Government policy and dynamic supply response: a study of the compulsory grain delivery system

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Abstract

The impact of government policy on the dynamics of agricultural supply in Ethiopia during the 1980s is explored. Specifically, an intertemporal acreage allocation model that allows for the impact of compulsory grain delivery is developed. Subsequently, an estimable dynamic acreage demand equation is derived, and estimated for a crop using region-level data. Generalized method of moments (GMM) estimators for dynamic panel data models are used. The elasticity estimates thus obtained suggest that the demand for crop acreage (and hence the supply of crop output) responded negatively to the level of forced grain procurement, and positively to output price.

1 Introduction

In the 1980's Ethiopian farm households were subject to a system of compulsory grain delivery (CGD). Under this system, such households were required to sell a portion of their output to the government at fixed prices[1]. After meeting this obligation (commonly referred to as the 'quota') these producers were allowed to buy and sell farm output on the local 'open' or 'free' market. Generally, such a system affects the welfare of producers. It may also affect their resource allocation decisions. The first objective of this paper is to investigate the impact of CGD on the production decisions of Ethiopian farm households. Accordingly, one important contribution of the paper is its quantitative inquiry into this aspect of the recent economic history of Ethiopia.

In principle the impact of the compulsory delivery system can be modelled in different ways. That it is an implicit form of taxation (or rent) seems to be the common view[2]. Thus, identifying an equivalent form of explicit taxation facilitates the analysis. Accordingly, it is proposed that the 'quota' should be viewed as a proportional output tax implicitly imposed on farm households. One way of modelling

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[1] The government agency responsible for administering the CGD was the Ethiopian Agricultural Marketing Corporation (EAMC).

[2] See Taffesse (1989), Franzel et al (1989), Azam (1992), Dercon (1994), Pickett (1991). This view is shared by those who analyzed the procurement system in general, as well as its specific applications - see Sah and Stiglitz (1992), Sah and Sirnivasan (1987).

this is to consider the 'quota' as a proportion of output. This is consistent with the most common criteria used in determining the level of a household's 'quota' obligation, namely[3]:

- the potential crop output of the household; and
- the wealth (or, more precisely, the overall income-generating capacity) of the household, measured by variables including size of land-holding, number of oxen and other livestock owned, and nonfarm income.

In contrast, Azam (1992) identifies the 'quota' as an implicit lump sum tax, and proceeds to model its impact accordingly. This formulation excludes the possibility of the 'quota' system affecting the production decisions of farmers. It also does not accurately reflect the process of 'quota' allocation to peasant households. Moreover, the alternative characterisation of the 'quota' adopted in this paper and presented in detail below has the added advantage of allowing the study of the impact of an agricultural price policy (i.e., CGD) in the context of supply response models. This is an important advantage, since the second objective of the paper is to assess the price responsiveness of farm households' crop supply in Ethiopia during the period of study. The possibility of jointly studying these effects is created by defining the average price of crops subject to CGD as follows:

$$P = \phi P^s + (1 - \phi) P^m$$

where: P = the weighted average price; P^s = the procurement (or EAMC) price; P^m = the 'free' or 'open' market price; ϕ = the 'quota' as a proportion of the farm household's total output (or the rate of 'quota').

To achieve the objectives stated above, a simple dynamic farm household model is developed. The model is a variant of the linear rational expectations model [Sargent (1987), Hansen and Sargent (1980)] as applied to agricultural supply response analysis [Eckstein (1984, 1985), Tegene, Huffman, and Miranowski (1988)]. The main innovation is the direct introduction and analysis of CGD in that framework. Furthermore, the decision problem of the farm household is explicitly placed in the agricultural household models framework in a very simple manner. On the basis of the model elasticities of acreage demand for crop cultivation are computed. Subsequently, an estimable acreage demand equation is derived and estimated for a crop using region-level data. The elasticity estimates thus obtained suggest that the demand for crop acreage (and hence the supply of crop output) responds negatively to the 'quota' and positively to output price. These findings have significance to current dialogue on agricultural price support in Ethiopia. Moreover, the analytical framework and empirical strategy adopted are both applied to Ethiopian crop supply data for the first time and thus can inform future work in this area.

The rest of the paper is organized as follows. Section (5.2) presents a simple dynamic model of farm household production choices and the elasticities thereof. Section (5.3) describes the details of the empirical analysis including the data, econometric specification, estimation procedure, and estimation results. Section (5.4) concludes. The final section is an appendix detailing the procedure used for obtaining

[3] To the extent that it was not based on a 'quota' schedule, the determination of 'quota' levels to be delivered by households was not uniform. Nevertheless, the most common practice was the imposition of relatively higher 'quota' on households with higher outputs [see Alemayehu (1987)].

an explicit solution for the acreage decision rule, as well as some of the properties of the generalized method of moments (GMM) estimators employed.

2 A dynamic model of farm household production choice

A simple dynamic model is presented in this section as a means of investigating the impact of CGD on the intertemporal production choices of the farm household[4].

2.1 Assumptions and Characterization

1. Consider a representative infinitely-lived dynastic farm household which maximizes its discounted expected intertemporal utility via its consumption, production, and saving choices[5]. This farm household is assumed to have a (common) one-period utility function, $u(x_{t+j})$ which is linear, i.e.,

$$u(x_{t+j}) = \varrho_0 + \varrho_1 x_{t+j} \ ; \ \varrho_0, \varrho_1 > 0, \ t, j = 0, 1, \ldots \tag{1.1}$$

   where x_{t+j} represents consumption in period $t+j$. In other words the household is deemed to be risk-neutral. In other words, the impact of the randomness of some variables on the choices farmers make is considered without modelling their behaviour towards risk. It is further assumed that the intertemporal utility function is additively separable, and that in each period yield and price risk are realized before consumption decisions are taken. Under these circumstances, the farm household's production and consumption decisions are separable. Thus the farm household maximizes its discounted expected utility by first maximizing its discounted expected profits, and subsequently choosing the level of consumption and/or savings subject to the corresponding budget constraint. This budget constraint has three components, savings from the previous period, s_{t+j-1}, the interest (or return) accruing to those savings at a rate, r (which is assumed to remain constant over time), and current profits, π_{t+j}, i.e.,

$$x_{t+j} + s_{t+j} = (1 + r)s_{t+j-1} + \pi_{t+j} \ \ ; \ t, j = 0, 1, \ldots \tag{1.2}$$

   Savings represent the cash-equivalent of different saving instruments available to the farm household, including cash, other financial assets, and grain storages.

2. Using its exogenously given total cultivable land, A_{t+j}, and subject to yield risk, the farm household is assumed to produce two (groups of) annual crops under a fixed-proportions technology of production[6]. This technology is represented

[4]The model stated below is an adaptation of Eckstein (1985). Eckstein (1985) considers the demand for acreage (in levels rather than shares) by farmers in the absence of forced crop procurement by the state. He also does not address the question of separability of production and consumption decisions.

[5]The structure of our model is such that the conditions for exact aggregation are satisfied. Hence, the 'representative' household is equivalent to the 'average' household. In fact, Eckstein (1985) aggregates a closely related model over a (stable) population of farmers to characterise a rational expectations equilibrium of the market for a crop.

[6]The size of the farm household's landholdings may vary over time, primarily due to land redistribution. But this is beyond the control of the household. Note also that renting out land was illigal. Moreover, renting-out lnad carried the threat of losing a fraction of one's holdings in the next round of redistribution. Due to these circumstances renting land was not widespread during the period under study.

by two production functions which are linear in acreage, stochastic, and involve a one-period lag between cultivation and harvest (harvest at $t+j$ is a function of acreage at $t+j-1$)[7]. Formally[8]:

$$Q_{1,t+j} = y_1 A_{1,t+j-1} + \varepsilon_{1,t+j} \; ; \; y_1 > 0, \quad t, j = 0, 1, \ldots \tag{1.3}$$

$$Q_{2,t+j} = y_2 A_{2,t+j-1} + \varepsilon_{2,t+j} \; ; \; y_2 > 0, \quad t, j = 0, 1, \ldots \tag{1.4}$$

$Q_{i,t+j}$ = output of crop i ($i = 1, 2$) at time $t+j$; $A_{i,t+j}$ = the proportion of total acreage allocated to crop i at time $t+j$; y_1 and y_2 are parameters; $\varepsilon_{i,t+j}$ = exogenous shocks to production during $t+j$ which have zero mean, constant variance, and are serially uncorrelated. In line with the fact that crop production involves biological gestation periods of some (sometimes considerable) length, the one-period lag in production captures the phenomenon that the farm household has to make acreage decisions in terms of its expectations about unknown future output prices. This introduces price risk into the decision problem of the farm household.

3. It is assumed that the direct cost of producing a crop is a function of acreage allocated to its production. This cost has two components distinguished by the period during which they are incurred (or known); costs known at the time of planting and costs known at the time of harvest. The latter is an attempt to capture the flexibility of input use after planting and up to and including harvest and the uncertainty of output given the lag in production. The focus here is on Crop 1. Given this focus it is assumed that there are additional adjustment-cost-like expenses related to Crop 1. To capture these costs as well as the direct costs it is assumed that a quadratic cost function is associated with that crop. This function takes the following specific form[9]:

$$C_{1,t+j} = (v_{1,t+j-1} + f_{1,t+j})\, A_{1,t+j-1} + \frac{b}{2} A^2_{1,t+j-1} + d A_{1,t+j-1} A_{1,t+j-2} \quad ; \quad b > 0; \; d \lesseqgtr 0 \tag{1.5}$$

where: $v_{1,t+j-1}$ and $f_{1,t+j}$ are non-land costs of producing Crop 1 over the total available acreage at the time of cultivation $(t+j-1)$ and at the time of harvest $(t+j)$, respectively[10]. The term $\frac{b}{2}A^2_{1,t+j-1}$ eventuates decreasing returns to scale in the long-run. Two counteracting dynamic effects are captured by d [Eckstein (1985)]. The first is the tendency to rotate crops if successive cultivation of the

[7] Under the assumed fixed-coefficients technology, each crop is produced by using land and non-land factors in fixed proportions. The output of each crop, as well as the direct cost of its production, can thus be expressed as a function of the amount of acreage allocated to its cultivation. It is in this sense that (1.3) and (1.4) are production functions. See also Tegene, Huffman, and Miranwski (1988).

[8] Crop 1 is identified as the crop subject to CGD while Crop 2 may be considered as free from CGD. However, even if both are subject to CGD the analysis below will not be affected.

[9] Although quadratic cost functions are commonly used, this specific form as applied to agricultural supply response analysis is due to Eckstein (1985). In this regard, Eckstein (1985) notes that a combination of the terms $\frac{b}{2}A^2_{1,t+j-1}$ and $dA_{1,t+j-1}A_{1,t+j-2}$ (with $d < 0$) is equivalent to the standard adjustment cost formulation.

[10] More explicitly, v_i represents the total non-land costs that would be incurred during the cultivation period if total acreage is planted with crop i ($i = 1, 2$), i.e.:

$$v_i = (non - land\ cultivation\ costs\ of\ crop\ i\ per\ hectare) \times A$$

same crop on a plot substantially reduces soil fertility and increases the cost of production. The second is the incentive to recultivate the crop planted last period if the cost of land preparation for that crop has been high and the current cost of production is lower as a result[11]. The sign of d is determined by which of these two dominate. If the first effect dominates, then $d > 0$, while $d < 0$ if the second effect is dominant. For simplicity it is also assumed that a linear cost function of the following form is associated with Crop 2:

$$C_{2,t+j} = (v_{2,t+j-1} + f_{2,t+j})\, A_{2,t+j-1} \tag{1.6}$$

where: $v_{2,t+j-1}$ and $f_{2,t+j}$ are non-land costs of producing crop 2 over the total available acreage at the time of cultivation $(t+j-1)$ and at the time of harvest $(t+j)$, respectively.

4. At the beginning of this paper it is argued that the 'quota' should be viewed as a proportional output tax implicitly imposed on farm households[12]. Accordingly, the impact of the 'quota' is analyzed by defining an average price in the following manner[13]:

$$P_1 = \phi_1 P_1^s + (1 - \phi_1) P_1^m$$

where: P_1 = the weighted average price of Crop 1; P_1^s = the procurement (or EAMC) price of Crop 1; P_1^m = the 'free' or 'open' market price of Crop 1; ϕ_1 = the 'quota' as a proportion of the farm household's total output of Crop 1 (or the rate of 'quota'). The average price defined this way represents the household's marginal value (or revenue) of a unit of output. It increases with P_1^s and P_1^m, and falls with ϕ_1. Since P_1^s is less than P_1^m, and since, $0 < \phi_1 < 1$, the average price is less than the corresponding market price[14]. The valuation of the corresponding crop output at P_1 thus captures the tax nature of the 'quota'. As will be clear shortly, however, using this expression for the average price in a dynamic setting is very cumbersome. In particular, it is difficult to accommodate within the linear-quadratic framework set out below. The main problem stems from its nonlinearity in the variables, such that it introduces higher-order moments in the otherwise linear solution (in first-order moments). Hence it is useful to adopt a linear alternative. To do so, a first-order Taylor

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where A is total available acreage in hectares. Similarly:

$$f_i = (non - land\ harvest\ costs\ of\ crop\ i\ per\ hectare) \times A$$

[11] In other words, planting a crop different from the one cultivated last period involves costs higher than replanting with the same crop. In that sense, this tendency is induced by the presence of adjustment costs.

[12] The analysis below does not consider ways other than adjusting crop-mix that households may have devised to avoid delivering the quota or minimize its impact. Thus ϕ_1 has to be viewed as relating to the implicit output tax actually paid by farm households. In line with that the empirical analysis uses actual procurement by the EAMC to compute ϕ_1.

[13] If Crop 2 is also subject to CGD, then the same procedure can be applied to define its average price. None of the results will be affected as a consequence. But, additional results pertaining to the effects of the 'quota' rate and market price of that crop will be obtained.

[14] There are anecdotes of some farm households buying crops to meet their 'quota' obligations. In such instances $\phi_1 > 1$, and thus, $P_1 < P_1^s$. Hence, the definition of the average price can accommodate these cases. However, these cases are not considered since they are unlikely to be typical .

approximation around the means of the three variables involved is combined with the fact that procurement prices changed very little over time (see section 3.1.3 below) and that the means of the quota rate and the market price are constants to simplify the expression. Letting $x = \left[\begin{array}{ccc} \phi_1 & P_1^m & P_1^s \end{array}\right]$ and $\overline{x} = \left[\begin{array}{ccc} \overline{\phi_1} & \overline{P_1^m} & \overline{P_1^s} \end{array}\right]$, the latter representing the means, this leads to:

$$P_1(x) \simeq \iota_0^{'} + \iota_1 \phi_1 + \iota_2 P_1^m \tag{1.7}$$

where:

$$\begin{aligned} \iota_0 &= \iota_0^{'} - \iota_1 \overline{\phi_1} - \iota_2 \overline{P_1^m} + \iota_3 (P_1^s - \overline{P_1^s}), \quad \iota_0^{'} = P_1(\overline{x}), \quad \iota_1 = \left(\frac{\partial P_1}{\partial \phi_1}\right)_{\overline{x}}, \\ \iota_2 &= \left(\frac{\partial P_1}{\partial P_1^m}\right)_{\overline{x}}, \quad \iota_3 = \left(\frac{\partial P_1}{\partial P_1^s}\right)_{\overline{x}} \end{aligned}$$

The subscript $\overline{x}$ indicates that the derivatives are evaluated at $\overline{x}$[15]. Observe also that $\iota_1 < 0$; $0 < \iota_2 < 1$; and $0 < \iota_3 < 1$. Thus the alternative expression possesses all the key properties of the original.

5. Finally, the farm household is assumed to form expectations rationally. Following the most common characterization, rational expectations are identified as expectations which, in the context of specific models describing the behaviour of the relevant variables, are equal to the mathematical expectations of those variables conditional on the information available at the time the forecasts are made[16].

2.2 The model

With the above assumptions, the farm household's problem can be characterized as maximizing its discounted intertemporal expected utility by choosing decision rules for consumption, savings, and acreage allocations under yield and price risk. These choices are made subject to the sequence of budget constraints, which is partly determined by the linear production technology, the exogenously given total household land-holdings, and the relevant information available to the household. The exogenously given initial level of savings, s_{t-1}, constitutes an additional constraint. The optimization problem can thus be summarized as follows[17]:

$$\max_{\{x_{t+j}, s_{t+j}, A_{i,t+j}\}} \quad \lim_{T \to \infty} \mathbf{E} \left\{ \sum_{j=0}^{T} \beta^j \left(\varrho_0 + \varrho_1 x_{t+j}\right) \mid \Omega_t \right\}; \quad t = 0, 1, \ldots \tag{2.1}$$

subject to:

$$x_{t+j} + s_{t+j} = (1+r) s_{t+j-1} + \pi_{t+j}; \quad t, j = 0, 1, \ldots \tag{2.2}$$

[15] The partial derivative with respect to ϕ_1 captures only the direct impact of the 'quota' rate on the average price. The effect that may operate via P_1^m is introduced later.

[16] The nature and/or validity of rational expectations will not be considered any further. There is a huge literature concerning these issues. Among others, see Sargent (1987), Pesaran (1987), Cuthberston and Taylor (1987), and Blanchard and Fischer (1989).

