The Dynamics of the World Cocoa Price

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Initial draft: 12 September 2012
This revision: 15 September 2012

Abstract

I develop a structural econometric model of the world cocoa market estimated over the 62 crop year period 1950-51 to 2011-12. Shortfalls in the cocoa crop can result in high prices over the flowing nine years. Although quantitatively smaller, demand side shocks have a comparably large and long impact. There is some evidence of links between the coffee and cocoa markets which are difficult to explain in terms of the fundamentals of physical production and consumption. The analysis in this paper generally confirms the insights in Weymar's (1968) pioneering monograph.

This paper has been prepared for the First Conference on the Economics and Politics of Chocolate, University of Leuven, Belgium, 16-18 September 2012. I am grateful to Simone Pfuderer for comments in the initial draft. Comments will be welcome. Address for correspondence: Department of Economics and Management, University of Trento, via Inama 5, 38122 Trento, Italy. Email: christopher.gilbert@unitn.it

1. Introduction

"The dynamics of the world cocoa market" is the title of the 1968 monograph written by F. Helmut Weymar (Weymar, 1968) and based on his 1965 MIT PhD thesis. In his preface, Weymar described his book as an exercise in applied econometrics which should be considered as "required reading for anyone who plans to make a killing or chooses to make his living by trading in the cocoa market". Famously, Weymar did go on to make a killing in trading cocoa, first for Nabisco and then for Commodities Corporation, which Weymar founded in 1969 in conjunction with his MIT professors Paul Cootner and Paul Samuelson. Commodities Corporation was probably one of the first hedge funds and may have been a model for LTCM (Mallaby, 2010). It went through a rocky period in the early 1970s but made enormous profits in the 1973-74 commodity price boom. It was acquired by Goldman Sachs in 1997.

In the brief Acknowledgements section of Weymar (1968, page viii), the author remarks, "Most of the empirical literature on commodity prices attempts to explain price movements in terms of variations of various supply and demand variables, without any explicit consideration of the general theory of commodity prices". The relevant theory is supply of storage theory. Weymar references, among others, Working (1948, 1949), Samuelson (1957), Brennan (1958) and Cootner (1961). Much of this theory was developed in relation to the U.S. grains market and was based on the assumption, reasonable in that context, of limited elevator capacity resulting in positively sloped supply curve for storage.[1] This theory yields a nonlinear relationship between the commodity price and production and consumption fundamentals as a consequence of the rising price of storage. The modern storage literature (Williams and Wright, 1991; Deaton and Laroque, 1992, 1995, 1996) takes the supply of storage to be infinitely elastic and emphasizes the nonlinearities in price dynamics resulting from stockout.

The modern theory of storage also differs from earlier accounts in that it is firmly based on rational expectations and yields outcomes which are compatible with the Efficient Markets Hypothesis (EMH, Fama, 1965). Cootner, Weymar's thesis supervisor was the author of a

[1] The recent problems with crude oil storage capacity at Cushing (OK) indicate that this would also be the appropriate assumption for the US crude oil market.

compilation of papers on efficient markets (Cootner, 1964). Nevertheless, Weymar had made money trading orange juice while still an undergraduate and radically disbelieved the random walk hypothesis. Mallaby (2010) quotes him as saying in a 2007 interview, "I thought random walk was bullshit. The whole idea that an individual can't make serious money with a competitive edge over the rest of the market is wacko". He appears to have persuaded Cootner who became an investor in Commodities Corporation. Both Weymar, for Nabisco, and Commodities Corporation did make serious money but both came close to losing everything before the markets came to their rescue. The accounts of this period leave it unclear as to whether Weymar did have a competitive edge, or whether instead he happened to be lucky and was therefore not disabused of his belief in his own abilities.

Weymar's basic model may be summarized as follows:

a) The short term dynamics of the cocoa price result from shocks to the cocoa crop – in particular, occasional crop failures.
b) Cocoa consumption ("grindings") is price elastic.
c) Long term price expectations are constant and unaffected by shocks.

In an extended version of the model, the crop shock is permitted to affect long term price expectations adaptively. The model is incompatible with the EMH and, if accepted as a valid representation of the market, would allow profitable trading. This was the model Weymar implemented for Nabisco.

Combination of these relationships yields a model in which the cocoa price rises in response to a negative supply shock as beans are withdrawn from inventory but then converges back to its long term level as the high price reduces grindings allowing inventory levels to be restored. Lags are long – Weymar estimates that it takes nine years for the market to return to its equilibrium state after a major harvest shortfall.

Weymar (1968) used a relatively short sample (eleven years, 1953-63) of monthly data and his focus was therefore as much on intra-annual as well as inter-annual price movements. I analyze a much longer sample of crop year data (1950-51 to 2011-12,[2] 62 observations) and therefore look just at inter-annual price movements. However, my approach is similar in

[2] Data for 2011-12 are provisional.

that I base the analysis on storage theory. Like Weymar, I build a structural econometric model, although I also compare the results of that model with those from a Vector AutoRegression (VAR) model. Like Weymar, I do not impose rational expectations. Like Weymar, I view consumption and storage as adapting to crop shocks. Again like Weymar, I find that there are indeed very long lags in price adjustment such that prices only return to their base level nine years after a harvest shortfall. Unlike Weymar, I find that demand shocks, although quantitatively smaller than harvest shocks, have a comparably large effects and even greater persistence.

The structure of this paper is as follows. In section 2 I discuss the historical cocoa price series and analyze its time series properties. Section 3 looks at storage theory and the extent to which this may explain cocoa prices. In section 4, I develop a simple aggregate four equation econometric model of cocoa production, consumption and price and in section 5 I look at the dynamic properties of the prices generated by this model. Section 6 concludes.

2. The real cocoa price

In Gilbert (2012), I derive an annual series for the real cocoa price over the 162 year period 1850-2011. The series is in nominal US dollars deflated by the US PPI to give cocoa prices in 2005 values. It is charted in Figure 1.

The price series appears to show a downward trend but this is mostly from comparison of the twentieth and nineteenth centuries. Table 1 reports ADF tests both on the sample of 157 years of annual calendar year data (1855 to 2011)[3] and over the sample of 62 years of crop year data (1950-51 to 2011-12) used in the modelling exercise reported in the following sections. The real cocoa price is neither stationary nor trend-stationary over either sample. There is thus no evidence of any constant trend in cocoa prices. I discuss this issue at greater length in Gilbert (2012).

The ADF statistics reported in the third column of Table 1 show that the the change in logarithmic real cocoa prices, Δln*rcp*, series is I(0). Consequently, information on the dynamics is completely represented by the autocorrelation function (ACF). The empirical

[3] The five years 1850-54 are lost through lag creation.

ACF, estimated over the sample 1854-2011, is shown in Figure 2. The salient feature of the ACF is the substantial negative autocorrelation at the second lag. This is the only autocorrelation which differs significantly from zero on an individual basis. This is despite the suggestion that the autocorrelations at lags 10-13 may be non-zero. The portmanteau test rejects the white noise hypothesis (χ^2_{20} = 33.52 with tail probability 0.0295) but the test that the autocorrelations from lags 3 to 20 are all zero fails to reject (χ^2_{18} = 17.33 with tail probability 0.5005).

Table 1 **Stationarity tests**				
		ln*rcp*		Δln*rcp*
		Constant	Constant + trend	Constant
1855- to 2011	ADF statistic 5% critical value	ADF(2) = - 2.53 - 2.88	ADF(2) = -2.89 -3.44	ADF(1) = -11.56 -2.88
1950-51 to 2011-12	ADF statistic 5% critical value	ADF(2) = - 1.77 - 2.91	ADF(2) = - 2.66 - 3.48	ADF(1) = -7.27 - 2.91
The test lag length is selected using the AIC.				

The ACF therefore strongly suggests that price changes can be represented by a second order process. While both the ACF and the partial ACF (PACF, not shown) appear consistent with either an autoregressive or moving average representation, estimation chooses an AR(2). The estimated equation is[4]

$$\begin{array}{l} \Delta \ln rcp_t = \underset{(1.44)}{0.1095} \Delta \ln rcp_{t-1} - \underset{(4.12)}{0.3120} \Delta \ln rcp_{t-2} \\ \text{Sample 1853-2011} \quad R^2 = 0.1038 \quad s.e. = 0.220 \\ \text{Autocorrelation: } F_{2,155} = 0.16 \text{ [0.8527]} \\ \text{Heteroscedasticity: } F_{4,154} = 0.45 \text{ [0.7749]} \\ \text{Normality: } \chi^2_2 = 7.75 \text{ [0.0207]} \\ \text{Reset: } F_{2,155} = 1.15 \text{ [0.3208]} \end{array} \qquad (1)$$

The equation indicates that a jump in price in year *t* will be offset by a partial fall two years later, and *vice versa*. There is no evidence of either residual autocorrelation or heteroscedasticity. Nesting within a GARCH(1,1) specification also allows rejection of the

[4] *t* statistics in (.) parentheses, tail probabilities in [.] parentheses. The equation omits the intercept which as associated with a t statistic of 0.0081 in a prior regression.

hypothesis of autoregressive conditional heteroscedasticity (χ_2^2 = 0.77 with tail probability 0.6790). Neither is there any clear evidence of nonlinearity – see the Reset test.[5] However, the residuals do depart from normality. The negative autocorrelation is insensitive to variation in the sample dates.

3. Prices and storage

Economists emphasize the role of storage in smoothing the impact of production and consumption shocks. By reducing the price for the current crop year, an abundant harvest makes it attractive to buy the commodity and store until the following crop year. Conversely, if the harvest is short and the price for the current year is high, it will be advantageous to consume out of storage supposing the existence of a positive carryover from the previous year. The most important contributions to the modern literature are Samuelson (1957), Gustafson (1956), Wright and Williams (1991) and Deaton and Laroque (1992, 1995, 1996).

These models imply two important features:

a) Price changes will tend to be positively autocorrelated even if shocks are serially uncorrelated. This is because an abundant harvest will tend to depress both the price in the current and the following crop year because part of the surplus will be carried over.
b) Price responses will be nonlinear. In the absence of stocks, a harvest shortfall will impose a large price adjustment while if stocks are available the shortfall can be partially met by destocking.

Neither of these features is apparent in the price series analyzed in section 2. Both the price change ACF (Figure 2) and equation (1) show evidence of negative second order serial correlation[6] and the Reset statistic in the shock-based price equation (1) fails to indicate nonlinearity. This suggests that stockholding behaviour may only make a small contribution to explaining inter-year cocoa price movements.

[5] Calculated using the squares and cubes of the fitted values.
[6] The attempts by Cafiero *et al* (2011) to save the DL model by demonstrating that it can generate high positive price autocorrelation are therefore irrelevant to cocoa.

It is most straightforward to base the analysis on the Deaton and Laroque (DL, 1992) model. This model posits a random harvest h_t governed by a stationary distribution, consumption c satisfying an inverse demand curve $p_t = P(c_t)$ where p_t is the commodity price and stock demand determined by the risk-neutral Kuhn-Tucker condition

$$p_t \geq kE_t\left[p_{t+1}\right] \quad : \quad s_t \geq 0 \tag{2}$$

Where $k = \frac{1}{1+r+w} < 1$ and the colon indicates that at least one of these two relationships must hold as an equality. Here, $E_t\left[p_{t+1}\right]$ indicates the expectation of the price in crop year t+1 formed on the basis of information in crop year t. With positive carryover s_t to crop year t+1, the price in year t must equal the discounted price in year t+1 where r_t is the risk-free interest rate and w is the warehousing cost (including any losses due to deterioration). Stockholding therefore earns the risk-free rate of return. However, the current price may exceed the discounted future price (backwardation) in the absence of a carryover, it being impossible to take advantage of this price disparity by borrowing from next year's crop. The model rules out profits from intertemporal arbitrage and is therefore compatible with the EMH.

