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RESPONDING TO THE COFFEE CRISIS:

WHAT CAN WE LEARN FROM PRICE DYNAMICS

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Responding to the coffee crisis: What can we learn from price dynamics? ☆

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Abstract

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1. Introduction

By historical standards, real green coffee prices have been very low over the last few years (see Fig. 1). These low prices have had adverse effects on coffee growing nations[2] and disastrous consequences for coffee farmers.[3] This has prompted calls for a policy intervention to stabilize international coffee prices.[4] The purpose of this paper is to provide an empirical assessment of the functioning of the coffee markets and of the dynamic effects of past policy interventions over various time horizons. The analysis stresses the importance of long-run supply adjustments in market dynamics. The results urge caution when designing interventions in this complex, long-term and poorly understood market.

Four attempts to control and raise international coffee prices were made in the twentieth century.[5] Only the fourth attempt succeeded, during the cold war years of the International Coffee Agreements (ICA).[6] The ICA[7] collapsed in July 1989. Its success is attributed to the political backing it enjoyed from the US State Department, and other organs in consuming countries. This political support meant that under the ICA, coffee importers colluded actively with exporters in restraining exports through the use of export quotas. All other price-control agreements, which only involved the collusion of producers, fell apart within five to seven years, under pressure from excess supply. Coincidentally, this was roughly the length of time that it took the fruits of a newly planted coffee crop to be brought to market. Coffee can be grown in a variety of locations around the world, and there have been frequent shifts in the global pattern of coffee production over the last two hundred years (Wrigley, 1988), some of which coincided with the introduction of price control agreements. This history suggests that while the incentives to control prices and restrict supply are significant, attempts to do so without the involvement of consuming nations eventually succumb to free-riding and longer term market supply response to higher and more stable prices (Bates, 1997).

Modern coffee trees take four to five years to become fully productive,[8] and then remain productive for a further 15–25 years (Clinton, 1992; Junguito and Pizano, 1999). Pruning and other maintenance decisions also affect yields at the one to three year horizon.[9] As a consequence, if price interventions promote planting, the impact of these new trees on prices is likely to be long-lived, potentially resulting in long term gluts, and perhaps price cycles. The long term effects of price interventions are therefore expected to depend upon the responsiveness of planting decisions to current prices. This responsiveness in turn depends upon how farmers interpret price movements to predict future market conditions when making investments in their tree stocks. In particular, while there is circumstantial evidence that price stabilization agreements promote planting, it is not clear what impact an isolated price intervention would have. Thus, it is necessary to understand the

[2] For examples of the macroeconomic influence of global coffee prices in producing countries, see Otero (2000, 2001), and Junguito and Pizano (1999).

[3] See, for example, Delios (2002), International Coffee Organization (2004), Varangis et al. (2003). and Weiner (2002).

[4] For example, see Oxfam (2002), ICO (2004) and the concluding section of Talbot (2004).

[5] The Association of Coffee Producing Countries, the fifth attempt to control prices in the mid-1990s, was a virtual non-starter (Daviron and Ponte, 2005, pp.88–89).

[6] For a discussion of the many attempts to control coffee markets, see Bates (1997), Krasner (1973) and Gordon-Ashworth (1984).For more details on the history of the ICAs, see Gilbert (1987) and Akiyama (2001).

[7] While there were in fact multiple agreements, as they functioned on roughly the same principles, for purposes of this paper, we treat them as if there was a single agreement.

[8] The 5–7 years referenced previously reflects the life cycle of commercial coffee varieties during the first two-thirds of the twentieth century.

[9] For evidence that maintenance patterns are at least perceived to respond to, and affect, prices, see the USDA Foreign Agricultural Service's Tropical Products bulletins.

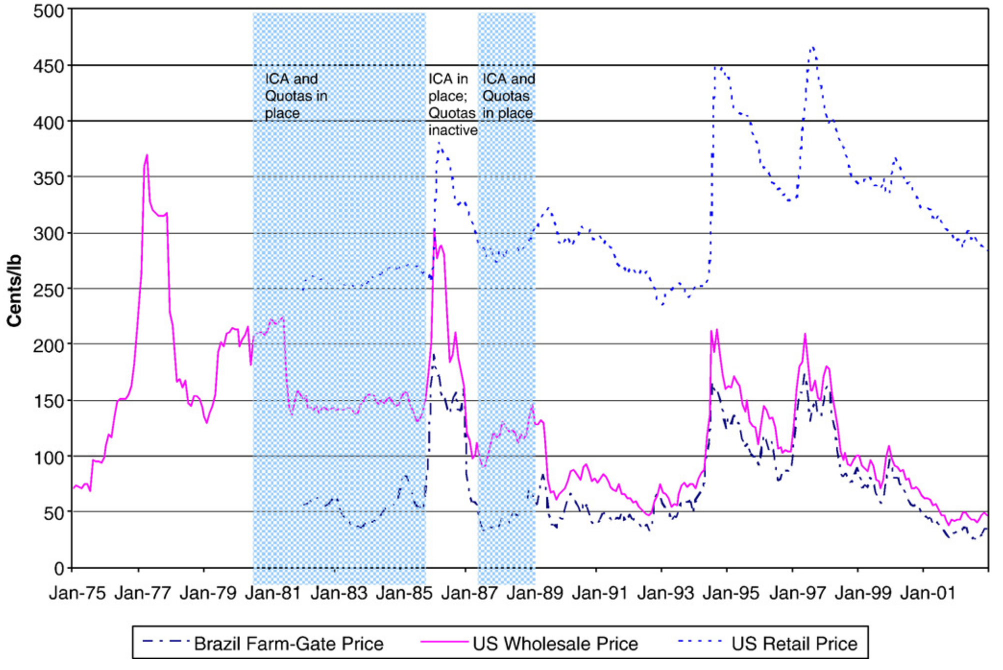


Fig. 1. Coffee prices.

long term (more than four years in the future) and medium term (one to three years in the future) dynamics of coffee prices, both with and without price policy interventions.

These medium and long term price effects can be complex (e.g., they can be sensitive to particular policy scenarios). Exploring such issues requires a refined economic analysis of coffee markets. In this context, three features of Fig. 1 appear particularly relevant. The first is a gradual historical expansion in the retail-wholesale margin. Several recent contributions have highlighted this increasing margin (Calfat and Flores, 2002; Ponte, 2002; Shepherd, 2004; Talbot, 1997) and most have linked it to consolidations and increased market power in the roasting industry.[10] It is often suggested that this contributed to asymmetric price responses, where retail prices rise in response to wholesale price increases, but do not fall when wholesale prices do.

With a focus on Brazil as the largest coffee producer, the second observation is that the price difference between wholesale and Brazilian farm-gate prices is considerably larger during the ICA than it is following the ICA, while the wholesale and farm prices appear to track each other far better after the ICA collapsed (see Fig. 1). This indicates economic rents accruing to holders of ICA export permits — typically producing governments or their patrons. Indeed, the rationale for US support to the ICA was to provide economic support to friendly regimes in Central and South American producing nations. This suggests another important issue to be addressed in the

[10] While most of these authors find evidence of market power in the U.S. roasting industry, Bettendorf and Verboven (2000) find price transmission in the Netherlands to be fairly competitive. Also in European roasted coffee markets, Durevall (2003, 2005) finds no direct evidence of market power, but does find asymmetric wholesale-retail price transmission. Daviron and Ponte (2005) argue that roasters command significant power relative to retailers (ch. 3).

evaluation of past or future price controls. Export restraints generate rents, which must be distributed across countries, and within the vertical supply channel. The distribution of these rents (e.g., how much is captured by farm producers) is always an important aspect of the policy design and its long term viability.[11]

The third observation is that coffee prices have been the subject of tremendous volatility. The high volatility is due to the susceptibility of output to frosts and droughts, magnified by the inelasticity of demand with respect to prices and income,[12] and inelastic supply.[13] In general, the magnitudes of the effects of adverse production shocks exceed those of bumper crops. This suggests a need to understand better the implications of this volatility for market dynamics. Indeed, the volatility can directly influence decisions to invest in trees, as argued by the real option value theories of Dixit and Pindyck (1994). Given the longer term effects of supply decisions, the volatility of past market conditions makes coffee price dynamics very complex.

Finally, it seems important to allow for non-linearities in price dynamics. As described above, retail prices have been shown to react asymmetrically to wholesale price movements. It is also possible that planting and pruning patterns depend upon prices in different ways depending upon whether prices are rising or falling. And the volatility of price shocks may depend upon the state of coffee stocks, which in turn depend on the price level itself. Each of these factors embodies significant potential for hysteresis (or irreversibility), indicating that the effects of any policy intervention might not be easily undone if they are found to be disagreeable. This could be a concern whether the intervention raises prices (by destroying coffee stocks, for example), or lowers them (by encouraging entry into green coffee production). Given our limited empirical knowledge on these issues, a refined analysis of coffee price dynamics offers good prospects for improving our understanding of policy intervention and its interactions with market dynamics.

This paper investigates empirically the economics and dynamics of the impacts of price interventions in coffee markets. This is done by specifying and estimating a detailed econometric model of price dynamics for farm, wholesale and retail coffee prices. We focus on farm prices in Brazil, since Brazil is the leading coffee producer and exporter. While previous studies have looked at the short and medium term dynamics of coffee prices, the long term dynamics of coffee prices have not been analyzed before. This is mostly due to two factors: the large time lags required to capture the long term dynamics of supply, and the lack of good historical data on tree stocks or tree planting. This latter factor severely limits the feasibility of structural models to evaluate the dynamics of coffee prices empirically. However, a reduced from approach remains feasible. On that basis, we specify and estimate a reduced-form econometric model, starting from its structural foundations relating the dynamics of supply to the evolution of prices through the marketing channel. The model relies on a five year iterative representation of long term dynamics, which reduces the number of time lags required for estimation purposes. The model allows for

[11] The central hypothesis of Cardenas (1994) is that the behavior of domestic prices in consuming nations, and therefore of the distribution of coffee rents, is driven by how the coffee boards are arranged institutionally.

[12] Price elasticities of demand from the literature include: Akiyama and Varangis (1990) −0.33; Akiyama and Duncan (1982) — between −0.067 and −0.40; Hermann (1986) −0.27; and Behrman (1978) −0.2. Akiyama and Varangis (1990) report an income elasticity of demand of 0.6.

[13] Akiyama and Varangis (1990) estimated that at the one year horizon price elasticities of export supply averaged 0.04 across a large sample of producing nations. They estimated price elasticities of export supply of around 0.06 to 0.68 at the five year horizon across several countries. Hermann (1986) also found a short term export supply elasticity of 0.04. Akiyama and Duncan (1982) report price elasticities of world production of 0.12 in the short run (reaction to prices up to a year in the past) and of 0.74 in the long run (reaction to prices 10–13 years in the past). More recent estimates of supply elasticity are unavailable, perhaps due to the lack of well publicized planting information post liberalization.

asymmetric short, medium and long run price transmission, heteroscedasticity reflecting changing price volatility, and different dynamics between ICA years and non-ICA years. The analysis provides new and useful insights on the dynamic interactions between prices, supply response, and policy intervention.

The paper is organized as follows. In Section 2, we review the literature on the effects of the ICA agreement and its implications for price determination and dynamics. Section 3 presents the data. The econometric model is presented in Section 4 and estimated in Section 5. Policy simulations are analyzed in Section 6. Section 7 discusses our findings, their interpretations and policy implications, and concludes.

2. Coffee price interventions and price dynamics

Oxfam (2002) has called for the burning of 5 million 60 lb. bags of coffee, as well as quality controls requiring the exclusion of a significant portion of coffee supply from the market. The International Coffee Organization (ICO) has also called for tighter quality controls. Meanwhile, many involved with the 'fair trade' movement offer guaranteed minimum prices to select growers, and argue for the expansion of these programs. As described above, each of these interventions could have significant long term consequences, which would depend upon whether the intervention is isolated or part of a long term stabilization plan. While the effects of the ICA have been examined before (Akiyama and Varangis, 1990; Bohman et al., 1996; Hermann et al., 1990; Palm and Vogelvang, 1991), previous studies have largely ignored the agreements' effect on long term supply.