[17] Note that consumption is the numeraire, i.e., all prices are measured relative to an index of consumption goods' prices (say, for instance, a consumers' price index). This reflects the view that farm households consider relative prices in making their choices.

$$Q_{1,t+j} = y_1 A_{1,t+j-1} + \varepsilon_{1,t+j}; \quad t,j = 0,1,\ldots \tag{2.3}$$

$$Q_{2,t+j} = y_2 A_{2,t+j-1} + \varepsilon_{2,t+j}; \quad t,j = 0,1,\ldots \tag{2.4}$$

$$1 = A_{1,t+j-1} + A_{2,t+j-1}; \quad t,j = 0,1,\ldots \tag{2.5}$$

and s_{t-1} given; where: $\pi_{t+j} \equiv (P_{1,t+j}Q_{1,t+j} - C_{1,t+j}) + (P_{2,t+j}Q_{2,t+j} - C_{2,t+j})$ = farm profits at time $t+j$; $\beta = (1+\tau)^{-1}$ = the discount factor, τ being the household's rate of time preference; $P_{i,t+j}$ = average price (as defined above) of crop i ($i = 1,2$) at $t+j$; $\mathbf{E}$ = the mathematical expectations operator; Ω_t = the farm household's information set at time t. In this regard, the information set is assumed to contain: current and past realizations of prices, costs, and production shocks; as well as the history of household production, consumption, and savings choices up to and including $(t-1)$. Note that $0 < \beta < 1$. The rest of the notation is as above.

First, consumption is factored out from (2.1) by using (2.2) to substitute for it. Then, π_{t+j} in (2.1) is expanded by using (2.3)-(2.4), (1.5)-(1.6), and (2.5) to respectively substitute for $Q_{1,t+j}$, $Q_{2,t+j}$, $C_{1,t+j}$, $C_{2,t+j}$, and $A_{2,t+j}$. Correspondingly, the objective of the farming household can be summarized as:

$$\begin{aligned}\max_{\{A_{1,t+j},s_{t+j}\}} \lim_{T\to\infty} \mathbf{E}_t \sum_{j=0}^{T} \beta^j \{ & \varrho_0 + \varrho_1[(P_{1,t+j}y_1 - R_{1,t+j} - V_{1,t+j})A_{1,t+j-1} - \frac{b}{2}A^2_{1,t+j-1} \\ & -dA_{1,t+j-1}A_{1,t+j-2} + (P_{2,t+j}y_2 - v_{2,t+j-1} - f_{2,t+j}) \\ & +P_{1,t+j}\varepsilon_{1,t+j} + P_{2,t+j}\varepsilon_{2,t+j} + (1+r)s_{t+j-1} - s_{t+j}]\} \end{aligned} \tag{2.6}$$

subject to $(A_{1,t-1}, s_{t-1})$ given. $\mathbf{E}_t$ represents $\mathbf{E}(\,.\, \mid \Omega_t)$, while $R_{1,t+j} \equiv P_{2,t+j}y_2$, and $V_{1,t+j} \equiv (v_{1,t+j-1} + f_{1,t+j}) - (v_{2,t+j-1} + f_{2,t+j})$. The sum of R_1 and V_1 captures the total (actual and opportunity) cost of producing Crop 1. Briefly, the farm household chooses a contingency plan $\{A_{1,t+j}, s_{t+j}\}$ to maximize its discounted expected intertemporal utility. Obviously x_{t+j} and $A_{2,t+j}$ are obtained via (2.2) and (2.5), respectively.

Equation (2.6) represents a linear-quadratic optimization problem in discrete time. The corresponding first order conditions (including the transversality conditions) are obtained by differentiating the equation with respect to $A_{1,t+j}$ and s_{t+j} $(j = 0,1,...,T)$[18]. In this regard, note that A_{t+j} directly affects π_{t+j+1} and π_{t+j+2} , which in turn affect contemporaneous consumption and utility via the budget constraints. Similarly, s_{t+j} impacts on consumption and utility during $(t+j)$ and $(t+j+1)$ through the corresponding budget constraints. After rearranging, the following Euler equations for $j = 0,1,\ldots,T-1$ are thus obtained:

$$\mathbf{E}_t\{\beta^{j+1}[u'(x_{t+j+1})(P_{1,t+j+1}y_1 - R_{1,t+j+1} - V_{1,t+j+1} - bA_{1,t+j} - dA_{1,t+j-1}) - \beta u'(x_{t+j+2})dA_{1,t+j+1}]\} = 0 \tag{2.7a}$$

$$-\mathbf{E}_t\left\{\beta^j\left[u'(x_{t+j}) - \beta(1+r)u'(x_{t+j+1})\right]\right\} = 0 \tag{2.7b}$$

[18] The relevant rule of differentiation is Leibniz's rule [Whiteman (1983)].

and for $j = T$, the transversality conditions:

$$\lim_{T\to\infty} \mathbf{E}_t \left[\beta^{T+1} u'(x_{t+T+1}) \left(P_{1,t+T+1}y_1 - R_{1,t+T+1} - V_{1,t+T+1} - bA_{1,t+T} - dA_{1,t+T-1}\right) A_{1,t+T}\right] = 0 \tag{2.8a}$$

$$\lim_{T\to\infty} \mathbf{E}_t \left[\beta^{T+1} u'(x_{t+T+1})(1+r)s_{t+T}\right] = 0 \tag{2.8b}$$

where $u'(.)$ represents the partial derivative of $u(.)$ with respect to x.

Two remarks about the first-order conditions. First, by the linearity of the one-period utility function, the marginal utility of consumption over time is constant. By (1.1) it is equal to ϱ_1. Hence the $u'(.)$ terms drop out of all first order conditions. Second, they reveal that, under the specified circumstances, production and consumption decisions are separable. Combined with the production functions, (2.7a) and (2.8a) determine household production choices independent of consumption. Accordingly the production decision of the farm household can be separately considered via the first-order conditions relating to $A_{1,t+j}$. As a first step towards a solution the Euler equations are restated by applying the law of iterated conditional expectations to (2.7a) and rearranging[19]:

$$\begin{aligned} \mathbf{E}_t \left[\mathbf{E}_{t+j} \left(P_{1,t+j+1}y_1 - R_{1,t+j+1} - V_{1,t+j+1} - bA_{1,t+j} - dA_{1,t+j-1} - \beta dA_{1,t+j+1}\right)\right] &= 0 \\ t &= 0, 1, \cdots \\ j &= 0, 1, \cdots, T-1 \end{aligned}$$

For these equations to hold for all realizations of ($P_{1,t+j+1}, R_{1,t+j+1}, V_{1,t+j+1}$) it is necessary that the term in parentheses is equal to zero. Therefore, after substituting for P_1 from (1.7) above, the first-order conditions for the farm household's production problem can be stated as:

$$\begin{aligned} \beta \mathbf{E}_{t+j} \left[A_{1,t+j+1} + \frac{b}{d\beta} A_{1,t+j} + \frac{1}{\beta} A_{1,t+j-1}\right] &= \mathbf{E}_{t+j} \frac{1}{d} \left[\left(\iota_0 + \iota_1 \phi_{1,t+j+1} + \iota_2 P^m_{1,t+j+1}\right) y_1\right] \\ &\quad - \mathbf{E}_{t+j} \frac{1}{d} \left[R_{1,t+j+1} - V_{1,t+j+1}\right] \end{aligned} \tag{2.9}$$

for all $j = 0, 1, \cdots, T-1$.

Equations (2.9) form a set of stochastic Euler equations. Since these equations are linear, it is possible to explicitly solve for the optimal decision rule if the additional assumption is made that the exogenous stochastic processes $\{P^m_{1,t+j+1}\}_{j=0}^{\infty}$, $\{R_{1,t+j+1}\}_{j=0}^{\infty}$, and $\{V_{1,t+j+1}\}_{j=0}^{\infty}$ are of mean exponential order less than $\frac{1}{\sqrt{\beta}}$ such that for some $M > 0$, and $1 \leq q < \frac{1}{\sqrt{\beta}}$ [see Sargent (1987, 393); Hansen and Sargent (1980, 12)]:

$$\left|\mathbf{E}_t(P^m_{1,t+j+1})\right| < Mq^{t+j+1}; \quad \left|\mathbf{E}_t(R_{1,t+j+1})\right| < Mq^{t+j+1}; \quad \left|\mathbf{E}_t(V_{1,t+j+1})\right| < Mq^{t+j+1}$$

[19] The law of iterated conditional expectations states that, for $\Omega_t \subseteq \Omega_{t+j}$ (i.e., for a nondecreasing information set):

$$\mathbf{E}(\,.\mid \Omega_t) = \mathbf{E}\left[\,\mathbf{E}(\,.\mid \Omega_{t+j}) \mid \Omega_t\right]$$

In the short-hand we use:

$$\mathbf{E}_t(.) = \mathbf{E}_t\left[\,\mathbf{E}_{t+j}(.)\right]$$

for all t and all $j \geq 0$[20]. The assumption (roughly) implies that $\mathbf{E}_{t+j}(P^m_{1,t+j+1})$, $\mathbf{E}_{t+j}(R_{1,t+j+1})$, and $\mathbf{E}_t(V_{1,t+j+1})$ will not grow faster than $\beta^{(t+j+1)/2}$ [Epstein and Yatchew (1985, 238)], or, more formally, the two stochastic processes are bounded in the mean [Eckstein (1985, 206)]. This assumption is made to ensure that the solution satisfy the transversality condition.

With this assumption equation (2.9) can be solved for $A_{1,t+j+1}$, the solution being:[21,22]

$$\begin{aligned} A_{1,t+j} &= \lambda_1 A_{1,t+j-1} \\ &\quad -(\frac{\lambda_1}{d}) \sum_{i=0}^{\infty} (\beta\lambda_1)^i \mathbf{E}_{t+j} \left[y_1(\iota_0 + \iota_1 \phi_{1,t+j+1+i} + \iota_2 P^m_{1,t+j+1+i}) - R_{1,t+j+1+i} - V_{1,t+j+1+i} \right] \end{aligned} \tag{2.10}$$

where λ_1 is the smaller of the roots satisfying $\frac{1}{\lambda_1} = -\frac{b}{d} - \beta\lambda_1$.

Equation (2.10) represents the farm household's demand for land relating to Crop 1. It implies that this demand is a function of past allocation of acreage to Crop 1, expected output prices, expected rate of 'quota', and realized and expected non-land input and opportunity costs. Because the terms $\mathbf{E}_{t+j}(\phi_{1,t+j+1+i})$, $\mathbf{E}_{t+j}(P_{1,t+j+1+i})$, $\mathbf{E}_{t+j}(R_{1,t+j+1+i})$, and $\mathbf{E}_t(V_{1,t+j+1+i})$ are present, that equation does not yet constitute a decision rule. To make it one, it is necessary to express those expectational variables as functions of elements of the current information set (Ω_{t+j}), i.e., as functions of variables known to the farm household at time $t + j$. This is done in the second sections of rhe appendix. Nevertheless, as it stands, (2.10) can be used to derive expressions for the acreage demand elasticities with respect to relevant variables.

2.3 Elasticities

One of the main objectives in this paper is to examine the impact of CGD on the intertemporal production choices of farm households under risk. The simple model presented above reduces this to analyzing the effect of CGD on the acreage allocation decisions of farm households. The obvious route, in this regard, is to identify the long-run and short-run elasticities of expected acreage with respect to changes in the expected rate of 'quota', using equation (2.10). The response of these allocations to prices can also be examined in a similar fashion. This section deals with the task[23].

Recall that Crop 1 is subject to CGD, the rate of 'quota' being ϕ_1. Also recall the definition of the average price of that crop as:

$$P_1 = \iota_0 + \iota_1\phi_1 + \iota_2 P^m_1$$

[20] Since, by definition, it is bounded within the interval $[0, 1]$ there is no need to make the same assumption about ϕ_1.

[21] The solution procedure used is described in the first section of the paper's appendix.

[22] The solution stated as (2.10) displays the certainty equivalence property, i.e., the same solution would result if we had maximized the criteria formed by substituting $[\mathbf{E}_t(P_{1,t+j}), \mathbf{E}_t(R_{1,t+j}), \mathbf{E}_t(V_{1,t+j})]$ for $[P_{1,t+j}, R_{1,t+j}, V_{1,t+j}]$ and dropping the expectations operator from outside the sum in the objective function (2.6). Also see Sargent (1987), and Hansen and Sargent (1980).

[23] The discussion below focuses on acreage elasticities. Note, however, that the linear production functions can be used to translate the response of acreage demand in to that of output supply.

Hence, the unconditional and conditional expectations of the average price can be respectively represented as:

$$\begin{aligned}
\mathbf{E}(P_1) &= \iota_0 + \iota_1 \mathbf{E}(\phi_1) + \iota_2 \mathbf{E}(P_1^m) \\
\mathbf{E}_{t+j}(P_{1,t+j+1+i}) &= \iota_0 + \iota_1 \mathbf{E}_{t+j}(\phi_{1,t+j+1+i}) + \iota_2 \mathbf{E}_{t+j}(P_{1,t+j+1+i}^m) \quad (2.11a)
\end{aligned}$$

The previous equations express the argument that the expected rate of 'quota' as well as the expected output market price operate via the expected average price of Crop 1. As noted earlier a change in the 'quota' rate has a direct, negative effect on P_1. That impact is captured by the negative parameter ι_1. That an 'average' farm household is being considered implies that the 'average' quota rate may also influence the corresponding market price. The possible routes through which this effect may occur include: the income effect on farm households' demand for goods (including Crop 1); the effect on the supply of Crop 1 in the rural market; the impact on the purchases of Crop 1 made by urban consumers/traders. A rise in the 'quota' rate reduces the income of farm households. It may thus lower their demand for Crop 1 if it is a normal good. It is also likely to induce a fall in that part of urban demand for Crop 1 which is met via direct purchases on the rural grain market. This is a consequence of the fact that a fraction of the amount of Crop 1 procured goes to urban consumers. On the other hand, a rise in the 'quota' rate leads to a decreased supply on the rural market. The first two tend to push the market price downwards, while the third exerts a pressure in the opposite direction. The ultimate effect on the market price of Crop 1 in the rural market is dependent on the relative strength of these counteracting pressures.

In line with the observations in the previous paragraph, (2.11a) is differentiated with respect to the relevant expected ϕ_1, to derive the impact of the latter on the unconditional and conditional means of the average price of Crop 1, respectively:

$$\begin{aligned}
\frac{\partial \mathbf{E}(P_1)}{\partial \mathbf{E}(\phi_1)} &= \iota_1 + \iota_2 \frac{\partial \mathbf{E}(P_1^m)}{\partial \mathbf{E}(\phi_1)} \\
\frac{\partial \mathbf{E}_{t+j}(P_{1,t+j+1+i})}{\partial \mathbf{E}_{t+j}(\phi_{1,t+j+1+i})} &= \iota_1 + \iota_2 \frac{\partial \mathbf{E}(P_{1,t+j+1+i}^m)}{\partial \mathbf{E}(\phi_{1,t+j+1+i})} \quad (2.11b)
\end{aligned}$$

The analogous expressions for the effect of P_1^m are:

$$\frac{\partial \mathbf{E}(P_1)}{\partial \mathbf{E}(P_1^m)} = \frac{\partial \mathbf{E}_{t+j}(P_{1,t+j+1+i})}{\partial \mathbf{E}_{t+j}(P_{1,t+j+1+i}^m)} = \iota_2 \quad (2.11c)$$

Note that an expected rise in P_1^m always increases the expected average price ($\iota_2 > 0$). In contrast, a rise in expected ϕ_1 generates two potentially counteracting effects. The direct effect is always negative since, given P_1^s and P_1^m, a higher 'quota' rate results a lager expected share of the lower P_1^s in the average price. The indirect effect, which operates via P_1^m, is ambiguous since the impact of ϕ_1 on P_1^m cannot be signed *a priori*. If the indirect effect is negative (or zero), then, an expected rise in the 'quota' rate leads to an expected fall in the average price of Crop 1. In contrast, if the indirect effect is positive, but the direct impact exceeds the induced change in P_1^m in absolute value, i.e.,

$$\begin{aligned}
|\iota_1| &> \iota_2 \frac{\partial \mathbf{E}(P_1^m)}{\partial \mathbf{E}(\phi_1)} \\
|\iota_1| &> \iota_2 \frac{\partial \mathbf{E}(P_{1,t+j+1+i}^m)}{\partial \mathbf{E}(\phi_{1,t+j+1+i})}
\end{aligned}$$

then, the net effect is an expected fall in the average price of Crop 1[24].