This model has a single state variable, availability a_t equal to the current harvest plus the lagged carryover: $a_t = h_t + s_{t-1}$ – it is irrelevant whether supply comes from this year's or a previous year's crop. It follows that price and stock must both be functions of availability - $p_t = f(a_t)$ and $s_t = g(a_t)$. Since the fundamental processes are stationary, these functions will be time-invariant. Deaton and Laroque (1992) show that, under rational expectations, these functions are defined by the pair of equations

$$\begin{gathered} p_t = f(a_t) = \max\left\{P(a_t), kE_t\left[P\left(h_{t+1} + g(a_t) - g\left(h_{t+1} + g(a_t)\right)\right)\right]\right\} \\ s_t = g(a_t) = a_t - P(a_t) \end{gathered} \tag{3}$$

These equations require numerical solution. The stock function $g(a_t)$ yields zero carryover for availability levels less that a critical availability level a^*, typically slightly greater than the normal harvest, and thereafter is close to linear. One can therefore approximate the storage function as

$$g(a_t) = \begin{cases} 0 & a_t \le a^* \\ \gamma(a_t - a^*) & a_t > a^* \end{cases} \quad (4)$$

The price function follows as $f(a_t) = P(a_t - g(a_t))$. The accuracy of this approximation will depend on the functional form of the demand equation but it is in any case useful for illustrative purposes.

The production and consumption model set out below in section 4 is similar to the DL model in that the current harvest is independent of the price in the current crop year, and also of those in the past two crop years whereas grindings do react to the current prices. Grindings and stocks therefore need to accommodate the current harvest shock. The model differs in other respects:

- The crop *wq* grows on an exponential time trend (rate δ) but is otherwise only affected by the change in price three years ago. In the stylized model set out below, I ignore this price effect since the time lag is such that it will have only a small impact on the current storage decision. This allows me to consider the scaled variable $h_t = e^{-\delta t} wq_t$ as having a stationary distribution and hence corresponding to the DL harvest. However, there is also positive serial correlation in crop sizes around the trend.
- Grindings *wgr* also depend on an exponential time trend and a lagged distribution of cocoa prices rather than just the current price. Grindings and production must have a common time trend. It is therefore sufficient to consider $c_t = e^{-\delta t} wgr_t$.
- Grindings depend on the price in the previous crop year as well as on the current price. This introduces an additional state variable, the previous year's price, into the DL model. This modification of the DL model is potentially important,

In what follows, I consider a stylized model in which the harvest *h* has a stationary distribution but in which consumption *c* depends on both the current and lagged price $c_t = C(p_t, p_{t-1})$. Prices and storage remain defined by equation (2). There are now two state variables, current availability a_t and the lagged price p_{t-1} so that the price and storage functions are $p_t = f(a_t, p_{t-1})$ and $s_t = g(a_t, p_{t-1})$. It appears difficult to find an equilibrium set of price and stock functions for this model.[7] I therefore experiment by allowing the parameters a^* and γ of the linear approximation (4) to depend on the lagged price.[8] I find that the storage propensity γ is positively related to the lagged price p_{t-1} but there is no evidence of any effect on the trigger availability level a^*. The positive dependence of the carryover on the previous year's price arises since a high lagged price depresses current consumption resulting in an increased current surplus while a low price in the previous year boosts current consumption reducing the quantity available for the carryover. The correlation between the carryover (months of normal consumption) and the lagged real cocoa price over the 62 crop years 1950-51 to 2011-12 is - 0.74.

Figure 3 is a chart of a time series of 157 price realizations (corresponding to the sample 1855-2011 analyzed in section 2) generated by the estimated cocoa process. I use a demand elasticity of 0.45 but suppose this comprises a current year elasticity of 0.30 and an elasticity with respect to the lagged price of 015. Two features stand out in this plot

- Extended periods in which the price is negatively autocorrelated, high price and low price years following each other. These periods correspond to periods in which there is either a low or zero carryover.
- Other extended periods in which the price varies very little. These correspond to periods of high carryover.

The negative price autocorrelation arises because a high price in year *t* depresses consumption in year *t*+1 and vice versa. However, if there was a positive carryover from year *t*-1, a deficit in period *t* can be met from inventory so that the year *t* price is smoothed to equal the discounted expected price in year *t*+1.

This result obtains partial support from a regression of the stock-consumption ratio (*scr*, closing stocks divided by trend grindings and converted to "months of normal

[7] Wright and Williams (1991) use numerical methods to solve the storage problem with two state variables, including the case in which there are two harvests each year. They do not consider the case analyzed here with lagged responses in consumption.

[8] I generate 1000 observations on the basis of a normal harvest of 4 million tons and a normal price of \$2000/ton, a current demand elasticity of 0.30 and an elasticity with respect to the lagged price of 0.15. The interest rate is 5%. I choose the parameters a^* and γ, and also the parameter relating γ to the lagged price, to minimize the squared storage return in years with positive storage plus the squared positive return on (counterfactual) storage in years in which no storage takes place.

consumption")[9] on availability (*avail*, measured in the same metric), the lagged log real cocoa price, an interaction between the two and a time trend:

$$\ln scr_t = -\underset{(2.81)}{48.82} + \underset{(9.59)}{0.634} avail_t + \underset{(2.14)}{5.169} \ln rcp_{t-1} - \underset{(2.18)}{0.310} avail_t \times \ln rcp_{t-1} + \underset{(3.78)}{0.0240} t$$

Sample 1950-51 to 2011-12 $R^2 = 0.8222$ $s.e. = 0.7471$

Autocorrelation: $F_{2,58} = 77.6$ [<0.001] (5)

Heteroscedasticity: $F_{8,56} = 2.54$ [0.020]

Normality: $\chi_2^2 = 2.68$ [0.263]

Reset: $F_{2,58} = 0.92$ [0.403]

The equation, estimated by OLS,[10] shows that a high price in the previous year both increases the current year's carryover but also reduces the propensity to store. The Reset statistic fails to offer any evidence of nonlinearity and an attempt to fit a nonlinear relationship did not offer any improvement over least squares. However, the very high residual serial correlation indicates that the equation is probably misspecified and inference on the basis of these parameters is unreliable.

Figure 4 shows the Autocorrelation Function (ACF) for the log price changes from the simulated model[11] and is to be compared with the cocoa ACF in Figure 2. Both ACFs show negative autocorrelation but this is more acute in Figure 4. Figure 4 also identifies an AR(1) process while Figure 2 identifies and AR(2). I conclude that the negative autocorrelation seen in cocoa prices over the past 150 years probably does result from the dependence of cocoa consumption on previous years' prices as well as the current price but that the simple model set out above is too stylized to fully account for this dependence.

Similarly with the carryover equation (5), we can estimate equations relating the cocoa price to availability. Results are shown in Table 2. The first column of the table regresses the price ln*rcp* just on availability *avail* and a time trend. The second column adds the previous year's

[9] The stock series excludes the buffer stock held by the International Cocoa Organization from 1981 to 1994 under the terms of the International Cocoa Agreements.

[10] Instrumental variables estimation did not alter the qualitative results. There is no evidence that the ICCO buffer stock reduced private stockholding.

[11] Based on 10,000 simulations.

price.[12] In the third column I include the lagged stock consumption ratio *scr* in addition to availability to test the hypothesis that the current harvest and the carryover from the previous year have the same impact. Estimation here is by OLS.

Table 2 **Estimated price-availability equations**			
Dependent variable lnrcp_t	(1)	(2)	(3)
Intercept	10.73 (46.2)	6.043 (5.87)	6.005 (5.40)
Availability $avail_t$	-0.146 (10.2)	- 0.088 (4.99)	- 0.089 (4.15)
Lagged carryover scr_{t-1}	-	-	0.003 (0.10)
Lagged price lnrcp_{t-1}	-	0.446 (4.64)	0.452 (4.02)
Trend /100	- 0.938 (5.53)	- 0.490 (2.80)	- 0.494 (2.74)
R^2	0.769	0.831	0.831
standard error	0.225	0.193	0.195
AIC	- 2.940	- 3.224	- 3.192
Residual serial correlation $F_{2.57}$, $F_{2.56}$, $F_{2.55}$	29.6 [<0.001]	9.78 [<0.001]	9.84 [<0.001]
Residual heteroscedasticity $F_{4.57}$, $F_{6.55}$, $F_{8.53}$	3.62 [0.011]	1.16 [0.339]	0.91 [0.515]
Normality $\chi^2(2)$	2.64 [0.267]	4.94 [0.085]	4.89 [0.087]
Sample: 1950-1 to 2011-12 (62 observations). Estimation is by OLS. Tail probabilities in [.] parentheses; t statistics in (.) parentheses.			

There is no evidence that the coefficient on lagged stocks differs from that on the current harvest – see the *t* statistic on scr_{t-1} in column 3. The estimated equations support availability as the driver of the price. However, the price is clearly positively autocorrelated, even though price changes are negatively autocorrelated. However, as was the case with the carryover equation (5), the high degree of residual serial correlation indicates probable dynamic misspecification.

This discussion leads me to conclude that storage theory can potentially account for the observed negative autocorrelation of changes in cocoa prices as the result of positive

[12] I also experimented with an interaction term of availability multiplied by the lagged price, as in equation (5). This interaction was estimated with a small and statistically insignificant coefficient and so was dropped.

autocorrelation in grindings levels. However, simple storage models, even when extended in this direction, remain dynamically misspecified. This motivates construction of a structural model based on empirically estimated equations for grindings and the crop size and with a price equation that is based on the storage model but allows for more general dynamic responses.

4. A structural model of cocoa production, consumption and price

Data on world cocoa production and consumption ("grindings") is made available by the ICCO (www.icco.org) and historical data on a crop year (October – September) basis, are provided in the *Quarterly Bulletin of Cocoa Statistics* (QBCS) . Earlier figures were produced by cocoa broker Gill and Duffus, now part of ED&F Man and, previous to that, by the League of Nations. I have data on a consistent basis from crop year 1946-47 to 2011-12.[13] The production (crop) and consumption (grindings) figures are graphed together in Figure 5.

A number of features stand out in this figure.

- Crop size appears substantially more variable than grindings. In fact, the standard deviation of log annual changes in crop size (10.2%) is double that of the corresponding grindings standard deviation (5.1%). This is a general feature of agricultural commodities for which consumption changes smoothly in line with incomes while production is subject to weather-related shocks.
- Although production and consumption both grow at an average rate of 2.8% per annum over the sample, the average masks periods of relatively fast and slow growth. Visually, one can distinguish three periods – a period of relatively high consumption growth from the start of the sample to 1971 (3.5% annual growth in grindings) followed by a period of slower growth to 1982 (1.4% annual growth) followed by a recovery to the end of the sample (3.1% annual growth).
- There were two relatively long periods in which production ran ahead of grindings – the first part of the 1960s and the second half of the 1980s. Not surprisingly, these two periods were associated with low real cocoa prices.

[13] Data for 2011-12 are preliminary.

I focus initially on grindings which are determined by chocolate consumption.[14] This will depend on tastes, incomes and prices. My income variable is a series for "world" GDP calculated from Maddison (2010) and extrapolated from 2008 to 2011 using IFS data. The "world" is all those countries for which Maddison provides a continuous GDP series from 1946. This excludes many emerging economy countries but also countries in Eastern Europe and the ex-USSR.[15] These data are on a calendar and not a crop year basis. The price is the real price discussed in section 2 but now on a crop year basis.

