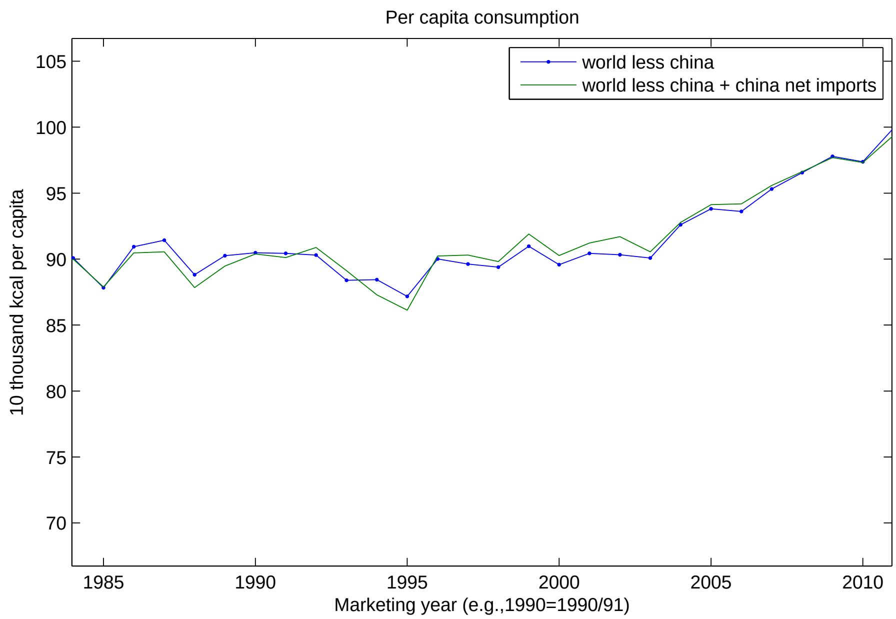
Notes: b is the parameter of the log-linear inverse consumption demand function, which is assumed to remain constant over the entire sample period for estimation. The estimate for the decay factor λ in the deflated price index of grain calories is obtained by detrending each of the two segments of the sample using the log-linear trend estimated in the corresponding segments. F is the value of the log likelihood function evaluated at the estimates. The real interest rate, r, is fixed at 2% in the estimation.

Figure 1: World less China per capita production and consumption of grain calories



Notes: The sequence with dot markers represent the per capita production of grain calories in corn, rice and wheat from 1960/61 to 2010/11. The sequence without markers represent the per capita consumptions of grain calories in the three grains over the same period. The per capita production (consumption) is obtained by dividing the production (consumption) of grain calories by the world population. The production (consumption) of grains calorie is obtained by aggregating the productions (consumptions) of corn, rice and wheat in terms of grain calories, converted the weight data in the USDA PS&D Online using the conversion rates from the USDA National Nutrient Database. The population data are from the United Nations World Population Prospects: the 2010 revision.

Figure 2: Per capita consumptions and net China imports



Notes: The sequence with dot markers represent the world less China per capita consumption of grain calories in corn, rice and wheat from 1984/85 to 2010/11. The sequence without markers represents the sum of world less China per capita consumptions and net China imports of grains calories in the three grains over the same period. The per capita consumption (imports) is obtained by dividing the consumption (imports) of grain calories by the world less China population. The consumption of grain calories is obtained by aggregating the consumptions of corn, rice and wheat in terms of grain calories, converted using the weight data in USDA PS&D Online using the conversion rates from the USDA National Nutrient Database. The population data are from the United Nations World Population Prospects: the 2010 revision.