2.3.1 Long-run elasticities

The long-run elasticities express the impact of expected changes in mean prices and the mean 'quota' rate on the farm household's mean acreage demand. Consider the effect of the 'quota' rate first. The long-run elasticity of expected acreage demand with respect to expected ϕ_1, $\left(\xi^L_{A,\phi}\right)$, is derived by first taking the unconditional expectation of (2.10), differentiating with respect to $\mathbf{E}(\phi_1)$ and making use of (2.11b), and weighting the result by the ratio of the unconditional means $\mathbf{E}(\phi_1)$ and $\mathbf{E}(A_1)$[25]. The final result is:

$$\begin{aligned}
\xi^L_{A,\phi} &= \left[\frac{\partial\mathbf{E}(A_1)}{\partial\mathbf{E}(P_1)}\frac{\partial\mathbf{E}(P_1)}{\partial\mathbf{E}(\phi_1)}\right]\frac{\mathbf{E}(\phi_1)}{\mathbf{E}(A_1)} \\
&= -\left(\frac{\lambda_1 y_1}{d(1-\lambda_1)(1-\beta\lambda_1)}\right)\left[\iota_1+\iota_2\frac{\partial\mathbf{E}(P_1^m)}{\partial\mathbf{E}(\phi_1)}\right]\frac{\mathbf{E}(\phi_1)}{\mathbf{E}(A_1)} \qquad (2.12a)
\end{aligned}$$

The long-run elasticity of expected acreage demand with respect to expected market price of Crop 1, ξ^L_{A,P^m}, is derived in analogous manner:

$$\begin{aligned}
\xi^L_{A,P^m} &= \left[\frac{\partial\mathbf{E}(A_1)}{\partial\mathbf{E}(P_1)}\frac{\partial\mathbf{E}(P_1)}{\partial\mathbf{E}(P_1^m)}\right]\frac{\mathbf{E}(P_1^m)}{\mathbf{E}(A_1)} \\
&= -\left(\frac{\lambda_1 y_1}{d(1-\lambda_1)(1-\beta\lambda_1)}\right)\iota_2\frac{\mathbf{E}(P_1^m)}{\mathbf{E}(A_1)} \qquad (2.12b)
\end{aligned}$$

The corresponding elasticity with respect to R_1 is obtained in the same way:

$$\begin{aligned}
\xi^L_{A,R} &= \frac{\partial\mathbf{E}(A_1)}{\partial\mathbf{E}(R_1)}\frac{\mathbf{E}(R_1)}{\mathbf{E}(A_1)} \\
&= \left(\frac{\lambda_1}{d(1-\lambda_1)(1-\beta\lambda_1)}\right)\frac{\mathbf{E}(R_1)}{\mathbf{E}(A_1)} \qquad (2.12c)
\end{aligned}$$

Recall that: $0<\beta<1$; $0<|\lambda_1|<1$; y_1 is positive; and λ_1 and d can be positive or negative. However, the latter two will have opposite signs since $d \gtrless 0$ implies $\lambda_1 \lesseqgtr 0$[26]. In addition, the nature of the CGD implies that $0<\mathbf{E}(\phi_1)<1$, ι_1 is

[24] Obviously, the two oppsite effects may cancel each other out if they are equal.

[25] Take unconditional expectations of both sides of (2.10) and rearrange to obtain:

$$(1-\lambda_1)\mathbf{E}(A_1) = -(\frac{\lambda_1}{d})\mathbf{E}\left[y_1(\iota_0+\iota_1\phi_1+\iota_2P_1^m)-R_1-V_1\right]\sum_{i=0}^{\infty}(\beta\lambda_1)^i$$

Given $|\beta\lambda_1|<1$, it is also the case that:

$$\sum_{i=0}^{\infty}(\beta\lambda_1)^i = \frac{1}{(1-\beta\lambda_1)}$$

such that:

$$(1-\lambda_1)\mathbf{E}(A_1) = -\left[\frac{\lambda_1}{d(1-\beta\lambda_1)}\right]\mathbf{E}\left[y_1(\iota_0+\iota_1\phi_1+\iota_2P_1^m)-R_1-V_1\right]$$

[26] That, $\lambda_1\lambda_2=\frac{1}{\beta}$, and, $0<\beta<1$, imply, $\lambda_1\lambda_2>0$, such that λ_1 and λ_2 have the same sign. Further, with b and β positive, $\lambda_1+\lambda_2=-\frac{b}{\beta d}$, means that the sign of λ_1 and λ_2 depends on that of d. In short, if $d\gtrless 0$, then, $\lambda_1+\lambda_2\lesseqgtr 0$, and thus, $\lambda_1,\lambda_2\lesseqgtr 0$.

negative, and $0 < \iota_2 < 1$. By making use of these features, the following can be inferred from (2.12a)-(2.12c)[27].

1) The long-run 'quota' elasticity, $\xi^L_{A,\phi}$, is negative if both the direct and indirect effects of ϕ_1 are negative, or if the latter, though positive, is less than the former in absolute value:
$$|\iota_1| > \iota_2 \frac{\partial \mathbf{E}(P_1^m)}{\partial \mathbf{E}(\phi_1)}$$
It implies that the imposition of, or increase in the rate of, the 'quota' on Crop 1 reduces the acreage share of that crop in the long-run. The impact occurs via the average price, P_1. A rise in the mean rate of 'quota' decreases the mean P_1, and thereby makes Crop 1 less profitable. As a result the household lowers its mean acreage demand for that crop, provided that it is feasible to do so. The reduction is conditioned by production possibilities via b, y_1, and d, as well as household rate of time preference through β. If Crop 2 is free from the 'quota' the household switches into that crop. If Crop 2 is also subject to 'quota', however, the choice between the two crops will be affected not only by production possibilities, but also by the relative magnitude of the two 'quota' rates[28]. Briefly, in the long-run, the system of forced grain procurement may reduce the production of the crops it directly affects, and may even lead to a fall in crop production as whole. On the other hand, the $\xi^L_{A,\phi}$ is positive if:
$$|\iota_1| < \iota_2 \frac{\partial \mathbf{E}(P_1^m)}{\partial \mathbf{E}(\phi_1)}$$
In other words, a positive indirect effect more than compensates for the negative direct effect, such that mean P_1 rises. This rise, in turn, provides the incentive for the household to increase its long-run acreage demand for Crop 1.

2) The long-run price elasticity, ξ^L_{A,P^m}, is positive but lower than what it would have been in the absence of CGD. Indeed a one percent rise in Crop 1's market price counts as a ι_2 percent (less than one percent) increase for the farm household's acreage decisions. Thus, the system of compulsory grain delivery reduces the long-run price responsiveness of crop supply.

3) The long-run elasticity of acreage demand for Crop 1 production with respect to R_1, $\xi^L_{A,R}$, is negative. A permanent rise in the revenue (per hectare) obtainable from the cultivation of Crop 2 creates the incentive for the household to switch into that crop, and out of Crop 1.

2.3.2 Short-run elasticities

The short-run elasticities capture the effect, on current acreage demand, of changes in expected prices and 'quota' rates, $(i+1)$ periods hence. These elasticities are computed in the same way as their long-run counterparts, but directly using (2.10),

[27]Note that analogous results hold in the static case under certainity (see Taffesse (1999)).

[28]Note, however, that this possible impact on acreage allocations to Crop 1 will operate through the 'profitability' of Crop 2. In the empirical application below this profitability is included in the acearage equation.

with (2.11b), and (2.11c). For ϕ_1, P_1^m, and R_1 these elasticities, evaluated at the unconditional means of ϕ_1, P_1^m, R_1, and A_1, are:

$$
\begin{aligned}
\xi_{A,\phi}^{i+1} &= \left[\frac{\partial \mathbf{E}_{t+j}(A_{t+j})}{\partial \mathbf{E}_{t+j}(P_{1,t+j+1+i})}\frac{\partial \mathbf{E}_{t+j}(P_{1,t+j+1+i})}{\partial \mathbf{E}_{t+j}(\phi_{1,t+j+1+i})}\right]\frac{\mathbf{E}(\phi_1)}{\mathbf{E}(A_1)} \\
&= -\left(\frac{\lambda_1 y_1}{d}\right)(\beta\lambda_1)^i\left[\iota_1 + \iota_2\frac{\partial \mathbf{E}_{t+j}(P_{1,t+j+1+i}^m)}{\partial \mathbf{E}_{t+j}(\phi_{1,t+j+1+i})}\right]\frac{\mathbf{E}(\phi_1)}{\mathbf{E}(A_1)} \qquad (2.13a)
\end{aligned}
$$

$$
\begin{aligned}
\xi_{A,P^m}^{i+1} &= \left[\frac{\partial \mathbf{E}_{t+j}(A_{t+j})}{\partial \mathbf{E}_{t+j}(P_{1,t+j+1+i})}\frac{\partial \mathbf{E}_{t+j}(P_{1,t+j+1+i})}{\partial \mathbf{E}_{t+j}(P_{1,t+j+1+i}^m)}\right]\frac{\mathbf{E}(P_1^m)}{\mathbf{E}(A_1)} \\
&= -\left(\frac{\lambda_1 y_1}{d}\right)(\beta\lambda_1)^i\iota_2\frac{\mathbf{E}(P_1^m)}{\mathbf{E}(A_1)} \qquad (2.13b)
\end{aligned}
$$

$$
\begin{aligned}
\xi_{A,R}^{i+1} &= \frac{\partial \mathbf{E}_{t+j}(A_{t+j})}{\partial \mathbf{E}_{t+j}(R_{1,t+j+1+i})}\frac{\mathbf{E}(R_1)}{\mathbf{E}(A_1)} \\
&= \left(\frac{\lambda_1}{d}\right)(\beta\lambda_1)^i\frac{\mathbf{E}(P_1^m)}{\mathbf{E}(A_1)} \qquad (2.13c)
\end{aligned}
$$

Again the aforementioned results concerning λ_1, β, d, y_1, ι_1, and ι_2 are used. In addition, note that, given the sign of d, the sign of $(\beta\lambda_1)^i$, depends on whether i is even or odd. Suppose the decline in land productivity is the dominant dynamic effect such that d is positive. Then λ_1 and $(\beta\lambda_1)$ are negative. Hence, $(\beta\lambda_1)^i$ is negative (positive) with i odd (even). In contrast, d is negative if adjustment costs dominate dynamic behaviour. Accordingly, λ_1, and $(\beta\lambda_1)$, are positive, such that $(\beta\lambda_1)^i$, is positive for all i. Hence:

$$
\begin{aligned}
(\beta\lambda_1)^i &< 0, \; if \;\; (d > 0 \; and \; i \; is \; odd) \\
(\beta\lambda_1)^i &> 0, \; if \;\; (d > 0 \; and \; i \; is \; even) \;\; or \;\; (d < 0)
\end{aligned}
$$

Note also that $(\beta\lambda_1)^i$, approaches zero as i gets larger, implying the further into the future a period is the less important to current decisions it becomes. These features enable us to make the following observations concerning short-run elasticities on the basis of (2.13a)-(2.13c).

1) The short-run elasticity of acreage demand with respect to expected rate of 'quota' alternates sign with i if $d > 0$. It is, however, negative for all i provided that $d < 0$, and that the direct and indirect effects of ϕ_1 are both negative, or if: the latter, though positive, is less than the former in absolute value:

$$|\iota_1| > \iota_2\frac{\partial \mathbf{E}(P_{1,t+j+1+i}^m)}{\partial \mathbf{E}(\phi_{1,t+j+1+i})}$$

Furthermore, as the forecast period becomes longer (i.e., the higher i is), this elasticity gets closer to zero.

2) The short-run elasticity of acreage demand with respect to expected market price of Crop 1 alternates sign with i if $d > 0$. It is, however, positive for all i provided that $d < 0$. Like its long-run counterpart, this elasticity is lower than the level that would obtain in a CGD-free environment. In addition, the magnitude of this elasticity becomes smaller in absolute value as the forecast period gets longer.

3) The short-run elasticity of acreage demand with respect to R_1 alternates sign with i if $d > 0$. It is, however, negative for all i provided that $d < 0$. Like the other short-run acreage elasticities, this elasticity declines (in absolute value) towards zero as the forecast period gets longer.

Two examples illustrate some of these features. In both cases, assume that the effect of expected ϕ_1 on expected P_1 is negative. First, suppose the farm household anticipates a rise in next (or harvest) period's 'quota' rate. In this case, where $i = 0$, the short-run elasticity is negative, implying that the household responds by reducing the current acreage share of Crop 1. The household expects a lower return from cultivating Crop 1 and accordingly reduces its current acreage allocation to that crop. In contrast, an expected increase in the harvest period's P_1^m, and thus a higher profit from Crop 1, will induce a higher acreage share for the crop. Second, suppose the household expects ϕ_1 to rise two periods hence (i.e., $i = 1$ or during $t + j + 2$). Consequently that period's expected return from Crop 1 falls. Further assume that $d > 0$. Then deteriorating soil fertility means that the household has to plant more (less) of Crop 1 during $(t+j+1)$ depending on whether it has cultivated less (more) of that crop during the current period (i.e., $t+j$). To counter the potential loss of revenue and simultaneously satisfy the need for crop rotation the household grows more of Crop 1. In short, current acreage demand for Crop 1 rises because lower expected profitability combines with the dynamic effect of declining land productivity to make that crop more attractive for current production. On the other hand, since it involves a potential gain in income, the converse will apply for an expected increase in Crop 1's market price that will obtain during $(t + j + 2)$.

To summarize, by decreasing the returns to farm households, CGD is likely to have reduced, directly as well as through lower own-price responsiveness, the long-run acreage share (and thus output supply) of the crops it affected. The corresponding short-run effects are more complicated in that they also depend on the pattern of the dynamic effects at work. Moreover, both of these effects are further complicated by the impact of the 'average' rate of 'quota' on market price - an impact which cannot be signed *a priori*. On the other hand, it is shown that acreage demand generally responds positively to a crop's own price and negatively to the revenue from competing crops.

3 Empirical Analysis

3.1 The Data

The basic features of the data used are described in this section. The main sources of information are the publications of the Central Statistical Authority (CSA) and the Ethiopian Agricultural Marketing Agency (EAMC)[29]. The dataset thus compiled contains information on: acreage, output, and yield of major annual crops; producer prices of crops; and EAMC purchases and procurement prices.

Before moving on to considering other characteristics of the data, the following remarks about its spatial and temporal dimensions are deemed helpful.

1. The unit of observation are administrative regions. Up to 1988 there were 14 administrative regions in the country. Of these data is not available for two (Eritrea and Tigray). In 1988 a new administrative structure with thirty regions was introduced. Twenty-six of these are covered by the dataset used. In addition to Eritrea and Tigray, two new regions (Assab and Ogaden) are not covered by the reports available[30]. The twenty-six regions are aggregated into twelve to make the coverage compatible with that of the previous years[31]. Although inexact, this aggregation is not likely to involve substantial errors.

2. The data set covers the period from 1980/81 to 1989/90. There are a number of reason for restricting the analysis to this period. First, although introduced in 1979, the centralized CGD system was not fully operational until 1981. This was particularly true of its impact on farm households. Second, the main source of consistent time-series data is the annual Agricultural Sample Survey of the CSA. This Survey has began in 1980/81. Third, the CGD system was abolished in 1990. Fourth, a new government assumed power in 1991, and subsequently adopted a radically different administrative structure as well as an economic structural adjustment program. The first two facts mean that it is reasonable to start with 1980/81, whereas the last two imply that it is problematic to go beyond 1989/90.

3.1.1 acreage allocation patterns

Table 1 reports the average regional acreage shares of cereals as a group and its five main constituents[32]. The first row of figures in that table confirm what has

[29]As part of the grain market reforms, this agency has been reorganized and renamed the Ethiopian Grain Trade Enterprise (EGTE).

[30]Assab and Ogaden are not major crop producing areas. That they are not included for the years 1988/89 and 1989/90 is unlikely to materially affect compatiblity with the data for the years before 1988.

[31]The aggregation involved the following. For 1988/89 and 1989/90:

Old	**New**
Arssi =	Arssi
Bale =	Bale
Gamo Gofa =	North Omo + South Omo
Gojam =	East Gojam + West Gojam + Metekel
Gondor =	North Gondor + South Gondor
Hararghe =	West Hararghe + East Hararghe + Dire Dawa
Illubabor =	Illubabor + Gambela
Keffa =	Keffa
Shewa =	East Shewa + North Shewa + South Shewa + West Shewa
Sidamo =	Sidamo + Borena
Wellega =	Wellega + Asosa
Wollo =	North Wollo + South Wollo

[32]Note that Producers' Cooperatives and State Farms are excluded, such that all figures relate to private peasant producers

Table 1: **Mean Regional Acreage Shares (1981-90)**

Region	*Cereals*	*Barley*	*Maize*	*Sorghum*	*Teff*	*Wheat*
National	0.87 (0.06)	0.18 (0.13)	0.25 (0.18)	0.18 (0.16)	0.23 (0.13)	0.10 (0.10)
Arssi	0.83 (0.03)	0.37 (0.04)	0.11 (0.02)	0.05 (0.02)	0.10 (0.02)	0.34 (0.04)
Bale	0.89 (0.03)	0.43 (0.06)	0.12 (0.05)	0.01 (0.01)	0.08 (0.04)	0.25 (0.04)
Gamo Gofa	0.92 (0.04)	0.14 (0.03)	0.37 (0.12)	0.31 (0.07)	0.15 (0.08)	0.03 (0.02)
Gojam	0.81 (0.02)	0.21 (0.06)	0.13 (0.02)	0.05 (0.02)	0.43 (0.03)	0.08 (0.02)
Gondor	0.75 (0.02)	0.24 (0.07)	0.06 (0.02)	0.18 (0.04)	0.33 (0.04)	0.09 (0.03)
Hararghe	0.94 (0.02)	0.05 (0.02)	0.26 (0.08)	0.59 (0.08)	0.05 (0.01)	0.04 (0.01)
Illubabor	0.92 (0.02)	0.05 (0.02)	0.41 (0.03)	0.18 (0.03)	0.32 (0.02)	0.02 (0.01)
Keffa	0.90 (0.03)	0.06 (0.01)	0.41 (0.06)	0.19 (0.04)	0.26 (0.07)	0.04 (0.02)
Shewa	0.82 (0.02)	0.19 (0.03)	0.17 (0.03)	0.14 (0.03)	0.33 (0.03)	0.17 (0.02)
Sidamo	0.91 (0.02)	0.12 (0.04)	0.61 (0.10)	0.07 (0.03)	0.15 (0.05)	0.04 (0.02)
Wellega	0.87 (0.02)	0.07 (0.02)	0.33 (0.07)	0.15 (0.03)	0.36 (0.04)	0.02 (0.01)
Wollo	0.82 (0.04)	0.27 (0.09)	0.05 (0.02)	0.27 (0.08)	0.25 (0.04)	0.14 (0.02)

NOTES: Standard deviations in parentheses. Shares are computed from data copmiled from CSA, Statistical Bulletin No. 56, No. 74, No. 79, and No.103. The share of cereals is out of total acreage cultivated with annual crops, while those of individual crops are out of total cereal acreage.

been observed before; cereals constitute by far the most important annual crop to farm households, accounting for more than 80 per cent of the total area planted with annual crops. The rest is cultivated with pulses and oil seeds. From among cereals, maize and *Teff* have the largest shares, respectively accounting for 25 per cent and 23 per cent. The table also shows the considerable regional variation in land allocation among crops. For instance, Arssi and Bale farm households concentrate on growing barley and wheat, while those residing in Gojam, Gondar, Shewa, and Wollo allocate more than half of cereal-cultivated land to barley and *Teff.* Such variation reflects differences in natural endowments, technological possibilities, tastes, and the historical processes which affect all of these regional and individual attributes. In the analysis below, this regional variation will be exploited jointly with the variation across time periods.

