A prototype dynamic stochastic equilibrium model of the global food system

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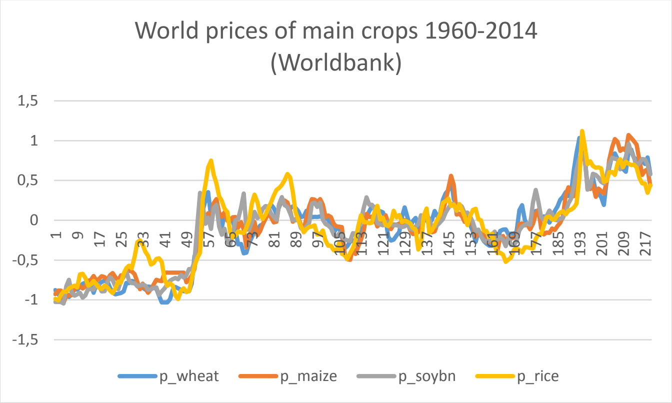
Food security

- Need for food is relatively smooth, while supply is stochastic and seasonal. The discrepancies lead to fluctuating food prices. Periods of high food prices are associated with food insecurity as low income people will no afford a sufficient diet. Price spikes $\rightarrow$ social unrest
- Price jumps so far have not been tipping points of global food balance and have led to adjustments after some time

Observations



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A research question

- Observations show:
  - High correlations between commodities and over time
  - Fluctuations with durations of years
  - Indications of underlying structure which might be modelled
- New periods of high prices are expected — and are bad enough to be analyzed and met with policies. However, the real problem is not the observed high price periods, but the risk of periods with even higher prices
- The modeling of price dynamics and its determinants is consequently essential for assessment of food security

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A plausible story

- Say there is a bad crop year by chance of nature. Price run high and stocks low
- Next year the price is expected above normal because of low stocks, consequently production intensity is somewhat increased
- That year is also a bad year by chance. Price run even higher and stocks even lower
- Even third year can be bad in terms of nature. Food supply can be a disastrous unless production intensity and other adaptations have changed sufficiently fast based on signals from the two previous years

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What can be learned?

- Price control might be popular among consumer first year, but would empty stocks faster, and cause more problems in second and third year
- Price spikes that are bad for consumers in the short run are important signals to producers who may counterweigh disasters in following years if they respond sufficiently quick
- A food security policy of storage might be required to keep stocks at levels which address consumer risk. Producers deal otherwise only with their own risk
- Storage rules should not dampen the price signals to producers
- Food security policies should aim at improving the welfare of consumers through reduced food supply risk and affect producers to small extent

How can the dynamic evolution of an economy dependent on stochastic nature be modelled?

- Dynamic stochastic general equilibrium models (DSGE) is in the economists tool-box
- Initiated by Kydland and Prescott (1977): "Rules rather than discretion: Inconsistency of optimal plans"
- Stochastic events need be modeled because markets for insurance are incomplete
- First best optimal plans do not exist with incomplete assets markets. Models should be therefore be positive as opposed to normative
- Policies should follow known rules rather than some hidden agenda

Paradigm of agricultural economics in contrast to DSGE

- Equilibrium described with normative deterministic models with stochastic events ignored with reference to Arrow-securities and complete asset market
- Major models are static
- Outcomes for 2050 say are formed by changing parameters from base (2010) to 2050 levels based on discussions. These may well happen to be sound, but do not say anything on the bumpy road towards that expected future.

More on DSGE

- Fitted to data from real business cycles. Mostly applied for analysis of fiscal and monetary policies
- Disturbingly technical despite oversimplified models: One single consumer good is typical.
- Less elegant than normative models
- Do not even think of making the DSGE perfect!
- Bayesian estimation of variables and parameters is possible (Smets and Wouters, 2003)
- Why not agriculture and food security?

Food security needs modeling of stochastic and seasonal supply and deterministic demand in terms of a DSGE

- A number of locations deliver crops to local market at various times
- Local price is determined by local supply and global demand for consumption, processing and storage
- Heterogeneity of locations can mirror the overall heterogeneity in the world
- Production need be planned ex ante with regard to expected weather and prices at harvesting time. Ex post harvest is affected by stochastic weather at location. Ex post price is also affected by stochastic events elsewhere
- Key question: Are the incentives for storage and production in front of possible food crises sufficiently large to carry the population through several bad crop years in a row?

Production and storage dynamics of a price-taking farmer/consumer

- Epstein and Zin (1989) show that utility functions, $U(\pi)$ over possibly infinite consumption lotteries, $\pi = \pi\left(\{c_t\}_{t=1}^{\infty}\right)$, exist in terms of stochastic consumption c_t in each period t
- At time 0 the consumption lottery of a price-taking farmer/consumer from time 1 on is contingent on decisions on controls taken at 0:
  - production efforts and outcomes (netputs) d
  - tradable real stocks stored for the future $k \geq 0$
  - units of accounts for the future (money) $m \geq 0$
- Control decisions depend in turn on the observed outcome of a stochastic process: nature n, market prices p, and states of a non-tradable real asset s — the farm

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Production and storage dynamics (2)

- Storage k plus production netputs d together with stochastic nature n_1 leaves the stochastic tradable stocks, $k + K(d, s, n_1)$, at disposal for consumption, further production effort or storage at time 1. The non-tradable asset takes likewise the stochastic state $s_1 = S(d, s, n_1)$.