Figure 3: Deflated price for grain calories

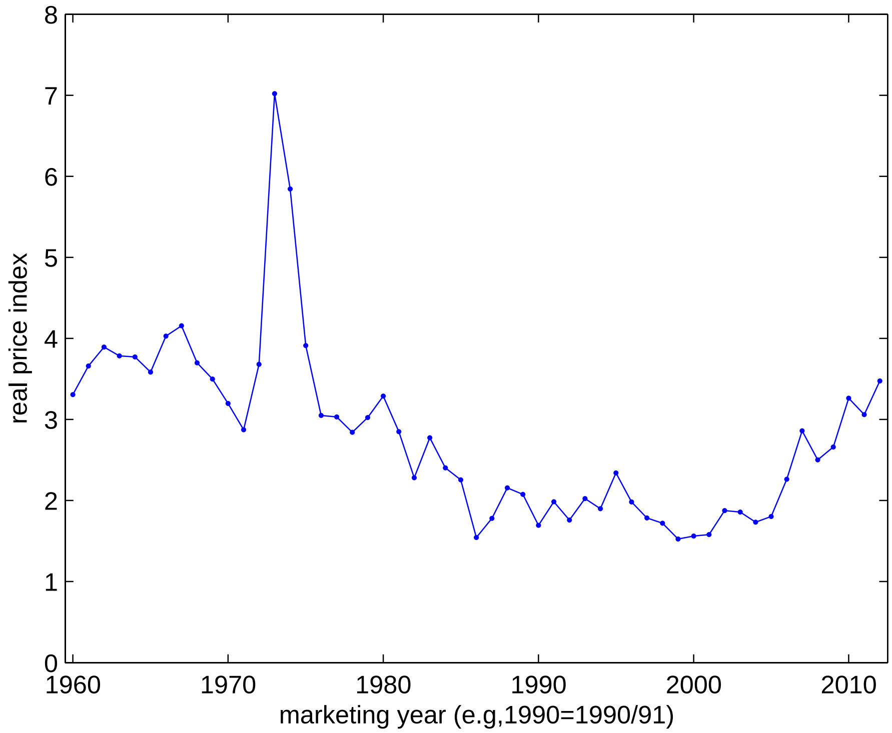
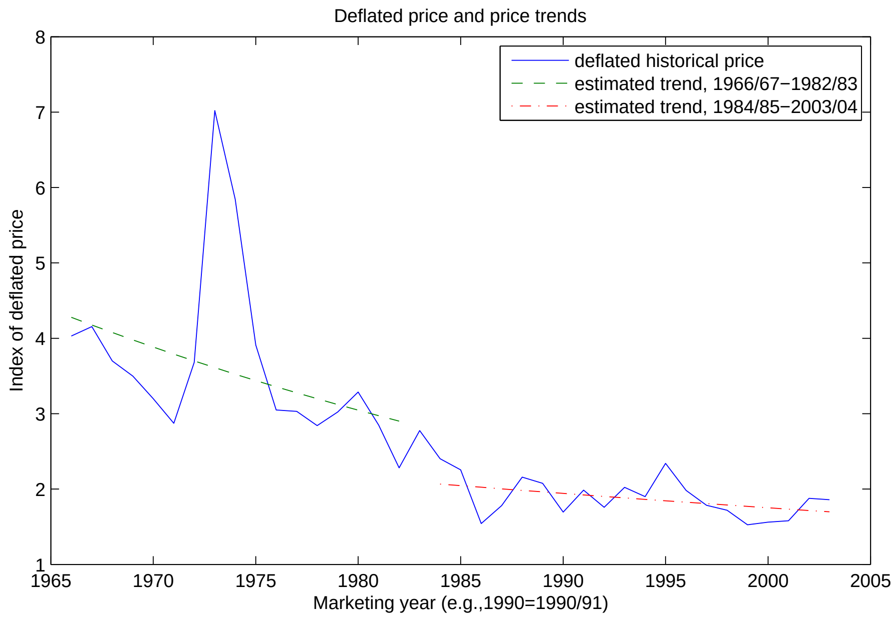
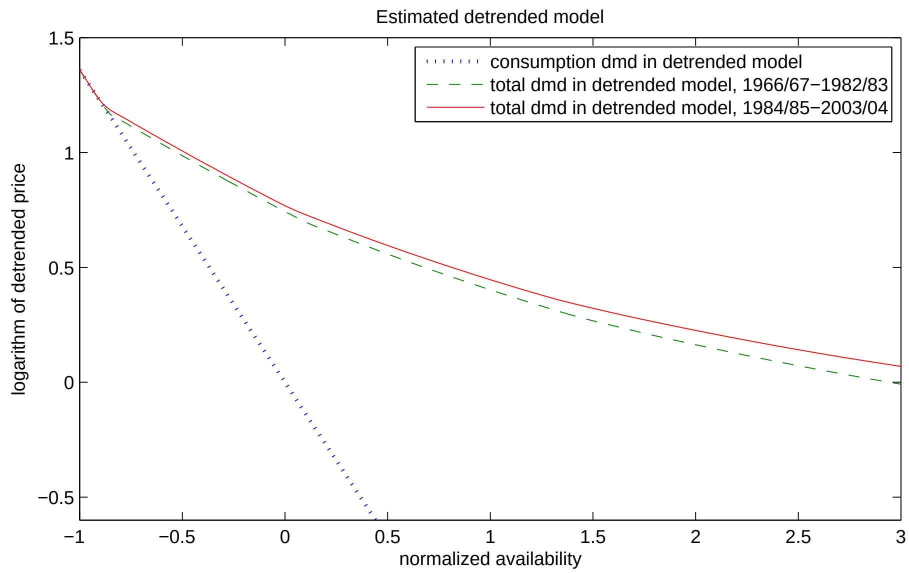