3.1.2 'quota' rates

The available data regarding EAMC's procurement of crops from farm households can be grouped into two[33]. The first group consists of the annual domestic purchases of EAMC by crop (including the five major cereals) and source of supply (including merchants, and farm households via Peasant Associations and Service Cooperatives). The second category is formed by the annual purchases of EAMC from farmers and merchants (together), by crop and administrative region. From the first set the share, at the national level, of farm households in the total domestic procurement of different crops by EAMC can be computed. The analogous share of merchants is similarly obtained. The relative shares of the two suppliers are then calculated, and the results are subsequently applied on the corresponding regional procurements from

[33]All the information concerning the operations of the EAMC are compiled from EAMC (1987) and EGTE (1995).

Table 2: **Mean Regional 'Quota' Rates (1981-90)**

Region	*Barley*	*Maize*	*Sorghum*	*Teff*	*Wheat*
National	0.02 (0.03)	0.02 (0.05)	0.02 (0.03)	0.03 (0.05)	0.05 (0.08)
Arssi	0.08 (0.05)	0.07 (0.15)	0.03 (0.03)	0.01 (0.01)	0.19 (0.08)
Bale	0.07 (0.07)	0.02 (0.02)	0.02 (0.02)	0.01 (0.03)	0.19 (0.11)
Gamo Gofa	0.00 (0.00)	0.01 (0.01)	0.00 (0.01)	0.01 (0.01)	0.00 (0.00)
Gojam	0.03 (0.02)	0.03 (0.02)	0.08 (0.05)	0.18 (0.06)	0.08 (0.03)
Gondor	0.01 (0.01)	0.01 (0.01)	0.02 (0.01)	0.01 (0.01)	0.01 (0.01)
Hararghe	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	0.01 (0.02)	0.03 (0.07)
Illubabor	0.00 (0.01)	0.01 (0.01)	0.01 (0.02)	0.01 (0.01)	0.00 (0.01)
Keffa	0.02 (0.04)	0.01 (0.01)	0.01 (0.01)	0.00 (0.01)	0.01 (0.01)
Shewa	0.03 (0.02)	0.08 (0.04)	0.04 (0.03)	0.05 (0.01)	0.06 (0.03)
Sidamo	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.03 (0.03)	0.01 (0.01)
Wellega	0.01 (0.01)	0.03 (0.03)	0.02 (0.02)	0.03 (0.02)	0.04 (0.03)
Wollo	0.00 (0.00)	0.03 (0.04)	0.02 (0.01)	0.01 (0.01)	0.01 (0.01)

NOTES: Standard deviations in parentheses.

farmers and merchants so as to arrive at an estimate of the annual level of 'quota' by crop and administrative region. Finally, the ratio of the 'quota' level thus obtained to the corresponding regional output gives us the desired 'quota' rates. In short the next formula is used:

$$\phi_{ikt} = \frac{\left(\frac{s_{it}^F}{s_{it}^F + s_{it}^M}\right) X_{ikt}}{Q_{ikt}}$$

where: ϕ_{ikt} is the rate of 'quota' applying to crop i and region k in year t; s_{it}^F and s_{it}^M are, respectively, the (national) share of farm households and merchants in EAMC's total domestic procurement of crop i in year t; X_{ikt} represents the total amount of crop i purchased by EAMC from the farmers and merchants of region k in year t; and Q_{ikt} is the total output of crop i produced by the farm households of region k in year t. The rates calculated in this manner are to be viewed as the average rates of 'quota' which farm households of region k faced during year t.

At the national level, the average share of farm households in EAMC's total domestic purchases range from 60 percent for maize to 76 percent for $Teff$. The corresponding 'quota' rates range from 2-5 percent (see Table 2). However, there were substantial regional differences in 'quota' rates. The relevant rates for the five main cereals are summarized in Table 2. The average regional 'quota' rate can be as low as zero for most crops (Gamo Gofa), and as high as 19 percent for wheat (Arssi and Bale). In this regard, the general pattern has been that higher regional output of a crop meant higher regional 'quota' level. The corresponding correlations are all positive, and are large and mostly significant (see Table 3). This pattern reflects the 'quota' determination process described above. It also provides some support to the argument that the 'quota' should be treated as an implicit proportional output tax[34].

[34] It does not however imply that these two variables are positively correlated overtime.

Table 3: **Correlations between Regional Crop Output and 'Quota' Level**

Year	*Barley*	*Maize*	*Sorghum*	*Teff*	*Wheat*
1980/81	0.60 (0.038)	0.77 (0.004)	0.59 (0.045)	0.63 (0.027)	0.70 (0.011)
1981/82	0.52 (0.083)	0.84 (0.001)	0.68 (0.016)	0.63 (0.029)	0.72 (0.008)
1982/83	0.49 (0.106)	0.36 (0.246)	0.58 (0.049)	0.79 (0.002)	0.60 (0.041)
1983/84	0.48 (0.113)	0.80 (0.002)	0.53 (0.075)	0.67 (0.016)	0.66 (0.018)
1984/85	0.90 (0.000)	0.77 (0.003)	0.20 (0.536)	0.84 (0.001)	0.92 (0.000)
1985/86	0.53 (0.076)	0.49 (0.102)	0.66 (0.019)	0.81 (0.001)	0.82 (0.001)
1986/87	0.59 (0.042)	0.81 (0.002)	0.80 (0.002)	0.75 (0.005)	0.77 (0.004)
1987/88	0.88 (0.000)	0.74 (0.006)	0.56 (0.059)	0.71 (0.010)	0.90 (0.000)
1988/89	0.81 (0.001)	0.86 (0.000)	0.39 (0.218)	0.70 (0.011)	0.86 (0.000)
1989/90	0.95 (0.000)	0.87 (0.000)	0.56 (0.057)	0.80 (0.002)	0.95 (0.000)

NOTES: Each entry is Pearson's correlation coefficient between regional output and 'quota' level of the crop identified in the column, during the year identified in the row. Figures in parentheses are two-tailed significance levels.

Table 4: **Mean Panterritorial Procurement Crop Prices (1981-90)**

Barley	*Maize*	*Sorghum*	*Teff*	*Wheat*
28.2 (1.93)	20.0 (1.83)	23.8 (1.34)	39.3 (2.21)	31.6 (0.97)

NOTES: Current prices in Birr per Quintal. Computed form the information in EAMC (1987). Standard deviations in parentheses.

3.1.3 crop prices

Two sets of crop prices are relevant for the present analysis, namely, procurement prices and market prices. Procurement prices were administratively determined by the central government. They were also pan-territorial in that they apply to all parts of the country. Mean procurement prices for the five main cereals are reported in Table 4. As indicated by the low standard deviations, these prices did not change significantly in the 1980s. In fact they were raised only once for barley and wheat, and twice for the remaining three cereals during that period. Not only were the increases infrequent, they were also very modest, involving Birr 1 - Birr 4 per quintal (or less than 10 percent for the entire period) [35].

Market prices, in contrast, refer to producers' prices which obtained on the 'free' market. In this regard, the CSA collects monthly retail and producers' prices in rural areas since 1981. The data thus collected are summarized as regional quarterly prices and are published[36]. Annual regional producers' prices of crops are computed as the simple mean of the corresponding quarterly prices[37]. Table 5 reports the cereal prices calculated in this manner. First, these prices are considerably higher than the corresponding procurement prices. Second, substantial regional variation in crop prices can be observed. It is reasonable to expect that this variation reflects regional aspects of demand and supply including production patterns, supply shocks, and the degree of urbanization.

[35] Unpublished EAMC document.

[36] For the years 1987/88-1989/90 the monthly prices themselves are reported.

[37] Ideally some weighting scheme is desirable to account for seasonality. In the absence of any information that can serve as a basis for devising such a scheme, the simple strategy is opted for.

Table 5: **Mean Regional Market Crop Prices (1981-90)**

Region	*Cereals*	*Barley*	*Maize*	*Sorghum*	*Teff*	*Wheat*
National	54.5 (19.9)	54.4 (19.2)	47.6 (19.4)	52.6 (21.6)	74.8 (25.0)	65.4 (20.2)
Arssi	44.7 (13.1)	38.2 (11.4)	38.1 (12.0)	46.0 (12.6)	68.6 (18.6)	51.3 (14.7)
Bale	45.3 (14.4)	44.9 (14.6)	47.1 (17.0)	54.8 (18.4)	72.1 (23.2)	60.4 (18.8)
Gamo Gofa	47.1 (12.0)	47.9 (11.3)	40.9 (12.3)	42.4 (11.8)	75.1 (16.0)	70.3 (14.7)
Gojam	43.6 (11.6)	42.7 (13.4)	36.2 (9.9)	33.2 (9.6)	51.6 (13.9)	48.8 (13.8)
Gondor	55.3 (15.4)	50.9 (16.3)	45.2 (14.0)	51.8 (16.7)	65.0 (18.0)	57.6 (16.4)
Hararghe	70.9 (22.4)	70.8 (23.6)	63.3 (18.9)	73.4 (23.9)	96.1 (22.1)	79.0 (24.2)
Illubabor	54.8 (15.3)	61.8 (14.7)	47.2 (13.8)	48.5 (14.6)	75.7 (23.7)	66.9 (15.1)
Keffa	47.8 (15.5)	52.4 (17.3)	41.0 (16.2)	43.9 (12.1)	68.9 (19.6)	62.6 (17.7)
Shewa	66.0 (23.6)	59.7 (20.5)	51.3 (21.6)	59.8 (25.9)	84.1 (27.7)	75.8 (21.6)
Sidamo	50.2 (11.3)	56.0 (11.4)	45.4 (10.5)	53.4 (23.0)	74.3 (17.3)	67.5 (12.6)
Wellega	53.4 (13.1)	58.9 (15.2)	45.8 (12.4)	50.5 (13.5)	68.3 (18.6)	67.9 (19.9)
Wollo	75.0 (33.9)	69.0 (28.9)	69.5 (36.8)	73.0 (34.0)	97.4 (42.1)	77.4 (28.8)

NOTES: Current prices in Birr per Quintal. Computed form the information in CSA (1985), CSA (1988a), CSA (1988b), CSA (1991a), CSA (1991b), CSA (1992) . Standard deviations in parentheses.

3.2 Econometric Specification

In this section an estimable form of the farm household's acreage demand decision rule is specified.[38] The formulation is a specific application of equation (A2.9) in the appendix, *Teff* taking the place of Crop 1[39]. *Teff* is a major cereal in terms acreage and output shares accounting, respectively, for 23 per cent and 17 per cent. It is highly demanded as a food crop, particularly in urban areas. Partly as a consequence of this demand, it is the most commercialized food crop, constituting a major (for many parts of the country the major) source of cash income for farm households. For the same reason *Teff* has also been the main target of EAMC in its cereal procurement effort. On average, it accounted for 36 per cent of EAMC's annual cereal purchases from farm households. As a result, the imposition of the *Teff* 'quota' on farm households is likely to have had a very large impact on their cash income and, through it, their welfare. These reasons are behind the decision to make *Teff* the focus of the empirical analysis.

Equation (A2.9) represents a closed form solution for the decision rule for A_{1t}. It expresses the optimal acreage allocation rule of the farm household as a function of acreage allocated last period, current output price, current and once-lagged 'quota' rate, and current actual and opportunity costs of cultivating Crop 1. As it stands, equation (A2.9) is nonstochastic, however. All right-hand-side variables are elements of the farm household's information set at t (or Ω_t). Moreover, data on V_{1t} is not available. A solution to both is provided by the Koyck transformation. Applying the Koyck transformation, $(A_{1t} - \omega A_{1,t-1})$, and using, $(1 - \rho L)V_{1t} = u_t^V$ (see equation (A2.4)), leads to:

$$A_{1t} \quad = \quad \kappa_0 + \kappa_1 A_{1,t-1} + \kappa_2 A_{1,t-2} + \kappa_3 P_{1t}^m + \kappa_4 P_{1,t-1}^m + \kappa_5 \phi_{1t} + \kappa_6 \phi_{1,t-1} + \kappa_7 \phi_{1,t-2}$$

[38]See the second section of the appendix for a discussion on why equation (2.10) does not represent a decision rule as well as the procedure used to derive an explicit acreage decision rule.

[39]For the sake of notational economy, the subscript 1 is retained, but now used to identify variables relating to *Teff* .

$$+\kappa_8 R_{1t} + \kappa_9 R_{1,t-1} + \epsilon_t \tag{3.1}$$

where: $\kappa_0 = \omega_0(1-\rho)$; $\kappa_1 = \lambda_1 + \rho$; $\kappa_2 = \rho\lambda_1$; $\kappa_3 = \omega_3$; $\kappa_4 = -\rho\omega_2$; $\kappa_5 = \omega_3$; $\kappa_6 = (\omega_4 - \rho\omega_3)$; $\kappa_7 = -\rho\omega_4$; $\kappa_8 = \omega_5$; $\kappa_9 = -\rho\omega_5$; and $\epsilon_t = \omega_6 u_t^V$. In the process a stochastic relation estimable with available data is obtained. In equation (3.1) ϵ_t represents shocks to non-land costs of producing *Teff* and other cereals. It can also be used as a means of including random errors of optimization and errors in data [Epstein and Yatchew (1985)]. This equation is directly estimated as the unrestricted reduced form of the structural model. In this regard no attempt is made to recover the structural parameters. Thus, the restrictions implied by the underlying model are neither exploited nor their validity established empirically. However, the primary objective of estimating acreage elasticities can be achieved using the unrestricted version. Next, a brief discussion of how these elasticities are computed.

The long-run elasticity of expected acreage demand with respect to mean ϕ_1, $\left(\xi^L_{A,\phi}\right)$, is derived by first taking the unconditional expectation of (3.1), differentiating with respect to $\mathbf{E}(\phi_1)$, and weighting the result by the ratio of the unconditional means $\mathbf{E}(\phi_1)$ and $\mathbf{E}(A_1)$. The result is:

$$\xi^L_{A,\phi} = \frac{\partial \mathbf{E}(A_1)}{\partial \mathbf{E}(\phi_1)} \frac{\mathbf{E}(\phi_1)}{\mathbf{E}(A_1)} = \left[\frac{\kappa_5 + \kappa_6 + \kappa_7}{(1-\kappa_1-\kappa_2)}\right] \frac{\mathbf{E}(\phi_1)}{\mathbf{E}(A_1)} \tag{3.2a}$$

The long-run elasticity of expected acreage demand with respect to mean P_1^m and mean R_1 are obtained similarly:

$$\xi^L_{A,P^m} = \frac{\partial \mathbf{E}(A_1)}{\partial \mathbf{E}(P_1^m)} \frac{\mathbf{E}(P_1^m)}{\mathbf{E}(A_1)} = \left[\frac{\kappa_3 + \kappa_4}{(1-\kappa_1-\kappa_2)}\right] \frac{\mathbf{E}(P_1^m)}{\mathbf{E}(A_1)} \tag{3.2b}$$

$$\xi^L_{A,R} = \frac{\partial \mathbf{E}(A_1)}{\partial \mathbf{E}(R)} \frac{\mathbf{E}(R)}{\mathbf{E}(A_1)} = \left[\frac{\kappa_8 + \kappa_9}{(1-\kappa_1-\kappa_2)}\right] \frac{\mathbf{E}(R)}{\mathbf{E}(A_1)} \tag{3.2c}$$

The corresponding short-run elasticities, $\xi^S_{A,\phi}$, ξ^S_{A,P^m}, and $\xi^S_{A,R}$ are computed in an analogous fashion. All are evaluated at the unconditional means of acreage shares, prices, and the rate of 'quota' associated with *Teff,* and appear as:

$$\xi^S_{A,\phi} = \frac{\partial(A_{1,t})}{\partial(\phi_{1t})} \frac{\mathbf{E}(\phi_1)}{\mathbf{E}(A_1)} = \kappa_5 \frac{\mathbf{E}(\phi_1)}{\mathbf{E}(A_1)} \tag{3.3a}$$

$$\xi^S_{A,P^m} = \frac{\partial(A_{1,t})}{\partial(P_{1t}^m)} \frac{\mathbf{E}(P_{1t}^m)}{\mathbf{E}(A_1)} = \kappa_3 \frac{\mathbf{E}(P_1^m)}{\mathbf{E}(A_1)} \tag{3.3b}$$

$$\xi^S_{A,R} = \frac{\partial(A_{1,t})}{\partial(R_{1t})} \frac{\mathbf{E}(R_{1t})}{\mathbf{E}(A_1)} = \kappa_8 \frac{\mathbf{E}(R_1)}{\mathbf{E}(A_1)} \tag{3.3c}$$

