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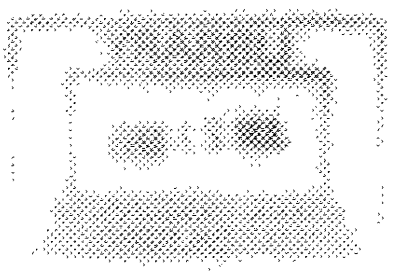

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Abstract

This paper analyzes the dynamic effects of the acreage restrictions and land diversion requirements that are characteristic of the farm subsidy programs in the United States. The subsidy payments a farmer receives are based upon historical base acreage, and it is sometimes optimal for a farmer not to participate in a program in order to increase base acreage in anticipation of higher future subsidies. This paper determines the farmer's optimal policy as the solution to a deterministic dynamic program. It shows that farmers with low base acreage typically opt out of these programs, whereas those with high base acreage participate in them. The paper concludes with an examination of aggregate data from the programs involving barley, corn, cotton, oats, rice, sorghum, and wheat during 1987. It shows that these programs actually increase the aggregate output of each of these crops and that they represent an annual deadweight loss of more than $3 billion.

The Dynamic Effects of Agricultural Subsidy Programs in the United States

by

Harry de Gorter

and

Eric O'N. Fisher[1]

> He was a long-limbed farmer, a God fearing, freedom-loving, law-abiding rugged individualist who held that federal aid to anyone but farmers was creeping socialism. ... His specialty was alfalfa, and he made a good thing of not growing any. The government paid him well for every bushel of alfalfa he did not grow. The more alfalfa he did not grow, the more money the government gave him, and he spent every penny he didn't earn on new land to increase the amount of alfalfa he did not produce. ... He invested in land wisely and soon was not growing more alfalfa than any other man in the country. ...
>
> [H]e was an outspoken champion of economy in government, provided it did not interfere with the sacred duty of government to pay farmers as much as they could get for all the alfalfa they produced that no one else wanted or for not producing any alfalfa at all.
>
> (Joseph Heller, *Catch 22*, pp. 82-83)

I. Introduction

The analysis of acreage restriction programs is one of the staples of an introductory course in economics. For example, Samuelson and Nordhaus (13th Edition, 1989, p. 433) explain:

> ...[I]n the 1980s the Treasury simply mailed a subsidy payment to farmers for every bushel of wheat or corn harvested.

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> One of the most common government farm programs requires farmers to restrict planted acreage. ... If the Department of Agriculture requires every farmer to "set aside" 20 percent of the last year's planted area of corn, this has the effect of shifting the supply curve of corn to the left. Because the demands for corn and most other agricultural products are inelastic, such crop restrictions not only raise the price of corn and other products; they also tend to raise the total revenues earned by farmers and total farm incomes.

This is a typical representation of farm policy in the United States; it emphasizes the effect of acreage restrictions in decreasing the supply of crops. However, these acreage restriction programs are voluntary, and hence the participation decision is endogenous. Although some acreage is diverted and some farmers do restrict plantings, these policies create incentives to expand current acreage in anticipation of future subsidies. Samuelson and Nordhaus recognize this dynamic aspect of the crop restriction programs; they explain in the paragraph above that this year's subsidies are based in part upon last year's planting. It is clear, then, that a forward-looking farmer may plant a large acreage in anticipation of next year's subsidies. One can consider this activity rent-seeking behavior on the part of a non-participant. It is, therefore, not immediately obvious what the net effect of these programs is on aggregate market supply.

We focus our analysis upon the individual farmer's choices under the incentives these programs offer. It is important to understand the net effect of these programs on output because farm subsidies have become such a controversial political issue in this decade. Indeed, agricultural policy is a central topic in the current Uruguay round of negotiations under the General Agreement on Tariffs and Trade. Further, the costs of these subsidy programs have risen dramatically during a period when the federal government's budget deficit has been an issue of pressing public concern. We develop a dynamic model of the effects of acreage restrictions precisely in order to determine the net effect of these programs on the outputs of the

seven major field crops. The advantage of this model is that it incorporates the microeconomic foundations of the farmer's decisions.

A key feature of these farm policies is that a participant in a program is not permitted to plant as much acreage as she desires. A farmer in a program is limited in her planting by her base acreage, a fixed proportion of which must be diverted in order to qualify for subsidies. The current policy in the United States determines historical base acreage for an individual farmer according to a five-year moving average of her "considered plantings"[2] of the subsidized crop. Farmers often find it in their long-run interest to opt out temporarily from the program and increase current planting.[3] This raises both base acreage and subsidy payments in the future. Hence any dynamic analysis of these programs must address the extent to which farmers are willing to forego current subsidy payments, incur extra production costs, and increase current planting in order to increase future subsidy payments.

The official jargon for these programs is "base acreage limitations" and "acreage diversion". The Treasury sends two different checks to participants in the program. One check covers the difference between the actual price of output and a predetermined target price, and the other covers the land that the farmer is required to divert. These are called "deficiency payments" and "diversion payments" respectively. The deficiency payment is a per unit subsidy that is the difference between a target price and the maximum of the market price and a "loan rate".[4] It is calculated as the product of this

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[2] Considered plantings are the sum of actual planting and acres diverted under the requirements of a subsidy program.

[3] See Ericksen and Collins (1985).

[4] This is an official predetermined selling price that the federal government guarantees for any farmer in the program. The government maintains the loan rate by stockpiling farm output. The cost of this policy is borne by the Commodity Credit Corporation, and it is independent of the deficiency and diversion payment schemes.

price differential, an "official" level of production,[5] and the total number of acres planted. The diversion payment is a per unit payment on land not planted. Further, for each subsidized crop, there is a maximum on the total subsidy payments that a farmer may receive in any one year.

To the best of our knowledge, there has been no dynamic analysis of these programs in the literature. The effects of these programs are typically analyzed using comparative statics. Wallace (1962) and Gardner (1984) model acreage diversion as a leftward shift of this supply curve and Gardner (1987) also uses this technique in his influential text. Lichtenberg and Zilberman (1986) give a static analysis of the welfare effects of environmental regulations on farmers who participate in these acreage restriction programs. Eckstein (1984) applies dynamic programming to the farmer's decision problem, but he analyzes the planting decisions of Egyptian cotton producers.