Table 3
Grindings cointegration results

	Without trend	Including trend
Unrestricted VAR(2) AIC	- 18.150	- 18.163
Johansen test statistic for zero rank	35.84 [0.008]	42.60 [0.052]
Johansen test statistic for unit rank	11.33 [0.195]	15.78 [0.518]
Cointegrating vector		
ln*wgr*	- 1.000	- 1.000
ln*wgdp*	0.842	0.483
ln*rcp*	- 0.188	- 0.137
Trend /100	-	1.290

Sample: 1950-1 to 2010-11 (61 observations)
Tail probabilities in [.] parentheses.
The estimated cointegrating (β) vector is normalized on the coefficient of ln*wgr.*

I first ask whether the (log) world grindings ln*wgr* series is cointegrated with (log) world GDP ln*wgdp* and the (log) real cocoa price ln*rcp*. Estimation is over the sample crop years 1950-51 to 2010-11 (61 observations). Table 3 reports cointegration test results using the Johansen (1988) trace test. An initial test shows that it is possible to reduce from a VAR(4) to a VAR(2). In the absence of time trend, the Johansen trace test allows rejection of the null hypothesis of no cointegration but fails to reject the subsequent null hypothesis that there is at most one cointegrating vector (Table 3, column 1). However, the AIC prefers the

[14] I regard cocoa powder as a by-product.
[15] The complete list of countries is Argentina, Australia, Austria, Belgium, Bolivia, Brazil, Canada, Chile, Colombia, Costa Rica, Denmark, Ecuador , El Salvador, Finland, France, Germany , Greece, Guatemala, Honduras, India , Ireland, Italy, Japan, Mexico, Netherlands, New Zealand, Nicaragua, Norway, Panama, Paraguay, Peru, Philippines, Portugal, South Korea, Spain, Sweden, Switzerland, UK, Uruguay, USA and Venezuela

specification which includes a time trend (Table 3, column 2). In this case, there is a marginal failure to reject the hypothesis of no cointegration at the 5% level.

The estimated cointegrating vectors (Table 3, lower panel) are normalized on the coefficient of the grindings variable. The estimates which exclude the time trend imply a slightly less than unit income elasticity and a price elasticity of slightly less than one fifth. Inclusion of a time trend gives an income elasticity of close to one half and a price elasticity of -0.14 together with trend growth, unconnected with income, of 1.3% per annum. Because the trend in world GDP is close to being log-linear, it is difficult, at an aggregate level, to distinguish econometrically between consumption growth induced by changing tastes (perhaps influenced by advertising) from that induced by rising incomes. This is an important issue to which I return.

The Granger Representation Theorem (Engle and Granger, 1987) allows us to specify a dynamic error correction equation embodying the estimated cointegrating vector. Here I use the one stage procedure which jointly estimates the cointegrating vector and the dynamic adjustment. I regress the change in (log) grindings $\Delta \ln wgr$ on the current and lagged change in the cocoa price $\Delta \ln rcp$ and the lagged levels of grindings, world GDP and prices, where the price variable is the average of the (log) real cocoa price lagged two, three and four years. There is no evidence of any impact from the change in world GDP $\Delta \ln wgdp$, as distinct from its level. Because the current price change $\Delta \ln rcp_t$ will be jointly determined with the current year's rise in grindings $\Delta \ln wgr_t$, I treat the latter variable as endogenous and estimate using Instrumental Variables (IV). The instruments are availability $avail_t$, equal to current production plus lagged stocks divided by the consumption trend, and the real coffee price lagged one and two years $\ln rcfp_{t-1}$ and $\ln rcfp_{t-2}$ – see below. Identification requires that the current year's production and consumption shocks are independent and the current production does not depend on the current year's price.

Table 4 **Estimated grindings error correction equations**			
Dependent variable $\Delta \ln wgr_t$	(1) 2SLS	(2) 2SLS	(3) 3SLS
Intercept	1.481 (2.00)	1.697 (1.71)	2.171 (4.04)
Current price change (endogenous) $\Delta \ln rcp_t$	- 0.088 (0.68)	- 0.105 (0.93)	- 0.046 (1.44)
Lagged price change $\Delta \ln rcp_{t-1}$	- 0.107 (4.53)	- 0.104 (4.62)	- 0.112 (6.97)
Lagged grindings $\ln wgr_{t-1}$	- 0.209 (1.54)	- 0.222 (1.43)	- 0.306 (3.99)
Change in world GDP $\Delta \ln wgdp_t$	1.228 (2.93)	1.291 (2.79)	1.168 (3.60)
Lagged world GDP $\ln wgdp_{t-1}$	0.153 (1.48)	0.091 (1.28)	0.083 (1.56)
Lagged price $\frac{1}{3}\sum_{i=2}^{4} \ln rcp_{t-i}$	- 0.066 (2.94)	-0.064 (2.77)	- 0.052 (2.93)
Trend /100	-	0.260 (0.68)	0.534 (2.63)
Implied long run equation			
$\ln wgdp$	0.731	0.412	0.271
$\ln rcp$	- 0.319	- 0.288	- 0.171
Trend /100	-	1.170	1.743
standard error	0.0333	0.0341	0.0319
AIC	- 9.767	- 10.10	-
Sargan instrument validity test $\chi^2(1)$	0.01 [0.903]	0.03 [0.866]	-
Residual serial correlation $F_{2.53}$, $F_{2,52}$, $F_{2,48}$	0.00 [0.917]	0.09 [0.916]	2.85 [0.068]
Residual heteroscedasticity $F_{12,49}$, $F_{14,47}$, $F_{21,40}$	2.09 [0.036]	2.03 [0.033]	1.59 [1.02]
Normality $\chi^2(2)$	4.23 (0.121)	0.99 [0.608]	0.10 [0.949]
Sample: 1950-1 to 2011-12 (62 observations) Additional instruments (columns 1 and 2): scr_{t-1}, $\Delta \ln rcp_{t-3}$ The 3SLS estimates are from a four equation model relating production, consumption (grindings), price and stocks. Tail probabilities in [.] parentheses; t statistics in (.) parentheses.			

Estimation results are reported in Table 4, both without (column 1) and with (column 2) a time trend. The lagged price coefficient is well-determined but the contemporaneous change is less so, reflecting possibly weak instruments. The Sargan test does not reveal any instrument validity problem. A rise in GDP causes a greater than proportionate increase in grindings but the long run income elasticity is less than unity. This long run income effect and the trend coefficient (in column 2) are poorly determined as the result of collinearity.[16] The implied long run equation indicates a higher price elasticity (around -0.3) than those given by the Table 3 estimates.[17] The estimated long run GDP elasticities are similar to those in Table 3. As in Table 3, the AIC prefers the equation which includes the time trend.

Column 3 repeats the estimates from column 2 using the Three Stage Least Squares (3SLS) system estimator of the four equation model for grindings, crop size, price and the stock-consumption ratio.[18] The 3SLS estimates of the price and income elasticities are lower and greater emphasis is placed on the time trend.

I now turn to cocoa production. A Dickey-Fuller unit root test[19] over the sample 1947-48 to 2011-12 shows the log of cocoa production to be trend stationary (DF = -4.93 relative to a 5% critical value of -3.48 and a 1% critical value of -4.11). I use a simple model in which the trend is augmented by the difference in the cocoa price lagged three years and a lagged dependent variable. Three years is approximately the time it takes a newly planted tree to start producing fruit.

The estimated equation, which represents a partial adjustment process as these newly planted trees come to maturity, is reported in column 1 of Table 5. A sustained 10% rise in the real cocoa price is seen as raising production by 1.5% in the long run (and *vice versa* for a fall).

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[16] Weymar (1964) failed to find a statistically significant impact of real income on cocoa grindings.
[17] Weymar (1964) reports an elasticity of – 0.41.
[18] This model is structurally recursive – crop size enters the price equation, the current price enters the grindings equation and both current grindings and the crop size determine the carryover. OLS estimates of a structurally recursive model will not exhibit simultaneity bias provided the equation errors are independent. In fact, there is a significant correlation between the residuals on the grindings and crop size equations. Weymar's (1964) states "There is no issue here as to whether or not cocoa production can be considered exogenous for statistical estimation purposes; clearly it can" (page 141, footnote 19). This is incorrect if the residuals are correlated.
3SLS estimates are potentially more efficient that the 2SLS estimates reported in columns 1 and 2 of Table 4.
[19] The AIC selects the specification without lags.

Column 2 of Table 5 reports estimates of the same equation augmented by the lagged real coffee price.[20] The estimates suggest that a high coffee price results in lower cocoa production in the following crop year. This result is difficult to rationalize – although many cocoa-producing countries also produce coffee, production is seldom in the same zones so there is little opportunity for farmers to substitute between the two crops. In any case, coffee and cocoa areas cannot be altered at short notice. One possibility is that the effect comes through diversion of governmental support (provision of fertilizers and pesticides, extension) between the two crops. For these reasons, I regard the column 1 estimates as the more reliable.

Table 5
Estimated cocoa production equations

Dependent variable $\ln wq_t$	(1) OLS	(2) OLS	(3) 3SLS	(4) 3SLS
Intercept	3.802 (5.10)	4.927 (5.57)	3.386 (5.24)	4.722 (6.58)
Lagged dependent variable $\ln wq_{t-1}$	0.419 (3.65)	0.332 (2.81)	0.483 (4.86)	0.362 (3.70)
Lagged price change $\Delta\ln rcp_{t-3}$	0.088 (2.07)	0.102 (2.45)	0.076 (2.30)	0.088 (2.78)
Lagged coffee price $\ln rcfp_{t-1}$	-	- 0.062 (2.20)	-	-0.061 (2.74)
Trend /100	1.568 (4.95)	1.686 (5.41)	1.392 (5.06)	1.597 (6.09)
R^2	0.973	0.975	-	-
standard error	0.0834	0.0808	0.0844	0.0809
AIC	- 4.905	- 4.954	-	-
Residual serial correlation $F_{2,56}$, $F_{2,54}$, $F_{2,56}$, $F_{2,55}$	0.33 [0.720]	0.13 [0.880]	0.43 [0.654]	0.36 [0.700]
Residual heteroscedasticity $F_{6,55}$, $F_{10,51}$, $F_{6,55}$, $F_{8,53}$	1.20 [0.320]	0.98 [0.465]	1.29 [0.279]	1.21 [0.311]
Normality $\chi^2(2)$	0.78 [0.676]	2.06 [0.357]	0.56 [0.756]	2.08 [0.354]
Reset $F_{2,56}$, $F_{2,54}$	1.05 [0.356]	3.35 [0.043]	-	-

Sample: 1950-1 to 2011-12 (62 observations)
The 3SLS estimates are from a four (column 3) and five (column 4) equation model relating production, grindings, price, stocks and (column 4) the coffee price.
Tail probabilities in [.] parentheses; t statistics in (.) parentheses.

[20] Brazilian coffee, New York, crop year basis from 1957-78, calendar years 1946-56. Source: IMF, *International Financial Statistics*. Deflation is by the US Producer Price Index, as with the cocoa price.

Column 3 repeats the estimates from column 1 using the 3SLS system estimator of the four equation model discussed in relation to the estimated grindings equation. Column 4 performs the same exercise for the estimates reported in column 2 using a five equation model which includes an equation for the real coffee price. In this case, the 3SLS estimates differ little from the OLS estimates reported in columns 1 and 2.[21]

The equation standard errors in the equations reported in Table 5 are approximately double that on the grindings equation – see Table 4. It is tempting to draw the conclusion that cocoa price movements are dominated by supply shocks, in line with the standard agricultural economics paradigm. In section 5, below, I show that this conclusion is too simple.