3.3 Estimation Procedure

The models for A_1, P_1^m, ϕ_1 are estimated using available data on the relevant variables. As noted above the data set employed is composed of region-level information over ten years. To exploit this panel dimension, the equations are restated in the appropriate form by introducing regional effects. The resulting *Teff* acreage demand can be written as:

$$y_{it} = \kappa_1 y_{i,t-1} + \kappa_2 y_{i,t-2} + K_3 x'_{it} + K_4 x'_{i,t-1} + K_5 x'_{i,t-2} + \eta_i + \nu_{it}, \qquad t \geq 3 \tag{3.4}$$

where: i $(i = 1, \cdots, N)$ identifies regions; $y \equiv A_1$; $x = \left[\begin{array}{ccc} P_1^m & \phi_1 & R_1 \end{array} \right]$; η_i = unobserved region-specific effects; and

$$K_3 = \left[\begin{array}{ccc} \kappa_3 & \kappa_5 & \kappa_8 \end{array} \right], \quad K_4 = \left[\begin{array}{ccc} \kappa_4 & \kappa_6 & \kappa_9 \end{array} \right], \quad K_5 = \left[\begin{array}{ccc} 0 & \kappa_7 & 0 \end{array} \right]$$

To ensure stationarity, it is also assumed that, $\kappa_1 + \kappa_2 < 1$, $\kappa_2 - \kappa_1 < 1$, and $\kappa_2 > -1$[40]. Similarly, the following for the *Teff* price equation and the *Teff* 'quota' rate equation are respectively obtained:

$$y_{it}^P = \theta_1 y_{i,t-1}^P + \theta_2 x_{i,t-1}^P + \theta_3 x_{i,t-2}^P + \eta_i^P + \nu_{it}^P, \qquad |\theta_1| < 1, \;\; t \geq 3 \qquad (3.5)$$

$$y_{it}^\phi = \gamma y_{i,t-1}^\phi + \eta_i^\phi + \nu_{it}^\phi, \qquad |\gamma| < 1, \;\; t \geq 2 \qquad (3.6)$$

where: $y^P = P_1^m$, $x^P = \phi_1$, and $y^\phi = \phi_1$. Again, the subscript i indexes regions. Note that:

$$\eta_i + \nu_{it} = \epsilon_{it}, \qquad \eta_i^P + \nu_{it}^P = u_{it}^P, \qquad \eta_i^\phi + \nu_{it}^\phi = u_{it}^\phi$$

represent the "fixed effects" decomposition of the disturbance terms commonly adopted in panel data models, with ν_{it}'s representing white noise..

Equations (3.4)-(3.6) form a set of dynamic panel data models. Thus each has to be estimated using estimation techniques applicable to such models. Recently, a variety of estimators have been developed for the parameters of these models [Anderson and Hsiao (1982), Arellano and Bond(1991), Arellano and Bover (1995), Blundell and Bond (1995)]. From among alternatives, a specific variant of the linear Generalized Method of Moments (GMM) estimator is chosen, namely, the system estimator proposed by Blundell and Bond (1995). This estimator is based on the estimation of the first-difference equations and the levels equations together as a system. In this process, lagged levels of (y, x) are used as instruments for the equations in first differences, while lagged differences are used as instruments for the equations in levels. To distinguish between them, this estimator and the usual GMM estimator based on the equations in first differences, are referred to as the GMM(II) estimator and the GMM(I) estimator, respectively[41].

The estimation results are reported in Tables 6-8. To highlight the advantages derived from using the GMM(II) estimator, results relating to some of the alternatives are also presented. The GMM(I) and GMM(II) estimates are reported for all equations. Two more estimates for the *Teff* acreage demand equation are also reported. The first is obtained by applying OLS directly to the pooled data (i.e., ignoring regional effects). The results included in the column of Table 8 identified as OLS. The second is derived by applying the Within-groups estimator. To accommodate regional effects, this estimator uses the data transformed by subtracting the appropriate time-means of the relevant variables. The resultant estimates are reported under the heading 'Within' in Table 8.

In addition to the estimates themselves, a number of test statistics are reported.

1. The first pair relate to the Wald tests of the joint significance of the regressors and the time-dummies, respectively. One is a test of the null hypothesis that the estimated coefficients of the regressors in an equation are all zero. Under

[40] These conditions ensure the stationarity of an AR(2) process [see, for instance, Davidson and MacKinnon (1993)]. In this regard, recall that, in the present case, $|\kappa_1| = |\lambda_1 + \rho| < 2$, and $|\kappa_2| = |\lambda_1 \rho| < 1$, since $|\lambda_1| < 1$ and $|\rho| < 1$.

[41] Further details regarding the two estimators are provided in the appendix.

the null the test statistic is asymptotically distributed $\chi^2(p)$, where the degrees of freedom p is equal to the number of regressors. This statistic is reported as χ^2-Regressors. The other relates to the null hypothesis that the coefficients of the time dummies are jointly zero. It is asymptotically distributed $\chi^2(q-1)$ under the null, where q is equal to the number of time-dummies. This statistic is reported as χ^2-Time dummies.

2. The second pair of reported test statistics is associated with testing the absence of first-order and second-order serial correlation in the residuals. Because, the first-differenced residual is an MA(1) process, first-order serial correlation is to be expected. On the other hand, if the original residuals are serially independent, there will be no second-order autocorrelation in the residuals of the equations in first differences. Thus, not rejecting the null of no second-order serial correlation in the first-difference residuals implies either no serial correlation in the errors in levels or the residuals in levels follow a random walk. The former is necessary for the consistency of the GMM estimators, while the latter will make both OLS and GMM estimates of the first-difference equation consistent. Which of the two possibilities (no serial correlation in the errors in levels or the residuals in levels follow a random walk) apply may be determined by the test for first-order serial correlation in the differenced residuals. In this regard, Arellano and Bond (1991) developed test statistics for first-order and second-order serial correlation based on the residuals from the equations in first-differences. Under the respective nulls these tests are distributed asymptotically as standard normal[42]. The tests are reported as m_1 and m_2.

3. The Sargan test of the overidentifying (moment) restrictions is the third test reported. It is based on the two-step estimates of the model in first-differences. Under the null of optimal instruments, the Sargan test-statistic is asymptotically distributed $\chi^2(r)$ with as many degrees of freedom as overidentifying restrictions[43]. In the tables of results, this statistic is reported as χ^2-Sargan test.

4. Finally, the Akaike Information Criteria (AIC) is reported for the market price and the 'quota' rate equations. It is computed as[44]:

$$AIC = \ln\left(\frac{RSS}{N(T-2)}\right) + \frac{2K}{N(T-2)}$$

where: RSS is the residual sum of squares, and K represents the number of regressors. A lower AIC suggests a better specification.

[42] For further details regarding these tests consult Arellano and Bond (1988, 1991).

[43] See Arellano and Bond (1988, 1991).

[44] The common formula for AIC is [Greene (1993)]:

$$AIC = \ln\left(\frac{RSS}{T}\right) + \frac{2K}{T}$$

The formula in the text is adopted to account for the panel dimension of the data used and the lag structure of the equations estimated.

3.4 Results

This section presents the main empirical findings[45,46]. These findings are summarized in Tables 6-9. Before considering other results, let us remark on the merits of the two main estimators employed. Overall, the GMM(II) estimator performed better than its GMM(I) counterpart. The efficiency gains due to the former are substantial. All standard errors (except one) are lower compared to those associated with the GMM(I) estimator. Accordingly, the discussion of results, including the comparison between the AR(1) and AR(2) models for the *Teff* market price and the *Teff* 'quota' rate, refer to the corresponding GMM(II) estimator.

1) The main results pertaining to the market price of *Teff* are reported in Table 6. First, the AR(1) and AR(2) specifications for the market price of *Teff* are compared on the basis of the respective GMM(II) estimates (Column 3 and 5 of Table 6). The AR(1) model is superior in that: the coefficient of $P^m_{1,t-2}$ (i.e., $\widehat{\theta}_2$ in the last column of Table 6) is not significantly different from zero; the AR(2) model induces second-order serial correlation in the errors, which can be viewed as a sign of misspecification; and the AIC is smaller for the AR(1) model. Second, the estimate of the coefficient of $P^m_{1,t-1}$ in the preferred AR(1) process shows that the process is stable ($\widehat{\theta}_1 = 0.39$). Third, the coefficient of ϕ_{1t-1} is positive but insignificant, while that of ϕ_{1t-2} is negative and significant. It suggests that temporary or short-run changes in the 'quota' rate do not affect the market price of *Teff.* In contrast, permanent or long-run changes in ϕ_1 reduce the market price of *Teff.*

2) Table 7 summarizes the results relating to the law of motion of the *Teff* 'quota' rate. First, GMM(II) estimates favour the AR(1) specification. Apart from generating an insignificant coefficient of $\phi_{1,t-2}$, the AR(2) model leads to second-order autocorrelation in the errors. Second, the estimate of γ_1 ($\widehat{\gamma}_1 = 0.74$) indicate the stability of the AR(1) process.

3) Estimates of the parameters of the *Teff* acreage equation (equation 3.1) are reported in Table 8. They correspond to the OLS, Within-groups, GMM(I), and GMM(II) estimators. The first three of these are included for comparison purposes. GMM(II) estimates are the preferred estimates. Observe that the estimates of κ_1 and κ_2 ($\widehat{\kappa}_1 = 0.37$ and $\widehat{\kappa}_2 = 0.53$) satisfy the stationarity conditions for an AR(2) process.

Finally, the long-run and the short-run elasticities of acreage demand for *Teff* production are computed using the equations (3.2) and (3.3) together with the GMM(II) parameter estimates in Table 8. The results are reported in Table 9. All the elasticities are evaluated at the sample means of the relevant variables.

[45] Note that all prices used in the analysis are deflated by the national rural consumers' price index.

[46] The estimation is implemented using the current version of DPD developed by Arellano and Bond (1988). Note further that the two-step GMM(I) and GMM(II) estimates involve substantial downward bias in asymptotic standard errors relative to the corresponding finite-sample standard deviations [Arellano and Bond (1991), Blundell and Bond (1995)]. As a result only one-step estimates are reported. The only exception is the Sargan test which is based on the two-step estimator.

Table 6: **One-step GMM Estimates of the *Teff* Market Price Equations**

Variable	*AR(1)*		*AR(2)*	
	GMM(I)	GMM(II)	GMM(I)	GMM(II)
$P^m_{1,t-1}$	0.24 (0.083)*	0.39 (0.052)*	0.05 (0.115)	0.37 (0.065)*
$P^m_{1,t-2}$	...	...	-0.52 (0.080)*	0.09 (0.097)
ϕ_{1t-1}	63.30 (43.687)	41.13 (34.795)	47.28 (17.190)*	39.42 (34.455)
ϕ_{1t-2}	-30.50 (50.269)	-98.52 (32.096)*	-25.56 (38.728)	-89.58 (25.413)*
χ^2-Regressors	16.92 [3]*	63.49 [3]*	52.88 [4]*	152.53 [4]*
χ^2-Time dummies	328.421 [7]*	248.83 [7]*	182.26 [7]*	359.07 [7]*
m_1	-2.55 *	-2.44 *	-2.57 *	-2.02 †
m_2	-1.01	-0.92	1.67 ‡	-2.00†
χ^2-Sargan test	–	11.92 [27]	–	11.44 [26]
AIC	10.33	9.91	10.77	10.37
N	120	120	120	120

NOTES: Standard errors in parentheses, and degrees of freedom in square brackets. All standard errors are consistent in the presence of general heteroskedasticity. The Sargan test statistic corresponding to GMM(I) is not reported, because it is not well-determined. (*), (†), and (‡) represent significance at 1 per cent, 5 per cent, and 10 per cent, respectively.

Table 7: **One-step GMM Estimates of the *Teff* 'Quota' Rate Equations**

Variable	*AR(1)*		*AR(2)*	
	GMM(I)	*GMM(II)*	*GMM(I)*	*GMM(II)*
ϕ_{1t-1}	0.38 (0.041)*	0.74 (0.026)*	0.19 (0.071)	0.75 (0.055)*
ϕ_{1t-2}	...	...	-0.91 (0.082)*	-0.03 (0.087)
χ^2-Regressors	87.2 [1]*	820.88 [1]*	329.68 [2]*	1152.12 [2]*
χ^2-Time dummies	26.86 [7]*	26.23 [7]*	17.22 [7]*	23.93 [7]*
m_1	-1.99†	-2.07†	-2.07*	-2.06†
m_2	-1.60‡	-1.52	1.45	-1.69‡
χ^2-Sargan test	4.96 [6]	4.88 [14]	4.62 [5]	1.66 [13]
AIC	-2.43	-2.92	-2.48	-2.66
N	120	120	120	120

NOTES: Standard errors in parentheses, and degrees of freedom in square brackets. All standard errors are consistent in the presence of general heteroskedasticity. (*), (†), and (‡) represent significance at 1 per cent, 5 per cent, and 10 per cent, respectively.

Table 8: **One-step GMM Estimates of the *Teff* Acreage Demand Equation**

Parameter	*OLS*	*Within*	*GMM(I)*	*GMM(II)*
A_{1t-1}	0.4665 (0.1190)*	0.2557 (0.1316)†	0.0384 (0.2303)	0.3751 (0.1368)*
A_{1t-2}	0.4496 (0.1364)*	0.2698 (0.1640)‡	0.2457 (0.3500)	0.5338 (0.1437)*
P^m_{1t}	0.0005 (0.0003)‡	0.0002 (0.0002)	0.0005 (0.0005)	0.0013 (0.0007)†
P^m_{1t-1}	-0.0004 (0.0002)†	-0.0008 (0.0003)*	-0.0012 (0.0005)*	-0.0011 (0.0005)†
ϕ_{1t}	0.1513 (0.1114)	0.1907 (0.1991)	-0.0180 (0.3294)	0.0398 (0.1484)
ϕ_{1t-1}	-0.2344 (0.2089)	-0.2253 (0.1859)	-0.3465 (0.1818)†	-0.3406 (0.1681)†
ϕ_{1t-2}	0.0885 (0.1750)	0.2000 (0.2089)	0.1230 (0.3320)	0.2727 (0.1370)†
R_{1t}	-0.00005 (0.00002)†	-0.00005 (0.00003)	-0.00004 (0.00002)‡	-0.00004 (0.00002)‡
R_{1t-1}	0.00001 (0.00001)	-0.00001 (0.00001)	0.00002 (0.0001)	0.00001 (0.00001)
χ^2-Regressors	9282.45 [9]*	68.48 [9]*	50.47 [9]*	4042.27 [9]*
χ^2-Time dummies	20.17 [7]*	15.96 [7]†	78.76 [7]*	22.43 [7]*
m_1	-1.03	-2.54*	-1.82†	-2.04†
m_2	0.54	2.16†	0.79	1.21
N	120	120	120	120

NOTES: Standard errors in parentheses, and degrees of freedom in square brackets. All standard errors are consistent in the presence of general heteroskedasticity. The Sargan test statistic corresponding to GMM(I) and GMM(II) is not reported, because it is not well-determined. (*), (†), and (‡) represent significance at 1 per cent, 5 per cent, and 10 per cent, respectively.

Table 9: **Elasticities of *Teff* Acreage Demand**

Long-run		*short-run*	
$\xi^L_{A,\phi}$	-0.04	$\xi^S_{A,\phi}$	0.005
ξ^L_{A,P^m}	0.48	ξ^S_{A,P^m}	0.31
$\xi^L_{A,R}$	-0.93	$\xi^S_{A,R}$	-0.13

1) The long-run elasticity of *Teff* acreage demand with respect to the 'quota' rate is negative but relatively small. That it is negative is consistent with the prediction of the theoretical model set out earlier in this paper. It suggests that the long-run acreage demand for *Teff* cultivation has been reduced by the institution and expansion of the CGD. The reduction appears to have been relatively small. In contrast, the associated short-run elasticity is positive, but very small. Observe, however, that the coefficients of ϕ_{1t} in the *Teff* acreage equation is insignificant. The latter suggests that the 'quota' rate did not affect contemporaneous acreage decisions of farm households - a result consistent with the fact that quota rates were determined after cultivation and can only influence acreage decisions in subsequent periods.

2) The long-run and short-run elasticities of acreage demand for *Teff* production with respect to the market price of *Teff* are positive. The signs of these elasticities conform with those of their theoretical counterparts. As would be expected, the long-run price elasticity is greater than the short-run one. In addition, the levels of the two elasticities are somewhat lower relative to those obtained by other studies[47]. This is particularly true of the long-run elasticity. This relatively low own-price responsiveness may be partly explained by the presence of CGD, which is an outcome predicted by the theoretical model.

3) Consistent with the prediction of the theoretical model, the long-run and short-run elasticities of *Teff* acreage demand with respect to revenue from other annual crops are negative. Again, the short-run elasticity is smaller (in absolute value) than the corresponding long-run elasticity. In fact, permanent changes in the revenue from other crops induce the strongest response from long-run acreage demand for *Teff* cultivation. This is due to the fact that such changes represent a favorable shift in the profitability profile of, not a single alternative crop, but, most likely, a number of other annual crops. As a result the farm household affords a greater degree of flexibility in its acreage reallocation decision.

To summarize, the demand for *Teff* acreage responds positively to the market price of *Teff,* and negatively to the revenue obtainable from other cereals and pulses. In addition, the long-run demand for *Teff* acreage is negatively affected by the 'quota' rate imposed on that crop.