Our own work incorporates six elements that are not found uniformly in the literature on agricultural subsidies. First, we emphasize that participation in the program is voluntary; hence, it must be modeled as an endogenous decision of the farmer. Second, we deal explicitly with the fact that farm acreage must be diverted into unproductive uses in order for a farmer to receive deficiency payments. Third, we use the fact that subsidies to a farmer are limited by her historical base acreage. Fourth, we treat the difference between the actual yield that a farmer realizes on her land and the official program yield that the federal government uses to determine subsidy payments. Fifth, we model the diversion payments that a farmer receives. Sixth, we incorporate the fact that the total value of deficiency

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[5] This "official" level of production is a predetermined yield per acre; this is called "program yield". This yield is set by the federal government, and it is public knowledge.

payments and diversion payments is currently limited to $50,000 per farm.

The rest of the paper is structured as follows. Section II sets out the model and shows that there is an optimal policy for the farmer. In Section III, we analyze a simple example to illustrate the nature of the optimal policy. Section IV presents simulated solutions to the dynamic program for the seven major field crops in 1987, the only year for which complete data on the distribution of farm base acreages are available. Section V presents our conclusions, and our data and sources are described in the Data Appendix.

II. The Model

Let us consider the long-run decisions of a farmer operating under the current acreage restriction policy in the United States. Because we are interested in the decisions of an individual farmer, we shall study a model of price taking behavior. It is important to emphasize that we assume that the farmer has perfect foresight. This will enable us to model the farmer's decision as a deterministic dynamic program. The assumption of perfect foresight is in part justified by the fact that the target price, the loan rate, the program yield, the diversion factor, the diversion payments, and the maximal subsidy payment available to a farmer are all known before the time of planting. Moreover, almost all of these parameters have not changed dramatically during this decade. As we shall see below, market price and a farmer's actual yield do influence the per period reward, but we assume that farmers outside the program can take covered positions by using forward contracts in order to insure against adverse price movements. Further, we assume that all farmers of a given crop are identical and that each farmer's

output is deterministic.[6] In essence, the farmer knows the long-run values of all parameters before she makes her planting decisions.

We begin by defining the net profit function of a farm facing a price p and having the cost function c(q) as

$$f(p, q) = p\,q - c(q) \tag{1}$$

where f(p, q) is net profits per period when the farmer plants enough acreage to produce q units of output.

We make the following assumptions about the cost function c(q).

Assumption 1: The cost function c(q) is positive, non-decreasing, and continuous on $\mathbb{R}_{++}$. Further, $\lim_{q \downarrow 0} c(q) \geq 0$, and $c(0) = 0$.

The analysis can be this general because the existence of a dynamic program is robust with respect to many specifications of the cost function. We can even allow for the possibility of no fixed costs if one places an upper bound on the amount of acreage that any farmer may plant. In practice, we shall simulate the solutions to the dynamic program using an arbitrary specification of c(q) as a third degree polynomial.

If a farmer is a participant in a subsidy program and plants sufficient land to yield q_t bushels, the deficiency payments she receives are given by

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[6] We recognize frankly that both land and farmers come in different qualities and that each farmer's output is stochastic. Since we are not limiting ourselves to quadratic cost functions, the effect of incorporating uncertainty about yield into the farmer's dynamic optimization would complicate the analysis considerably. Including individual farm characteristics would create analogous difficulties. Further, in the empirical work in Section IV, we cannot hope to analyze individual yield per farmer with aggregate data.

$$[\tau - \max\{P, L\}]\ [PY/AY]\ [q_t]$$

where τ is the target price, P is the market price, PY is the program yield, AY is the actual yield, and L is the loan rate. We shall assume, of course, that $\tau > \max\{P, L\}$. The farmer's revenues can be defined as

$$[\tau - \max\{P, L\}]\ [PY/AY]\ [q_t] + [\max\{P, L\}]\ [q_t]$$

where all the variables are as above. This expression shows that she sells her output at the maximum of market price and the loan rate and that her deficiency payments can actually be increased by a higher program yield.

We must add the further consideration that a participant is often paid for the acres that she is forced to divert in order to be in the subsidy program. Farmers receive a per unit payment γ for every unit's worth of land that they leave fallow.[7] Let the farmer's base acreage be given equivalent to x_t units of output. Now let $q_t \leq x_t$. Then the total revenues accruing to a participant in the program are

$$g(x_t, q_t; \tau, P, L, PY, AY, \gamma) \equiv$$
$$[\tau - \max\{P, L\}]\ [PY/AY]\ [q_t] + [\max\{P, L\}]\ [q_t] + \gamma\ [PY/AY]\ [x_t - q_t]$$

where we have defined the function $g(x_t, q_t; \cdot)$, with the variables and parameters defined as above. We can now define

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[7] It is more accurate to model diversion payments as a non-linear function of the number of acres diverted. There is typically a minimum number of acres that must be diverted for which there is no diversion payment. Then there is an increasing payment per additional incremental acres that are diverted by a participant in the program. We do not have data on these non-linearities, and leaving them out of the model does not affect our results in any substantive way. Indeed, these diversion payments were identically zero in 1987 for three of the crops we study.

$$h(x_t, q_t) \equiv g(x_t, q_t; \tau, P, L, PY, AY, \gamma) - c(q_t) \tag{2}$$

where $h(x_t, q_t)$ denotes net revenues a participating farmer receives from having base acreage equivalent to x_t units and planting acreage to yield only q_t units.

As we mentioned above, there is a maximal subsidy under the program; let us denote the planted output equivalent of this maximum by M.[8] This output equivalent is defined implicitly by the minimal x_t such that

$$\max_{q_t \in [0, x_t]} [\tau - \max\{P, L\}] [PY/AY] [q_t] + \gamma [PY/AY] [x_t - q_t] = 50000.$$

Since this expression is linear in q_t, it will attain its maximum at 0 or x_t. Indeed, if $[\tau - \max\{P, L\} - \gamma] \geq 0$, then it attains its maximum at x_t, and $M = 50000 [AY/PY][\tau - \max\{P, L\}]^{-1}$; if $[\tau - \max\{P, L\} - \gamma] < 0$ and $\gamma > 0$, then $M = 50000 [AY/PY] \gamma^{-1}$.