The key policy instruments for ICA were marketing quotas that restricted coffee supply on the world market. During the ICA years, signatory importing nations could only import coffee from member producing nations, and only up to those nations' quota allocations. The international quota allocations were adjusted in response to world price levels according to a well publicized schedule.[14] The goal was to restrict a coffee indicator price to a negotiated range, with quotas being tightened in response to price decreases, and loosened or suspended when prices increased.[15]

In this section we review the literature to show how the ICA altered price determination in *international* coffee markets (Akiyama and Varangis, 1990; Bates, 1997; Gilbert, 1987), while also partially insulating *domestic* producers from the price signals these markets generated (Bohman et al., 1996; Akiyama, 2001, page 85; Shepherd, 2004, Section 4.4). This insulation, apparent in Fig. 1, arose because producing nations' domestic pricing and taxation polices were designed to control domestic production responses. These interactions of domestic and international policy influenced price expectations, which in turn affected long term supply response.

Prior work on coffee price dynamics and the ICA can be classified into four groups. First, structural studies (Akiyama and Varangis, 1990; Palm and Vogelvang, 1991; Hermann et al., 1990) of world coffee markets utilize annual or quarterly data to estimate equations governing some combination of planting, output, export supply, demand, inventory accumulation and risk preference equations (governing the clearance of futures markets) for a representative number of producing and consuming nations. These structural models are then simulated under alternative

[14] The schedule was regularly published, for example, in the U.S. Foreign Agricultural Service's Tropical Products bulletins.

[15] For additional details on the functioning of the quota system, see Gilbert (1987).

policy scenarios. The principal shortcoming of these studies is that their assumptions are overly restrictive, failing to allow for important dynamic phenomena. Important omissions include allowances for the impacts of: supply on prices during the ICA; supply-control mechanisms on the wholesale-farm price margin; and price controls on expectations.[16]

The second set of studies estimate reduced-form time series specifications of price dynamics (e.g. Feuerstein, 2002; Shepherd, 2004). These studies are concerned with short term price transmission issues and seek evidence regarding the allegations of growing market power in the coffee roasting and retailing sector through the 1990s. They find that price transmission to the retail sector is asymmetric, with retail prices more responsive to increases than decreases. Given their interest in short term price transmission, however, these studies utilize lag structures that number in months, rather than years. As discussed in the introduction, coffee production is subject to very long lags, so that estimation of long term coffee price dynamics requires several years of price lags.

Studies belonging to the third set are also concerned with market power at the retail and roasting levels, but take either a structural or descriptive approach to the subject (Bettendorf and Verboven, 2000; Bewley, 1999; Calfat and Flores, 2002; Koerner, 2002; Ponte, 2002; Roberts, 1984. Durevall (2003, 2005) could be placed in either the second or third sets). Results from the studies in the second and third sets will be compared to ours in Section 5.

Studies in the fourth group (Bates, 1997; Bohman et al., 1996; Cardenas, 1994; Junguito and Pizano, 1999; McMahon, 1989) describe the policy instruments utilized by producing nations to ensure adherence to the ICA quotas. These studies focus on the efficiency, welfare and macroeconomic implications of the various instruments, but do not discuss their long term dynamic implications. Our discussion of the effects of the agreements on supply response begins with these studies and a further examination of Fig. 1.

As discussed earlier, the spread between international wholesale and domestic farm-gate prices during the ICA years was larger than in subsequent periods. Domestic policy instruments used to ensure compliance with quotas included direct production taxes, fixed producer prices, national stock management schemes, direct export taxes, confiscatory exchange rates on coffee exports, and auctions of coffee quotas. Most of these policy instruments have the effect of driving a wedge between farm and border prices if quota restrictions bind. For example, Brazil distributed its export quotas free of cost to exporters based upon recent export shares, until 1987.[17] In 1987, in response to concerns regarding the distribution of quota rents, it switched to a quota auction. Exporters therefore accrued quota rents prior to 1987, although it is likely that some rents were passed on to government agencies. Under the auction system, the quota rents were captured by the government.[18] Finally, Shepherd (2004, p.5) cites evidence of vigorous competition in the Brazilian export sector in the post-ICA years. This is consistent with the much smaller wholesale-farm price gap in the post-ICA years (see Fig. 1).

Multiple studies point out that under the ICA, increases in the effective price wedge were used to protect against monetary instability, Dutch Disease, or the costs to national marketing boards of absorbing large supply increases when world coffee prices rose (Junguito and Pizano, 1999; Otero, 2000, 2001). While macroeconomic incentives to sterilize coffee price shocks still exist,

[16] For a detailed discussion of the shortcomings of this literature, the reader is referred to Mehta and Chavas (2004).

[17] The quota restrictions were suspended from February 1986 until October 1987, due to a Brazilian drought which lifted prices above the ICA's target price.

[18] The preceding description of Brazil's internal coffee policies is drawn from Bohman, Jarvis and Barichello (1996), pp. 396–97, and Akiyama (2001), p.117.

the disbanding of national marketing systems following the ICA's demise has limited the possibility of protecting farm prices from volatile world prices (Akiyama, 2001). Indeed, there is statistical evidence that attempts to insulate farm prices from world market conditions succeeded while the agreement was in force, but not after it collapsed. For example, Shepherd (2004) finds that world prices generally fail to Granger cause farm prices under the ICA, but does Granger cause them after 1989. This provides evidence that domestic price wedges insulated farm prices from international price movements under the agreement, dampening incentives for farmers to alter their tree management decisions in response to world market conditions.

The ICA also governed the way in which coffee was traded globally. The determination of prices and quantities sold on the world market changed markedly between the ICA and post-ICA years. As described earlier, prices were constrained to operate within particular bandwidths by adjusting producing nations' export quotas. In contrast, since the ICA's demise, the global allocation of export shares has shifted freely and dramatically, with Brazil expanding its output significantly and Vietnam bursting out of the starting gates to become the world's second largest coffee producer.

It is likely that the highly visible process by which international prices and quantities traded were determined under the ICA had an impact on how market participants processed and responded to price information. Coffee producers may have entertained quite different considerations when forging expectations of future market conditions and adjusting supply in response to price movements. The notion that coffee supply responses are conditioned by marketing rules is not controversial. For example, Akiyama and Varangis (1990) estimate supply equations for many coffee producing nations and conclude that (p. 534) "Estimated [supply] elasticities tend to be high in countries where general economic and coffee policies have been stable and where data are reliable." The ICA not only stabilized coffee policy at the international level, but it probably improved the availability of quantity data by ensuring that exports hit well known targets.

The theory developed by Dixit and Pindyck (1994) implies potentially important effects of the ICA on investments in coffee trees. In particular, the ICA acted to reduce or eliminate downside international price risk. The tightening quota prevented prices from falling below a target price. But quotas were not very effective at dampening price spikes. Dixit and Pindyck argued that downside output price risk dissuades economic agents from making irreversible investment decisions. If the ICA was successful in reducing downside price risk at the farm level, it may well have stimulated farmers to adjust investment decisions in response to market conditions.

We note, however, that while the ICA may have stabilized the international marketing environment in the 1980s, it also led to a trial and error approach to domestic enforcement of export quotas in some countries, destabilizing the policy environment faced by their farmers.[19] These inconstant approaches to domestic policy owed much to changes in internal political currents,[20] and to the sterilization objectives of these policies described earlier.

The effects of the ICA on supply response, therefore, derive from a tension. On one hand, *domestic* quota allocation mechanisms, taxes and exchange rates have sometimes been designed to limit incentives to adjust supply in response to world price movements. This is illustrated in

[19] Bohman, Jarvis and Barichello (1996) provide evidence of this in the Indonesian case.

[20] Ones of Bates' (1997) central theses is that nations' coffee policies are shaped by their internal political and institutional circumstances.

Fig. 1 for Brazil, where domestic pricing policy drove a wedge between world prices and farm prices during the ICA years. Uncertainty introduced by domestic rent seeking behavior and adjustments to domestic quota distribution policies may have further limited incentives to respond to price signals. On the other hand, by providing a stable *international* policy environment, the ICA might have enabled producers to derive more information from price movements, thereby enabling them to respond actively to price changes. While these effects cannot be identified separately, there is a need to evaluate their *net* effect empirically. Below, we do so by investigating econometrically the effects of the ICA on supply response through the planting and maintenance of coffee trees.

3. The data

This study utilizes information on coffee prices, the dates when the ICA quotas and economic provisions were active, and on weather shocks. All price data are in nominal terms and measure a monthly average price in dollars per pound for the period 1975–2002 (see Fig. 1). Farm prices from Brazil were provided by the ICO, and were converted to U.S. dollars at contemporaneous exchange rates. Retail prices are from the U.S. Bureau of Labor Statistics, and reflect the national urban U.S. price of ground coffee only. Prices of whole bean gourmet coffee and coffee drinks are not reflected in this price. The bulk of the green coffees used in ground blends are Brazilian and lower grade Columbian *Arabica* coffees, as well as Asian and Brazilian *Robusta* beans.[21] We have, therefore chosen to utilize wholesale price information on the monthly average spot price of 'Brazilian and Other Natural Arabicas' determined at the New York Board of Trade. Because wholesale prices of the different varieties of coffee co-move (Otero and Milas, 2001), much can be learned about aggregate market behavior from an examination of just this one wholesale price indicator.

We have chosen to focus on the prices of commodity coffee because it accounts for the large majority of the coffee produced globally, and because a given 'market price' data series is more meaningful for homogenous commodity coffee. This focus comes at some cost, both because specialty niche markets are assuming a growing share of coffee trade (9–12% of sales to North America, Western Europe and Japan; see Lewin et al., 2004), and differentiation into niche-markets and improvements in quality are emerging as a key mechanism by which producers seek to recover a larger share of coffee rents (Daviron and Ponte, 2005).

The economic provisions of the ICA were active from October 1980, until July 1989. The economic provisions mandated that national quotas be loosened or suspended in response to price increases. Thus, the quotas themselves were active from October 1980 until January, 1986, and then again from October 1987 until July 1989. Dates for weather shocks are drawn from the ICO and confirmed by Akiyama (2001) and Bates (1997). These include a Brazilian drought in 1985, and frosts, also in Brazil, in 1994 and 1999.

4. Econometric specification

Our econometric model consists of reduced-form price determination equations, couched within a vector autoregression (VAR) specification allowing for conditional heteroscedasticity.

[21] Kamich (2002) reports that conventional wisdom puts Robustas' share of purchases by major U.S. roasters at 40%.

We begin with the underlying structural model representing the international coffee market. The market clearing equation equates the quantity of green coffee beans supplied at time t, Y_t, to the quantity demanded, $Q_t + \Delta I_t$.

$$Y_t = Q_t + \Delta I_t, \tag{1}$$

where Q_t is the quantity demanded by roasters, and ΔI_t, is the quantity demanded by inventory holders. Coffee supply is simply the product of the number of coffee trees N_t, and average yield per tree b_t.

$$Y_t = b_t N_t. \tag{2}$$

The evolution of number of trees is given by the state equation

$$N_t = \beta N_{t-12} + \varphi_t. \tag{3}$$

where $(1-\beta)$ is the annual depreciation rate of tree stocks, and φ_t is the number of new trees entered into production during the last twelve months.[22] Applying the lag operator (where $L^i x_t = x_{t-i}$) and substituting for N_t in Eq. (2) yields:

$$Y_t = b_t (1-\beta L^{12})^{-1} \varphi_t \tag{4}$$

Intuitively, this says that the tree stock is a depreciation weighted aggregate of all the trees ever entered into production, and total production is the yield times this effective tree stock.