The storage-based price equations reported in Table 2 show evidence of dynamic misspecification. In section 2, I provided evidence that cocoa prices follow an AR(2) process. I therefore augment the equation in column 2 of Table 2 by two lags of the price. The estimated dynamic relationship is reported in column 1 of Table 6. The AIC shows that this is an improvement over the equation reported in column 2 of Table 2 but, nevertheless, the LM residual correlation test shows that the equation still does not fully account for cocoa price dynamics.

The equation reported in column (1) of Table 6 does not fully account for the extreme price movements and is subject to residual non-normality. The cocoa production equation reported in column 2 of Table 5 suggests that the coffee may be jointly determined with the cocoa price. In column 2, I therefore report estimates of the same equation augmented by the current and lagged (real) coffee price. In these estimates, I treat the current coffee price as endogenous but lacking comprehensive production and consumption data over the long sample used for cocoa, I am obliged to identify by two dummy variables – one for the two years 1975-76 and 1976-77 associated with the major 1976 frost in the Brazilian coffee-producing zone, and the second for the two years 1989-90 and 1990-91 following the July 1989 ending of coffee export controls under the International Coffee Agreement – see Gilbert (1999). Identification by means of dummy variables is dangerous since there is no

[21] The estimated 3SLS grindings equation differs little from that reported in column 4 of Table 4 and hence is not reported.

clear basis for supposing that the dummies do reflect the events in question as distinct from other events in the relevant years. (Evidence for this may be seen in the unsatisfactory Sargan test on the over-identifying restrictions). These estimates should therefore be treated as being at most suggestive. Nevertheless, if these results can be sustained in a more rigorous analysis, they indicate a much closer link between cocoa and coffee prices than is generally acknowledged by analysts in either industry.

Table 6
Dynamic price-availability equations

Dependent variable ln*rcp*$_t$	(1) 2SLS	(2) 2SLS	(3) 3SLS	(4) 3SLS
Intercept	4.352 (3.18)	5.041 (4.42)	6.535 (7.38)	6.418 (7.68)
Availability (endogenous) *avail*$_t$	- 0.043 (1.69)	- 0.078 (3.70)	-0.117 (6.73)	-0.121 (7.06)
Lagged price ln*rcp*$_{t-1}$	0.829 (5.34)	0.439 (2.95)	0.632 (5.18)	0.587 (4.88)
Lagged price ln*rcp*$_{t-2}$	- 0.265 (2.41)	- 0.322 (3.20)	- 0.191 (1.77)	-0.122 (1.14)
Current coffee price ln*rpcf*$_t$ (endogenous)	-	0.659 (3.85)	-	0.426 (3.32)
Lagged coffee price ln*rpcf*$_{t-1}$	-	- 0.253 (1.92)	-	-
Trend /100	- 0.486 (2.66)	-0.271 (1.56)	-0.374 (2.15)	-0.365 (2.17)
standard error	0.1957	0.1712	0.2004	0.1976
AIC	- 3.396	- 7.186	-	-
Sargan instrument validity test $\chi^2(2)$, $\chi^2(3)$	4.51 [0.105]	10.88 [0.028]	-	-
Residual serial correlation $F_{2,55}$, $F_{2,52}$, $F_{2,53}$, $F_{2,50}$	3.63 [0.033]	3.60 [0.034]	6.89 [0.002]	15.68 [<0.001]
Residual heteroscedasticity $F_{8,53}$, $F_{12,49}$, $F_{12,49}$ $F_{16,45}$	1.47 [0.191]	1.42 [0.188]	0.95 [0.508]	1.15 [0.343]
Normality $\chi^2(2)$	9.28 [0.010]	3.32 [0.190]	2.86 [0.240]	1.02 [6.01]

Sample: 1950-1 to 2011-12 (62 observations)
Additional instruments: (column 1) ln*wq*$_{t-1}$,Δ ln*rcp*$_{t-3}$, *scr*$_{t-1}$;
(column 2) ln*wq*$_{t-1}$,Δ ln*rcp*$_{t-3}$, *scr*$_{t-1}$, Δln*wgdp*$_t$, , *dummy* (1975-76, 1976-77), *dummy* (1989-. 1990-91).
The 3SLS estimates are from a four (column 3) or five (column 4) equation model relating for production, consumption (grindings), price, stocks and (column 4 estimates), the coffee price.
Tail probabilities in [.] parentheses; t statistics in (.) parentheses.

3SLS estimates taken from the four and five equation systems, are reported in columns 3 and 4 respectively of Table 6.[22] They both show a larger price response to availability than the corresponding 2SLS estimates, consistent with the lower estimated grindings price elasticities in column 3 of Table 4.

The model set out in the foregoing explains how cocoa grindings, the cocoa price and (implicitly) stocks adjust to shocks in production. What is not explained is how, over the long term, cocoa grindings and cocoa production come to share a common time trend. In part, that would require an understanding of how the stock of cocoa trees adjusts to long term developments in cocoa prices and in part an understanding of how marketing and advertising expenditures in the chocolate and confectionary industries respond to these prices.

5. Dynamics

We can use the equations reported in section 4 to examine the dynamics of the cocoa price. It is simplest to examine these responses through a set of impulse response functions (IRFs). I prefer the single equation to the systems estimates on the basis that any misspecification bias is confined to the equation in question, and that the single equation estimates generally exhibit lower residual serial correlation.

Figure 6 shows the cocoa price IRF for the cocoa price using the base model.[23] The IRFs show the impact of a one standard deviation shock to the crop size, grindings and world GDP growth. For ease of comparison, the crop shock is taken as negative (a poor harvest) while the grindings and GDP growth shocks are positive. In each case, the price impact should be positive.[24]

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[22] The lagged coffee price, present in the 2SLS column 2 estimates, is dropped as statistically insignificant from the 3SLS price equation reported in column 4.

[23] I use the estimates reported in column 2 of Table 4, and columns 1 of Tables 5 and 6, together with an estimated approximation to the stock identity (not reported). (Although the change in stocks should be identically equal to production, adjusted for weight loss, and grindings, the change in the stock-consumption ratio has only a good but approximate relationship with log production and log grindings. It is therefore necessary to estimate this approximate relationship).

[24] The grindings shock is orthogonalized with respect to the crop shock but this has only a minor impact on shock size. The remaining error correlations are negligible. The resulting one standard deviation shocks are therefore 8.34% (crop size), 3.16% (grindings) and 1.17% (GDP growth). I take weight loss in the stock identity to be 2.75%. Because the model is mildly nonlinear (the behavioural

Looking first at the crop shock (a harvest shortfall of 8.3%), shown by the continuous line in Figure 6, this results in an immediate rise in the cocoa price of nearly 4½%. The rise in prices continues over the following three years to peak at 11¾% in the third year following the shortfall. The transmission mechanism here is the large lagged response of grindings to the price rise shown by the continuous line in the grindings IRFs charted in Figure 7. The price rise occasioned by the crop shortfall leads to a decline of 2¼% in grindings by the third year.

A positive shock to grindings (3.1%), shown by the dashed line in Figure 6, impacts the cocoa price by reducing the stock-consumption ratio. This is illustrated in Figure 8. Because of the positive autocorrelation in grindings levels, stocks fall over the three years following the grindings shock. The maximum price impact (8¾%) comes after five years. Although the size of the grindings shock is close to one third of that of the crop shock, the maximal price impacts are relatively similar.

This is also the case with shocks to world GDP which impacts the cocoa price through raising grindings and hence reducing the stock-consumption ratio.[25] The impact of a rise in GDP (here 1.2%) comes through more slowly as the result of lagged adjustment in grindings, and peaks at 10¾% after seven years. Because there is no mean reversion in GDP, a positive shock in one year results in permanently higher GDP and hence permanently higher grindings. With less than infinite production and consumption elasticities, this rightward shift in demand results in a permanently higher cocoa price. By contrast, production and consumption shocks are transient, even if long lasting, since both variables are modelled as trend stationary and hence revert back to their un-shocked paths.

Because crop size shocks are nearly three times larger than shocks to cocoa consumption, it is tempting to see cocoa prices as driven by supply more than demand shocks. This is indeed the standard paradigm for agricultural commodities. The price responses charted in Figure 6 IRFs show that this conclusion is too simple since the overall magnitudes of these impacts are of comparable size. This apparent paradox results from the fact that shocks to cocoa

equations are log-linear while the stock identity is linear), the IRFs are slightly sensitive to choice of base simulation. I take a historical simulation as the base and shock this in crop year 2006-07.

[25] As discussed in Section 4, it is not simple to disentangle the impact of changes in income from changes in taste. The GDP growth IRFs may therefore be subject to greater qualification than those relating to crop and grindings shocks.

grindings have a much greater persistence than cocoa production – compare the coefficients of the lagged levels in Table 4 and 5 (0.78 and 0.42 respectively).

A simple way to check this conclusion is to regress the change in the cocoa price on distributed lags of the shocks. Results are reported in Table 7 using a four year lag distribution. The first two columns report the estimates from an unrestricted regression while the final two columns report results where the sum of the coefficients in each of the lag distributions is restricted to zero. (A Wald test fails to reject this restriction).

The estimates reported in Table 7 suggest that shocks to grindings have a larger impact on cocoa prices despite their smaller magnitude. This is in line with the results obtained from the IRFs reported above. On the other hand, while the IRFs suggest that shocks to grindings feed through more slowly than crop size shocks, the estimates reported in Table 7 go in the other direction.

Table 7
Regressions of price changes on shocks

Lag	**Crop shock**	**Grindings shock**	**Crop shock**	**Grindings shock**
0	- 1.87 (6.64)	3.16 (4.30)	-1.92 (7.12)	2.73 (4.09)
1	- 0.04 (0.15)	1.06 (1.46)	- 0.12 (*)	0.69 (1.02)
2	0.91 (3.35)	-1.03 (1.47)	0.80 (3.29)	-1.51 (2.43)
3	0.77 (2.25)	- 0.37 (0.53)	0.71 (2.67)	- 0.82 (*)
4	0.57 (1.98)	-0.74 (1.08)	0.53 (1.92)	-1.10 (1.78)
R^2	0.648		0.628	
s.e.	0.1558		0.1569	
AIC	- 3.550		- 3.562	

Dependent variable: $\Delta \ln rcp_t$; t statistics in parentheses. The equations also include an intercept.
Sample: 1954-55 to 2011-12 (58 observations)
Columns 1 and 2 report an unrestricted regression. In columns 3 and 4, the sum of the coefficients in each lag distribution is restricted to zero ("*" indicates a restricted coefficient).
Wald test on the restriction $F_{2,47}$ = 1.36 (p-value 0.266).

A natural way to check on the simulation results reported in this section is to consider a VAR (Vector AutRegression) model. Once a lag length has been selected, VAR models leave the coefficients unrestricted. This is advantageous to the extent that it avoids misspecification resulting from the imposition of incorrect restrictions but disadvantageous because it supposes that the relationships are sufficiently well determined that they will be apparent in the empirical estimates without the aid of a theoretical structure. It is not my purpose here to argue that the VAR approach is in general terms superior or inferior to the so-called structural approach I have adopted. However, it does appear to be less satisfactory in the limited context of the world cocoa market.