We are now in a position to define the farmer's problem. Since x_t is the farmer's historical base acreage, we can consider it the state variable in a dynamic programming problem. Then the reward function can be written as

$$r(x_t, u_t) = \begin{cases} h(x_t, u_t) & \text{if } u_t \leq \min\{(1 - \delta)x_t, M\} \\ f(P, u_t) & \text{otherwise} \end{cases} \tag{3}$$

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[8] Farmers have been quite ingenious in circumventing this maximum. For example, they have subdivided farms into several corporations. It has been particularly easy to give such a corporation to one's child, thus keeping the benefits of federal subsidies in the family. They have also leased land on their farms to employees, charging rents high enough to capture a substantial part of the implicit government benefits. Sumner (1989) gives a good discussion of this issue.

where $\delta \in [0, 1)$ is the acreage diversion factor, u_t is the output equivalent to the planted acreage at time t, $h(x_t, u_t)$ is defined in equation (2), and $f(P, u_t)$ is as defined in (1). We consider u_t the farmer's control variable. Notice that $r(x_t, u_t)$, considered as a function of u_t, has at most two points of discontinuity; these may occur at 0 or $\min\{(1 - \delta)x_t, M\}$. These possible discontinuities notwithstanding, we can show that $r(x_t, u_t)$ is upper semi-continuous[9] since $\tau > \max\{P, L\}$.

Let us define the transition function as

$$x_{t+1} = \begin{cases} .8x_t + .2\delta x_t + .2u_t & \text{if } u_t < (1 - \delta)x_t \\ x_t & \text{if } (1 - \delta)x_t \le u_t \le x_t \\ .8x_t + .2u_t & \text{if } x_t < u_t \end{cases} \tag{4}$$

where x_{t+1} is the output equivalent to period t+1's historical base acreage and where for simplicity we have assumed that the five-year moving average x_t is the same as the average base acreage during the last four years.[10] This is the reason that we use the coefficient .8 in (4). This equation states that acreage planted in year t adds to historical base acreage in year t + 1 by a simple weighted-average formula. This simplification allows us to maintain the Markovian structure of the dynamic program. This transition is Markovian in a degenerate sense, because given x_t and a current choice of u_t, x_{t+1} is entirely deterministic.

Further, let the discount factor be given by β, with $0 \le \beta < 1$. Let us

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[9] A function f(x) is upper semi-continuous at x_0 if and only if $\lim_{x \to x_0} f(x) \le f(x_0)$; f(x) is upper semi-continuous if it is upper semi-continuous at each element in its domain.

[10] If a farmer diverts exactly the required acreage, then her historical base does not diminish; however, if she wishes to decrease her historical base, we assume that the required acreage diversion is part of her considered plantings.

denote the set of states by X, and let us define the set of controls by U.[11] Now we can define the discounted dynamic program of the farmer as a four-tupel $\langle X, U, z, \beta \rangle$ where X is the state space, U is the control space, $z: X \times U \rightarrow X$ is the transition rule, and β is the discount factor. A policy is a function $\pi: X \rightarrow U$, and the expected discounted total return from π is

$$I(\pi)(x) = \sum_{t=1}^{\infty} \beta^{t-1} r(\pi)(x)$$

where $I(\pi)$ is the expected value of following the policy π when the state is $x \in X$. An optimal policy is a plan π^* such that $I(\pi^*)(x) \geq I(\pi)(x)$ for all π and $x \in X$. We are interested in deriving this function. Notice that the optimal policy function does not vary with time; it is in this sense that this is the solution to a stationary dynamic program.

If there is an optimal policy, then the value of the state $x_t \in X$ is given by

$$V(x_t) = \max_{u_t \in U} r(x_t, u_t) + \beta V(x_{t+1}) \tag{5}$$

where u_t is chosen according to π^* and where x_{t+1} is given by the transition equation (4). Equation (5) has the interpretation that a farmer with base acreage equivalent to output x_t who follows an optimal plan will have $V(x_t)$ as the present discounted value of the subsidy program. Equation (5) characterizes the optimal policy function implicitly.

We make a further assumption about X and U

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[11] A more general formulation of a dynamic program allows the set of controls to depend upon x_t, but we are not losing any generality to treat U as a fixed set, perhaps the set of all arable land in the United States.

Assumption 2: The state space X and the control space U are compact.

This assumption is innocuous enough; it says that yields are not infinite, that a farmer can have only a finite base acreage, and that she can plant only a finite plot of land. We may now state

Theorem: There is a solution to the farmer's dynamic program. Further, the value function is upper semi-continuous.

Proof: Since $\tau > \max\{P, L\}$, it is easy to check that $r(x_t, u_t)$ is upper semi-continuous in u_t. The transition function given in equation (4) is continuous in u_t and it is degenerate; hence, it is trivially continuous in the sense of the weak convergence of measures. Since X and U are compact and $r(x_t, u_t)$ is upper semi-continuous, we may apply Maitra's (1967) theorem. □

It will be useful to give some characterization of the optimal policy that the solution to the farmer's program entails. It will be convenient to define the function

$$\phi(q) \equiv [\tau - \max\{P, L\} - \gamma]\,[PY/AY]\,[q] + [\max\{P, L\}]\,[q] - c(q).$$

Note that if x_t is sufficiently large $\phi(q) = h(x_t, q) - [PY/AY]\,\gamma x_t$, where $h(q)$ is as defined above. Since both $f(P, q)$ and $\phi(q)$ are continuous in q, we may define $q^*(P) \in \operatorname{argmax}_{q\in[0,M]} f(P, q)$ and $q^*(\tau) \in \operatorname{argmax}_{q\in[0,M]} \phi(q)$. If there are several elements in either of these sets, let us consider only the smallest such element. The quantities $q^*(P)$ and $q^*(\tau)$ are the (smallest) static profit maximal outputs for a farmer with sufficiently large base acreage facing price P and subsidy program parameters (τ, L, PY, γ). We can

now state

Proposition 1: (i) If $h(x_t, q^*(\tau)) < f(P, q^*(P))$ for $x_t \in [q^*(\tau)/(1 - \delta), M]$, then $\pi^*(x_t) = q^*(P)$ for all x_t;

(ii) If $q^*(\tau) \leq M$ and $h(q^*(\tau)/(1 - \delta), q^*(\tau)) > f(P, q^*(P))$, then $\pi^*(x_t) = q^*(\tau)$ for all $x_t \geq q^*(\tau)/(1 - \delta)$; and

(iii) Assume that $M < q^*(\tau)$ implies that M maximizes $\phi(q)$ on $[0, M]$. If $f(P, q^*(P)) < \phi(M)$, then $\pi^*(x_t) = M$ for all $x_t \geq M/(1 - \delta)$.