Turning to the demand side of the market, the inverse demand for green coffee for roasting is given by:

$$p_t^{\mathrm{W}} = a_t - cQ_t; \tag{5}$$

where p_t^{W} is the international wholesale price of green coffee, and $c>0$. Substituting for Y_t from Eq. (4) into Eq. (1), substituting the resulting expression for Q_t into Eq. (5), and multiplying through by $(1-\beta L^{12})$ yields:

$$p_t^{\mathrm{W}} = \beta p_{t-12}^{\mathrm{W}} + (a_t - \beta a_{t-12}) + c(\Delta I_t - \beta \Delta I_{t-12}) - c b_t \varphi_t. \tag{6}$$

To interpret Eq. (6), consider a market in a steady state, with no change in inventories ($\Delta I_t = 0$, $\forall t$) and stationary market conditions($b_t = b$, $\varphi_t = \varphi$, $a_t = a$, $p_t = p; \forall t$). In this case, Eq. (6) becomes:

$$p^{\mathrm{W}} = a - cb\left(\frac{1}{1-\beta}\right)\varphi, \tag{7}$$

[22] Note that Eq. (3) neglects any uprooting of trees. We have only found a few accounts of trees being uprooted or abandoned in response to price movements during the period when our data were drawn. In all cases, it was older, depreciated trees that were removed from production. Thus this omission is likely to be without significant loss. Future research will probably have to cope with the phenomenon which may have become considerably more frequent around 2002.

where $\varphi/(1-\beta)$ is the steady state tree stock (from Eq. (3)). Eq. (7) simply relates the steady state price to the steady state quantity produced via the demand curve. It tells us that an increase in planting (φ) or the survival rate of trees (β) will increase coffee supply, depressing the steady state price.

Eq. (6) contains a powerful and rather general intuition. Even though prices more than five years ago have an impact on current prices (because they may have resulted in the planting of trees that are still around today), they do not need to explicitly appear in the specification. This is because the output of trees that were already in production at time $(t-12)$ were already fully reflected in the price twelve months ago (p^{W}_{t-12}). This proves very important for our analysis: by defining the process iteratively in this way, long term price effects can be assessed using the limited years of market data available.

Having established a structural model of market dynamics in the quantity and price domains, we proceed to investigate its reduced form implications for prices. This is important for our analysis because information about international coffee supply or coffee trees is too sparse (only being collectable annually) and often of poor quality, making it somewhat unreliable to support a statistical analysis of market dynamics. Given the greater availability and reliability of price data, we proceed with an examination of price dynamics in reduced form.

We begin with consideration of the medium and long run dynamics. As argued earlier: the medium run dynamics (at the one to three year horizon) of the coffee market are directly driven by yield effects of pruning and other maintenance; long run dynamics (four to five year horizon) derive mostly from planting effects; the response of planting and tree maintenance to prices could be different depending on whether prices are rising or falling; and these responses could also depend upon whether quotas are in place, because quotas effect the relationship between farm and world prices as well as the manner in which current market conditions are interpreted to predict future prices. Denote by P_{t-T} the average annual wholesale price T years ago, with $T=I$, II, III, IV and V (where upper case Roman numerals denote annual period averages, so that, for example, P_{t-V} reflects the average wholesale price sixty-one to seventy-two months ago). Let D^{+}_{t-T} be a dummy variable indicating whether wholesale prices T years ago exceeded those $(T+1)$ years ago periods). Similarly, the proportion of year $t-V$ for which the ICA's economic provisions were operative is written $\mathrm{ICA}_{\mathrm{V}}$. Then, assuming that planting and yields are linear functions of prices gives the following specification:

$$b_t = \left(b_0 + \sum_{T=I,\mathrm{II},\mathrm{III}} \left[\left(b_T + b_T^A ICA_{t-T} \right) P_{t-T} \right] + \left(b_{\mathrm{II}}^{+} + b_{\mathrm{II}}^{A+} ICA_{t-\mathrm{II}} \right) D_{t-\mathrm{II}}^{+} P_{\mathrm{II}} \right) \tag{8}$$

$$\varphi_t = \left(\varphi_0 + \sum_{T=\mathrm{IV},V} \left(\varphi_T + \varphi_T^A ICA_{t-T} + \varphi_T^{+} D_{t-T}^{+} + \varphi_T^{A+} ICA_{t-T} D_{t-T}^{+} \right) P_{t-T} \right). \tag{9}$$

This captures the dynamics of pruning decisions. Newly pruned coffee branches grow for a year before flowering. A further ten to eleven months pass before the branch yields berries. If the branch is not pruned, it will flower again and yield berries just over a year later. The volume of berries declines with the age of the branch. It follows that alterations to pruning cycles in response to price movements can have implications for price dynamics at the two year horizon. Because these pruning decisions can involve lumpy adjustments (postpone or prepone), we allow for asymmetric effects at the two year horizon.

Turning next to the short run dynamics of the system, we note that demand by roasters may shift over time, t, and seasonally, which we capture through three quarterly dummy variables.[23] Hence:

$$a_t = a(t, Q_{1,t}, Q_{2,t}, Q_{3,t}) \tag{10}$$

The modeling of inventory behavior can be challenging. The standard theories[24] do not explain stock behavior well when stocks are low. A debate dating back to Muth (1961) regarding how inventory managers forge expectations remains largely unresolved. In addition, some coffee inventory managers, especially during the ICA years, were "large" relative to the market, raising questions about the applicability of competitive storage theory.[25]. Finally, Daviron and Ponte (2005) describe how the institutional arrangements and strategies for managing coffee stocks have changed in the post-ICA era. As such, we model inventory behavior loosely, presuming only that incentives to build up stocks will vary with market conditions and with ICA activity, allowing the dynamic implications of these prices to be empirically determined. We allow accumulation decisions to be influenced by recent prices[26] (p_{t-1},…, p_{t-r}) and whether the quotas were active in the recent past (as captured by the dummy variable d_{t-1}). Inventory accumulation is therefore given by:

$$\Delta I_t = \Delta I(d_{t-1}, p_{t-1}, p_{t-2}, \ldots, p_{t-r}), \tag{11}$$

where $p_t=(p_t^{\mathrm{F}}, p_t^{\mathrm{W}}, p_t^{\mathrm{R}})$ is a price vector containing the farm price (p_t^{F}), the wholesale price (p_t^{W}) and the retail price (p_t^{R}).

Finally, we allow for asymmetric price transmission in the short run, as Shepherd (2004) and Feuerstein (2002) indicate that this is relevant in coffee markets. Specifically, we allow the impact on inventory accumulation of price increases to differ from those of price decreases. If S=F, W, R denotes respectively the farm, wholesale or retail prices, let $D^{+}_{S,t-k}$ equal unity if $\Delta p^S_{t-k}=p^S_{t-k}-p^S_{t-k-1}>0$, and zero otherwise. Denoting parameters of the inventory equation by k^{W}, we specify:

$$\Delta I_t = k_0^{\mathrm{W}} + k_{quota}^{\mathrm{W}} d_{t-1} + \sum_{S=\mathrm{F,W,R}} \left\{ k_S^{\mathrm{W}} p_{t-1}^S + \sum_{k=1}^{r-1} (k_{S,k}^{\mathrm{W}} + k_{S,k}^{\mathrm{W}+} D^{+}_{S,t-k}) \Delta p_{t-k}^S \right\}. \tag{11'}$$

For example, if $k^{\mathrm{W}}_{\mathrm{R},1}>0$, but, $k^{\mathrm{W}+}_{\mathrm{R},1}>0$, this indicates that a retail price increase (decrease) a month ago would increase (decrease) wholesale prices today, but that the effect would be larger in the case of a price increase.

[23] In our specification the first quarter begins in January. Using a quarter scheme commencing in February or March yielded slightly lower likelihood scores.

[24] See, for example, Deaton and Laroque (1996).

[25] Karp and Perloff (1993), however, find Brazilian and Colombian export behavior to be rather competitive at the time.

[26] Using the Schwartz criterion we chose r=2.

Substituting Eqs. (8), (9), (10) and (11') into Eq. (6) yields a specification for p_t^{W} expressed entirely in terms of lagged prices and exogenous variables. This generates a reduced form model for wholesale price of the form:

$$\begin{aligned} p_t^{\mathrm{W}} &= \beta p_{t-12}^{\mathrm{W}} + \text{ Short term effects } + \widetilde{b}_t \widetilde{\varphi}_t \\ &= \beta p_{t-12}^{\mathrm{W}} + \text{ Short term effects} \\ &\quad + \left(b_0 + \sum_{T=I,\mathrm{II},\mathrm{III}} [(b_T + b_T^A ICA_{t-T}) P_{t-T}] + (b_{\mathrm{II}}^+ + b_{\mathrm{II}}^{A+} ICA_{t-\mathrm{II}}) D_{t-\mathrm{II}}^+ P_{\mathrm{II}} \right) \\ &\qquad \times \left(1 + \sum_{T=\mathrm{IV},V} (\varphi_T + \varphi_T^A ICA_{t-T} + \varphi_T^+ D_{t-T}^+ + \varphi_T^{A+} ICA_{t-T} D_{t-T}^+) P_{t-T} \right). \end{aligned} \tag{12}$$

where the factors $\tilde{b}_t$ and $\tilde{\varphi}_t$ are normalized for identification purposes.

To illustrate, suppose that $\tilde{b}_t > 0$. Then, finding that $\varphi_V < 0$ would indicate that lower prices five years ago induced farmers to plant less coffee trees when the agreement was not in effect. The direct effect would be to drive up current prices. Further, finding that $\varphi_V^A < 0$ would indicate that the ICA stimulated this supply response to low prices at the five year horizon. If $\varphi_V^+ < 0$, this would indicate that, in non-ICA years planting decisions responded more aggressively to price increases five years ago, than they did to price decreases. The same interpretation would hold during the ICA years if $\varphi_V^A + \varphi_V^{A+} < 0$. Planting asymmetry would be enhanced by the agreement if $\varphi_V^{A+} < 0$.

Having established a specification for international wholesale prices, we turn to the vector autoregressive (VAR) specification in which this is embedded. The VAR is specified as follows:

$$p_t = \begin{bmatrix} p_t^{\mathrm{F}} \\ p_t^{\mathrm{W}} \\ p_t^{\mathrm{R}} \end{bmatrix} = \begin{bmatrix} f(p_{t-1}, p_{t-2}, \dots p_{t-1}, x_t, x_{t-1}) \\ g(p_{t-1}, p_{t-2}, \dots p_{t-m}, x_t, x_{t-1}, \dots x_{t-n}) \\ h(p_{t-1}, p_{t-2}, \dots p_{t-n}, x_t, x_{t-1}) \end{bmatrix} + e_t; \tag{13a}$$

where the wholesale price functional form $g(\cdot)$ is given by Eq. (12).