I estimated a five variable VAR(2) (i.e. with two years lags) of the from $x_t = \mu_t + A(L)x_t + \varepsilon_t$ where μ_t is deterministic (constant plus time trend) and ε_t is a vector of serially independent shocks. The vector x_t of variables included in the model comprises the log change in cocoa crop (Δln*wq*), the log change in cocoa grindings (Δln*wgr*), the ratio of cocoa stocks to trend consumption (as defined earlier, *scr*), the log change in the real cocoa price (Δlnwc*p*) and the log change in world GDP (Δlnw*gdp*). (It is necessary to include world GDP as a modelled variable since VARs are closed systems). The VAR is estimated over the same sample as the structural model (1950-51 to 2011-12). All five *x* variables are stationary. The lag length of two resulted from testing down from an initial specification with four lags. World GDP growth is not Granger-caused by any of the cocoa market variables allowing simplification of the GDP growth equation to a trend-augmented AR(2). No other restrictions were imposed.

Figure 9 shows the simulated price IRF from this model and may be compared with the structural price IRF charted in Figure 11. As in the structural model simulation, all three shocks were defined such as to imply a positive price response (i.e. a harvest shortfall and positive shocks to grindings and world GDP). [26] The pattern of the price response to a shock to grindings is reasonable but the order of magnitude of the response is only around one quarter of that shown by the structural model and reported in Figure 11. A harvest shortfall is seen as having a perverse negative price impact in the following crop year, subsequently reversed as stocks fall. A rise in GDP is also seen as having a perverse negative price impact. These perverse impacts both arise from the very poorly determined VAR price equation in

[26] For ease of comparison, the three shock magnitudes are of the same magnitude as those applied in the simulation of the structural model.

which many coefficients are large but none is statistically significant – a classic symptom of multicollinearity arising from inclusion of an excessive number of regressors – here eleven plus the intercept. I conclude that the unrestricted VAR fails to account for the dynamics of the world cocoa price.

One response to poor coefficient determination in a VAR is to impose a weak Bayesian prior. I have followed a different route in estimating a structural VAR (SVAR) of the form $A_o x_t = \mu_t + A(L)x_t + \varepsilon_t$ where A is no longer diagonal and reflects the recursive structure of the structural model. The structure of the SVAR is shown in Table 8. The lag distributions specify that the crop depends only on its own past and past prices, that grindings depend on their own past, past prices and present and past GDP growth, that the cocoa price depends on its own history, the current year's crop and past stock levels. It is affected by past changes in crop size and grindings only via their impact on stocks. GDP growth affects the cocoa price only via its impact on grindings. The stock-consumption ratio depends on its own history and past and present changes in crop size and grindings but not directly on the price. This is the same broad structure as that in the structural model of section 7 and 8. The SVAR was estimated by 3SLS over the same sample as that used previously, crop years 1950-51 to 2011-12.

Table 8
SVAR structure

	A_0					A(L)				
	Δln*wgdp*	Δln*wq*	Δln*rcp*	Δln*wgr*	*scr*	Δln*wgdp*	Δln*wq*	Δln*rcp*	Δln*wgr*	*scr*
Δln*wgdp*	1	0	0	0	0	*	0	0	0	0
Δln*wq*	0	1	0	0	0	0	*	*	0	0
Δln*rcp*	0	*	1	0	0	0	0	*	0	*
Δln*wg*	*	0	*	1	0	*	0	*	*	0
scr	0	*	0	*	1	0	*	0	*	*

Each row of the table defines an equation in the SVAR, The left hand block of coefficients relate to the contemporaneous A_0 interactions. "1" indicates the coefficient on a dependent variable, "0" a coefficient which is restricted to zero and "*" to an estimated coefficient. This matrix has no non-zero coefficients above the diagonal giving a recursive structure. The right hand block specifies the distributed lags entering each equation using the same notation.

The simulated IRF from the SVAR is charted in Figure 10. The shock sizes are the same as those administered in the structural model (Figure 6) and unrestricted VAR (Figure 9) simulations. The pattern of responses to the crop size and grindings shocks is closer to that of the structural model than to those of the unrestricted VAR. The impact of the grindings shock is of similar magnitude in the two sets of simulations but it is seen as decaying much more slowly. The magnitude of the impact of a crop size shock is, however, around double that suggested by Figure 6. Again, decay is much slower. The impact of a GDP growth shock is tiny. The relative size of the impact of crop size shocks compared to that of grindings shocks stems from a large but poorly determined coefficient of the current change in crop size in the estimated price equation. The difference between the GDP impacts in the structural and SVAR models stems from the presence of error correction (lagged levels) term in the former, reflecting the cointegration result in Table 3, and its absence from the SVAR. A further reconciliation between the two models might be obtained by moving to a cointegrated SVAR.

Finally, I revert to the base (structural) model and augment this by including the real coffee price. The model therefore consists of the equations detailed in column 2 of Table 4 (unchanged from the base model), column 2 of Table 5 and column 2 of Table 6 together with an approximation to the stock-consumption ratio identity and an adjustment equation for the coffee price.[27] The cocoa price IRF yielded by this augmented model is graphed in Figure 11. The overall response pattern exhibited in this IRF is similar to that in the IRF from the base model (Figure 6) although the estimated maximal magnitudes of the price responses are both higher and faster than in the base case. A one standard deviation crop shortfall is now seen as raising the cocoa price by 16¼% after one year compared with 11¾% after two years. An (orthogonalized) one standard deviation shock to grindings raises the cocoa price by 9¾% after three years in the augmented model compared with 9% after five years in the base case. A shock to world GDP now raises the cocoa price by 12¼% after two years compared with 10¾% after seven years in the base case. Finally, an (orthogonalized) one standard deviation shock to the coffee price (21.3%) is seen as having a comparable impact to that of a one standard deviation harvest shortfall, raising the cocoa price by 15% in the year of impact and a further 1¼% in the following year. Unlike the case of the crop

[27] Lacking information on coffee production and roastings over the sample from 1950-51, I relate the change in the coffee price through an error correction equation to its lagged value, the lagged change in the cocoa price, the (log) levels of the coffee and cocoa prices lagged two years and the current change in world GDP.

shock, however, the impact is short-lived with the cocoa price returning to close to its base level within four years.

I have noted that I lack the information on coffee production, roastings and stocks to be able to reliably identify the impact of coffee market developments on the cocoa price. The conclusions from this section of the paper must therefore be seen as tentative. However, the estimated short duration of the cocoa response to high and low coffee prices and the absence of strong links of coffee prices with cocoa production and grindings suggest that any link between the two markets works through a channel other than that of market fundamentals.

6. Conclusions

This paper has taken the form of an update of Weymar (1968) although, unlike Weymar, I am not confident that it will provide a basis for profitable trading in cocoa futures – there are now too many well-informed hedge funds for this to be straightforward. The analysis differs from Weymar's in that I use a long sample of crop year data whereas he used a much shorter sample of monthly data. This precludes me from considering intra-annual price dynamics which formed a large part of Weymar's work. Despite this I am able to confirm Weymar's principle finding that a shortfall in cocoa production in a particular year will raise cocoa prices over the following nine years and conversely with an abnormally abundant harvest. Lags are therefore very long.

In other respects, my conclusions differ from or extend those reached by Weymar. Weymar's model was constructed on the premise that shocks to the cocoa market originate entirely from crop variability.[28] I concur that supply side harvest shocks are quantitatively larger than demand side shocks but find that, as a consequence of the positive autoregression in annual changes in grindings, demand side shocks are of comparable

[28] Weymar (1968,, pages 13-15) acknowledges the importance of demand side shocks in generating the 1953-54 bull market in cocoa, but regards this as exceptional: "This sharp, eighteen-month uptrend was unique among recent bull markets in cocoa in that it found its cause initially in a rapid shift in demand, rather than supply, conditions". He attributed this shift to the 1953 lifting of World War II controls on UK confectionary consumption. At that time, the UK accounted for 15% of total world cocoa imports.

importance to supply side shocks in generating cocoa price variability. Furthermore, the price impact of demand side shocks is even longer than that of harvest shocks.

The long sample which I have utilized has allowed me to obtain greater precision than Weymar in disentangling the impact of GDP growth from that of what economists call changing tastes. I find that the long run income elasticity of demand for cocoa is around 0.4, although the short run elasticity is over one, and that in the long run there is also an annual increase in consumption of somewhat over 1% independently of income growth. That may be good news for the chocolate and cocoa industry in the current recessionary environment. The price elasticity of demand is around -0.3, somewhat lower than Weymar's estimate. Much of the price response occurs in the crop year following a rise in cocoa prices. This may result from pricing practices in the chocolate and confectionary industry. This lag in consumption has two consequences. The first is a reduced incentive to store cocoa since a crop shortfall in the current year will provoke a lower price in the succeeding year. The second is as tendency for price changes to be negatively autocorrelated when stocks are low – absent speculative stockholding, a shortfall this year will cause a high current price but, by depressing next year's consumption, a low price next year. This may explain the negative autocorrelation pattern which is apparent in the cocoa prices.

My analysis has also thrown up evidence of a possible link between the cocoa and coffee industries. This evidence takes two forms. First, there is evidence that a high coffee price in one crop year depresses cocoa production in the following crop year (and *vice versa* for a low coffee price). Second, there is evidence that a high (low) current coffee price is directly transmitted into a high (low) cocoa price. This link can potentially explain the very high cocoa prices in 1976-77 and 1977-78 (frost impact in the Brazilian coffee producing zone) and low prices in 1999-2000 and 2000-01 (ending of coffee market controls resulting in a surge of exports).

These supposed links are both problematic. Although cocoa and coffee are grown in many of the same countries, they are seldom grown by the same farmers in the same zones of these countries. I have suggested that, if there is a link from coffee prices to cocoa production, it may result from decisions taken by governments, for example in relation to input allocation, rather than to decisions taken by farmers. The direct link form coffee to cocoa prices is less robust than the production link from an econometric standpoint. Given that cocoa production is only weakly linked to it the coffee price and grindings appear only weakly linked to it, a direct link between the two prices is difficult to rationalize in terms of the fundamentals of physical supply and demand. One notes that both cocoa and coffee trade on what, in the days of pit trading, were adjacent futures markets and that many trade participants are common to the two markets. This is a topic on which further analysis is required.

There are few policy implications which follow directly from the analysis in this paper. However, three important questions have arisen which demand further work. The first relates to the possible links between the coffee and cocoa markets. It is possible that fluctuations in price of coffee transmit significant short term volatility into cocoa prices. I have suggested that, if this is the case, it is possibly a non-fundamental factor relating to futures trading in the two commodities. It is difficult to reduce the price volatility arsing out of shocks to production and consumption. However, if non-fundamental factors are responsible for a proportion of volatility, it may be possible to limit their effects simply by throwing light on the sources of this "gratuitous" volatility.

The second issue which would benefit from further analysis is the source of demand growth in cocoa chocolate. My measure of world GDP has grown at an average of around 3½% over the sample I have analyzed. Using an income elasticity of 0.4, this translates into an average income- generated growth in cocoa grindings of around 1.35%. Grindings have grown at an average rate of 2.7%. Income growth therefore only explains one half of overall consumption growth. The other 1.35% is attributed to what economists call "change in tastes". Such taste changes do not just happen. I suspect that the marketing divisions of the major chocolate manufacturers are likely to claim responsibility for this process. It would be good to see some scientific analysis relating to this issue.

The third and most difficult issue relates to long term equilibrium between cocoa production and consumption and in particular, how they come to grow with a common trend. My model finesses that issue. What is required here is both a model of farm level and governmental decisions to plant new cocoa trees and an analysis of brand-related investment decisions in the marketing of chocolate and chocolate confectionary.