4 Conclusion

This paper set out to investigate the impact of compulsory grain delivery (CGD) and crop prices on the production choices of farm households in Ethiopia. For that purpose, a simple dynamic agricultural household model is developed under rational expectations and risk neutrality. In that model the effect of CGD is introduced via a weighted average price of crops. This price is approximated as a linear combination of the relevant 'quota' rate, crop procurement price, and crop market price. The model is then used to characterize acreage demand elasticities with respect to the

[47]Scandizzo and Bruce (1980) report more than forty elasticities for different crops in different countries. Fifty-six per cent of the reported long-run elasticities are above 0.5. The corresponding proportion for short-run elasticities is forty per cent.

'quota' rate, the market price of the crop, and the revenue from alternative crops. It is demonstrated that, in general, these elasticities depend on the technology of production, the cost of adjusting acreage allocations, the pattern of dynamic productivity effects, and household time preference. More specifically, it is shown that the long-run and current acreage allocations to a crop respond positively to that crop's market price, and negatively to the corresponding 'quota' rate and the revenue from competing crops.

Subsequently, an estimable dynamic acreage demand equation is derived by explicitly solving for the farm household's acreage allocation decision rule. This equation is then estimated for *Teff* - a major crop produced by Ethiopian farm households - using region-level data. Recently developed techniques for estimating dynamic panel data models are employed for that purpose. The resulting estimates of elasticities of acreage demand for *Teff* production are consistent with the predictions of theoretical model.

The empirical evidence suggests that CGD is likely to have reduced the long-run acreage share (and thus the long-run supply) of the crops to which it applied to. It is likely to have done so by directly and indirectly (through lower market prices) reducing farm households' returns from these crops. The estimated elasticities of acreage demand for *Teff* production imply that CGD have reduced the long-run acreage share (and thus the long-run supply) of *Teff*. It is likely to have done so by directly and indirectly (through lower market prices) reducing farm households' returns from this crop, though the direct effect appears small. Specifically the results imply that the discontinuation of CGD (i.e., the reduction of ϕ_1 to zero, which is a 100 percent decline) will increase *Teff* acreage by 4 percent in the long-run (see Table 9 above). That this is a reasonable estimate is corroborated by the 6.4 percent increase in the median *Teff* acreage during the post-CGD period (1990/91-1996/97) relative to the CGD period (1980/81-1989/90). Needless to say, the abolition of CGD is only part of the expalnation for this increase. Moreover, if comparable effects were exerted on other crops by CGD the overall direct impact may have been significant, particularly in the light of considerable food insecurity Ethiopia suffers from.

It should also be noted that CGD may have affected crop supply in ways other than acreage reallocations. For instance, the lower crop profitability induced by CGD may adversely affect the farm households' efforts towards raising farm productivity, such as adoption of new cultivation practices and crop varieties. Or it may even have forced some of these households to reduce their dependence on crop cultivation and seek alternative income sources, such as animal husbandry. These possibilities, viable or otherwise, cannot be explicitly captured by the simple model employed in this paper. Nevertheless, on the basis of that model and the related empirical results, it is possible to conclude that the policy of compulsory grain delivery is unlikely to have been beneficial to the growth of crop production.

The empirical results also imply that acreage demand for the cultivation of a crop rises with the crop's price, and falls with revenue obtainable from competing crops. In other words, the empirical evidence supports a normal supply response to prices. Furthermore, a comparison with elasticities reported by other studies indicate that the output price elasticities of acreage demand may have been somewhat lower in Ethiopia during the 1980's. It appears that this is in part explained by CGD.[48] The

[48]In the light of the above, it is reasonable to expect that the process of market liberalization, which begun with the abolition of CGD in 1990, stimulates greater supply responsiveness to market

implication to more recent periods is that since the supply decisions of Ethiopian farm households are reasonably responsive to prices and since crop price volatility is considerable in the country, a systematic look at the need for and feasibility of alternative agricultural price support schemes is warranted.

References

[1] Alameyehu Lirenso (1987). *Grain Marketing and Pricing in Ethiopia: A Study of the Impact of Grain Quota and Fixed Prices on Grain Producers*, Research Report no. 28, Institute of Development Research, Addis Ababa University, Addis Ababa.

[2] Anderson, T.W. and C. Hsiao (1982). "Formulation and Estimation of Dynamic Models Using Panel Data*," Journal of Econometrics,* **18**, 47-82.

[3] Arellano, M., and S. Bond (1988). *Dynamic Panel Data Estimation Using DPD - A Guide for Users*, mimeo.

[4] ____,____ (1991). "Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations," *Review of Economic Studies,* **58**, 277-97.

[5] Arellano, M and O. Bover (1995). "Another look at the instrumental variable estimation of error-components models", *Journal of Econometrics*, **68**, 29-52.

[6] Azam, J.P. (1992). *Grain Market Decontrol in Ethiopia (1990).* D.I.A.L.

[7] Blanchard O. and S. Fischer (1989). *Lectures on Macroeconomics*, The MIT Press, Cambridge, Massachusetts.

[8] Blundell, R., and S. Bond (1995). "Initial Conditions and Moment Restrictions in Dynamic Panel Data Models," Economics Discussion Paper No 104, Nuffield College Oxford, UK.

[9] Central Statistical Authority, *Statistical Bulletin,* Nos. 44, 56, 59, 65, 74, 79, 85, 95, 103, and 105, Addis Ababa, Ethiopia.

[10] Cuthbertson, B. and P. Taylor (1987). *Macroeconomic Systems*, Basil Blackwell, Oxford, UK.

[11] Davidson, R. and J.G. MacKinnon (1993). *Estimation and Inference in Econometrics*, Oxford University Press, Oxford.

[12] Dercon, S. (1994). "Food Markets, Liberalization and Peace in Ethiopia: an econometric analysis," mimeo, CSAE, Oxford University.

[13] Eckstein, Z. (1984). "A Rational Expectations Model of Agricultural Supply," *Journal of Political Economy*, **92**, 1, 1-11.

[14] Eckstein, Z. (1985). "The Dynamics of Agriculture Supply: A Reconsideration," *American Journal of Agricultural Economics*, **67**, 204-14.

forces. The composition and extent of this improvement is systematically studied in a sequel. See Taffesse (2003).

[15] Epstein, L.G. and A.J. Yatchew (1985). "The Empirical Determination of Technology and Expectations: A Simplified Procedure," *Journal of Econometrics*, **27**, 235-258.

[16] Ethiopian Agricultural Marketing Agency (1987). *Statistical Digest,* Addis Ababa, Ethiopia.

[17] Ethiopian Grain Trade Enterprise (1995). *Statistical Bulletin,* No. 3, Addis Ababa, Ethiopia.

[18] Franzel, S. et al. (1989) "Grain Marketing Regulations: Impact on Peasant Production in Ethiopia," *Food Policy*, **14**, 1, 347-58.

[19] Greene, W.H. (1993). *Econometric Analysis*, 2nd edition, Prentice-Hall Inc. New Jersey.

[20] Hansen, L.P. and T.J. Sargent (1980)."Formulating and Estimating Dynamic Linear Rational Expectations Models," *Journal of Economic Dynamics and Control*, **2**, 7-46.

[21] Hsiao, C. (1986). *Analysis of Panel Data.* Cambridge University Press. Cambridge, UK.

[22] Nickell, S. (1981). "Biases in Dynamic Models with Fixed Effects," *Econometrica,* **49**,1417-26.

[23] Pesaran, M.H. (1987). *The Limits to Rational Expectations*, Basil Blackwell, Oxford, UK.

[24] Pickett, J. (1991). *Economic Development in Ethiopia: Agriculture, the Market and the State*, OECD, Paris.

[25] Sah, Raaj Kumar, and Sirnivasan, T. N. (1988). " Distributional Consequences of Rural Food Levy and Subsidized Urban Rations." *European Economic Review,* **32,** 141-159.

[26] Sah, Raaj Kumar, and Stiglitz, J. E. (1992). *Peasants Versus City-dwellers : Taxation and the Burden of Economic Development.* Clarendon Press. Oxford.

[27] Scandizzo, P. and C. Bruce (1980). Methodologies for Measuring Agricultural Price Intervention Effects, Staff Working Paper no. 394, Washington, D.C. World Bank.

[28] Sargent, T.J. (1987). *Macroeconomic Theory,* (2nd edition)) Academic Press, Inc., Boston, USA.

[29] Taffesse, Alemayehu S. (2003). "Agricultural Production and Government Policy Regimes in Ethiopia: A Dynamic Analysis," *in progress.*

[30] ______ (1999). "An Economic Model of the Ethiopian Farm Household," *Working Paper Series*, **WPS/99-26**, Centre for the Study of African Economies, University of Oxford.

[31] ______ (1989). " Technical and Allocative Efficiency of Farm Households in Ethiopia : Tentative Findings of a Case-Study of Two Peasant Associations." in *Proceedings of the Workshop on Rural Development in Ethiopia.* Institute of Development Research , Addis Ababa University.

[32] Tegene, A., W.E. Huffman, and J. A. Miranowski (1988). "Dynamic Corn Supply Functions: A Model with Explicit Optimization," *American Journal of Agricultural Economics*, February, 103-111.

[33] Whiteman, C.H. (1983) *Linear Rational Expectations Models: A User's Guide*, University of Minnesota Press, Minneapolis, USA.

Appendix

1 Solution procedure

1.1 General

For the purpose of solving for $A_{1,t+j}$ the method suggested by Sargent (1987, 395) is adopted. The method involves the operator $\mathbf{B}$, which, for each integer i, is defined by:

$$\mathbf{B}^{-i}\mathbf{E}_{t+j}(x_{t+j+1}) = \mathbf{E}_{t+j}(x_{t+j+1+i}) \tag{A1.1}$$

i.e., the application of $\mathbf{B}^{-i}$ shifts forward by i periods the date on the variables whose conditional expectations are being computed, but leaves the information set unchanged. To simplify notation let us use

$$Z_{t+j+1} \equiv \frac{1}{d}\left[(\iota_0 + \iota_1\phi_{1,t+j+1} + \iota_2 P^m_{1,t+j+1})y_1 - R_{1,t+j+1} - V_{1,t+j+1}\right]$$

and restate the Euler equations as:

$$\beta\mathbf{E}_{t+j}A_{1,t+j+1} + \frac{b}{d}\mathbf{E}_{t+j}A_{1,t+j} + \mathbf{E}_{t+j}A_{1,t+j-1} = \mathbf{E}_{t+j}Z_{t+j+1} \tag{A1.2}$$

By (A1.1) equation (A1.2) can be rewritten as:

$$\left[\beta\mathbf{B}^{-2} + \frac{b}{d}\mathbf{B}^{-1} + 1\right]\mathbf{E}_{t+j}(A_{1,t+j-1}) = \mathbf{E}_{t+j}(Z_{t+j+1}) \tag{A1.3}$$

Rewriting the term in square brackets on the left-hand-side of the preceding equation and factorizing leads to:

$$\beta\left(\mathbf{B}^{-2} + \frac{b}{d\beta}\mathbf{B}^{-1} + \frac{1}{\beta}\right) = \beta\left(\mathbf{B}^{-2} - (\lambda_1+\lambda_2)\mathbf{B}^{-1} + \lambda_1\lambda_2\right) = \beta(\lambda_1 - \mathbf{B}^{-1})(\lambda_2 - \mathbf{B}^{-1})$$

where the roots λ_1, λ_2 satisfy; $(\lambda_1 + \lambda_2) = -\frac{b}{d\beta}$ and $\lambda_1\lambda_2 = \frac{1}{\beta}$. Thus equation (A1.3) can be expressed as:

$$\beta(\lambda_1 - \mathbf{B}^{-1})(\lambda_2 - \mathbf{B}^{-1})\mathbf{E}_{t+j}(A_{1,t+j-1}) = \mathbf{E}_{t+j}(Z_{t+j+1}) \tag{A1.4}$$

Select λ_1 to be the smaller of the two roots, with $|\lambda_1| < 1$ and $\lambda_2 = (1/\beta\lambda_1)$[49]. Operate on both sides of (A1.4) with $(\lambda_2 - \mathbf{B}^{-1})$ and rearrange to obtain the solution:

$$(\lambda_1 - \mathbf{B}^{-1})E_{t+j}(A_{1,t+j-1}) = \frac{1}{\beta}\left(\frac{1}{\lambda_2}\frac{1}{(1-\frac{1}{\lambda_2}\mathbf{B}^{-1})}\right)\mathbf{E}_{t+j}(Z_{t+j+1}) + c\lambda_2^{t+j} \tag{A1.5}$$

[49] Combining: $\lambda_1 + \lambda_2 = -\frac{b}{\beta d}$, and $\lambda_1\lambda_2 = \frac{1}{\beta}$, we have:

$$\frac{1}{\lambda_1} = -\frac{b}{d} - \beta\lambda_1$$

The left-hand-side of the previous equation is a hyperbola (in λ_1), while the right-hand-side is a straight line(again in λ_1) with a slope of $-\beta$. The latter intersects the former in the negative (positive) values of λ_1 provided that $\frac{b}{d}$ is positive (negative). Thus, given $\left|\frac{b}{d}\right| > 1 + \beta$, there exist two real solutions for λ_1, one of them being less than one in absolute value. Therefore, λ_1 and λ_2

where c is a constant [50].

That $\left|\frac{1}{\lambda_2}\right| < 1$, implies:

$$\frac{1}{(1-\frac{1}{\lambda_2}\mathbf{B}^{-1})} = \left(1 + \left(\frac{1}{\lambda_2}\right)\mathbf{B}^{-1} + \left(\frac{1}{\lambda_2}\right)^2 \mathbf{B}^{-2} + \dots\right).$$

Futhermore, by construction, the following hold:

$$\mathbf{E}_{t+j}(A_{1,t+j-1}) = A_{1,t+j-1} \quad ;$$

$$\mathbf{B}^{-1}\mathbf{E}_{t+j}(A_{1,t+j-1}) = \mathbf{E}_{t+j}(A_{1,t+j}) = A_{1,t+j}$$

Using these to rewrite equation (A1.5) implies:

$$-(A_{1,t+j} - \lambda_1 A_{1,t+j-1}) = \frac{1}{\beta}\frac{1}{\lambda_2}\left[1 + \left(\frac{1}{\lambda_2}\right)\mathbf{B}^{-1} + \left(\frac{1}{\lambda_2}\right)^2 \mathbf{B}^{-2} + \dots\right]\mathbf{E}_{t+j}(Z_{t+j+1})$$

Successive application of the $\mathbf{B}^{-i}$ operator on $\mathbf{E}_{t+j}(Z_{t+j+1})$ and summing reduces the term on the right-hand-side of the preceding equation to $(1/\beta\lambda_2)\sum_{i=0}^{\infty}(1/\lambda_2)^i_{t+j}\mathbf{E}(Z_{t+j+1+i})$. By substituting for λ_2 and $Z_{t+j+1+i}$ from their respective definitions above, and rearranging the solution is finally obtained as:

$$\begin{aligned} A_{1,t+j} &= \lambda_1 A_{1,t+j-1} \\ &\quad -(\frac{\lambda_1}{d})\sum_{i=0}^{\infty}(\beta\lambda_1)^i \mathbf{E}_{t+j}\left[y_1(\iota_0 + \iota_1\phi_{1,t+j+1+i} + \iota_2 P^m_{1,t+j+1+i}) - R_{1,t+j+1+i} - V_{1,t+j+1+i}\right] \end{aligned} \tag{A1.6}$$

1.2 An explicit solution for the acreage decision rule

As noted earlier, equation (2.10) in the text (or equation A1.6 in the previous section of this appendix) does not constitute a decision rule because the expectational terms $\mathbf{E}_{t+j}(\phi_{1,t+j+1+i})$, $\mathbf{E}_{t+j}(P_{1,t+j+1+i})$, $\mathbf{E}_{t+j}(R_{1,t+j+1+i})$, and $\mathbf{E}_{t+j}(V_{1,t+j+1+i})$ are present. To transform it into such a rule, it is necessary to express those expectational variables as functions of elements of the current information set (Ω_{t+j}). One

are real and distinct roots, which satisfy:

$$|\lambda_1| < 1 < \frac{1}{\sqrt{\beta}} < |\lambda_2|$$

provided that:

$$\left|\frac{b}{d}\right| > 1 + \beta.$$

For further details see Sargent (1987) and Eckstein (1985).

[50] Note that $c\lambda_2^{t+j}$ is included because it is the general solution to a first-order homogenous difference equation, i.e., when $\mathbf{E}_{t+j}(Z_{t+j+1}) = 0$. (A1.5) is an extension of that to the nonhomogenous case with a variable-term. Note also that $c = 0$ must be imposed if the solution $\{A_{1,t+j}\}$ sequence is to be bounded (or the solution is to satisfy the transversality condition). If that is not the case, then $\lambda_2^{t+j} \to \infty$ as $j \to \infty$, since $|\lambda_1| < 1$ and $0 < \beta < 1$ imply $|\lambda_2| > 1$. Also see Sargent (1987).

way of achieving this involves first postulating autoregressive processes for P_1^m, ϕ_1, R_1, and V_1, and then apply the Weiner-Kolmogorov prediction formula to solve for the expectational variables[51]. Towards that end, alternative specifications for these processes are explored using the available data.