The farm and retail prices are assumed to follow reduced form autoregressive processes. Each depends upon lagged values of the price vector and a vector of exogenous variables ($\mathbf{x_t} = x_t, x_{t-1}$). These include a time trend (t), seasonal dummy variables ($Q_t = \{Q_{1,t}, Q_{2,t}, Q_{3,t}\}$), and indicators of whether the ICA quotas were in effect in the recent past (d_{t-1}). These quota effects are required because the quotas were designed to raise wholesale prices, and were usually enforced by implicit production taxes which placed a wedge between wholesale and farm prices. Allowances for short term asymmetric price transmission are permitted exactly as they are in the wholesale inventory accumulation equation. The retail and farm price equations are:

$$\begin{aligned} p_t^{\mathrm{R}} &= k_0^{\mathrm{R}} + k_t^{\mathrm{R}} t + k_{\mathrm{quota}}^{\mathrm{R}} d_{t-1} + k_Q^{\mathrm{R}\prime} Q_t \\ &\quad + \sum_{S=\mathrm{W,R}} \left\{ k_S^{\mathrm{R}} p_{t-1}^{\mathrm{S}} + \sum_{k=1}^{l-1} (k_{S,k}^{\mathrm{R}} + k_{S,k}^{\mathrm{R}+} D_{S,t-k}^+) \Delta p_{t-k}^S \right\} \end{aligned} \tag{13b}$$

$$\begin{aligned} p_t^{\mathrm{F}} &= k_0^{\mathrm{F}} + k_t^{\mathrm{F}} t + k_{\mathrm{quota}}^{\mathrm{F}} d_{t-1} + k_Q^{\mathrm{F}\prime} Q_t \\ &\quad + \sum_{S=\mathrm{F,W}} \left\{ k_S^{\mathrm{F}} p_{t-1}^S + \sum_{k=1}^{n-1} (k_{S,k}^{\mathrm{F}} + k_{S,k}^{\mathrm{F}+} D_{S,t-k}^+) \Delta p_{t-k}^{\mathrm{S}} \right\}. \end{aligned} \tag{13c}$$

We permit wholesale prices to effect retail and farm prices as per Eqs. (13b) and (13c). Farm and retail prices enter the wholesale price specification (12) through the inventory term (11). However, we do not permit Brazilian farm prices to directly affect retail prices; nor the reverse. Retail and farm prices therefore interact through the wholesale market in our model. We place the wholesale price equation at the center of our model, taking our wholesale price series to capture aggregate behavior in world markets and to capture long term dynamics.[27]

The error vector ($\boldsymbol{e}_t$) possesses a conditionally heteroscedastic normal distribution. This is allowed for using a time-varying Cholesky matrix ($\mathbf{A}_t$) to transform a vector of standard normal disturbances (ε_t).

$$\boldsymbol{e}_t = \begin{bmatrix} \boldsymbol{e}_t^{\mathrm{F}} \\ \boldsymbol{e}_t^{\mathrm{W}} \\ \boldsymbol{e}_t^{\mathrm{R}} \end{bmatrix} = A_t \varepsilon_t = \begin{bmatrix} a_{1t} & a_{4t} & a_{6t} \\ 0 & a_{2t} & a_{5t} \\ 0 & 0 & a_{3t} \end{bmatrix} \begin{bmatrix} \varepsilon_t^{\mathrm{F}} \\ \varepsilon_t^{\mathrm{W}} \\ \varepsilon_t^{\mathrm{R}} \end{bmatrix}; \qquad \epsilon_t \sim \mathrm{N}(0, \mathrm{I}_3); \tag{13d}$$

$$a_{it} = a_i(p_{t-1}, W_t, d_{t-1}); \qquad \mathrm{i} = 1, \ldots, 6. \tag{13e}$$

The dummy variable W_t equals unity if t coincides either with Brazil's frosts of 1994 and 1999, or its drought of 1985. As before, the dummy d_{t-1} indicates whether export quotas were in effect at time $t-1$. The Cholesky decomposition ensures a symmetric positive semi-definite variance matrix:

$$\begin{aligned} \Sigma_t = V(e_t) &= \begin{bmatrix} \sigma_{\mathrm{F}}^2 & \sigma_{\mathrm{FW}} & \sigma_{\mathrm{FR}} \\ \sigma_{\mathrm{FW}} & \sigma_{\mathrm{W}}^2 & \sigma_{\mathrm{WR}} \\ \sigma_{\mathrm{FR}} & \sigma_{\mathrm{WR}} & \sigma_{\mathrm{R}}^2 \end{bmatrix}_t = A_t A_t{}' \\ &= \begin{bmatrix} a_1^2 + a_4^2 + a_6^2 & a_2 a_4 + a_5 a_6 & a_3 a_6 \\ a_2 a_4 + a_5 a_6 & a_2^2 + a_5^2 & a_3 a_5 \\ a_3 a_6 & a_3 a_5 & a_3^2 \end{bmatrix}_t \end{aligned} \tag{13f}$$

The time-varying Cholesky matrix (A_t) allows price volatility in sector i (σ_{it}^2) and the covariance of price shocks in sectors i and j (σ_{ijt}) to vary with market conditions (p_{t-1}), weather events and the existence of export quotas in the month prior.

The covariance terms capture the contemporaneous transmission of shocks between sectors. Specifically, from the elements of the Cholesky matrix, we can calculate coefficients of contemporaneous price transfer between sectors. For example, from Eq. (13f) and the properties of a multivariate normal distribution, we note that a one dollar shock in retail prices will increase

[27] This is a reasonable modeling choice for several reasons. As discussed, our wholesale price series is that of 'Brazilian and Other Natural Arabicas', also known as 'Unwashed Arabicas', on the New York Board of Trade. Otero and Milas (2001) investigate the New York spot prices of the four major coffee varieties: Columbian Mild Arabicas (CMA), Other Mild Arabicas (OMA), Unwashed Arabicas (UA) and Robustas (R). They find two long run relationships between subsets of the four spot price series. First, they find that UA and R are cointegrated, with UA fetching a long run premium over R. The bulk of U.S. retail ground coffee sales consist of these two coffees, as do all measured Brazilian exports. Thus, the UA series should capture the long run world price dynamics relevant to U.S. retail pricing decisions on the input side, as well as to the determination of Brazilian farm prices. Second, they find that UA, CMA and OMA, being closely related botanically, are cointegrated. Thus, long run movements of CMA and OMA prices should also be reflected in UA prices. Moreover, Otero and Milas (2001) find that "the speed of adjustment in both (cointegrating) vectors is relatively fast, implying that economic forces act rapidly and discrepancies in the equilibrium relationships are short lived" (p. 627). We therefore take our UA wholesale price series to reflect the long run behavior of the entire wholesale market well, its shorter term behavior fairly well, and the input (output) prices relevant to U.S. retail (Brazilian farm) prices, adequately.

wholesale prices by $C_{\mathrm{WR}}=\partial p_t^{\mathrm{W}}/\partial p_t^{\mathrm{R}}=\sigma_{\mathrm{WR}t}/\sigma_{\mathrm{R}t}^2=a_{5t}/a_{3t}$ dollars. This time varying covariance specification will allow us to examine two critical features of coffee price dynamics. First, it allows us to test whether contemporaneous price transmission was altered by the presence of ICA quotas. It is of particular interest to see if domestic policies insulated farm prices from international price fluctuations, as we have argued, by reducing C_{FW}. Second, covariances that vary with market conditions generate asymmetric responses to price shocks through the vertical sector.

In keeping with the argument that farm and retail prices interact only through the wholesale market we apply restrictions to the Cholesky elements. To wit: a_{3t} and a_{5t} drive the volatility of retail prices and transmission from the wholesale to retail levels. We restrict these to be independent of the farm price. Similarly, the retail price is not permitted to effect a_{1t} and a_{4t}.

5. Econometric estimates

We estimated the specification[28,29] provided by Eqs. (12), (13a)–(13f) using maximum likelihood.[30] Because five year lagged dependent variables are required, 238 observations are usable. Estimates of the price Eqs. (12), (13b) and (13c) are presented in Tables 1a and 1b. The number of months of lagged prices upon which to condition retail and farm level prices was determined using the Schwartz criterion to be 2. Similarly, the number of lags necessary to capture inventory effects in the wholesale price equation was also determined to be 2.

We begin our analysis with consideration of the intercept shifters. First, likelihood ratio tests found the seasonal effects to be jointly significant. Second, the direct short-run impact of the ICA quotas on average prices is statistically insignificant. This is not surprising, given that quotas were intended to raise prices, but were suspended when prices rose. Third, only retail prices display a statistically significant upward trend. To examine this issue further, we calculated trends in the price spread using the Delta method. For example, the retail-wholesale price spread trends upward at $12*(k_t^{\mathrm{R}}-k_t^{\mathrm{W}})$ \$/lb annually, where k_t^{R} and k_t^{W} are the trend coefficients in the retail and

[28] Before estimating the full model specification, we conducted Augmented Dickey Fuller (ADF) tests on each of the three price series separately. The test is specified in Hamilton (1994), p. 529, case 4. Shepherd (2004), finds that price dynamics, including the existence of unit roots, depend on whether the period before or after July 1989 is examined. We therefore conducted the test separately on ICA and post-ICA price series. The number of lags appropriate for these simplified models was calculated using the Schwartz criterion, and is 2 in all cases, except for wholesale prices post-ICA (when it is 3). In all cases, we failed to reject the null of the unit root, although it should be noted that at a point estimate, the coefficient on once lagged price levels is between 0.88 and 0.92 in the pre-1989 period, and in the range of 0.95–0.96 in the latter period. These estimates are qualitatively similar to those of Shepherd (2004), who finds most coffee price series to be stationary pre-1989 and I(1) post-1989.

[29] The specification requires that the standardized residuals from the three equations be distributed independently and standard normal. To check this, the standardized residuals (ε_t) were first calculated using the inverse of the Cholesky matrix from Eq. (13d). The correlations between the standardized residual for the farm-wholesale, farm-retail and wholesale-retail pairs are 0.017, 0.001 and −0.006 — suggesting independence. The Ryan–Joiner standard normality test statistics are 0.9947 for retail, 0.9912 for wholesale, and 0.9674 for farm prices. The null hypothesis of standard normality is rejected below a critical value of 0.9835 at 5% significance. Thus wholesale and retail disturbances appear normal. The farm price residuals, however, possess a skewness of 0.77, and the null of normality is rejected at 5% significance, but not 10%. The mean of 0.015, and standard deviation of 1.002 provide some comfort. A more refined analysis of the third moments of prices appears to be a good topic for future research.

[30] The model of fundamental wholesale price determination under perfect market intelligence (Eq. (12)) yields multiple identification restrictions which relate ratios of coefficients on past prices to β. Likelihood ratio tests of these restrictions found them to be unacceptable. While back of the envelope calculations suggest values for β between 0.9 and 0.93, the model consistently puts β at around 0.1. We take this as an indication that short term dynamics are not driven by fundamentals alone. This would be consistent with the view that discount rates are significantly higher than interest rates suggest, as has been revealed by recent experimental economics literature (e.g., Frederick et al., 2002).

Table 1a
Short term price equation parameter estimates

Effects of:	Farm price		Wholesale price		Retail price	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Constant	0.0675	0.0577	0.0554	0.0925	0.0514	0.0402
Monthly time trend	−0.0001	0.0002	0.0002	0.0005	**0.0005**	**0.0001**
d_{t-1}	0.0094	0.0355	0.0061	0.0391	0.0058	0.0171
d_{t-13}			−0.0183	0.0429		
Quarter_1	−0.0113	0.0162	−0.0059	0.0153	**0.0290**	**0.0168**
Quarter_2	**−0.0315**	**0.0167**	−0.0210	0.0134	**0.0288**	**0.0140**
Quarter_3	−0.0286	0.0178	−0.0031	0.0140	0.0159	0.0154
p_{t-1}^{F}	**0.9731**	**0.0727**	**0.3848**	**0.1046**		
$\Delta p_{t-1}^{\mathrm{F}}$	0.2804	0.2557	0.3319	0.2272		
$D_{t-1}^{\mathrm{F}}\Delta p_{t-1}^{\mathrm{F}}$	0.0717	0.4132	0.0988	0.3418		
p_{t-13}^{F}			**0.1290**	**0.0599**		
$\Delta p_{t-13}^{\mathrm{F}}$			−0.2248	0.1472		
$D_{t-13}^{\mathrm{F}}\Delta p_{t-13}^{\mathrm{F}}$			0.1126	0.2315		
p_{t-1}^{W}	−0.0206	0.0653	**0.5943**	**0.0846**	**0.0815**	**0.0314**
$\Delta p_{t-1}^{\mathrm{W}}$	−0.1205	0.2247	0.0290	0.0324	−0.0331	0.1204
$D_{t-1}^{\mathrm{W}}\Delta p_{t-1}^{\mathrm{W}}$	−0.0029	0.3885	−0.0171	0.3385	**0.3598**	**0.1842**
p_{t-12}^{W}			0.0182	0.0590		
p_{t-13}^{W}			−0.0105	0.0281		
$\Delta p_{t-13}^{\mathrm{W}}$			0.0818	0.0643		
$D_{t-13}^{\mathrm{W}}p_{t-13}^{\mathrm{W}}$			−0.0581	0.1707		
p_{t-1}^{R}			−0.0119	0.0414	**0.9073**	**0.0235**
$\Delta p_{t-1}^{\mathrm{R}}$			−0.1669	0.1396	−0.1050	0.1566
$D_{t-1}^{\mathrm{R}}\Delta p_{t-1}^{\mathrm{R}}$			0.2827	0.1871	**0.3594**	**0.1812**
p_{t-13}^{R}			0.0299	0.0314		
$\Delta p_{t-13}^{\mathrm{R}}$			−0.1507	0.1303		
$D_{t-13}^{\mathrm{R}}\Delta p_{t-13}^{\mathrm{R}}$			0.1372	0.1617		

Coefficients in bold are significant at 90% significance level.

wholesale price equations. The trend in the wholesale-retail spread is statistically insignificant, amounting to a two cent increase in the retail-wholesale margin over ten years. Farm prices decline over the sample period, though not statistically significantly. Growth in the retail-farm margin is statistically significant, totaling 7 cents/lb in ten years.