Figure 4: Deflated price for grain calories and price trends



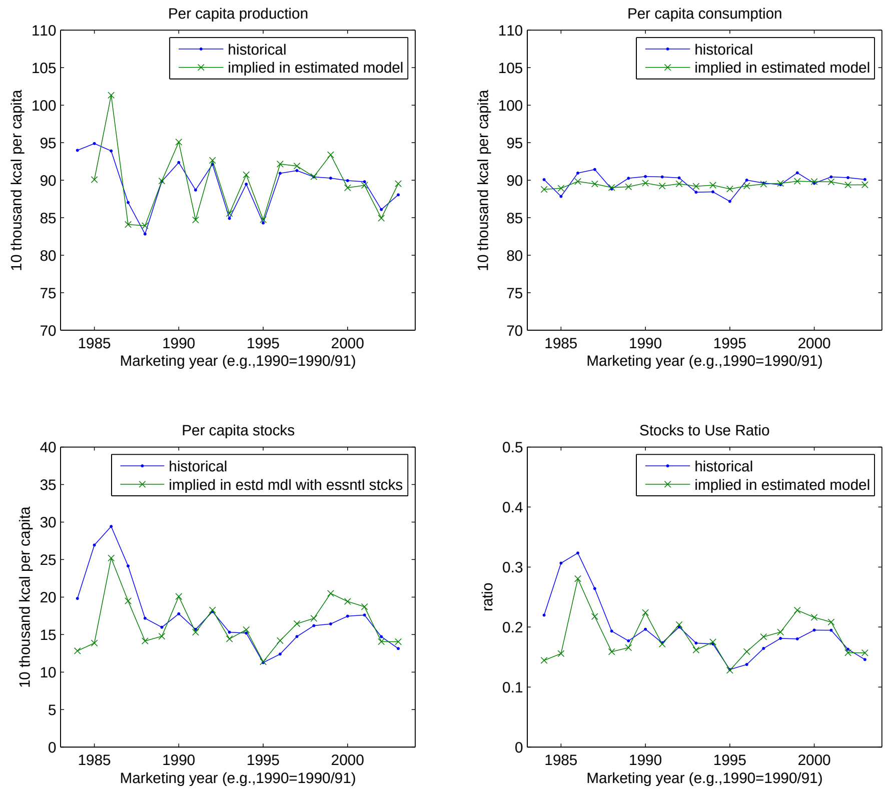
Notes: The sequence in the figure represents the deflated price index of grain calories. The dashed downward line on the left side of the figure represents the log-linear trend estimated in the sample segment 1966/67 - 1982/83. The dashed dot downward line on the right side of the figure represents the log-linear trend estimated in the sample segment 1984/85 - 2003/04. The log-linear trends in both segments are estimated using the OLS estimator.