Proof: If $h(x_t, q^*(\tau)) < f(P, q^*(P))$ for large x_t, then the static profit maximal choice of output is $q^*(P)$ even for farms with sufficiently large base acreage. This implies that for any state x_t, $\pi^*(x_t) = q^*(P)$. This proves (i)

Since $h(q^*(\tau)/(1 - \delta), q^*(\tau)) > f(P, q^*(P))$, the static profit maximal output for a participant with sufficiently large base acreage is $q^*(\tau)$. Hence, a farmer with base acreage $x_t \geq q^*(\tau)/(1 - \delta)$ may plant $q^*(\tau)$ and earn $h(q^*(\tau)/(1 - \delta), q^*(\tau))$ per period. Since $x_t \geq q^*(\tau)/(1 - \delta)$, $x_{t+1} \geq q^*(\tau)/(1 - \delta)$. This implies that the state next period will be such that the one-period profit maximal choice of acreage will again be possible. This establishes (ii).

If M maximizes $\phi(q)$ for $q \in [0, M]$ and $f(P, q^*(P))) < \phi(M)$, then planting M is one-period profit maximal. For $x_t \geq M/(1 - \delta)$, we can use the same argument as in (ii) above to show that the one-period choice is maximal for the dynamic problem. This shows (iii). □

Part (i) of Proposition 1 has the simple interpretation that all farmers will choose to opt out of the subsidy program and produce the quantity at which market price equals the marginal cost of production if the maximal subsidy

payments are sufficiently low. Now let the maximal subsidy payments be large. Then part (ii) of Proposition 1 states that farmers with sufficiently large historical base acreage plant the one-period profit maximal acreage. Part (iii) of this proposition deals with the case in which the maximal base acreage is a binding constraint; if costs are increasing then the farmer will be bound by this constraint. Still, if she has sufficiently large base acreage, planting M will maximize static and dynamic profits.

We now state a second proposition.

Proposition 2: The value function $V(x_t)$ is non-decreasing.

Proof: Let $x_t \le y_t$ and let $u^*_t \in \text{argmax } r(x_t, u_t)$ and $v^*_t \in \text{argmax } r(y_t, u_t)$. Since $[0, x_t] \subseteq [0, y_t]$, $r(x_t, u^*_t) \le r(y_t, v^*_t)$. Further, we may always choose u^*_t and v^*_t such that $u^*_t \le v^*_t$. This implies that $x_{t+1} = x_t + u^*_t \le y_t + v^*_t = y_{t+1}$. Hence $r(x_{t+1}, u^*_{t+1}) \le r(y_{t+1}, v^*_{t+1})$ where u^*_{t+1} and v^*_{t+1} are analogous to u^*_t and v^*_t. But this is true for every subsequent period $s \ge t+1$. Now let π^* be an optimal policy. Then $I(\pi^*)(x_t) \le I(\pi^*)(y_t)$ and thus $V(x_t) \le V(y_t)$. □

The intuition behind Proposition 2 is straightforward. It states that it never hurts to have a larger initial base acreage. Indeed if a farmer's base acreage is larger than max $\{M/(1 - \delta), q^*(\tau)/(1 - \delta)\}$, then it is costless to plant a lower acreage. Moreover next period's historical base will still be larger than max $\{M/(1 - \delta), q^*(\tau)/(1 - \delta)\}$.

In the rest of the discussion, we shall assume: (i) that $\phi(q^*(\tau)) > f(P, q^*(P))$; and (ii) that $M < q^*(\tau)$ implies that M maximizes $\phi(q)$ on $[0, M]$. Again, this states first that maximal allowable base acreage is large enough so that it pays a farmer to be in the subsidy program and second that if the

maximal base acreage constraint is binding, then it is one-period profit maximal to plant M. Let us define $\mu = \min\{q^*(\tau)/(1 - \delta), M/(1 - \delta)\}$; the parameter μ is simply the output equivalent of maximal base acreage that a participant in the program will maintain. We can now further describe the optimal policy function and the implied value function. We state

Proposition 3: If $x_t \geq \mu$, then $\pi^*(x_t) = (1 - \delta)\mu$ and $V(x_t) = (1 - \beta)^{-1} h(x_t, (1 - \delta)\mu)$. Further, there is an interval $(a, \mu]$ in which $\pi^*(x_t) = (1 - \delta)x_t$ for all $x_t \in (a, \mu]$; this implies that $V(x_t) = (1 - \beta)^{-1} h(x_t, (1 - \delta)x_t)$ for $x_t \in (a, \mu]$.

Proof: If $x_t \geq \mu$, then $h(x_t, (1 - \delta)x_t) \geq f^*(P, q^*(P))$. Then Proposition 1 implies that $\pi^*(x_t) = (1 - \delta)\mu$. This implies that $x_{t+1} \geq \mu$ and hence that $V(x_t) = (1 - \beta)^{-1} h(x_t, (1 - \delta)\mu)$.