We turn next to contemporaneous price transmission to address two concerns. First, we document the existence of hysteresis due to price sensitive transmission and volatility. The coefficients on lagged prices in Table 2 clearly suggest that some of the effects of prices on the variance matrix are important. Four lagged-price coefficients are statistically significant. Higher once-lagged wholesale prices clearly increase a_3, driving up retail price volatility. Similarly, higher farm prices increase wholesale price volatility through a_2. Higher farm and wholesale prices increase the covariance between farm and wholesale price shocks through a_4.[31] To assess the joint significance of prices in determining the variance of p_t, we ran a likelihood ratio test (LRT), restricting the variance matrix to vary only with weather conditions and the ICA. The resulting $\chi^2_{(14)}$ test statistic is 249.97, and the null is rejected. The variation of price volatility and price shock covariance with market conditions could, therefore, generate significantly asymmetric transmission of prices over time and across sectors. Price interventions are therefore unlikely to be readily reversible.[32]

[31] This interpretation requires that a_{2t} be positive, which it is at every period in the sample.

[32] Econometricians may prefer to consider these tests in different terms. The statistical significance of past prices in determining price variances implies that the allowance for autoregressive conditional heteroskedasticity was necessary.

Table 1b
Medium and long term wholesale price equation parameter estimates

Effects of:	Coeff.	S.E.
Parameters capturing medium term effects	−0.0161	0.0771
b_I	−0.0150	0.5679
b_I^A	**2.0379**	**0.9584**
b_{II}	0.3199	0.5360
b_{II}^A	**1.9133**	**1.0299**
b_{II}^+	−0.2702	0.2226
b_{II}^{A+}	0.8418	0.5117
b_{III}	**−0.7267**	**0.3715**
b_{III}^A	−0.5788	0.4257
Parameters capturing long term effects		
φ_{IV}	1.4349	1.8407
φ_{IV}^A	−0.4666	1.2014
φ_{IV}^+	0.3870	0.6028
$\varphi_{\mathrm{IV}}^{A+}$	−0.9817	0.8993
φ_V	**−2.7766**	**1.2030**
φ_V^A	**−2.5839**	**0.9401**
φ_V^+	**0.8887**	**0.4810**
φ_V^{A+}	−0.7342	0.6314

Coefficients in bold are significant at 90% significance level.

Second, we evaluate evidence of price wedge effects. In particular, we examine the coefficients of contemporaneous price transmission between the wholesale and farm sectors. Fig. 2 depicts these coefficients. C_{WF} captures the impact on wholesale prices of a \$1/lb. price shock originating at the farm level, while C_{FW} captures transmission in the other direction. The results are fascinating. We note that in the period since the dissolution of the ICA, both C_{WF} and C_{FW} are close to unity. Thus contemporaneous price transmission between these sectors is close to perfect

Table 2
Estimates of parameters determining variance

Cholesky equation						
Effects of:	a1		a2		a3	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Constant	**0.0119**	**0.0071**	−0.0231	0.0305	0.0067	0.0306
d_1	0.0009	0.0167	0.0224	0.0168	**−0.0218**	**0.0120**
p_{t-1}^F	0.0304	0.0298	**0.1436**	**0.0339**		
p_{t-1}^W	0.0075	0.0245	−0.0301	0.0244	**0.0379**	**0.0129**
p_{t-1}^R			0.0091	0.0099	0.0050	0.0113
Weather	**0.1387**	**0.0321**	**0.1434**	**0.0601**	**0.1818**	**0.0565**
Effects of:	a4		a5		a6	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Constant	0.0176	0.0167	0.0402	0.0615	−0.0071	0.0766
d_1	0.0350	0.0238			−0.0019	0.0342
p_{t-1}^{F}	**0.1964**	**0.0357**			−0.0282	0.0655
p_{t-1}^{W}	**−0.0903**	**0.0319**	−0.0043	0.0191	0.0244	0.0608
p_{t-1}^{R}			−0.0142	0.0218	0.0004	0.0291

Coefficients in bold are significant at 90% significance level.

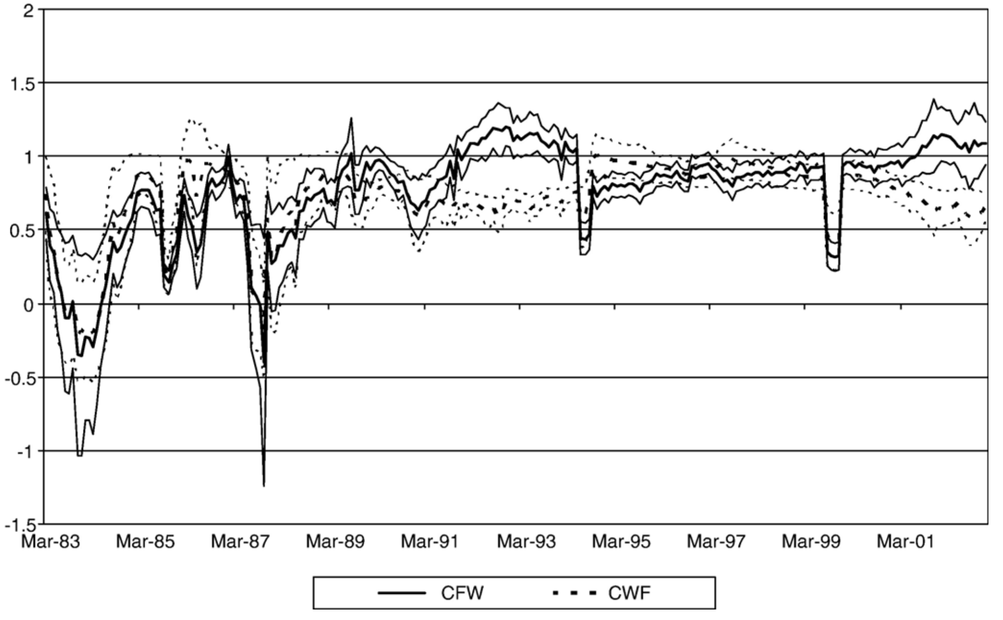


Fig. 2. Coefficients of contemporaneous price transmission — farm and wholesale prices (+/− one standard error).

without the agreement. A price shock in one sector is transmitted fully, within the same month, to the other. During the ICA, these transfer coefficients are much smaller, averaging around 0.3 and occasionally even falling into the negative region. This is compelling evidence that during the ICA years price transfer between the farm and wholesale sector was muted. In other words, quotas insulated farm prices from the world markets, as described by Talbot (2004, p. 108).

We now turn to evaluation of price transmission in the short term (i.e. the effects on current prices of price movements less than a year ago). Here, too, we are concerned with the issues of existence and symmetry of price transmission. Examination of only the significant short term coefficients in Table 1a reveals that:

(i) Farm prices depend positively upon past farm prices. However, their dependence upon lagged wholesale prices is negative and weak. Combined with the results on contemporaneous price transmission, it follows that transmission from the wholesale to farm levels was weak during the ICA years, but rapid in the non-ICA years. This result can be taken as further evidence that government policies in Brazil insulated farmers from world price movements under the ICA.[33]
(ii) Wholesale prices depend strongly and positively on lagged farm and wholesale prices. Short term retail price movements do not have a significant impact on wholesale prices. This suggests that increasing roasted coffee demand may not significantly increase wholesale (and therefore farm) prices.
(iii) Retail prices are impacted by recent wholesale and retail prices. Furthermore, the effects of recent wholesale and retail prices on retail prices are asymmetric. This is evident, because

[33] Cardenas (1994) finds strong evidence of such insulation in Colombia and Cote d'Ivoire, but not in Kenya and Costa Rica.

once-lagged wholesale or retail price decreases cause (statistically insignificant) *increases* in retail prices($k^{\mathrm{R}}_{\mathrm{W},1}$, $k^{\mathrm{R}}_{\mathrm{R},1}<0$); while, in contrast, once-lagged wholesale or retail price increases cause statistically and economically significant retail price increases ($k^{\mathrm{R}}_{\mathrm{W},1}+k^{\mathrm{R}+}_{\mathrm{W},1}$, $k^{\mathrm{R}}_{\mathrm{R},1}+k^{\mathrm{R}+}_{\mathrm{R},1}>0$). This result is consistent with the observations of Durevall (2003), Shepherd (2003) and Talbot (1997). Asymmetric responses of retail prices to lagged retail prices might result from a price leadership game. Bewley's (1999) finding that in an Australian context, movements in prices of certain instant coffee brands Granger-cause movements in others evokes a similar interpretation. So does Robert's (1984) finding that behavior by the two largest U.S. roasting firms is inconsistent with price taking, while that of the smallest fifty firms is consistent with it. Kamich (2002) indicates that in U.S. markets, Folgers is closely watched by the competition as a price leader, both when raising and lowering prices for ground roasted coffee. The tendency of retail prices to increase faster than they decrease could have important dynamic implications, especially in consideration of policies to burn coffee. In particular, the benefits of such policies may be substantially captured by retailers/roasters. We conduct policy simulations to address this issue in the next section.

(iv) In contrast to retail prices, there is little evidence that farm and wholesale prices respond asymmetrically to short term changes in market conditions. This is evident from Table 1a. Further, a LRT was conducted on the restriction that farm and wholesale prices respond asymmetrically in the short run. The restrictions carry a p-value of 0.23, consistent with the view that farm and wholesale level price dynamics are symmetric.

Next, we examine the estimates of the intermediate run dynamics (i.e. the effects on current prices of price movements one to three years ago). $\tilde{\varphi}_t$ is positive across the sample. Hence the signs of each b parameter correspond to their impact on current world prices. The overarching impression from analysis of these parameters is that yields responded significantly to prices when the ICA was in effect, and not much since the agreement's demise.

In particular, wholesale prices a year ago do not effect current prices significantly when the ICA was not in effect (i.e. b_I is not significant). In contrast, their impact is significant and positive when the ICA is in effect ($b_I+b_I^A>0$). Two-year lagged prices in non-ICA years also do not effect current prices, regardless of whether they fell (b_{II} is insignificant) or rose ($b_{\mathrm{II}}+b_{\mathrm{II}}^+$ is also insignificant). Again, in contrast to this, two-year lagged prices in ICA years do play a significant role, regardless of whether they rose ($b_{\mathrm{II}}+b_{\mathrm{II}}^++b_{\mathrm{II}}^A+b_{\mathrm{II}}^{A+}>0$) or fell ($b_{\mathrm{II}}+b_{\mathrm{II}}^A>0$). Also, under the ICA, evidence of asymmetric response at the two year horizon is weak (the sum $b_{\mathrm{II}}^++b_{\mathrm{II}}^{A+}$ is not statistically significant). At a point estimate, however, the results would suggest larger supply responses to price increases than to price decreases. Finally, higher prices three years in the past significantly reduce current prices ($b_{\mathrm{III}}<0$), especially during ICA years ($b_{\mathrm{III}}^A<0$).