Figure 5: Estimated equilibrium functions of detrended prices



Notes: The figure plots the logarithm of the estimated log-linear demands for the two segments in the estimation sample. The dotted line represents the inverse demand function that is assumed to be constant in the two segments. The solid curve represents the total demand estimated for the second segment (i.e., 1984/85 - 2003/04) while the dashed curve represents the total demand estimated estimated for the first segment (i.e., 1966/67 - 1982/83). The difference between the consumption demand and the total demand is storage demand. The mean harvest is normalized to zero and rescaled so quantity variables in the estimated model can become negative.

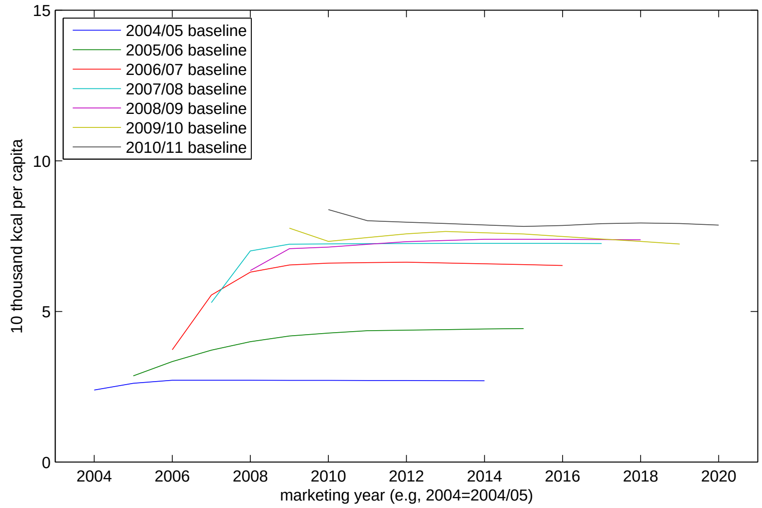
Figure 6: Actual data versus variables implied in the estimated model (1984/85-2003/04)



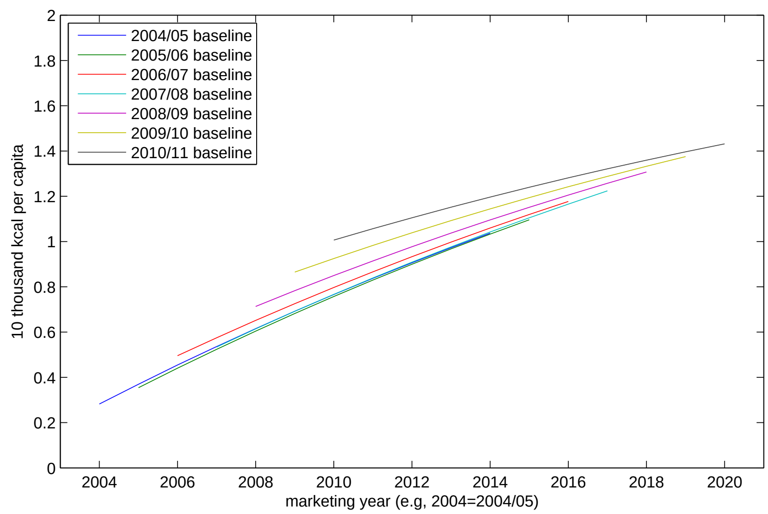
Notes: In all four charts in the figure, the sequence with dot markers represent the historical data while the sequence with cross markers represent the variables implied in the estimated model, rescaled to match the level and variance of the actual data. The parameters for rescaling are the same for all variables.