Now let $x_t \in (a, \mu]$ where a is sufficiently close to μ. Let us assume that there is an $x_t \in (a, \mu]$ such that $u_t = \pi^*(x_t) > (1 - \delta)x_t$. This implies that

$$\begin{aligned} V(x_t) &= f(P, u_t) + \beta V(x_{t+1}) \\ &\leq f(P, u_t) + \beta (1 - \beta)^{-1} h(\mu, (1 - \delta)\mu) \\ &\leq f(P, q^*(P)) + \beta (1 - \beta)^{-1} h(\mu, (1 - \delta)\mu) \end{aligned}$$

where the first inequality follows from the definition of the maximum of the value function and the second from the maximal flow profits accruing to a producer opting out of the subsidy program. Since we have assumed that $u_t = \pi^*(x_t)$ is an optimal policy and since the value function is not decreasing, we know that planting $u_t = (1 - \delta)x_t$ is not optimal; this means that $(1 - \beta)^{-1} h(x_t, (1 - \delta)x_t) \leq V(x_t)$. But this implies that

$$(1 - \beta)^{-1} h(x_t, (1 - \delta)x_t) \leq f(P, q^*(P)) + \beta (1 - \beta)^{-1} h(\mu, (1 - \delta)\mu)$$

which is equivalent to

$$h(x_t, (1 - \delta)x_t) \leq (1 - \beta) f(P, q^*(P)) + \beta h(\mu, (1 - \delta) \mu)$$

which is clearly contradicted for x_t sufficiently near μ because $h(x_t, (1 - \delta)x_t)$ is continuous in x_t and $P < \tau$ implies that, in a neighborhood of μ, $f^*(P, q^*(P)) < h(\mu, (1 - \delta)\mu)$. This contradiction establishes that $\pi^*(x_t) = (1 - \delta)x_t$. Then for $x_t \in (a, \mu)$, $V(x_t) = (1 - \beta)^{-1} h(x_t, (1 - \delta)x_t)$ from the definitions of the value and profit functions. □

The intuition behind Proposition 3 is simple. It states that it is never optimal for a farmer with sufficiently large base acreage to opt out of the subsidy program because the presented discounted value of the gains from increased future base acreage do not offset the current loss in flow profits owing to opting out of the subsidy program. This implies that the value of the subsidy program for sufficiently large farms is the present discounted value of maintaining their current base acreages.

We continue our characterization of the optimal policy with

Proposition 4: Assume that $f(P, q^*(P)) > 0$. Then there is a an interval $[0, b)$ such that for all $x_t \in [0, b)$, $\pi^*(x_t) > x_t$.

Proof: Let $x_t \in [0, b)$, with b sufficiently near 0. Assume that $\pi^*(x_t) = (1 - \delta)x_t$. Then since $x_t = x_{t+1}$,

$$V(x_t) = (1 - \beta)^{-1} h(x_t, (1 - \delta)x_t)$$
$$= (1 - \beta)^{-1} [g(x_t, (1 - \delta)x_t; \tau, P, L, PY, AY, \gamma) - c((1 - \delta)x_t)].$$

But $\lim_{x_t \downarrow 0} g(x_t, (1 - \delta)x_t; \tau, P, L, PY, AY, \gamma) - c((1 - \delta)x_t) \leq 0$. Since $f(P, q^*(P)) > 0$, this contradicts the optimality of π^*. □

Assume that it is at all profitable to produce the crop under conditions of perfect competition. Then Proposition 4 states that the there will be some states for which the farmer will find it optimal to opt out of the program. This follows from the fact that the acreage diversion policy gives small farms no deficiency payments in the limit.

We finish the characterization of the optimal policy with the following observation. Consider, a farmer whose historical base acreage is such that it is optimal to opt out of the subsidy program. If the cost and value functions are differentiable, then this farmer will plant an acreage equivalent to the output u_t that is greater than that the output at which the marginal cost of production is equal to market price P. This follows from the fact that the first order condition for the maximization of (5) is given by

$$P - c'(u_t) + .2\,\beta\, V'(.8x_t + .2u_t) = 0 \tag{6}$$

where we have assumed that $u_t > x_t$ and where we have used the definition of x_{t+1}. Since $V'(x_{t+1}) \geq 0$ by Proposition 2, we know that $u_t \geq q^*(P)$, the one period profit maximal output choice when a farmer faces price P. It is in this sense that the deficiency payments cause even nonparticipants to produce a quantity that is not economically efficient. Indeed the only situation in which it is optimal to produce $q^*(P)$ is when the farmer discounts the future

entirely or when the value function is flat.

III. A Simple Analytical Example

It is difficult to provide a closed from solution for the farmer's optimal policy because of the level of generality with which we are treating the cost function. In this section, we shall provide an analytical example of the dynamic effects of the deficiency payments program.

Assume that the cost function is given by

$$c(q) = c\,q$$

where c is the constant marginal cost of production. In order to keep the analysis tractable, we shall assume that max {P, L} = P = c. Further, we assume here that PY = AY = 1 and that $\gamma = 0$; these assumptions state that the program yield is the actual yield and that there are no diversion payments. This allows us to concentrate on the intertemporal effects of deficiency payments only.

The present value of maintaining the maximal base acreage is

$$V(\mu) = (1 - \beta)^{-1}\,(1 - \delta)\,(\tau - c)\,\mu$$

where all the variables are as above. This value is positively related to the target price, the effective maximal acreage, and the discount factor. Indeed, the more patient a farmer is, the more valuable a continuing flow of subsidies is to her. The maximal value is also negatively related to the diversion factor and the marginal cost of production.

Now consider a farmer whose base acreage x_t is quite low. By foregoing participation in the program, she must sell her current produce at market

price P and thus make no profits. Because costs are linear, she will find it optimal to produce $u_t = 5\mu - 4x_t$ so that the output equivalent to her base acreage in the next period is $x_{t+1} = \mu$. Of course, in every subsequent period, this will be her base acreage as well. The present value of this policy is

$$V(x_t) = \beta(1-\beta)^{-1}(1-\delta)(\tau - c)\mu$$

which is simply the present value of having $x_{t+1} = \mu$ in the next period.