Before turning to interpretations of these medium term effects, it is useful to examine their magnitudes when multiplied by planting effects ($\tilde{\varphi}_t$). By so doing, we arrive at values for $\partial p_t/\partial P_{t-I}$, $T=I$, II, III. For example, $\partial p_t/\partial P_{t-I}=b_I\tilde{\varphi}_t$ if $t-I$ was an ICA years, while $\partial p_t/\partial P_{t-I}=(b_I+b_I^A)\tilde{\varphi}_t$ if it was not. Fig. 3A plots values for $\partial p_t/\partial P_{t-I}$ and $\partial p_t/\partial P_{t-\mathrm{III}}$ actually obtained in the sample.[34] While the price response at the three year horizon does not seem to change systematically with the demise of the ICA, the one year effect certainly does. During the ICA, a one dollar annual price increase

[34] Note that the dates on the horizontal axis reflect the last month whose price affects the lagged average. For example, the three year derivative above January 1984 in the graph captures the impact of the average price between February 1983 and January 1984, on the price in January 1987. The one year derivative at the same date reflects the impact of the annual price over the same period on the price in January 1985.

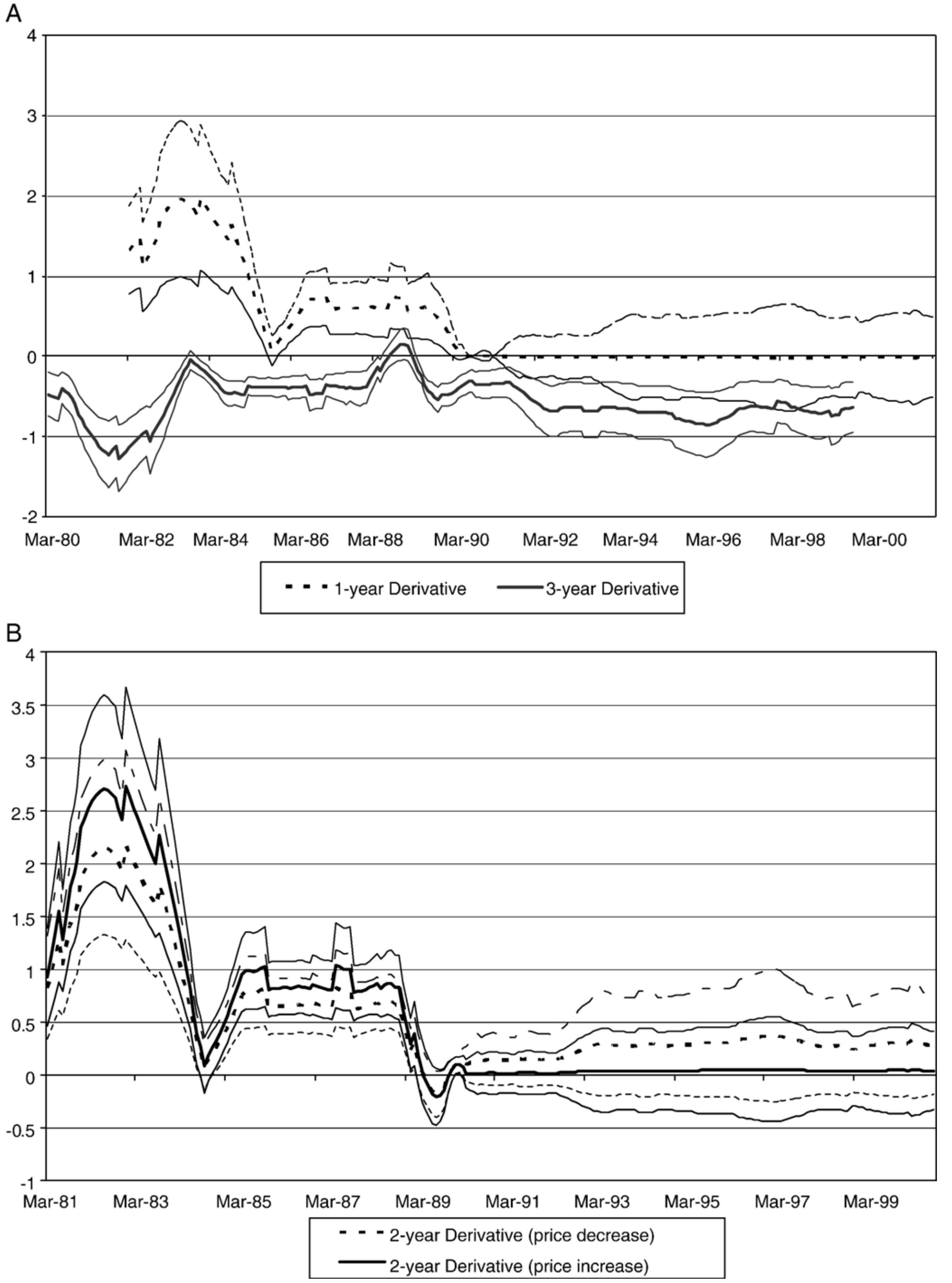
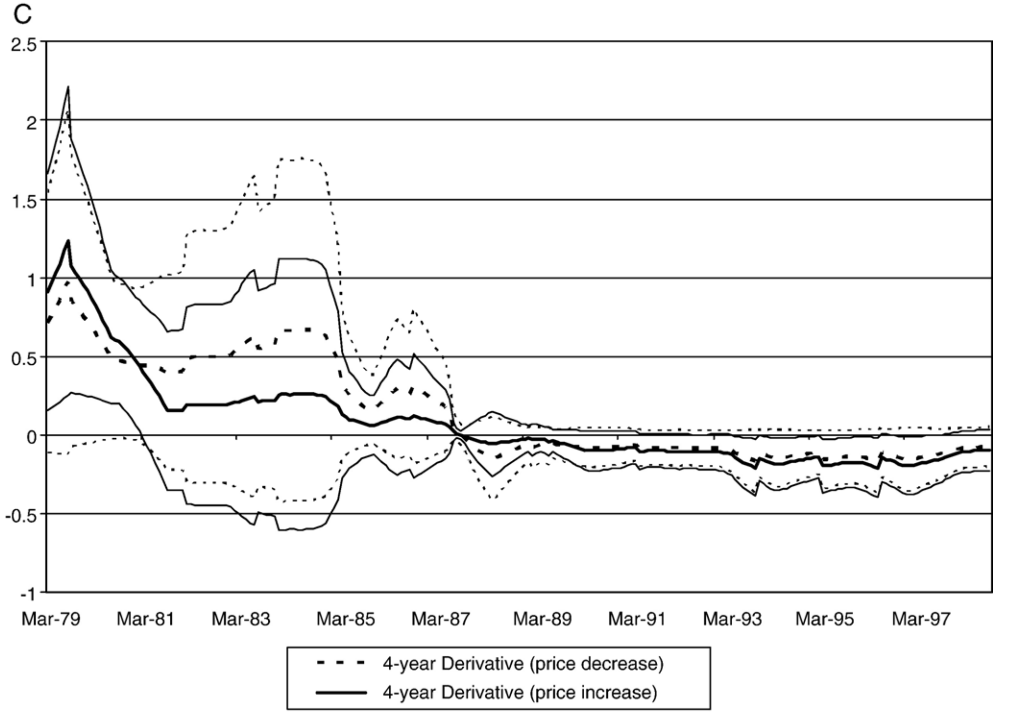


Fig. 3. A. Derivatives with respect to one- and three year-lagged prices (+/− one standard error). B. Derivatives with respect to two-year lagged prices (+/− one standard error). C. Derivatives with respect to four-year lagged prices (+/− one standard error). D. Derivatives with respect to five-year lagged prices (+/− one standard error).



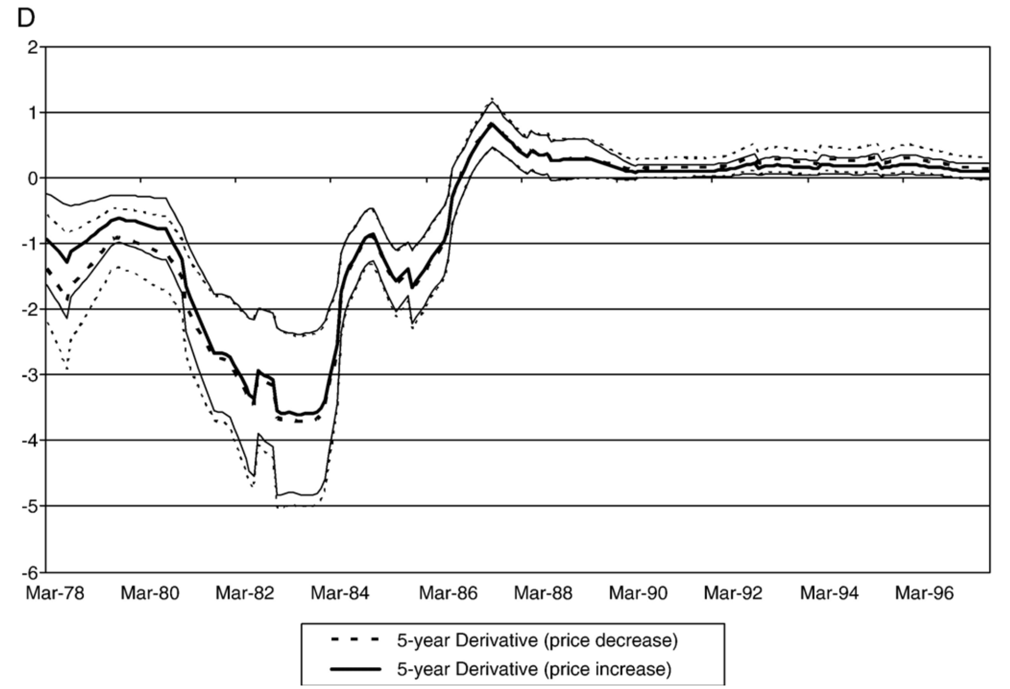


Fig. 3 (*continued*).

would raise prices a year later by between fifty cents and two dollars. With the agreements' demise, the derivative goes approximately to zero.

Fig. 3B plots values for analogous direct effects at the two year horizon. We plot two price derivatives, corresponding to the derivatives in the events that the two year lagged price was greater than, and less than, the three year lagged price. This graph also evinces a significant shift in price dynamics coinciding with the demise of the ICA. Both price derivatives are economically important in the ICA years. In the post-ICA years, only the effects of twice lagged annual price decreases are even marginally economically significant. These effects are also larger than those of price increases. During the ICA years, this situation is reversed, with the effects of price increases exceeding those of price decreases.

The estimated *reductions* in yield in response to higher prices one and two years ago under the agreement are consistent with producing governments taking strong actions to sterilize the effects of international price movements on production. Under this interpretation, finding positive relationships between prices at the two year horizon suggests that sterilization measures overshot their targets.

The normalized yield effect $\tilde{b}_t$ is positive and large during the ICA years, and becomes negative and very small shortly after the demise of the ICA. This makes the interpretation of the coefficients driving long term, planting effects, difficult. It is therefore useful to discuss the dynamic effects at this horizon with reference to the graphs of their direct effects on prices.

Planting responses to prices at the four year horizon are never statistically significant. This said, at a point estimate, Fig. 3C indicates that the four year price responses to price signals during the ICA years were larger than those in the post-ICA period. Once again, this demonstrates stronger price response under the agreement, and relatively little price response after the agreement expires.