A simple strategy is adopted for selecting from among alternative specifications. First, autoregressive models of the first- and second-order (AR(1) and AR(2), respectively) are specified for P_1^m and ϕ_1[52,53]. The model for P_1^m thus specified incorporate the possible impact that ϕ_1 may have. Second a combination of the Akaike Information Criteria (AIC) and tests for parameter significance is used to select the better specification. The details of this exercise are reported with the other results in section (3.4). In this section it suffices to report that the following specifications are selected in this manner.

$$P_{1t}^m = \theta_1 P_{1,t-1}^m + \theta_2 \phi_{1,t-1} + \theta_3 \phi_{1,t-2} + u_t^P \ ; \ \ |\theta_1| < 1 \tag{A2.1}$$

$$\phi_{1t} = \gamma \phi_{1,t-1} + u_t^\phi \ ; \ \ |\gamma| < 1 \tag{A2.2}$$

Moreover let us assume that the stochastic variables R_{1t} and V_{1t} are generated by the following AR(1) processes:

$$R_{1t} = \alpha R_{1,t-1} + u_t^R \ ; \ \ |\alpha| < 1 \tag{A2.3}$$

$$V_{1t} = \rho V_{1,t-1} + u_t^V \ ; \ \ |\rho| < 1 \tag{A2.4}$$

where u_t^P, u_t^ϕ, u_t^R and u_t^V are zero-mean, constant-variance, and serially uncorrelated random variables[54]. Two remarks have to be made at this point. First, the farm household is assumed to derive its decisions rules taking the price, cost, and 'quota' rate stochastic processes as given. In other words, it operates according to the belief that its actions do not affect these processes. Second, recall that the specific AR

[51] See Hansen and Sargent (1980) for further details.

[52] It is possible to postulate higher-order and/or vector autoregressive processes for P_{1t} and ϕ_{1t}. Solutions analogous to (3.1a) below can still be obtained [see Hansen and Sargent (1980)]. Indeed, the ideal procedure is to postulate AR processes without specifying the order, and then empirically choose the appropriate lag length. Restricting the choice to AR(1) and AR(2) processes reflects data constraints. To that extent it is rather arbitrary.

[53] Data on V_1 is unavailable. Consequently, it is excluded from this effort. However, we postulate that it is generated by an AR(1) process. The case of R_1 is more complicated. It measures the revenue per hectare from all cereals and pulses other than *Teff*, and is computed as:

$$R_1 = \sum_{j=2}^{J} P_j y_j$$

where: $P_j = \phi_j P_j^s + (1 - \phi_j) P_j^m$ = the average price of the crop j; P_j^s = the procurement price of crop j; P_j^m = the market price of the crop j; ϕ_j = the rate of 'quota' on crop j. All attempts to consistently estimate an AR(1) and AR(2) processes describing R_1 failed. It is possible to consider more complicated models. But the resulting acreage equation will be very problematic to implement using the data available. As a result, the assumption that the law of motion of R_1 is AR(1) is maintained.

[54] These variables are defined as:

$$u_t^P = P_{1t}^m - \mathbf{E}_{t-1}(P_{1t}^m), \quad u_t^\phi = \phi_{1t} - \mathbf{E}_{t-1}(\phi_{1t}), \quad u_t^R = R_{1t} - \mathbf{E}_{t-1}(R_{1t}), \quad u_t^V = V_{1t} - \mathbf{E}_{t-1}(V_{1t})$$

such that:

$$\mathbf{E}_{t-1}(u_t^P) = 0, \quad \mathbf{E}_{t-1}(u_t^\phi) = 0, \quad \mathbf{E}_{t-1}(u_t^R) = 0, \quad \mathbf{E}_{t-1}(u_t^V) = 0$$

processes for P_1^m and ϕ_1 are selected via a simple procedure involving estimation and testing. This procedure is legitimate only under rational expectations.. The reason is that, under rational expectations, the models used by the farm household to form expectations about random variables are identical to the actual laws of motion of those variables [Epstein and Yatchew (1985)].

Now turning to the task of solving for the farm household's acreage decision rule, begin by restating (2.10) for $j = 0$, to simplify notation:

$$A_{1t} \quad = \quad \lambda_1 A_{1,t-1} - (\frac{\lambda_1}{d}) \sum_{i=0}^{\infty} (\beta\lambda_1)^i \mathbf{E}_t \left[\left(y_1(\iota_0 + \iota_1 \phi_{1,t+1+i} + \iota_2 P_{1,t+1+i}^m) \right) - R_{1,t+1+i} - V_{1,t+1+i} \right] \tag{2.10a}$$

Also define $W_t \equiv \left[\begin{array}{cc} P_{1t}^m & \phi_{1t} \end{array} \right]'$and $U \equiv \left[\begin{array}{cc} 1 & 0 \end{array} \right]$, where $'$ represents the matrix transpose operation. Then, following Hansen and Sargent (1980), state:

$$U \sum_{i=0}^{\infty} (\beta\lambda_1)^i \mathbf{E}_t(W_{t+1+i}) = \sum_{i=0}^{\infty} (\beta\lambda_1)^i \mathbf{E}_t(P_{t+1+i}^m)$$

Furthermore, by defining $u_t \equiv \left[\begin{array}{cc} u_t^P & u_t^\phi \end{array} \right]'$, and combining (A2.1) and (A2.2) the law of motion of P_1^m can be rewriten as:

$$\Theta(\mathbf{L}) W_t = u_t$$

where:

$$\Theta(\mathbf{L}) = (I - \Theta_1 \mathbf{L} - \Theta_2 \mathbf{L}^2), \qquad \Theta_1 = \left[\begin{array}{cc} \theta_1 & \theta_2 \\ 0 & \gamma \end{array} \right], \qquad \Theta_2 = \left[\begin{array}{cc} 0 & \theta_3 \\ 0 & 0 \end{array} \right],$$

I is (2×2) identity matrix, and $\mathbf{L}$ is the lag operator with, $\mathbf{L}^k x_t = x_{t-k}$. Similarly rearranging using the lag operator it follows that:

$$\gamma(\mathbf{L}) \phi_{1t} = u_t^\phi, \qquad \alpha(\mathbf{L}) R_{1t} = u_t^R, \qquad \rho(\mathbf{L}) V_{1t} = u_t^V$$

where: $\gamma(\mathbf{L}) = (1 - \gamma\mathbf{L})$; $\alpha(\mathbf{L}) = (1 - \alpha\mathbf{L})$; and $\rho(\mathbf{L}) = (1 - \rho\mathbf{L})$. Note also that the assumption that $|\theta| < 1$, $|\gamma| < 1$, $|\alpha| < 1$, and $|\rho| < 1$ ensure the existence of moving average representations for W_t, ϕ_{1t}, R_{1t}, and V_{1t}[55]. Finally, note that the Wiener-Kolmogorov prediction formula provided by Hansen and Sargent (1980) explicitly solves for $\sum_{i=0}^{\infty} (\beta\lambda_1)^i \mathbf{E}_t(x_{t+i})$. Thus it has to be slightly modified in order to solve for $\sum_{i=0}^{\infty} (\beta\lambda_1)^i \mathbf{E}_t(x_{t+1+i})$. This is done by exploiting the following equality:

$$\sum_{i=0}^{\infty} (\beta\lambda_1)^i \mathbf{E}_t(x_{t+1+i}) = (\beta\lambda_1)^{-1} \sum_{i=0}^{\infty} (\beta\lambda_1)^i \mathbf{E}_t(x_{t+i}) - (\beta\lambda_1)^{-1} \mathbf{E}_t(x_t)$$

where $x \in (P_1^m, \phi_1, R_1, V_1)$. Substituting for $\sum_{i=0}^{\infty} (\beta\lambda_1)^i \mathbf{E}_t(x_{t+i})$ from the Hansen-Sargent version provides the desired formula. This modified version of the Wiener-

[55] In fact, for θ_1 and γ these assumptions are not rejected by the data.

Kolmogorov prediction formula is applied to obtain[56]:

$$\sum_{i=0}^{\infty}(\beta\lambda_1)^i\mathbf{E}_t(P^m_{1,t+1+i}) = \left(\frac{\theta_1}{1-(\beta\lambda_1)\theta_1}\right)P^m_{1t}+\left(\frac{\theta_2+(\beta\lambda_1)\theta_3}{[1-(\beta\lambda_1)\theta_1][1-(\beta\lambda_1)\gamma]}\right)\phi_{1t} + \left(\frac{\theta_3}{1-(\beta\lambda_1)\theta_1}\right)\phi_{1,t-1} \quad \text{(A2.5)}$$

$$\sum_{i=0}^{\infty}(\beta\lambda_1)^i\mathbf{E}_t(\phi_{1,t+1+i}) = \left(\frac{\gamma}{1-(\beta\lambda_1)\gamma}\right)\phi_{1t} \quad \text{(A2.6)}$$

$$\sum_{i=0}^{\infty}(\beta\lambda_1)^i\mathbf{E}_t(R_{1,t+1+i}) = \left(\frac{\alpha}{1-(\beta\lambda_1)\alpha}\right)R_{1t} \quad \text{(A2.7)}$$

$$\sum_{i=0}^{\infty}(\beta\lambda_1)^i\mathbf{E}_t(V_{1,t+1+i}) = \left(\frac{\rho}{1-(\beta\lambda_1)\rho}\right)V_{1t} \quad \text{(A2.8)}$$

Substituting these in $(2.10\text{a})'$, and rearranging results in:

$$A_{1t} = \omega_0+\omega_1 A_{1,t-1}+\omega_2 P^m_{1t}+\omega_3\phi_{1t}+\omega_4\phi_{1,t-1}+\omega_5 R_{1t}+\omega_6 V_{1t};\quad t=0,1,\ldots \quad \text{(A2.9)}$$

where[57]:

$$\omega_0 = -\left(\frac{\lambda_1 y_1}{d}\right)\left(\frac{\iota_0}{1-(\beta\lambda_1)}\right)$$

$$\omega_1 = \lambda_1$$

$$\omega_2 = -\left(\frac{\lambda_1 y_1}{d}\right)\left(\frac{\theta_1\iota_2}{1-(\beta\lambda_1)\theta_1}\right)$$

$$\omega_3 = -\left(\frac{\lambda_1 y_1}{d}\right)\left(\frac{\theta_2\iota_2}{[1-(\beta\lambda_1)\theta_1][1-(\beta\lambda_1)\gamma]}+\frac{\gamma\iota_1}{1-(\beta\lambda_1)\gamma}\right)$$

$$\omega_4 = -\left(\frac{\lambda_1 y_1}{d}\right)\left(\frac{\theta_3\iota_2}{1-(\beta\lambda_1)\theta_1}\right)$$

$$\omega_5 = -\left(\frac{\lambda_1}{d}\right)\left(\frac{\alpha}{1-(\beta\lambda_1)\alpha}\right)$$

---

[56]As applied to P^m_1 and z, the Weiner-Kolmogorov prediction formula appear as:

$$\sum_{i=0}^{\infty}\lambda^i\mathbf{E}_t(P^m_{1,t+1+i}) = U\left\{\lambda^{-1}\left(\Theta(\lambda)^{-1}\right)\left[I+\sum_{k=1}^{r-1}\left(\sum_{l=k+1}^{r}\lambda^{l-k}\Theta_l\right)\mathbf{L}^k\right]-\lambda^{-1}I\right\}W_{1t}$$

$$\sum_{i=0}^{\infty}\lambda^i\mathbf{E}_t(z_{t+1+i}) = \left\{\lambda^{-1}\left(\omega(\lambda)^{-1}\right)\left[1+\sum_{k=1}^{s-1}\left(\sum_{l=k+1}^{s}\lambda_l^{l-k}\omega_l\right)\mathbf{L}^k\right]-\lambda^{-1}\right\}z_t$$

where: $z\in(\phi_1,R_1,V_1)$; $\omega\in(\gamma,\alpha,\rho)$; $\lambda=\beta\lambda_1$; $\Theta(\lambda)=(I-\Theta_1\lambda-\Theta_2\lambda^2-\cdots-\Theta_r\lambda^r)$; $\omega(\lambda)=(1-\omega_1\lambda-\omega_2\lambda^2-\cdots-\omega_s\lambda^s)$. When $r=2$ and $s=1$, these expressions reduce to those stated in the text. For details regarding the derivation of the Weiner-Kolmogorov formula see Hansen and Sargent (1980).

[57]In deriving ω_0, the following equality is used:

$$\sum_{i=0}^{\infty}(\beta\lambda_1)^i = \frac{1}{1-(\beta\lambda_1)}$$

$$\omega_6 = -\left(\frac{\lambda_1}{d}\right)\left(\frac{\rho}{1-(\beta\lambda_1)\rho}\right)$$

Under the above assumptions, (A2.9) represents a closed form solution for the decision rule for A_{1t}. It expresses the optimal acreage allocation rule of the farm household as a function of acreage allocated last period, current output price, current and once-lagged 'quota' rate, and current actual and opportunity costs of cultivating Crop 1. All of these variables are elements of the current information set of the household. Note also that ω_3 and ω_4 jointly capture the direct and indirect effects of the 'quota' rate described in section 2.3).

2 The GMM estimators

This section summarizes some of the features of the GMM estimators[58]. The discussion focuses on an AR(2) model:

$$y_{it} = \kappa_1 y_{i,t-1} + \kappa_2 y_{i,t-2} + \kappa_3 x_{it} + \kappa_4 x_{i,t-1} + \kappa_5 x_{i,t-2} + u_{it} \tag{A3.1}$$

for $i = 1,...,N$ and $t = 3,...,T$, where: $\kappa_1 + \kappa_2 < 1$, $\kappa_2 - \kappa_1 < 1$, $\kappa_2 > -1$, and $u_{it} = \eta_i + \nu_{it}$. Thus, the discussion is restricted to the relevant stationary model. Following Blundell and Bond (1995), assume that[59]:

$$\mathbf{E}(\eta_i) = 0, \qquad \mathbf{E}(\nu_{it}) = 0, \qquad \mathbf{E}(\eta_i\nu_{it}) = 0 \tag{A3.2}$$

for $i = 1,...,N$ and $t = 3,...,T$;

$$\mathbf{E}(\nu_{it}\nu_{is}) = 0 \tag{A3.3}$$

for $i = 1,...,N$ and $t \neq s$; and

$$\mathbf{E}(y_{i1}\nu_{it}) = 0, \qquad \mathbf{E}(y_{i2}\nu_{it}) = 0 \tag{A3.4}$$

for $i = 1,...,N$ and $t = 3,...,T$.

Applying either the OLS estimator or the Within-groups estimator to (A3.1) results in biased parameter estimates [Nickell (1981), Hsiao (1986)][60]. The source of the problem for OLS is the correlation between $(y_{i,t-1}, y_{i,t-2})$ and u_{it} via the individual specific effects, η_i. For the Within-groups estimator, which involves transforming the variables by subtracting their time-means, the cause is the correlation between $(y_{i,t-1}, y_{i,t-2})$ and the time-mean of ν_{it}. An alternative is to employ an instrumental variable (IV) estimator after first-differencing equation (A3.1) to eliminate the individual-specific effects. More explicitly, it involves estimating:

$$\Delta y_{it} = \kappa_1 \Delta y_{i,t-1} + \kappa_2 \Delta y_{i,t-2} + \kappa_3 \Delta x_{it} + \kappa_4 \Delta x_{i,t-1} + \kappa_5 \Delta x_{i,t-2} + \Delta\nu_{it} \tag{A3.5}$$

[58] The characterization of the GMM(I) estimator follows Arellano and Bond (1991). The description of GMM(II) adapts the presentation in Blundell and Bond (1995) to the case of an AR(2) model with additional regressors.

[59] The specific details of the discussion of Blundell and Bond (1995) is restricted to an AR(1) process without additional regressors. However, they note that the properties of the estimators they consider extend to higher-order AR models. They also identify the further requirement that should be satisfied in order to exploit their additional linear moment restrictions in the presence of regressors. In the spirit of those remarks, assumptions (A3.2)-(A3.4) may be viewed as slightly modified versions of the ones they make. Note also that for the GMM(I) estimator it is not necessary to assume $\mathbf{E}(\eta_i) = 0$, $\mathbf{E}(\eta_i\nu_{it}) = 0$, and (A3.4).

[60] The OLS estimator is also inconsistent. In contrast, the Within-groups estimator is consistent as $T \to \infty$.

for $i = 1, ..., N$ and $t = 4, ..., T$, where Δ represents the first-difference operator with $\Delta z_{it} = z_{it} - z_{i,t-1}$. As long as ν_{it} are serially uncorrelated and the x's are exogenous, estimating (A3.5) using $(y_{i,t-2}, y_{i,t-3})$ or $(\Delta y_{i,t-2}, \Delta y_{i,t-3})$ as instruments results in consistent estimates of the parameters. That $(y_{i,t-2}, y_{i,t-3})$ and $(\Delta y_{i,t-2}, \Delta y_{i,t-3})$ are valid instruments, and thus lead to the consistency of the corresponding estimates, follows from the fact that they are not correlated with $\Delta\nu_{it}$ [Anderson and Hsiao (1982), Hsiao (1986)]. However, this IV estimation does not necessarily produce efficient estimates since it does not exploit all the linear moment conditions possible [Arellano and Bond (1991)]. As an alternative Arellano and Bond (1991) develop a more efficient linear Generalized Method of Moments (GMM) estimator. Below, this estimator is referred to as GMM(I).