We are interested in the maximal acreage for which this policy is optimal. Notice that any participant with base acreage x_t can achieve

$$I(\pi)(x_t) = (1-\beta)^{-1}(1-\delta)(\tau - c)x_t$$

simply by maintaining base equivalent to x_t and diverting the requisite proportion δ of it. Hence a farmer will opt out of the program in period t if and only if

$$(1-\beta)^{-1}(1-\delta)(\tau - c)x_t < \beta(1-\beta)^{-1}(1-\delta)(\tau - c)\mu$$

which is equivalent to $x_t < \beta\mu$.

This result is the crux of the example. Farmers with small base acreage will opt out of the program for one period in order to build up base acreage for all future periods. If farmers are identical in every way except for their initial base acreage, then the farms with small base acreage will opt out of the program and those with large base acreage will be participants in it. The aggregate effect on the market supply of this crop will depend of course upon the distribution of initial base acreages.

We can summarize this example by stating that the optimal policy is

$$\pi^*(x_t) = \begin{cases} 5\,\mu - 4\,x_t & \text{if } x_t < \beta\mu \\ \min\{x_t,\ \mu\} & \text{otherwise.} \end{cases}$$

Further, the value function is

$$V(x_t) = \begin{cases} \beta(1-\beta)^{-1}(1-\delta)(\tau - c)x_t & \text{if } x_t < \beta\mu \\ (1-\beta)^{-1}(1-\delta)(\tau - c)\ (\min\{x_t,\ \mu\}) & \text{otherwise.} \end{cases}$$

Notice that this example illustrates all of the features of the solution that we described in the previous section. There is an interval near zero where the optimal policy entails opting out, and there is an interval near μ where it entails no adjustment of base acreage. Further, the value function is increasing and upper semi-continuous. It is obvious that we could obtain a closed form solution for this example because the assumption of linear cost entailed that the optimal policy exhibited a full adjustment to the maximal base acreage in one step. This is not true in general; indeed, the curvature of the cost function has much to do with the level of adjustment that a farmer will undertake when she increases her base acreage. This idea will be developed more fully in the next section.

IV. Simulation Results for the Seven Major Field Crops

In this section, we simulate the dynamic program for the seven major field crops in 1987, the only year for which data on the distribution of base acreage are available. The crops we analyze are barley, corn, cotton, oats, rice, sorghum, and wheat.

The first step in the simulation procedure involves constructing an estimate for farmers' cost functions. It is generally recognized that a farm is a multi-product firm, but introducing several crops into the dynamic

program would complicate the analysis enormously. It is quite difficult to get estimates of single product cost functions in the literature, and we were forced to simulate them ourselves. We allowed the cost function for a farmer to be an arbitrary third order polynomial. Hence costs for a farm are given by

$$c(q) = F + \alpha_1 q + \alpha_2 q^2 + \alpha_3 q^3 \tag{7}$$

which has the advantage that it is flexible enough to allow for parabolic marginal costs.[12]

We used aggregate data from the Department of Agriculture to simulate these costs for each of the seven crops. These data are summarized in Table 1 and Table 2.

-- Place Table 1 here. --

-- Place Table 2 here. --

We have to simulate the four parameters of equation (7) for each of the seven crops. The data in Tables 1 and 2 allow us to compute average output per farm. From this, we can immediately recover fixed cost per farm; it is still necessary to determine the values α_1, α_2, and α_3. We did this using the following three relations

$$AVC = \alpha_1 + \alpha_2 q_0 + \alpha_3 q_0^2 \tag{8.1}$$

$$P = \eta\ (\alpha_1 + 2\alpha_2 q_0 + 6\alpha_3 q_0^2) \tag{8.2}$$

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[12] Since we are using a smooth cost function, we are assuming implicitly that the farmer faces no acreage limitation over the relevant ranges of planting. This is not unreasonable for the acreages that we analyze for the seven crops in this section,

$$0 = \alpha_1 \tag{8.3}$$

where AVC is the reported average variable cost per farm, q_0 is the observed average output per farm, η is the elasticity of market supply, and P is again the observed market price. The first relationship is simply the definition of average variable cost. The second equation uses the observed elasticity of market supply to derive a relationship between marginal cost and the second derivative of the cost function. The third relation is imposed arbitrarily to tie down the actual cost function; still, it has the economic interpretation that the marginal cost of the first unit of output is near zero. We present our simulated cost functions in Table 3.

-- Place Table 3 here. --

Even though the procedure we used to simulate these cost functions was *ad hoc*, the results correspond roughly to our intuition about the production techniques for the seven crops. In particular, cotton and rice are characterized by high fixed costs per farm, whereas the coarse grain crops typically have relatively low fixed costs.

The next step in the simulations is to collect the parameters that determine the optimal policy. We present the list of these parameters in Table 4.

-- Place Table 4 here. --

We refer the reader to the Data Appendix for a full description of the data and their sources.

We simulated the dynamic program by dividing the state space into five acre increments. The discount factor that used in all simulations was 1.05^{-1}

in order to capture the notion that the real interest rate in 1987 was roughly five percent per annum. The optimal policies for the seven major crops are presented in Figs. 1 through 7 at the end of the text. The optimal polices are graphed to show planting beyond base acreage; any farmer that does plant strictly less than her historical base is not a participant in the program. Otherwise, farmers divert at least the requisite proportion of their base acreages, and they may even plant a lower acreage in order to decrease their historical bases quickly. The actual optimal policy is simply the sum of base acreage and the functions shown in the figures.

It is striking that these optimal policy functions show that a farmer with small base acreage is not a participant in the crop restriction program. It has been the popular conception that agricultural subsidies in the United States have been intended to help the small family farm. But Proposition 2 above shows that these policies benefit big farms more than small ones. This theoretical result is corroborated by Fig. 8. The figure illustrates that the average base acreage of participants was much larger than that of non-participants for each of these seven crops in 1987.

In order to get a sense of the effect that the crop restriction policies had on the average farmer's output, we calculated the perfectly competitive outputs corresponding to the market prices given in Table 4 and the cost functions given in Table 3.[13] For barley, corn, cotton, oats, rice, sorghum, and wheat, these outputs are given by 40, 35, 60, 12.5, 75, 25, and 50 acres respectively, where we have rounded the numbers to the nearest five acre increment to make them comparable with Figs. 1 through 7.[14] Notice that the farmers participating in the program are typically planting roughly the

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[13] We are assuming for simplicity that the price of each of these crops is fixed by conditions in the world market.