At the five year horizon, planting responses under the ICA matter greatly (Fig. 3D), consistent with Talbot's (2004) view that the ICA encouraged oversupply. A $1 annual price increase can generate sufficient planting to directly reduce prices five years in the future by up to $3.50. Moreover, there is no reliable evidence of asymmetry at the five year horizon under the ICA. Yet again, in the post-ICA period, the price response due to planting effects seems inconsequential. If one takes into account the change in the sign of $\tilde{b}_t$ with the demise of the ICA, these results can be appreciated directly from the coefficients φ_V, φ_V^A, φ_V^+ and φ_V^{A+}.

These results provide compelling evidence that price dynamics under the ICA differed markedly from those once the agreement collapsed.[35] Contemporaneous and short term price transmission to Brazilian farmers was very weak under the ICA, consistent with Brazil's policy of providing export quotas to exporters rather than farmers. Estimated dynamic effects at the one and two year time horizons may indicate that quota allocation and sterilization policies pursued by producing governments under the ICA were more than successful in insulating farm prices from international price volatility. The dynamic effects observed at the two, three and five year horizons are also consistent with the view that by systematizing the global coffee market, the ICA encouraged farmers to forge planting and pruning decisions in response to changing market conditions.

When considered one at a time, the results presented above do not provide complete estimates of the impact of the ICA on the links between past and future prices. Dynamic price formation is

[35] A likelihood ratio test results in a near certain rejection of the joint null that the ICA does not effect price dynamics at any time horizon. The $\chi^2_{(17)}$ test statistic is equal to 71.10.

an iterative process, and all of the results presented interact in important ways to channel the future path of prices in response to a policy shock. We therefore turn to policy simulations.

6. Policy simulations

We conducted one thousand Monte Carlo simulations to uncover the impact of shocks on this system. Each simulation was conducted as follows: First, a pseudo-random matrix of standard normal i.i.d. disturbances was generated, corresponding to ε_t. Then, picking conditions at a given date as starting values, the process was simulated forward. Next, a deliberate shock was introduced in the first period of simulation, the simulation was repeated, and the impulse responses at the farm, wholesale and retail levels were calculated as the differences between their shocked and un-shocked price paths. All of these impulse responses were stored, and the 10th, 25th, 50th, 75th and 90th percentiles of their distribution at each point in time are plotted in Figs. 4A–C and 5A–C.

The shock sizes were selected to simulate the effects of Oxfam's proposal to burn five million bags of coffee. We combine figures for total annual world output from the ICO with information about the current wholesale price and the price elasticity of demand to calculate the initial wholesale price shock that this would generate. As reported in footnote 9, estimates of the elasticity of coffee demand range between −0.2 and −0.4. We therefore picked an elasticity of −0.3. Assuming perfectly inelastic supply in the very short run, we calculate that Oxfam's proposals would result in a 28 cent price shock in July 1985, and a 14 cent price shock in December 2002. July 1985 was a typical period in the life of the agreement. The agreement's economic provisions had been in place for four and a half years at the time. December 2002 is the last date in our sample. No agreement existed at this time. It is against these market conditions that Oxfam made its proposal, and it is against those conditions that the proposal should be evaluated. Our simulations assume the presence of an agreement and active quotas for the entire duration of the 1985 simulations. They assume no agreement for the 2002 simulations.

We are interested in answering two questions through these simulations. First, we ask whether such a shock would create a cyclical production response, and whether the answer to this question is influenced by the presence of a price stabilization agreement. Second, we ask how such a price shock would impact retail prices relative to wholesale and farm prices.

Fig. 4A demonstrates the effect of the shock in 2002. There is mild evidence of cycling in the wholesale response, but no disastrous countervailing price response. This is not surprising given the lack of supply responses to price information found in Section 4. The impact of the burn lasts for just under four years.

Fig. 4B, which depicts the retail price response to the same shock is especially interesting. The retail impulse response functions take much longer to die out (roughly ten years) than their wholesale counterparts (roughly four years). Second, the responses display significant economic asymmetry. Focusing on the median impulse responses, the positive shock is almost fully transmitted to the retail sector, rising to 13 cents within 9 months. In contrast, the median response to a negative shock (not shown), scarcely crosses negative 10 cents. This constitutes evidence of asymmetric price transmission in the direction alleged by Talbot (1997), Durevall (2003) and Shepherd (2004), and backed up by the asymmetric parameters of the retail price equation. The results show strong price transmission from the wholesale sector to the retail sector in the short term. As noted in Section 5, price transmission from the retail sector to the wholesale sector is weak.

Turning to the impact of the shock on the farm sector (Fig. 4C), we find several interesting comparisons to be made with the retail series. First, the farm price impulse response dies down a lot faster than the retail impulse response. This is evidence that the intended beneficiaries of the burn would not be its greatest beneficiaries. Second, instantaneous price transmission is complete, with the entire 14 cents being transmitted to farmers right away. This simply reflects the result discussed in connection with Fig. 3A, that price wholesale-farm price transmission is near perfect since the ICA's demise.

In order to investigate the distribution of rents from the burn further, we calculate the area under the median impulse response for fifteen years following the shock. We refer to this as the total price effect (TPE). Table 3 shows the TPEs for each impulse response function. While these numbers do not reflect any quantity information and therefore do not constitute legitimate welfare measures, they do provide a simple indication of the distribution of the gains from the price intervention. The TPE, measured in dollar-months per pound, clearly accrues mostly to the retail sector. Oxfam's proposal will result in a TPE of 3.97 $-months/pound at the retail level, while boosting wholesale prices by only 3.08 $-months/pound. Again, the evidence shows that the shock increases the retail-wholesale margin. In contrast, the TPE at the farm level is 2.83 $-months/pound.

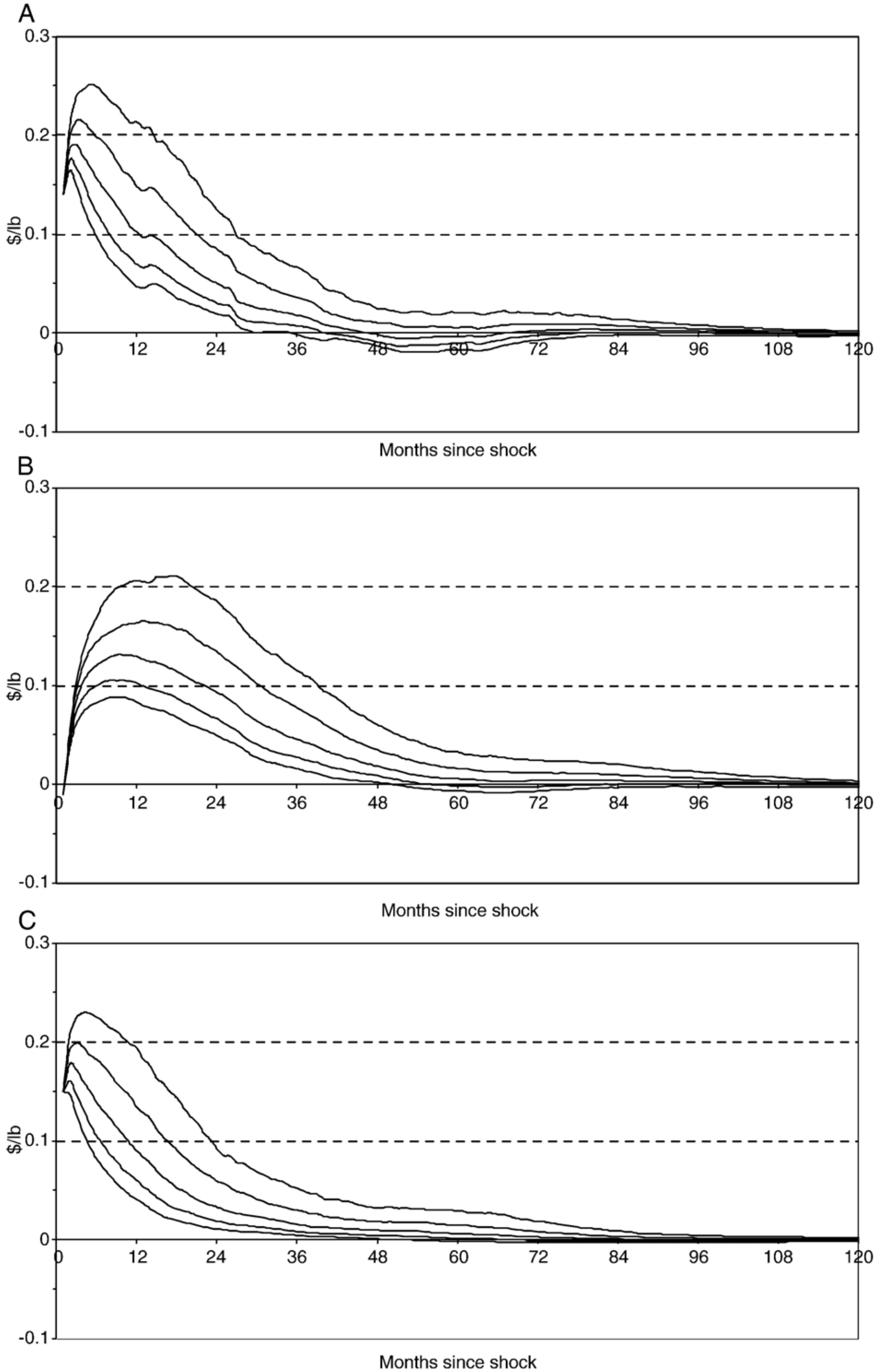
These results show that asymmetric retail price transmission will permit the retail sector to benefit tremendously from an attempt to shock the world coffee market. This is a particularly interesting finding, as several advocates of supply contractions have also noted that price transmission at the retail level is asymmetric, but have not questioned the relevance of this observation to their policy proposal.

The lower half of Table 3, corresponding to a shock in July 1985, shows that the TPE of a price shock would be more evenly distributed under the ICA. In order to examine this result in greater detail we turn next to the impulse response functions underlying these figures.

Fig. 5A–C presents dynamic multipliers capturing the effects on prices of a 28 cent wholesale price shock in July 1985. The evidence of a price cycle is dramatic. The initially higher prices stimulate planting, leading the median impulse response to become negative sixty months from the date of the shock. Moreover, this price trough occurs with a high probability — even the 90th percentile impulse response passes through the origin. This price downturn seems to create a countervailing upswing approximately five years later.