2.1 the GMM(I) estimator

The GMM(I) estimator involves the identification and use of valid instruments for estimating dynamic panel data models consistently and efficiently. The initial step in that process is first-differencing the levels equation to take out the individual effects. Doing so in the present case generates (A3.5). The second step is to exploit the assumptions of the model and the properties of the regressors to identify instruments. Assume that the regressors x_{is} are predetermined variables correlated with η_i[61]. In other words, current and past x's are elements of the current information set Ω_t. This assumption, combined with the assumptions $\mathbf{E}(\nu_{it}) = 0$ and $\mathbf{E}(\nu_{it}\nu_{is}) = 0$ above, imply the following linear moment restrictions:

$$\mathbf{E}(y_{i,t-k}\Delta\nu_{it}) = 0 \tag{A3.6a}$$

for $k = 3, \cdots, t-2$ and $t = 4, \cdots, T$; and

$$\mathbf{E}(x_{is}\Delta\nu_{it}) = 0 \tag{A3.6b}$$

for $(s \leq t-1)$. These moment restrictions can be stated more compactly as

$$\mathbf{E}(\overline{Z}_i'\overline{\nu}_i) = 0$$

where: $\overline{\nu}_{it} = \Delta\nu_{it}$, $\overline{\nu}_i = \begin{bmatrix} \overline{\nu}_{i4} & \overline{\nu}_{i5} & \cdots & \overline{\nu}_{iT} \end{bmatrix}'$, expresses, for each i, the $(T-3)\times 1$ vector of the errors in the first-differenced equation, and $\overline{Z}_i$ represents the $(T-3)\times[(T-3)(T+1)]$ matrix of valid instruments for each i over t, i.e.:

$$\overline{Z}_i = \begin{bmatrix} y_{i1} & y_{i2} & x_{i1} & x_{i2} & x_{i3} & 0 & 0 & 0 & 0 & \cdots & \mathbf{0} & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & y_{i1} & y_{i2} & y_{i3} & x_{i1}\cdots x_{i4} & \cdots & \mathbf{0} & \mathbf{0} \\ \vdots & & & & & & & & & \ddots & & \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} & \cdots & y_{i1}\cdots y_{i,T-2} & x_{i1}\cdots x_{i,T-1} \end{bmatrix}$$

[61] This assumption reflects one of the features of the equations of motion of the endogenous variables. Specifically, recall that the equations for A_{it} and P_{it} contain arguments (other than the respective lagged endogenous variable) all of which belong to the relevant information set. In line with that, for the purpose of estimation, these additional regressors are treated as predetermined, i.e., it is assumed that:

$$\begin{aligned} \mathbf{E}(x_{is}\nu_{it}) &= 0,\ t \geq s \\ &\neq 0,\ t < s \end{aligned}$$

Past and current x are not correlated with current and future shocks. However, past shocks may be correlated with current x.

(A3.7)

Stacking equation (A3.5) first by t for each i, and then by i leads to a compact expression. To do so define:

$$\begin{aligned} w_{it} &= \left[\begin{array}{ccccc} y_{i,t-1} & y_{i,t-2} & x_{it} & x_{i,t-1} & x_{i,t-2} \end{array}\right], \quad \overline{w}_{it} = \Delta w_{it}, \quad \overline{y}_{it} = \Delta y_{it} \\ \overline{\nu}_{it} &= \Delta\nu_{it}, \quad \boldsymbol{\kappa}= \left[\begin{array}{ccccc} \kappa_1 & \kappa_2 & \kappa_3 & \kappa_4 & \kappa_5 \end{array}\right]' \end{aligned}$$

Then (A3.5) for all i and $t \geq 4$ can be summarized as:

$$\overline{y} = \overline{W}\boldsymbol{\kappa}+\overline{\nu} \tag{A3.8}$$

where:

$$\begin{aligned} \overline{y} &= \left[\begin{array}{cccc} \overline{y}_1' & \overline{y}_2' & \cdots & \overline{y}_N' \end{array}\right]', \qquad \overline{y}_i = \left[\begin{array}{cccc} \overline{y}_{i4} & \overline{y}_{i5} & \cdots & \overline{y}_{iT} \end{array}\right]' \\ \overline{W} &= \left[\begin{array}{cccc} \overline{w}_1' & \overline{w}_2' & \cdots & \overline{w}_N' \end{array}\right]', \qquad \overline{w}_i = \left[\begin{array}{cccc} \overline{w}_{i4} & \overline{w}_{i5} & \cdots & \overline{w}_{iT} \end{array}\right]' \\ \overline{\nu} &= \left[\begin{array}{cccc} \overline{\nu}_1' & \overline{\nu}_2' & \cdots & \overline{\nu}_N' \end{array}\right]', \qquad \overline{\nu}_i = \left[\begin{array}{cccc} \overline{\nu}_{i4} & \overline{\nu}_{i5} & \cdots & \overline{\nu}_{iT} \end{array}\right]' \end{aligned}$$

Note that $\overline{y}$ and $\overline{\nu}$ are $N(T-3) \times 1$ vectors, while $\overline{W}$ is an $N(T-3) \times 5$ matrix. Similarly stacking the instruments matrix produces:

$$\overline{Z} = \left[\begin{array}{cccc} \overline{Z}_1' & \overline{Z}_2' & \cdots & \overline{Z}_N' \end{array}\right]'$$

where $\overline{Z}_i$ is as defined in (A3.7). With these definitions, the GMM estimator of $\boldsymbol{\kappa}$ can be identified as [Arellano and Bond (1991), Davidson and MacKinnon (1993)]:

$$\widehat{\boldsymbol{\kappa}} = \arg\min_{\boldsymbol{\kappa}} \left(\overline{\nu}'\overline{Z}\right) A_N \left(\overline{Z}'\overline{\nu}\right)$$

where A_N is a $(T-3)(T+1)$ symmetric positive-definite matrix. Substituting for $\overline{\nu}$ from (A3.8), and solving the first-order conditions yields:

$$\widehat{\boldsymbol{\kappa}} = (\overline{W}'\overline{Z}A_N\overline{Z}'\overline{W})^{-1}(\overline{W}'\overline{Z}A_N\overline{Z}'\overline{y})$$

Arellano and Bond (1991) obtain the one-step GMM estimator of $\boldsymbol{\kappa}$ using the sample analogues of the moments and the moment restrictions above, and setting:

$$A_N = \left(N^{-1}\sum_{i=1}^{N} \overline{Z}_i' H \overline{Z}_i\right)^{-1}$$

where H is a $(T-3)$ square matrix which has 2's in its principal diagonal, -1's in the first sub-diagonals, and zeros elsewhere, i.e.[62]:

$$H = \left[\begin{array}{ccccc} 2 & -1 & & & \mathbf{0} \\ -1 & 2 & -1 & & \\ & -1 & 2 & \ddots & \\ & & \ddots & \ddots & -1 \\ \mathbf{0} & & & -1 & 2 \end{array}\right]$$

[62]The structure of H reflects the fact that $\overline{\nu}_{it}$ is a first-order moving average (MA(1)) process with a unit root.

These are the GMM(I) estimates reported in the text. Note, however, that another estimator is obtained if the following A_N is used instead:

$$A_N = N^{-1}\left(\sum_i \overline{Z}_i'\widehat{\overline{\nu}}_i\widehat{\overline{\nu}}_i'\overline{Z}_i\right)$$

where $\widehat{\overline{\nu}}_i$ is the differenced residuals from a preliminary consistent estimator of $\boldsymbol{\kappa}$. This is the two-step GMM estimator of Arellano and Bond (1991). It is nted here because the reported Sargan test of the overidentifying (moment) restrictions is based on the two-step estimates.

2.2 the GMM(II) estimator

Blundell and Bond (1995) note that the GMM(I) estimator performs poorly when the parameter(s) of the lagged endogenous variable is relatively large and the number of time-series observations is relatively small. Under such circumstances lagged levels are week instruments for first differences. Specifically, they demonstrate, via a Monte Carlo analysis, that the GMM(I) estimator suffers from a large downward bias and very low precision. To alleviate these problem without involving non-linear restrictions, they propose a linear GMM estimator in a system of first-differenced and levels equations. In order to obtain the requisite linear moment conditions Blundell and Bond (1995) introduce restrictions on the initial conditions process. The additional moment conditions thus obtained allow the use of lagged first differences as instruments in the equations in levels. The resulting estimator has much improved precision and substantially lower finite sample bias. Here, this system estimator is referred to as the GMM(II) estimator. Below, the framework of Blundell and Bond (1995) is adapted to this paper's AR(2) model with regressors.

Begin by restating the levels equation (A3.1) for $t \geq 4$:

$$y_{it} = \kappa_1 y_{i,t-1} + \kappa_2 y_{i,t-2} + \kappa_3 x_{it} + \kappa_4 x_{i,t-1} + \kappa_5 x_{i,t-2} + u_{it} \tag{A3.1$'$}$$

The objective is to exploit $(\Delta y_{i,t-1}, \Delta y_{i,t-2}, \Delta x_{i,t}, \Delta x_{i,t-1}, \Delta x_{i,t-2})$ as instruments in $(\mathrm{A2.1})'$ for $(y_{i,t-1}, y_{i,t-2}, x_{i,t}, x_{i,t-1}, x_{i,t-2})$. To do so without violating the consistency of the estimates, it is necessary to have:

$$\mathbf{E}(u_{it}\Delta y_{i,t-1}) = \mathbf{E}(u_{it}\Delta y_{i,t-2}) = 0 \tag{A3.9a}$$
$$\mathbf{E}(u_{it}\Delta x_{i,t}) = \mathbf{E}(u_{it}\Delta x_{i,t-1}) = \mathbf{E}(u_{it}\Delta x_{i,t-2}) = 0 \tag{A3.9b}$$

for $t \geq 4$.

Consider (A3.9b) first. Decomposing u_{it} and rearranging implies:

$$\mathbf{E}(u_{it}\Delta x_{i,t-\tau}) = \mathbf{E}(\eta_i\Delta x_{i,t-\tau}) + \mathbf{E}(\nu_{it}\Delta x_{it-\tau}), \qquad \tau = 0,1,2$$

That x_{it} are predetermined implies that:

$$\mathbf{E}(\nu_{it}\Delta x_{is}) = 0 \tag{A3.10a}$$

for all $s \leq t$. Therefore, condition (A3.9b) reduces to:

$$\mathbf{E}(\eta_i\Delta x_{it}) = 0 \tag{A3.10b}$$

for all t. (A3.10b) states that changes in x_{it} are uncorrelated with the individual effects[63]. This assumption is made here.

A number of steps are involved in the process of identifying the restrictions that validate the moment conditions (A3.9a). First, recalling that the model is stationary, rewrite equation (A3.1) using the lag operator $\mathbf{L}$:

$$y_{i,t} = \frac{1}{(1-\kappa_1\mathbf{L}-\kappa_2\mathbf{L}^2)}\left[\kappa(\mathbf{L})x_{it}+\eta_i+\nu_{it}\right] \tag{A3.1$''$}$$

where: $\kappa(\mathbf{L}) = \left(\kappa_3+\kappa_4\mathbf{L}+\kappa_5\mathbf{L}^2\right)$. By long division it can be shown that[64]:

$$\frac{1}{(1-\kappa_1\mathbf{L}-\kappa_2\mathbf{L}^2)} = \sum_{s=0}^{\infty}\delta_s\mathbf{L}^s$$

where: $\delta_0 = 1$, $\delta_1 = \kappa_1$, and $\delta_s = \kappa_1\delta_{s-1}+\kappa_2\delta_{s-2}$, for all $s \geq 2$. Similarly:

$$\frac{1}{(1-\kappa_1-\kappa_2)} = \sum_{s=0}^{\infty}\delta_s$$

where δ_s is defined as above. Using these results, and recalling that η_i is time-invariant, (A3.1$''$) can be stated as:

$$\begin{aligned} y_{i,t} &= \frac{\eta_i}{(1-\kappa_1-\kappa_2)}+\kappa(\mathbf{L})\sum_{s=0}^{\infty}\delta_s x_{i,t-s}+\sum_{s=0}^{\infty}\delta_s\nu_{i,t-s} \\ &= \frac{\eta_i}{(1-\kappa_1-\kappa_2)}+\kappa(\mathbf{L})\sum_{s=-1}^{\infty}\delta_{s+1}x_{i,t-(s+1)}+\sum_{s=-1}^{\infty}\delta_{s+1}\nu_{i,t-(s+1)} \end{aligned} \tag{A3.11}$$

where the fact that $\sum_{s=0}^{\infty}\delta_s z_{t-s} = \sum_{s=-1}^{\infty}\delta_{s+1}z_{t-(s+1)}$ have been used to get the second line of (A3.11). Applying (A3.11) to $t=1$ and $t=2$, yields:

$$\begin{aligned} y_{i1} &= \frac{\eta_i}{(1-\kappa_1-\kappa_2)}+\kappa(\mathbf{L})x_{i1}+u_{i1} \\ y_{i2} &= \frac{\eta_i}{(1-\kappa_1-\kappa_2)}+\kappa(\mathbf{L})x_{i2}+u_{i2} \end{aligned} \tag{A3.12}$$

where:

$$\begin{aligned} x_{i1} &= \sum_{s=-1}^{\infty}\delta_{s+1}x_{i,-s}, \quad x_{i2} = \sum_{s=-1}^{\infty}\delta_{s+1}x_{i,1-s} \\ u_{i1} &= \sum_{s=-1}^{\infty}\delta_{s+1}\nu_{i,-s}, \quad u_{i2} = \sum_{s=-1}^{\infty}\delta_{s+1}\nu_{i,1-s} \end{aligned}$$

Second, rewrite (A3.5) by successively substituting for $(\Delta y_{i,t-1}, \Delta y_{i,t-2})$ for $t \geq 4$. This yields:

$$\Delta y_{it} = \delta_{1,t-4}\Delta y_{i3}+\delta_{2,t-4}\Delta y_{i2}+\kappa(\mathbf{L})\sum_{s=0}^{t-4}\delta_{3s}\Delta x_{i,t-s}+\sum_{s=0}^{t-4}\delta_{3s}\Delta\nu_{i,t-s} \tag{A3.13}$$

[63]Indeed, this is the condition that Blundell and Bond (1995) identify (without providing details) as the further requirement which should be met in models with additional regressors.

[64]See, for instance, Sargent (1987:183).

where: $\delta_{10} = \kappa_1,\ \delta_{11} = (\kappa_1^2 + \kappa_2),\ \delta_{20} = \kappa_2,\ \delta_{21} = \kappa_1\kappa_2$, and:

$$\delta_{js} = \kappa_1 \delta_{j,s-1} + \kappa_2 \delta_{j,s-2}, \qquad j = 1,2, \qquad s = t-4, \qquad t > 5$$

and $\delta_{30} = 1,\ \delta_{31} = \kappa_1$, with $\delta_{3s} = \kappa_1 \delta_{3,s-1} + \kappa_2 \delta_{3,s-2}$, for $s \geq 2$.

Now it is possible to have a closer look at the moment conditions (A3.9a). Given assumptions (A3.2)-(A3.3) and (A3.10), and equation (A3.13) those conditions reduce to:

$$\mathbf{E}(u_{it}\Delta y_{i3}) = \mathbf{E}(u_{it}\Delta y_{i2}) = 0$$

Since Δy_{i3} and Δy_{i2} are observed at $t = 4$, the following two additional restrictions apply[65]:

$$\begin{aligned} \mathbf{E}(u_{i4}\Delta y_{i3}) &= 0 \\ \mathbf{E}(u_{i4}\Delta y_{i2}) &= 0 \end{aligned} \tag{A3.14}$$

Substituting for Δy_{i3} and Δy_{i2} from (A3.13), using (A3.12) and (A3.1$'$), exploiting assumptions (A3.2)-(A3.4) and (A3.10a), and manipulating provides the conditions necessary for the validity of the restrictions (A3.14). These are:

$$\begin{aligned} \mathbf{E}(\eta_i x_{i2}) &= \mathbf{E}(\eta_i x_{i1}) = 0 \\ \mathbf{E}(\eta_i u_{i2}) &= \mathbf{E}(\eta_i u_{i1}) = 0 \\ \mathbf{E}(\nu_{i4} u_{i2}) &= \mathbf{E}(\nu_{i4} u_{i1}) = 0 \end{aligned} \tag{A3.15}$$

These are restrictions on the initial condition process generating y_{i1} and y_{i2}. They are analogous to the restriction that Blundell and Bond (1995) impose on that process in an AR(1) model without additional regressors.

The GMM estimator exploiting restrictions (A3.9)-(A3.10) and (A3.14) requires a stacked system composed of $(T-3)$ equations in first differences and $(T-3)$ levels equations for periods $t \geq 4$ (the lagged first differences are available as instruments only beginning $t = 4$). The corresponding instrument matrix for each i (Z_i) can be written as:

$$Z_i = \begin{bmatrix} \overline{Z}_i & 0 & & \\ 0 & \Delta w_{i4} & & \mathbf{0} \\ & & \ddots & \\ & \mathbf{0} & & \Delta w_{i,T} \end{bmatrix} \tag{A3.16}$$

where $\overline{Z}_i$ represents the instruments for the first differenced equations as defined by (A3.7) above, and $\Delta w_{it} = \begin{bmatrix} \Delta y_{i,t-2} & \Delta y_{i,t-1} & \Delta x_{i,t-2} & \Delta x_{i,t-1} & \Delta x_{it} \end{bmatrix}$, for $t \geq 4$. The computation of the one-step estimator follows the same steps briefly noted for the GMM(I) estimator. One difference should be noted, however. The weighting matrix H has to be modified [see Blundell and Bond (1995)]. The two-step estimator is also identified in a similar fashion.

[65] These are analogous to the single additional restriction that Blundell and Bond (1995) identify in an AR(1) model with no additional regressors, namely:

$$\mathbf{E}(u_{i3}\Delta y_{i2}) = 0$$