Figure 7: Baseline projections for grain calories use for biofuel production

(a) US corn

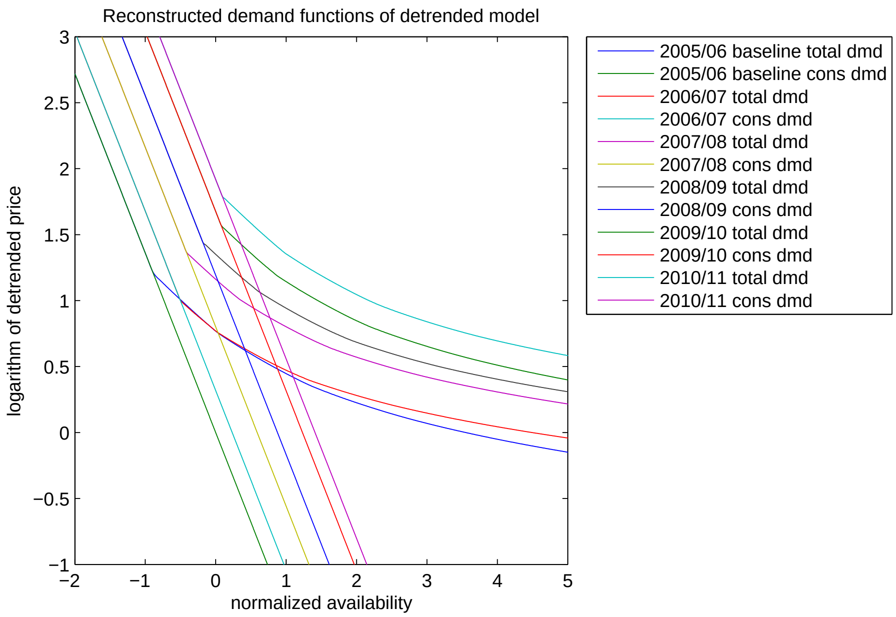


(b) World wheat plus coarse grains outside US



Note: In the top left chart are the per capita baseline projections for US use of corn for biofuels. They are calculated based on the USDA Agricultural Baseline Projections. In the bottom chart are the baseline projections for world use of wheat for biofuels production and world less US use of coarse grains for biofuels productions. The data are from the FAO OECD Agricultural Outlook. The first data point in each baseline projection is the actual per capita use in the baseline year while the rest 10 data points in a projection are projected value for future years. The original quantity data are measured in weight. We convert them to calorie and then to per capita terms.

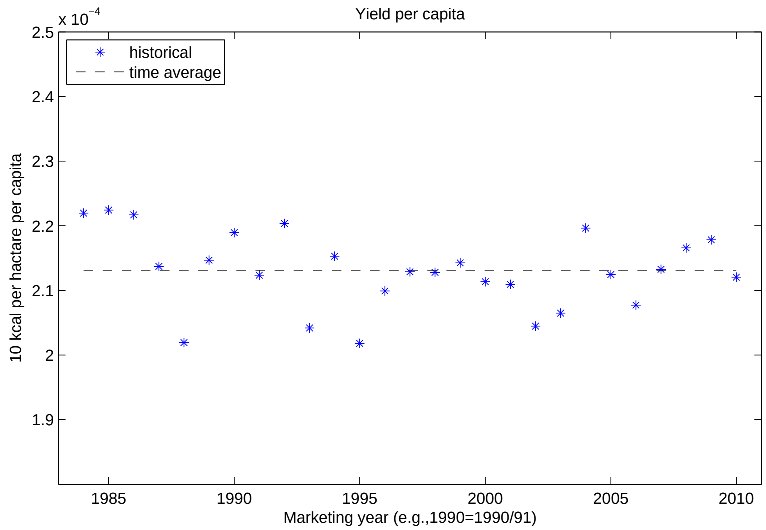
Figure 8: Solved equilibrium functions of detrended prices