[14] It was necessary to use 2.5 acre increments for oats.

perfectly competitive acreage. But the farmers with low historical base acreage are planting far beyond these levels. This is especially true of those farms whose base acreage is near the thresh-hold that defines participation in the subsidy program; this is precisely when these farms find it advantageous to expand their base acreages. These rough calculations are a good indication that policy makers have chosen the diversion factors have so that the net effect of these policies on aggregate output is to produce near the perfectly competitive output if all farmers participated. But we shall show below that the rent-seeking behavior of farmers outside the programs has expanded aggregate output substantially for all the crops but oats. A more accurate prediction of the effects that these policies have on aggregate output depends, of course, upon the distribution of historical base acreage.

We obtained data on this distribution of farms through private correspondence with the United States Department of Agriculture, Agriculture Stabilization and Conservation Service, Commodity Analysis Division; the source of these unpublished data was the Commodity Analysis Division/National Agricultural Statistical Services database, and the data are dated 30 December 1988. Using these data and the simulated optimal policy functions, we calculated predicted aggregate output for each crop. We present these calculations in Table 5. It is appropriate to compare these predicted outputs with the actual outputs from Table 2. We have fairly accurate predictions for the aggregate outputs of barley, cotton, oats, and rice. The prediction for wheat output is the most inaccurate, and this is incorrect by roughly thirty percent. Considering that we imposed the restriction that $\alpha_1 = 0$ arbitrarily in (8.3), we feel that these predictions are quite credible.

-- Place Table 5 here. --

The predictions on the relative effects of the programs on aggregate outputs are apt to be quite accurate because any bias in our determination of the cost functions affects the simulation results of the dynamic program and the predicted perfectly competitive outputs equally. We turn our attention now to the summary data on output presented in the first half of Table 5. It is a remarkable fact that, in almost every case, crop restriction programs result in output that is roughly thirty percent higher than would have occurred in their absence.

It is of course interesting to analyze the effect that these crop restriction programs have on producer surplus. The solutions to the dynamic programs are value functions; these are precisely the present value of the producers surplus. We have not reported the value functions here in order to save space, but it is an easy calculation to determine producer surplus for all farmers for a given crop because we have the distribution of the farms' base acreages for 1987. It is also quite simple to calculate producer surplus under perfect competition at the market prices given in Table 2. The present value of this surplus is the discounted sum of one period producer surplus in perpetuity. The results of our calculations are reported in the second half of Table 5. We see that the existence of crop restriction programs typically quadruples producer surplus.[15] Indeed, we calculate that these crop restriction programs raises the present value of producer surplus for these seven crops by $232.1 billion; this represents a flow transfer of $11.6 billion per year, slightly less than 0.3% of the United States' gross national product.

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[15] Oats were the exception in 1987; this occurred because their market price was so high as a result of the recent discovery that oat bran has beneficial health effects.

We conclude this section with a calculation of the production deadweight loss that these programs entail.[16] We are in a second best world, and hence the present value of these subsidies may be an inevitable part of the political process. It is still interesting to calculate the the deadweight loss to society of these programs as a proportion of the total economic transfer to farmers. We did this by calculating the incremental costs, net of the value of increased output, that the induced excess production for each of these crops entails. We present these data in Table 6. It is interesting that society could save $66 billion in present value of wasted resources simply by giving these farmers a lump-sum transfer of $232.1 billion and then abolishing all these programs.

-- Place Table 6 here. --

V. Conclusion

This paper develops the first dynamic analysis of the crop restriction programs of the United States. The model emphasizes the fact that the decision to participate in these programs is voluntary. We solved the dynamic program that the farmer's decision problem entails, and we showed that farmers with small base acreage tend to opt out of these programs. The optimal policy for small farmers to produce in order to build up base acreage; this is akin to rent-seeking behavior even by producers who are not currently participating in these programs. We have shown how acreage diversion, the target price, the loan rate, the difference between actual and program yields, and diversion payments affects the incentives of both

[16] Since we are assuming that output prices are fixed, there is no consumption deadweight loss.

participants and non-participants.

We have not explored the implications of this model on the long-run distribution of farm sizes, but we have shown that small farms tend to increase their plantings. This may explain in part the evolution of the structure of farming in the United States in this half century. The family farm may be simply too small to take full advantage of the government's price support programs. The single most important empirical finding is that these crop restriction programs result in production levels that are typically more than thirty percent higher than would have been the case in the absence of these programs. We showed that the present value of resources wasted in this rent-seeking behavior was $66 billion.

It is ironic that our analysis has immediate application for agricultural policy in centrally planned economies. In these economies, it is typical to establish a production quota for a collective farm. Any production beyond the quota results in a reward to the farm. It is obviously in the interest of managers of these collective farms to produce at relatively low levels for several years in order to keep their quotas low. If a farm does exceed its quota, it is also in its long-run interest not to exceed the quota by too much; a successful year only means that the collective farm will likely be punished for not meeting its future quota. This has been commonly called the "ratchet effect"; see, for example, Johnson and Brooks (1983). The dynamic inefficiencies that these policies entail are quite similar to those of policy of the United States. The current initiatives in the Soviet Union to reform this policy have met with political opposition, just as has any proposed change to the price support programs in the United States. An alfalfa farmer is an alfalfa farmer, no matter where she lives.

Data Appendix

The data on costs of production are reported in McElroy, Ali, Dismukes, and Clauson. Fixed costs are based upon the gross value of a crop relative to that of all crops grown on a farm. The national average is obtained by taking a weighted average of these fixed costs. These authors use a similar technique in calculating aggregate data on variable costs.

The data we report on the number of farms in the United States refer to farms that have base acreage of the crop in question in 1987. These farms may or may not be participants in the relevant programs in that year. The source is as indicated in the text.

The data we report for total output of these crops is obtained from the United States Department of Agriculture's Economic Research Service's *Situation and Outlook Report for Wheat* (August 1989), *Situation and Outlook Report for Feed* (August 1989), *Situation and Outlook Report for Rice* (April 1989), and *Situation and Outlook Report for Wool and Cotton* (May 1989). The yield per acre refers to planted acres, and these data are again from McElroy, Ali, Dismukes, and Clauson.