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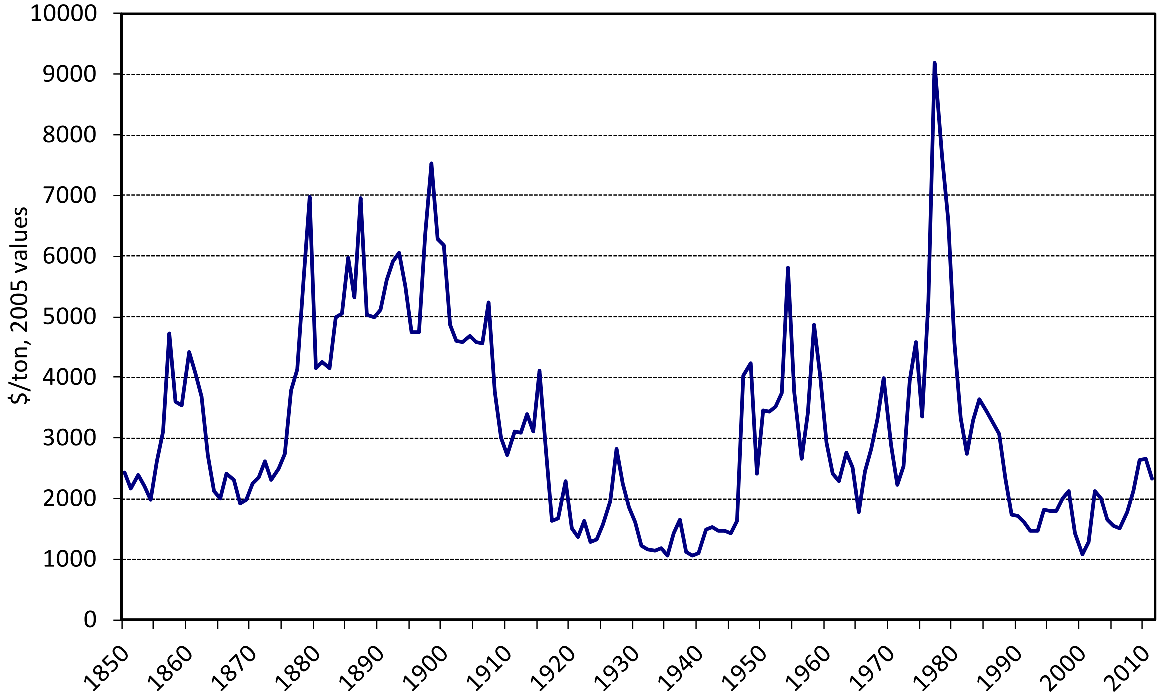

Figure 1: The real cocoa prices, 1850-2011 (calendar year basis, 2005 values)