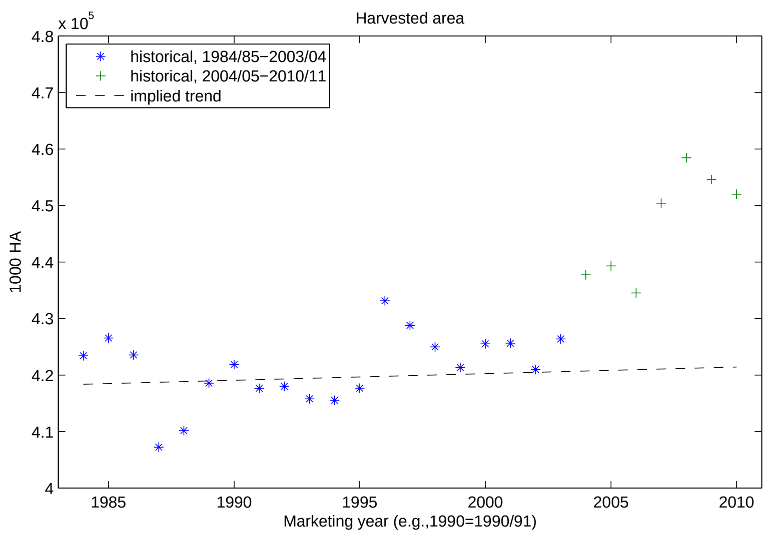
Notes: The figure presents the logarithm of the solved shifted demand functions. The straight lines represent the inverse consumption demand functions. The curves represent the total demand functions. The inverse consumption demand shifts to the right, representing the increase in biofuels mandates. The shifts in total demand reflect not only the current grain calories use for biofuels but only the expectation for future biofuels uses and future harvested area expansion.

Figure 9: Yield per capita and harvested area of grain calories

(a) Yield per capita

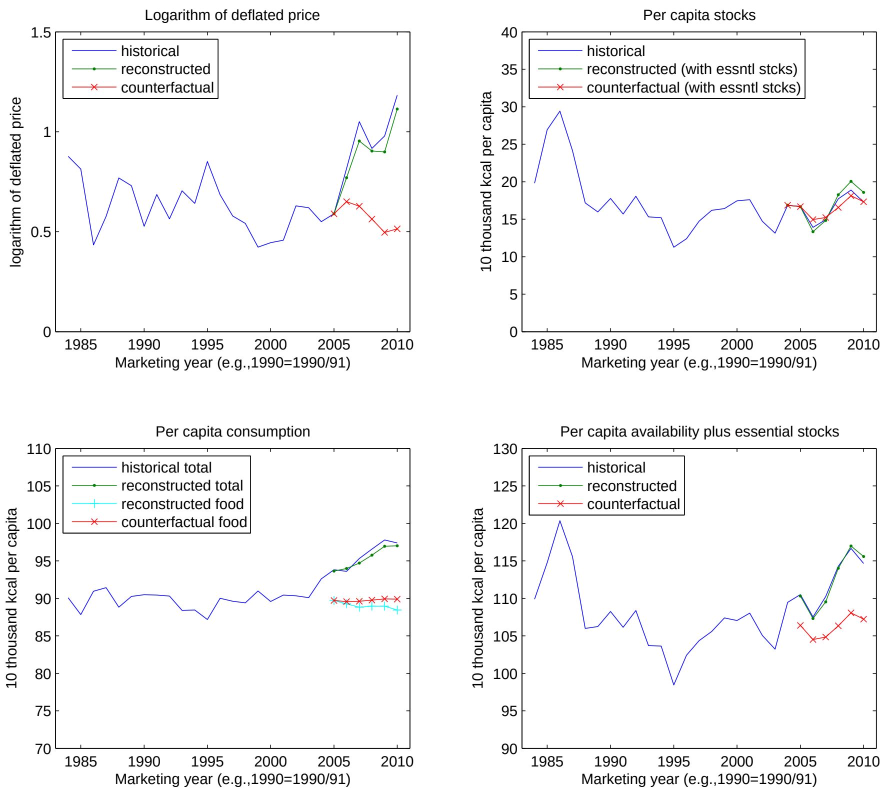


(b) Harvested area (maize, rice and wheat)