These dynamics resemble those predicted by a cobweb model (Ezekiel, 1938; Kaldor, 1934). The cobweb model presumes that farmers use adaptive expectations to predict future prices. Then, current high prices induce suppliers to invest in coffee plantations, increasing supply five to six years in the future. This drives down future prices, reducing the rate of investment in the future, which in turn drives up the price five to six years beyond that. The cobweb model also predicts that if the elasticity of supply at the five year horizon were smaller than the elasticity of demand in absolute value terms, the amplitude of the price cycle should decline as seen in Fig. 5A–C. If the five-year supply elasticity exceeds the demand elasticity, the amplitude of the price cycle should grow over time. In footnotes 12 and 13 we report on the estimated price elasticity of demand in the short run, as well as that of supply at various time horizons. As the long-run price elasticity of demand should exceed the short-run elasticity, these estimates suggest that at the five year horizon, the supply elasticity is less than the demand elasticity in absolute value. The assumption that farmers' expectations are adaptive is probably too simple. Nevertheless, the fundamental insight of the cobweb model seems to apply. Delayed supply response to investment decisions

Fig. 4. A: Wholesale price response to a fourteen cent wholesale price shock in December 2002. B: Retail price response to a fourteen cent wholesale price shock in December 2002. C: Farm price response to a fourteen cent wholesale price shock in December 2002.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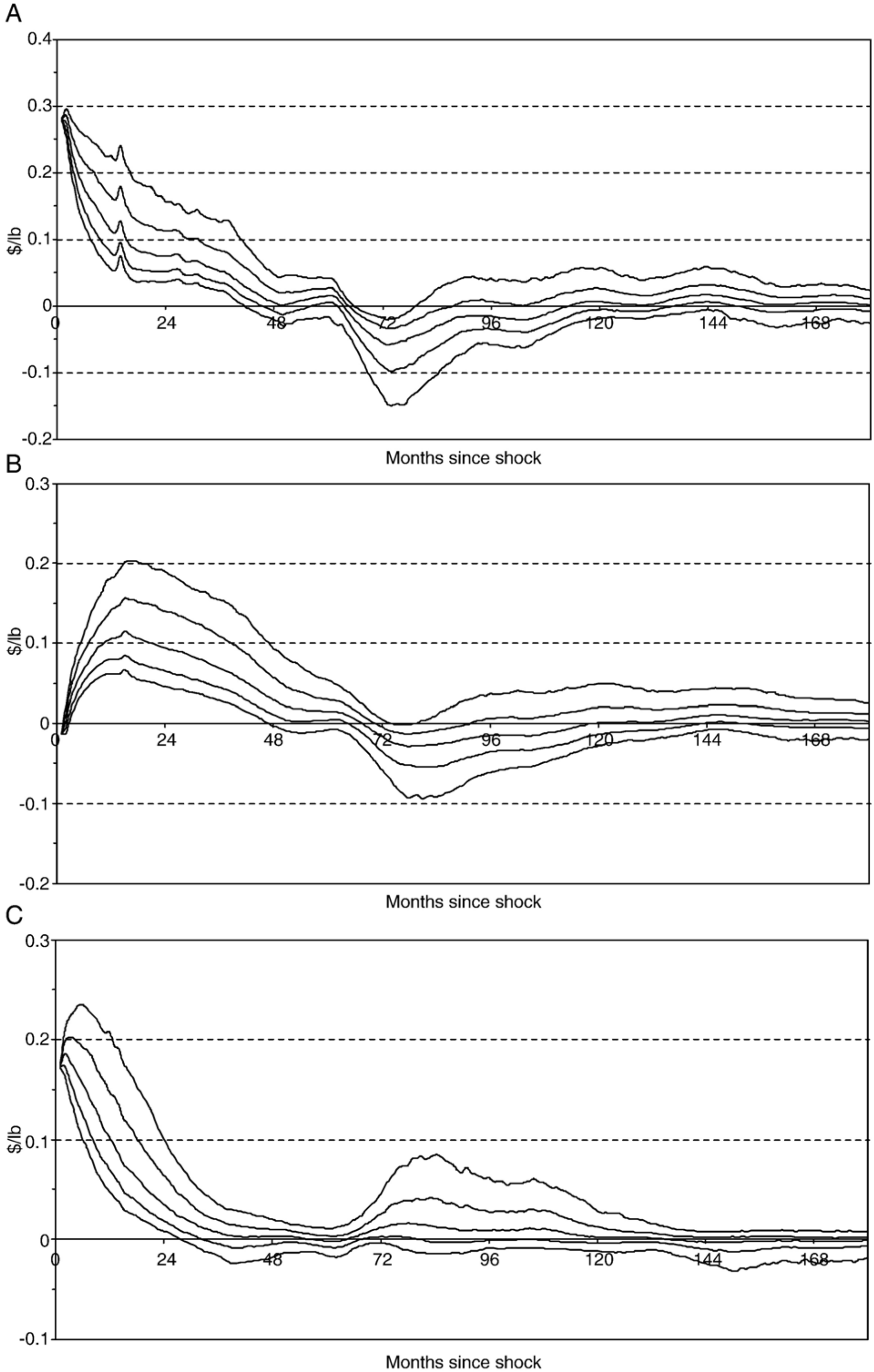
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Table 3
Total price effects

Regime	Shock	TPE (in $-months)		
		Farm	Wholesale	Retail
Non-ICA (December 2002)	Positive 14 cents	2.838	3.083	3.970
	Negative 14 cents	−2.726	−2.895	−3.190
ICA (July 1985)	Positive 28 cents	3.212	3.618	3.331
	Negative 28 cents	−3.058	−3.372	−2.857

wherein present prices are presumed to correlate positively with future prices can cause a price cycle which declines in magnitude when supply is price-inelastic.

Comparison of 5a with 4a provides visually arresting evidence that long run supply response was much stronger under the ICA, and that the ICA deepened or caused price cycling in coffee markets.

Farm price responses to the wholesale shock during the ICA years (Fig. 5C) drop off precipitously within two years. In the Brazilian context, this might reflect a rapid conversion of the price increase into quota rents. Curiously, while the wholesale impulse responses are in a trough five to nine years after the shock, the farm prices impulse responses spread upwards over the same period. The median farm price response, though, remains fairly close to neutral from about 40 months onwards. This is consistent with Brazil's system for distributing export quotas, where flexible quota rents would absorb world price movements, leaving farm prices more or less untouched. Again, this drives home the point that there is little merit to discussing interventions to control exports or production, unless the mechanisms for distributing the rents they generate are also debated clearly.

All the forgoing results indicate that our statistical findings of exaggerated supply response under the ICA are economically meaningful. The ICA did, indeed, deepen the coffee price cycle. Further, it did so while insulating farm prices in Brazil from this cycle. Retail prices rise faster than they fall, enabling the retail/roasting sector to benefit from price movements. Burning five million bags of coffee will therefore raise prices for a while, especially at the retail level. However, the impact of doing so would depend critically on whether market participants think it likely that this intervention will be a recurring event or not.

7. Discussion

We have developed a methodology to examine the consequences of coffee price interventions over several time horizons. The methodology starts with a supply-demand model of the coffee markets and derives its associated dynamic reduced form model. The model is capable of capturing the consequences of price shocks in the immediate, short, medium and long-run. We allow these dynamics to be influenced by the presence of an international coffee price control agreement.

This methodology is employed to probe four issues. First, we ask whether planting and maintenance decisions, made in response to long ago prices, propagate the effects of past prices. We find strong evidence that they did under the International Coffee Agreement (ICA), but much

Fig. 5. A: Wholesale price response to a twenty-eight cent wholesale price shock in July 1985. B: Retail price response to a twenty-eight cent wholesale price shock in July 1985. c.i: Farm price response to a twenty-eight cent positive wholesale price shock in July 1985.

weaker evidence that they have done so since the ICA's demise. We also document how the existence of the ICA altered these supply responses, and hence, future price dynamics. We find that by strengthening supply response to price movements at some time horizons, the ICA generated cyclical responses to price shocks. This finding might help to explain why coffee agreements, or at least their economic provisions, have never been long-lived. Increasing and stabilizing prices leads to increased incentives to invest in coffee trees.

Second, we ask whether price transmission in coffee markets between the Brazilian farm sector, U.S. wholesale sector and U.S. retail sector is asymmetric, as has been alleged by some authors concerned with the increased market concentration at the roasting/retail level since the late 1980s. We confirm their assertion that in the short run, retail prices respond more to wholesale and retail price increases than to price decreases. Wholesale and farm prices, in contrast, do not display significant asymmetry, appearing to be more closely tied to market fundamentals.

Third, motivated by these two findings, we ask what the impact of Oxfam's proposal to raise prices by burning five million bags of coffee would be. Our simulations suggest that in the absence of a price control agreement, the impact of such a policy would be felt for a year and fade away within two years. However, during the ICA years, such a policy would have triggered a price cycle. We also find evidence that much of the rents accruing from such a burning post-ICA would be captured by roasters and/or retailers because retail prices rise faster in response to the burn, than they fall as wholesale prices subside.

Fourth, we examine the impact of export quotas on price transmission to farmers. We find that the quota regime, as it was implemented in Brazil under the ICA, greatly dampened the transmission of international price movements to the farm level. The quotas also generated economic rents, which resulted in a price wedge, reducing farm prices relative to wholesale prices. This highlights the importance of distributional issues in designing or evaluating such interventions: who gets the economic rents generated by quantity restraints can affect significantly the distribution of welfare among market participants as well as the market response and its dynamics. Price interventions today can have long-lived effects, especially if an expectation is created that such actions to defend wholesale prices are likely to be repeated in the future. And interventions create rents, the distribution of which has significant welfare effects that can vary with the time horizon. The cautionary message of this paper is therefore quite clear. Interventions in coffee markets, if they should be made at all, should be carefully evaluated both for their short run and long effects on prices and on the welfare of various market participants. In particular, policy makers should keep in mind that short term effects can be very different from longer term effects, and that supply response may undermine the long term viability of quantity restrictions. Interventions probably should not create the impression that they will be repeated, lest this enhance unintended supply responses.

Our analysis has not answered every question it raised. For example, our dynamic price analysis does not explain *why* supply response to price information has been so limited in the post-ICA years. This probably relates to shifts in the global location of coffee production. Since its economic liberalization in the early 1990s, and the collapse of the ICA's cold war quota allocations, Vietnam has steadily increased its coffee production, passing Colombia to become the worlds' second largest coffee producer. Significant expansion in coffee production in Asia and Brazil has not been matched by decreased supply from other countries. In addition, new cleaning and roasting technologies have permitted roasters to utilize cheaper Robusta coffees from Asia, Brazil and parts of Africa, while Brazilian and Vietnamese coffee quality has improved. Lewin et al. (2004) suggest at least two additional interpretations. First, better access to financial and futures markets in several producing countries enables farmers to better manage risk, obviating frequent planting and pruning responses to price shifts. Second, producers jockeying to increase market share through product differentiation (a trend whose importance Daviron and Ponte, 2005, highlight) will tend to oversupply in aggregate. Under any of these interpretations, our findings appear consistent with a story of disequilibrium due to hysteresis. In terms of policy solutions, our results suggest strongly the importance of delinking economic assistance to coffee farmers from coffee production.

One additional clarification on the interpretation of our results is necessary. The ending of the ICA coincided roughly with a substantial reduction in the role of marketing policies in producing countries. Our analysis does not capture the effects of the two changes separately and implicitly assumes a direct linkage between the marketing boards and the ICA. Indeed, the international agreement not only required many of the domestic marketing policies (to ensure that the international quotas were met), it also rendered several of their activities economically feasible.[36] In other words, when we refer to the ICA, we are implicitly referring not just to the international quota system, but also to the domestic policies that went along with it. While from a microeconomic perspective it would no doubt be useful to understand the positive economic effects of the various domestic and international arrangements separately, we believe it is institutionally useful to think of them as components of one system.

An emerging, albeit partial, solution to the serious problem of low coffee producer prices, is to improve quality, consistency and differentiability of product. Producers in several countries, notably Brazil and Vietnam, are focusing on improving the quality of their beans. Others are trying to obtain higher prices through various environmental and social certification and fair trade schemes. As more data on these endeavours becomes available, we hope that future research will assess their effects and sustainability, as well as focus more broadly on the question of coffee quality. Daviron and Ponte (2005) provide an excellent starting point for such investigations.

Finally, we must admit that our current understanding of investment behavior in the coffee sector remains limited. Making progress on this front is hampered by data issues. Indeed, without good quantity information on tree planting, we focused our analysis on the price domain. To gain insights on investment behavior relevant to coffee markets, good data on tree stocks and tree planting would be needed. Collecting detailed and internationally consistent data on production, cost and tree stocks from around the world would be extremely useful to coffee producers, as this would facilitate improved long term projections of coffee prices. And, such improvements in price discovery would permit farmers and policy makers to make more realistic and long-term decisions, potentially shifting prices and the distribution of welfare in coffee markets profoundly.

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[36] For example, Talbot (2004, p.109) describes how the collapse of coffee prices along with the ICA led some growers to agitate for the removal of several marketing policies/institutions. Further, a message arising out of Bates (1997) is that the US State Department's support for the ICA resulted from the agreement's ability to support domestic marketing arrangements that would permit friendly regimes to accumulate coffee rents.

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