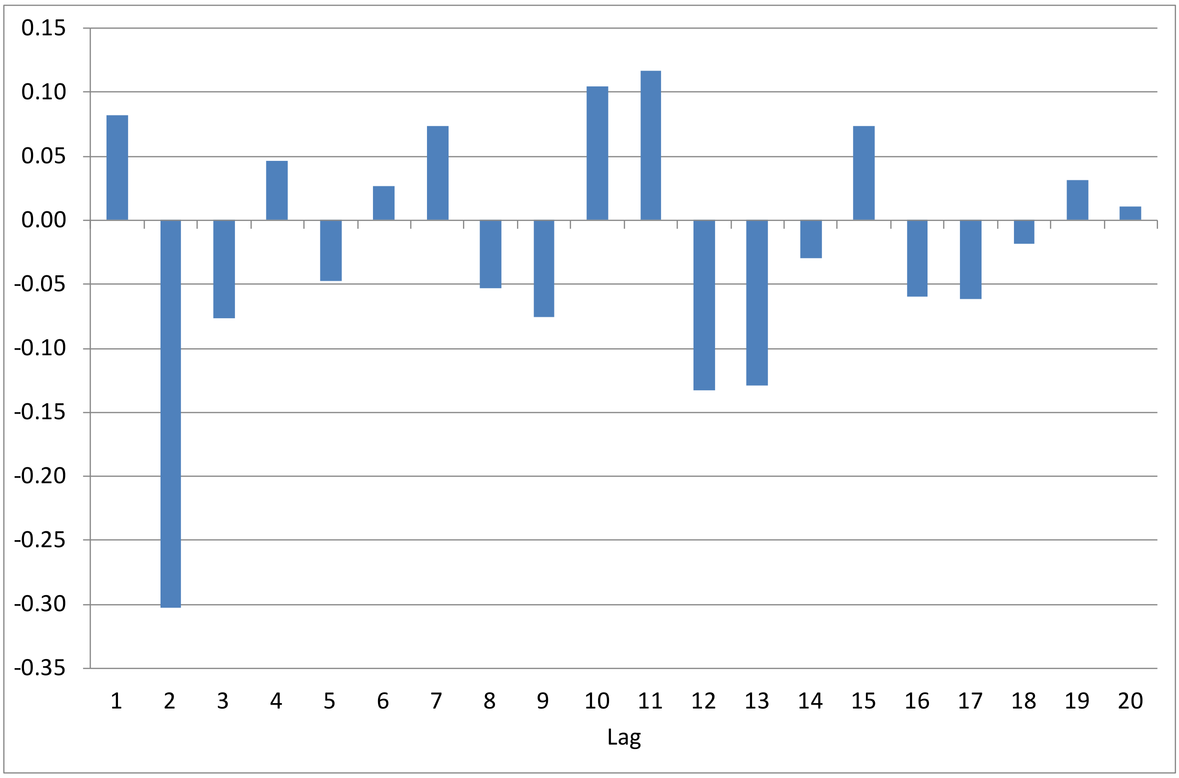

Figure 2: Autocorrelation function, Δln*rcp*, 1854-2011

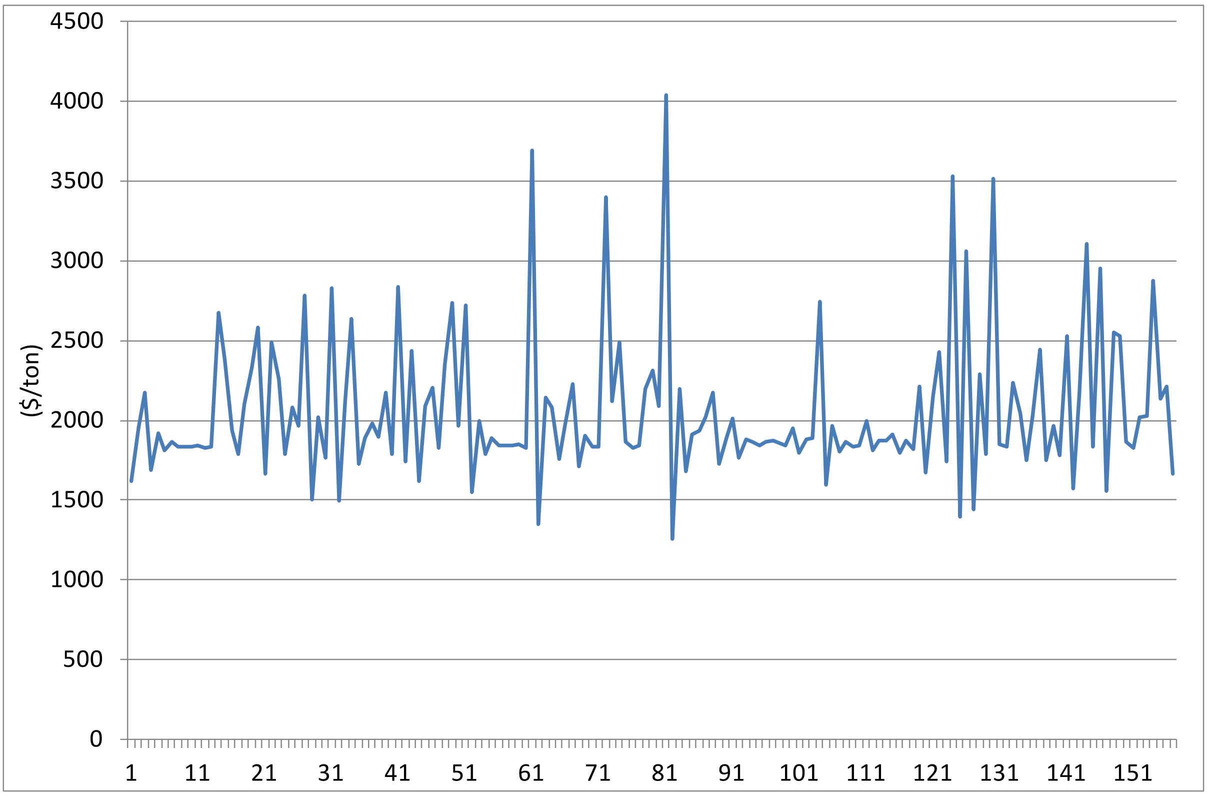

Figure 3: Simulated price realizations

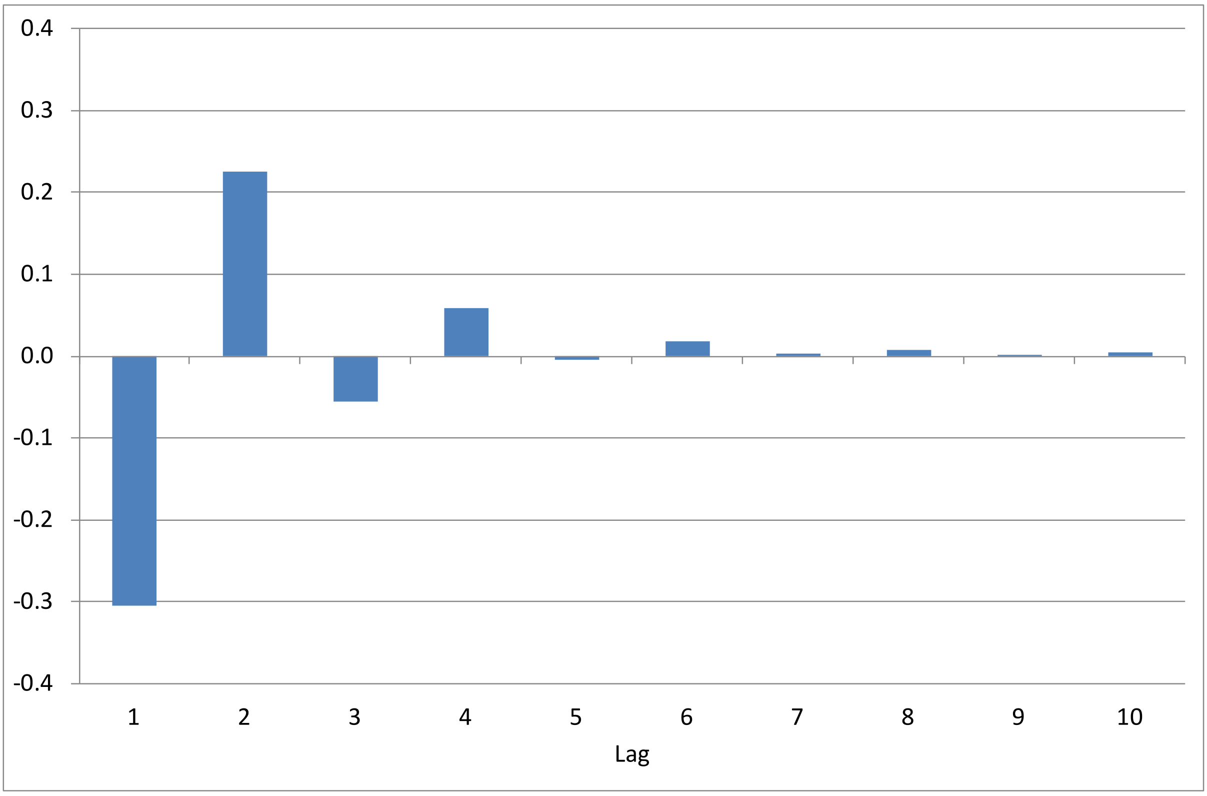

Figure 4: Autocorrelation function, simulated price realizations

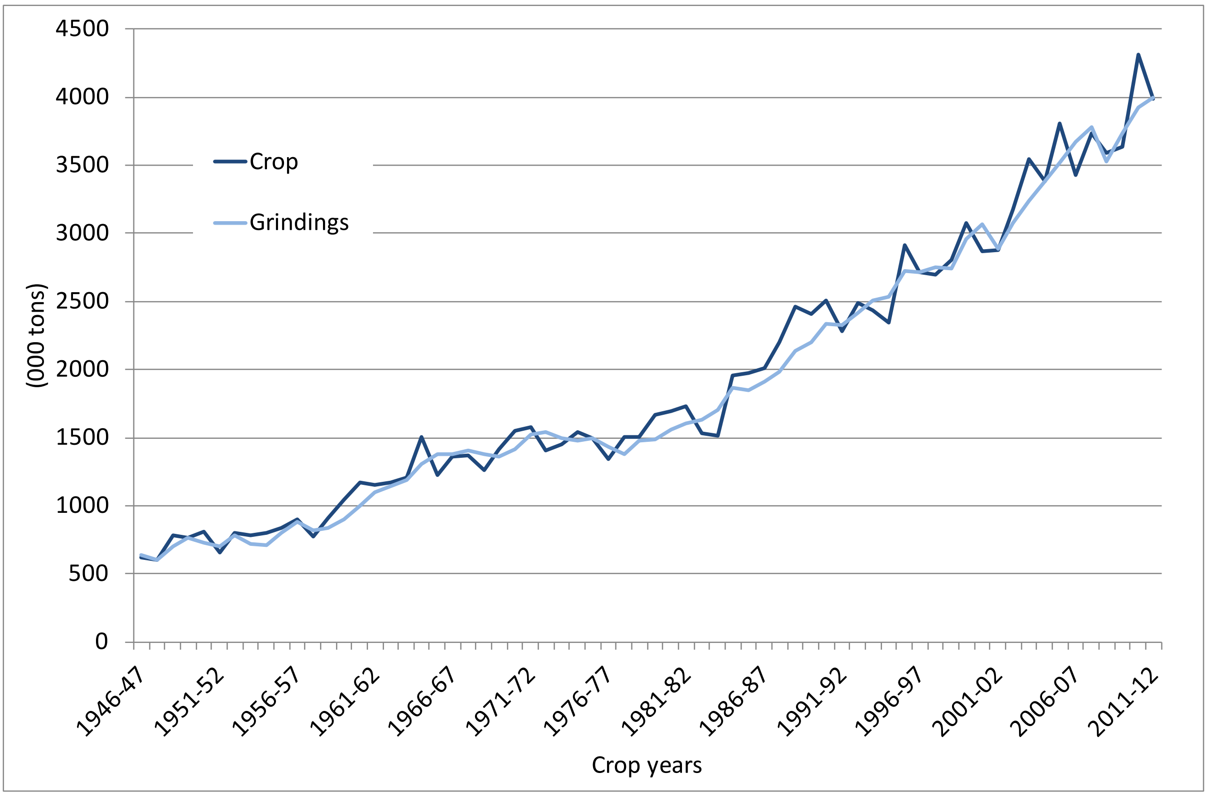

Figure 5: Cocoa production (crop) and consumption (grindings), 1946-47 to 2011-12

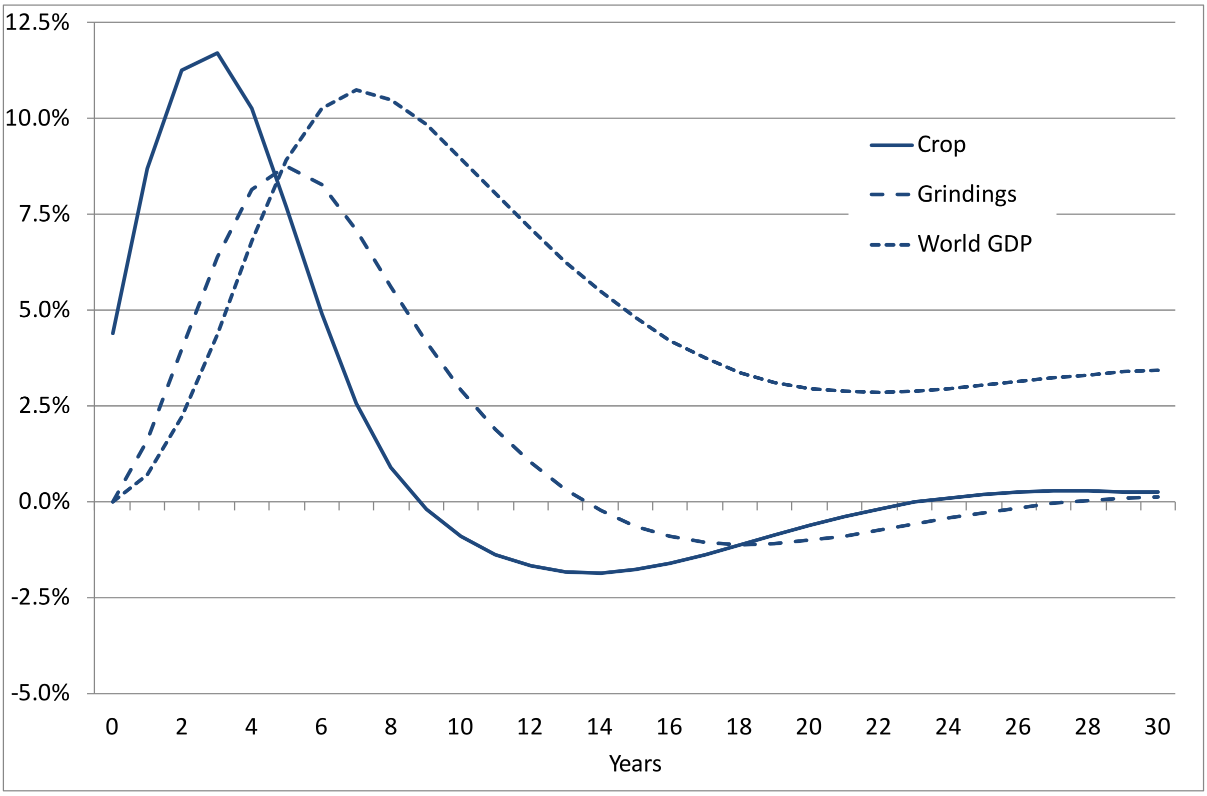

Figure 6: Simulated cocoa price impulse response functions (base model)

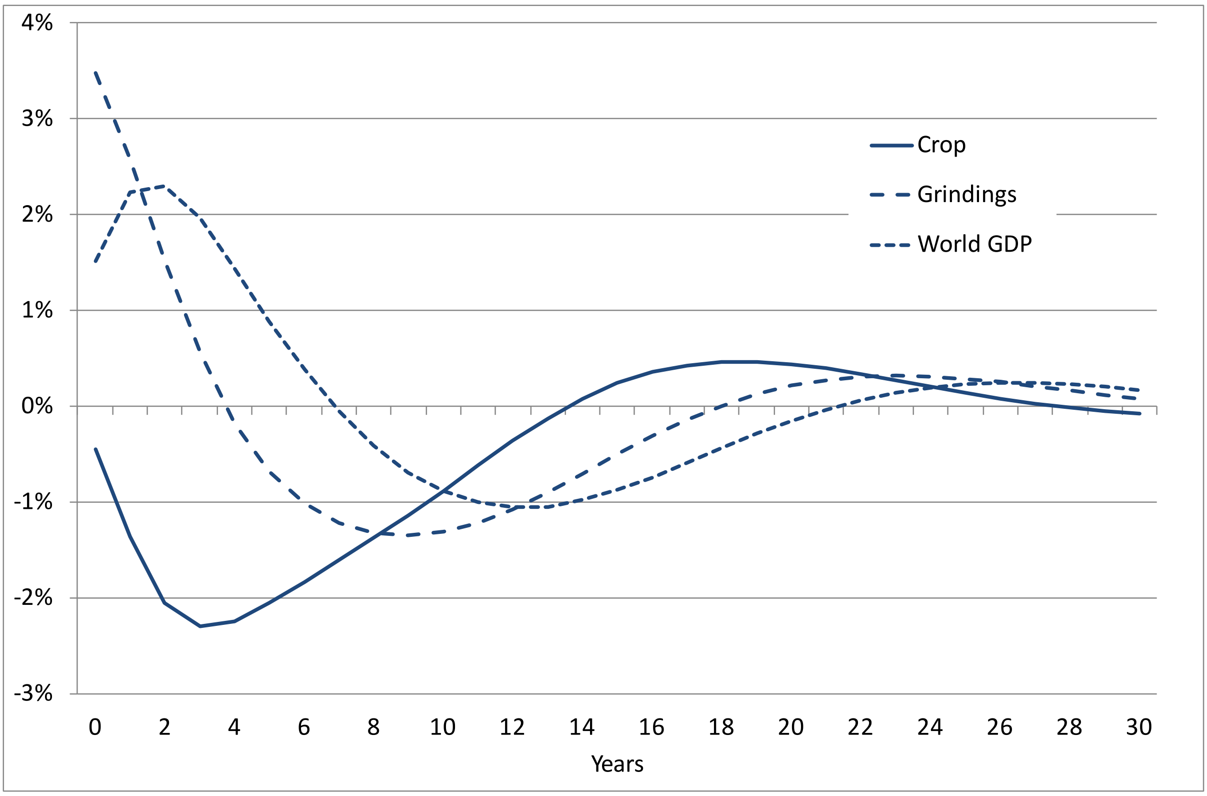

Figure 7: Simulated cocoa grindings impulse response functions (base model)