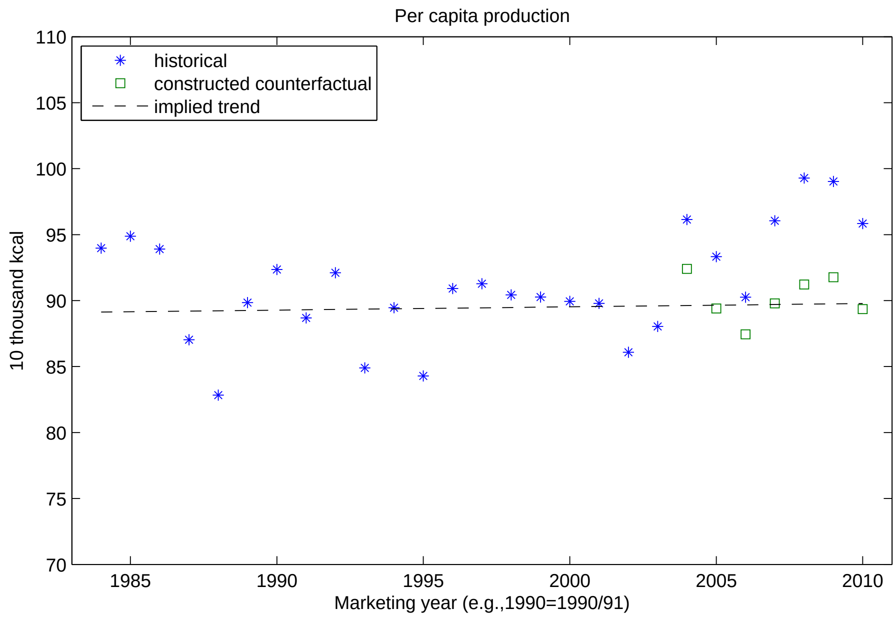
Notes: In the top chart, the * markers represent the yield per capita of grain calories in corn, rice and wheat from 1984/85 to 2010/11. The dashed line represents the average of yield per capita. The per capita yield data are obtained by dividing the production of grain calories by world population and then by aggregate harvested area. In the bottom chart, the * markers represent the aggregate area harvested for corn, rice and wheat from 1984/85 to 2003/04. The + markers represent the aggregate area harvested for corn, rice and wheat from 2004/05 to 2010/11. The dashed line represents the implied linear trend in aggregate area harvested. The production of grain calories is obtained by aggregating the production of corn, rice and wheat in terms of grain calories, converted from the weight data in the USDA PS&D Online and the conversion rates from the USDA National Nutrient Database. The population data are from the United Nations World Population Prospects: the 2010 revision. The area harvested is the sum of area harvested for corn, rice and wheat, all obtained from the USDA PS&D Online database.

Figure 10: Results of simulation analysis



Notes: The simulation analysis starts with actual ending stocks of 2004/05. So the generated stocks in the top right chart begins in 2004/05. The generated price, consumption and availability, however, begin in 2005/06 as they are generated in the model using the 2004/05 stocks and the 2005/06 production. During the construction, the proportion of essential stocks to per capita consumption trend is fixed at 5%.

Figure 11: Actual and counterfactual per capita production of grain calories



Notes: The * markers represent the per capita production of grain calories in corn, rice and wheat from 1984/85 to 2010/11. The square markers represent the counterfactual per capita production. The dashed line represents the implied linear trend in per capita production. The per capita production of grain calories is obtained by dividing the production of grain calories by the world population. The production of grain calories is obtained by aggregating the productions of corn, rice and wheat in terms of grain calories, converted using the weight data in the USDA PS&D Online and the conversion rates from the USDA National Nutrient Database. The population data are from the United Nations World Population Prospects: the 2010 revision.