Production and storage dynamics (3)

- We assume that decisions at time t are taken with respect to the following problem involving the stochastic production functions, K and S, and a budget constraint:

$$(c_t^*, d_t^*, k_t^*, m_t^*) = \operatorname{argmax}_{(c \geq 0, d, k \geq 0, m \geq 0)}$$
$$U\left[c, U\left[\pi\left(\{c_{t'}\}_{t'=t+1}^{\infty} \mid d, k, m, n_t, p_t, s_t\right)\right]\right]$$

subject to:

$$p_t^T\,(c + d + k - K(d_{t-1}, s_{t-1}, n_t) - k_{t-1}) + m - m_{t-1} \leq 0$$
$$s_t - S(d_{t-1}, s_{t-1}, n_t) = 0$$

- To simplify, we denote the controls $(d_t, k_t, m_t) = x_t$, the states $(n_t, p_t, s_t) = y_t$, the *future utility function* $U\left[\pi\left(\{c_{t'}\}_{t'=t+1}^{\infty} | x_t, y_t\right)\right] \equiv W(x_t, y_t)$, and the constraints as $F(c_t, x_t, y_t, x_{t-1}) \leq 0$
- Observe that the future utility function mixes the preferences and the probability distribution of consumption, $\pi(c_{t+1} \mid x_t, y_t)$, and can in principle be estimated from first order conditions

Production and storage dynamics (4)

- The optimization at $t = 1$ with its value function V then takes the form:

$$V(y_1, x) \equiv \max_{(c_1 \geq 0, x_1 \geq 0)} U\left[c_1, W(x_1, y_1)\right]$$

$$\text{subject to:} \qquad F(c_1, x_1, y_1, x) \leq 0$$

- The stochastic law of motion, π^*, which the farmer adapts to, appears in the relationship between the future utility function and the value function:

$$W(x, y) \equiv \mathrm{E}_{\pi^*(y_1|x,y)} V(y_1, x)$$

which can be exploited for joint estimation of the future utility function and the law of motion

Price equilibrium

- Temporary equilibrium prices p_t are formed among a set of agents, $i = (1, \ldots, I)$, when their optimal net demands which are functions of p_t sum to zero

$$\sum_{i=1}^{I} [c_{it}^*(p_t) + d_{it}^*(p_t) + k_{it}^*(p_t) - K(d_{i,t-1}, s_{i,t-1}, n_{i,t})] = 0$$

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A comment on expectations and rationality

- If the laws of motion implicit in each future utility function W_i are all consistent with observed and future sequences of states and decisions, the agents can be said to have rational expectations. However, all possible future situations are then framed in the laws of motion and no Knightian uncertainty is present
- A more credible situation is that agents apply laws of motion in their planning which to some extent deviates from each other and the later sequence of states because of Knightian uncertainty. In that case, the somewhat subjective laws of motion and future utility functions are expected to vary between agents and over time

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Future utility functions, DSGE and policy experiments

- A collection of future utility functions and laws of motion calibrated to a sequence of observed states and controls constitute a DSGE which can be simulated over time
- Policy experiments will be modifications of the law of motion: of nature (climate change), states of non-tradable asset (new technology), or prices (market distortion or creation)

Future utility functions, DSGE and policy experiments (2)

- First order consequences on future utility functions of changed moments of laws of motion, Ey and $\mathrm{Var}\ y$:

$$
\begin{aligned}
V(y, x_{-1}) \approx & V(\mathrm{E}y, x_{-1}) + \partial_y V\left(\mathrm{E}y, x_{-1}\right)\left(y - \mathrm{E}y\right) \\
& + \frac{1}{2}(y - \mathrm{E}y)^T \partial^2_{yy^T} V\left(\mathrm{E}y, x_{-1}\right)\left(y - \mathrm{E}y\right)
\end{aligned}
$$

$$
\begin{aligned}
W(y_{-1}, x_{-1}) = & \mathrm{E}_{\pi(y|x_{-1}, y_{-1})} V(y, x_{-1}) \\
\approx & V(\mathrm{E}y, x) + \frac{1}{2}\mathrm{trace}\left(\partial^2_{yy^T} V\left(\mathrm{E}y, x_{-1}\right)\left(\mathrm{Var}\ y\right)\right) \\
dW(y_{-1}, x_{-1}) \approx & \partial_y V(\mathrm{E}y, x) d\mathrm{E}y \\
& + \frac{1}{2}\mathrm{trace}\left(\partial^2_{yy^T} V\left(\mathrm{E}y, x_{-1}\right) d\mathrm{Var}\ y\right)
\end{aligned}
$$

Future utility functions, DSGE and policy experiments (3)

- A change in expectation and variance of next state will lead to an approximate modification in future utility function which can be used for approximate counterfactual simulations
- Most likely, a modified the law of nature, also modifies the law of non-tradable asset states, which in turn modifies the law of prices. If so, that will turn up in the approximate simulations, from which a better approximate future utility function can be derived
- Continue until convergence. The future utility function is then consistent with the overall law of motion which the policy change induced

Conceptual conclusions

- A conceptual frame of DSGE-models is created. In contrast to standard approaches which approximate stochastic dynamics around a steady state, our approach approximates around a reference path of observations which itself has stochastic dynamics
- Process models with endogenous management, eventually based on biological insights, play a decisive role in the construction
- Further extensions of the model with markets for liabilities and financial instruments seems possible but has not been demonstrated here
- A major challenge will be to reconcile the details of biological science with the structure presented here within a computable structure

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Thanks for the attention

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