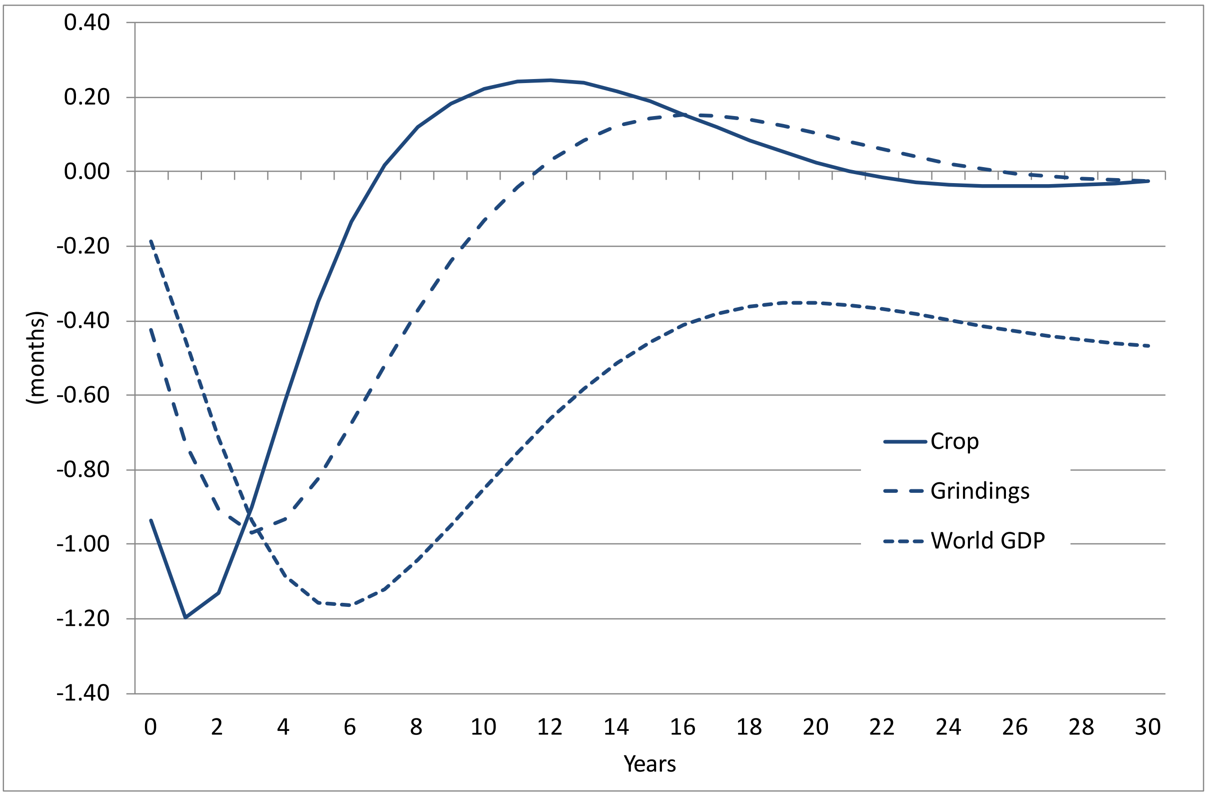

Figure 8: Simulated impulse response functions – cocoa stock-consumption ratio (base model)

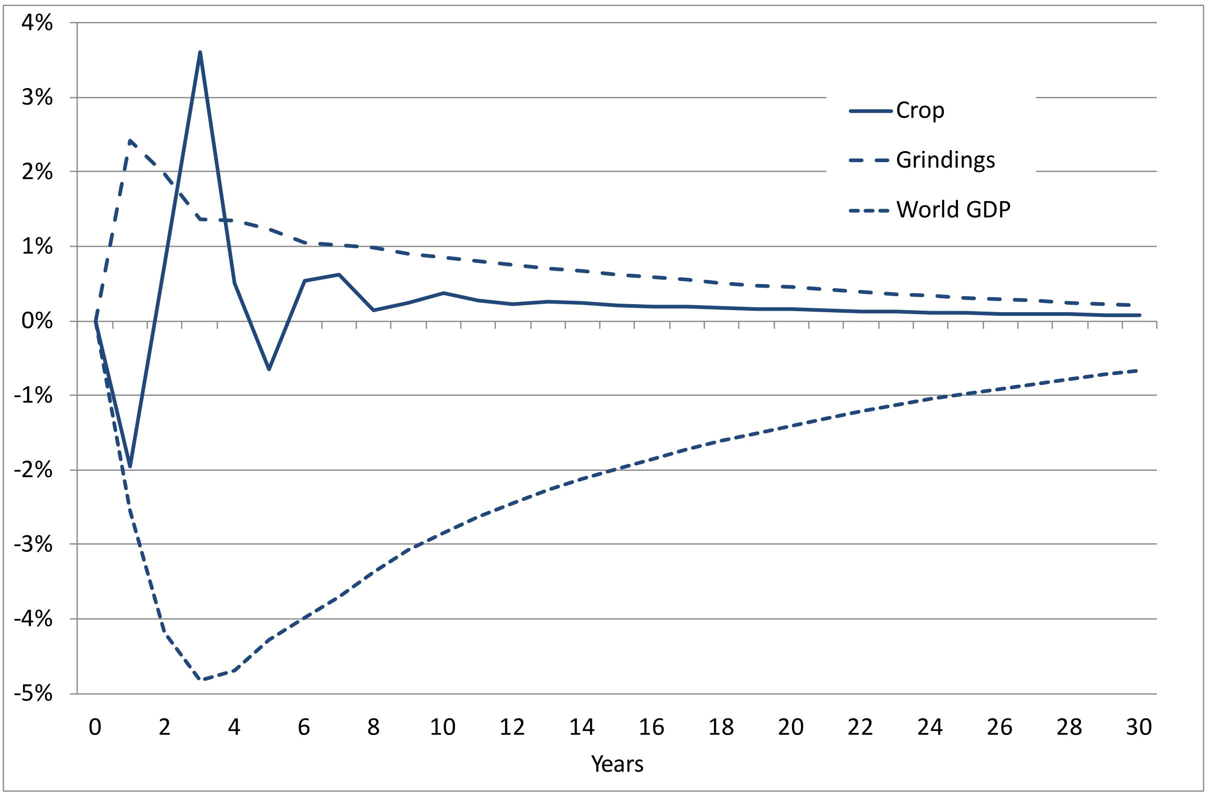

Figure 9: Simulated cocoa price impulse response functions (unrestricted VAR)

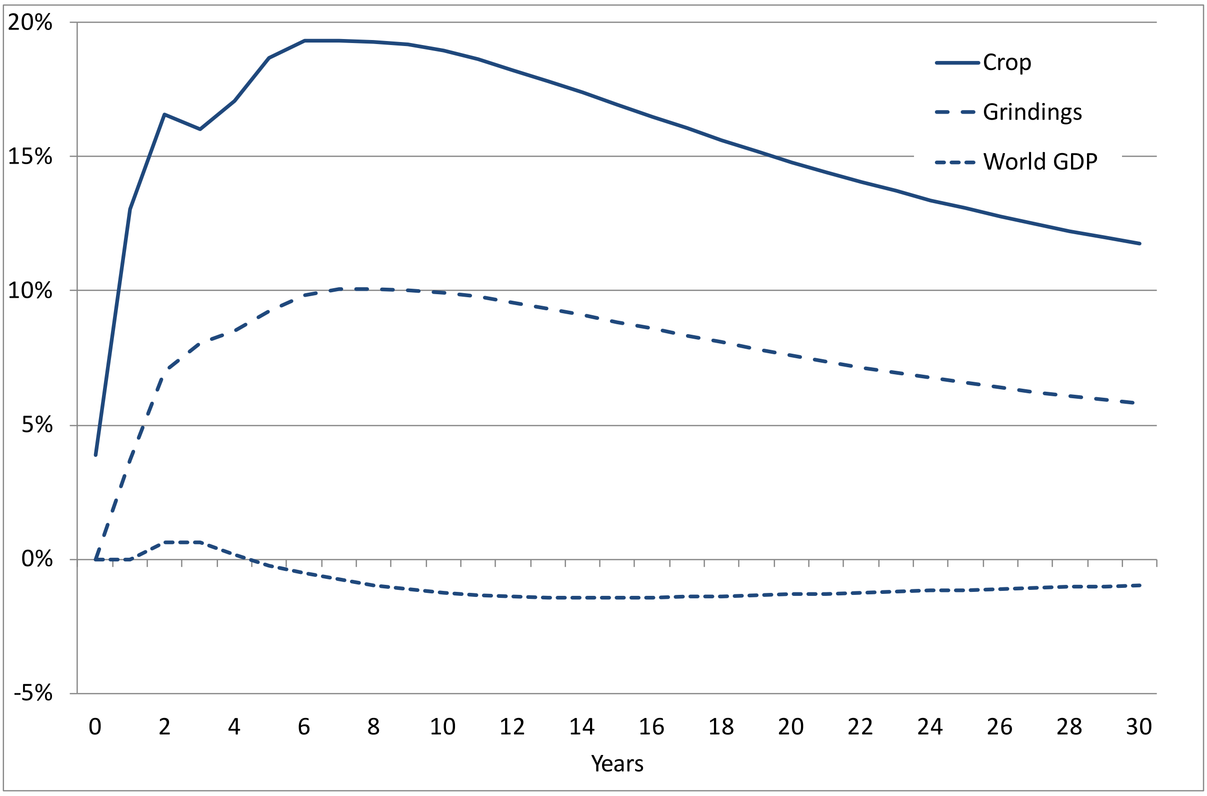

Figure 10: Simulated cocoa price impulse response functions (SVAR)

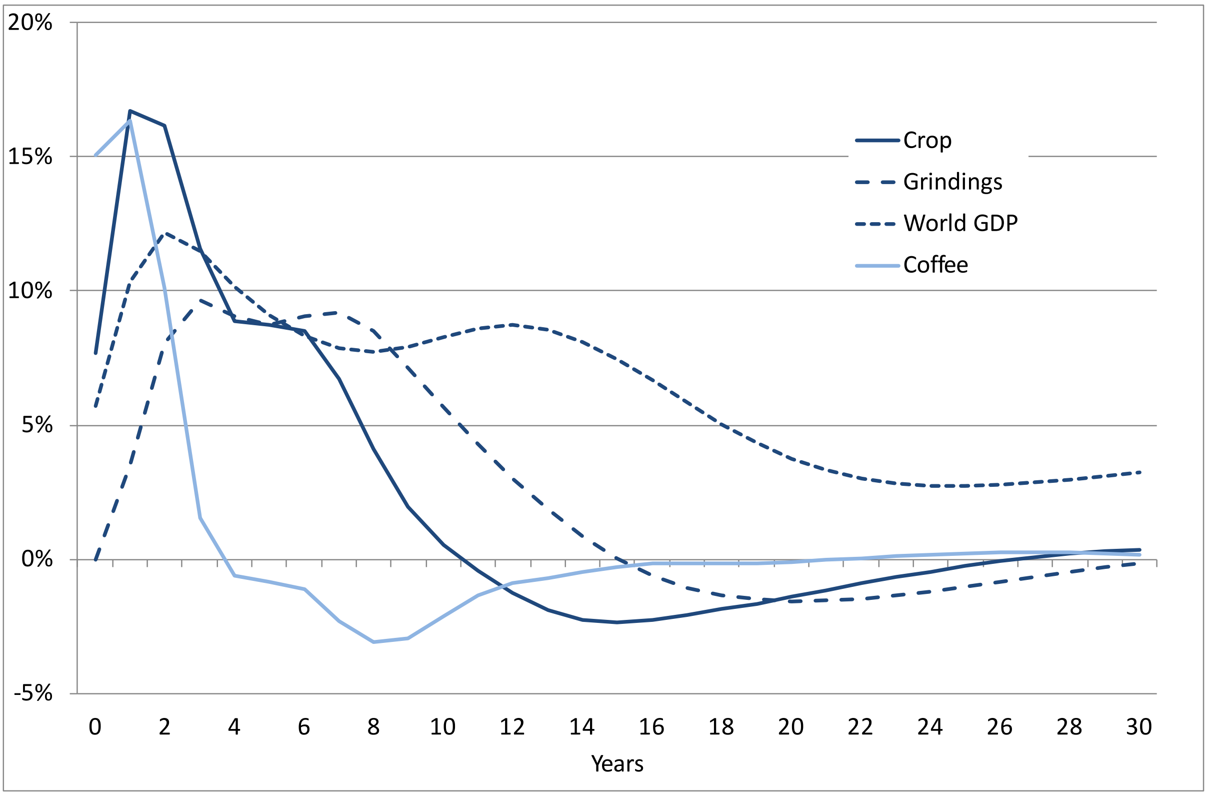

Figure 11: Simulated cocoa price impulse response functions (base model augmented to include coffee)