Market prices, target prices, and loan rates are from the *Situation and Outlook Reports* for the relevant crops. The diversion requirements are calculated as the ratio of acres diverted to total base acreage for each of the crops. Acres diverted include those in programs involving "acreage reduction", "paid land diversion", "payment in kind", "0/92", and "50/92". The acres placed into the long-term conservation reserve program are not included in acres diverted. For all crops but cotton, the source for the data on acres diverted and base acreages is the United States Department of Agriculture's Agricultural Stabilization Conservation Service, Commodity Analysis Division. These data are not published. The data for barley, corn, oats, and sorghum are dated July 1989, the data for wheat is dated 10 May 1989, and the data for rice is dated October 1989. The corresponding data about acreage diverted for upland cotton is from the United States Department of Agriculture's publication *News*, dated 10 March 1988, and the data on cotton base acreage are found in Stults, Glade, Sanford, and Meyer on pages 77 and 79.

The program yields are in units per acre planted. The diversion payments per unit not planted are calculated as the ratio of total diversion payments to this product: total acres diverted multiplied by program yields. For all the crops except cotton, the sources for these data are the same as those for acres diverted as described in the paragraph above. The data for cotton are found in Stults, Glade, Sanford, and Meyer on page 79.

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Table 1: Data Used in Simulating the Cost Functions
(1987 Dollars per Acre, Except for the Number of Farms)

	Fixed Costs	Variable Costs	Number of Farms
Barley	28.81	48.37	224,900
Corn	56.18	119.90	1,459,600
Cotton[17]	250.00	99.32	139,800
Oats	39.74	35.00	543,200
Rice	254.02	57.25	22,980
Sorghum	54.74	26.37	407,800
Wheat	44.56	23.88	1,118,100

Sources: The cost data are from McElroy, Ali, Dismukes, and Clauson (1989). The number of farms represent all farms with base acreage in 1987 as defined by the Agricultural Stabilization and Conservation Service, Commodity Analysis Division on 30 December 1988.

[17] Throughout this study we have examined upland cotton only.

Table 2: Data Used in Simulating the Cost Functions

	Total Output (billions)	Yield per Acre	Elasticity
Barley	.5295	46.96	0.6
Corn	7.0721	122.49	0.48
Cotton	6.9498	679.32	0.74
Oats	.3740	35.00	0.6
Rice	.1296	54.67	0.4
Sorghum	.7392	68.79	0.6
Wheat	2.1070	31.64	0.6

Notes: The units are all in bushels, except for cotton and rice. In these cases, it is pounds and cwt, respectively. The elasticities have no units.

Sources: The output data are from various USDA publications; see the Data Appendix for details. The data on yields per acre are from McElroy, Ali, Dismukes, and Clauson (1989). The elasticity parameters are from Roningen and Dixit (1989); we have imputed the elasticity 0.6 given for "other coarse grains" to barley, oats, and sorghum.

Table 3: The Simulated Cost Functions

	Fixed	α_1	α_2	α_3
Barley	1444.4	0	3.36×10^{-4}	4.31×10^{-8}
Corn	2222.5	0	9.45×10^{-5}	2.22×10^{-8}
Cotton	7268.2	0	6.78×10^{-6}	1.26×10^{-11}
Oats	436.5	0	6.24×10^{-4}	6.12×10^{-7}
Rice	5906.8	0	4.60×10^{-4}	6.35×10^{-8}
Sorghum	704.2	0	3.00×10^{-4}	7.70×10^{-8}
Wheat	1422.3	0	5.50×10^{-4}	1.03×10^{-7}

Note: Calculated as described in the text.

Table 4: The Parameters in 1987

	Market Price	Target Price	Loan Rate	Diversion Factor	Diversion Payments	Program Yield
Barley	$1.81	$2.60	$1.49	0.274	$0.22	49.0
Corn	$1.94	$3.03	$1.82	0.314	$0.59	105.0
Cotton	$0.64	$0.79	$0.52	0.286	$0.00	593.0
Oats	$1.56	$1.60	$0.94	0.209	$0.20	50.0
Rice	$6.95	$11.66	$6.84	0.392	$0.00	49.1
Sorghum	$1.56	$2.88	$1.74	0.275	$0.58	60.0
Wheat	$2.57	$4.38	$2.28	0.312	$0.00	35.0

Notes: Prices are dollars per bushel, pound, or cwt., as relevant. Diversion payments are in dollars per bushel, pound or cwt., <u>not planted</u>. Program yields are in bushels, pounds, or cwt. per acre, as relevant.

Sources: See the Data Appendix for a full description.

Table 5: Predicted Aggregate Outputs and Predicted Present Values of Producer Surplus

	Output (billions)		Producer Surplus (billions)	
	Perfect Competition	Crop Restrictions	Perfect Competition	Crop Restrictions
Barley	0.44	0.58	2.3	9.2
Corn	6.1	8.1	80.2	216.6
Cotton	5.9	7.3	1.9	3.4
Oats	0.35	0.39	1.7	2.3
Rice	0.09	0.13	1.2	5.0
Sorghum	0.66	0.8	6.1	26.0
Wheat	1.8	2.8	20.0	83.0

Notes: Output for cotton is in pounds and that for rice is in cwt. Predicted total output is typically larger than the actual output as presented in Table 2. Producer surplus is in present value dollars.

Table 6: The Social Cost of the Crop Restriction Programs

	Annual Deadweight Production Loss (billion 1987 dollars)	Deadweight Loss as a Percentage of Increased Farmer Surplus
Barley	0.1	28%
Corn	1.6	25%
Cotton	0.2	28%
Oats	0.03	85%
Rice	0.1	28%
Sorghum	0.1	12%
Wheat	1.2	40%

Note: The first column is the incremental production costs owing to the crop restriction programs net of the increased value of farm output, both measured in annual rates. The second column is the present value of the first column of this table as a percentage of the difference between the fourth and third columns of Table 5.

Fig. 1: Optimal Policy for Barley

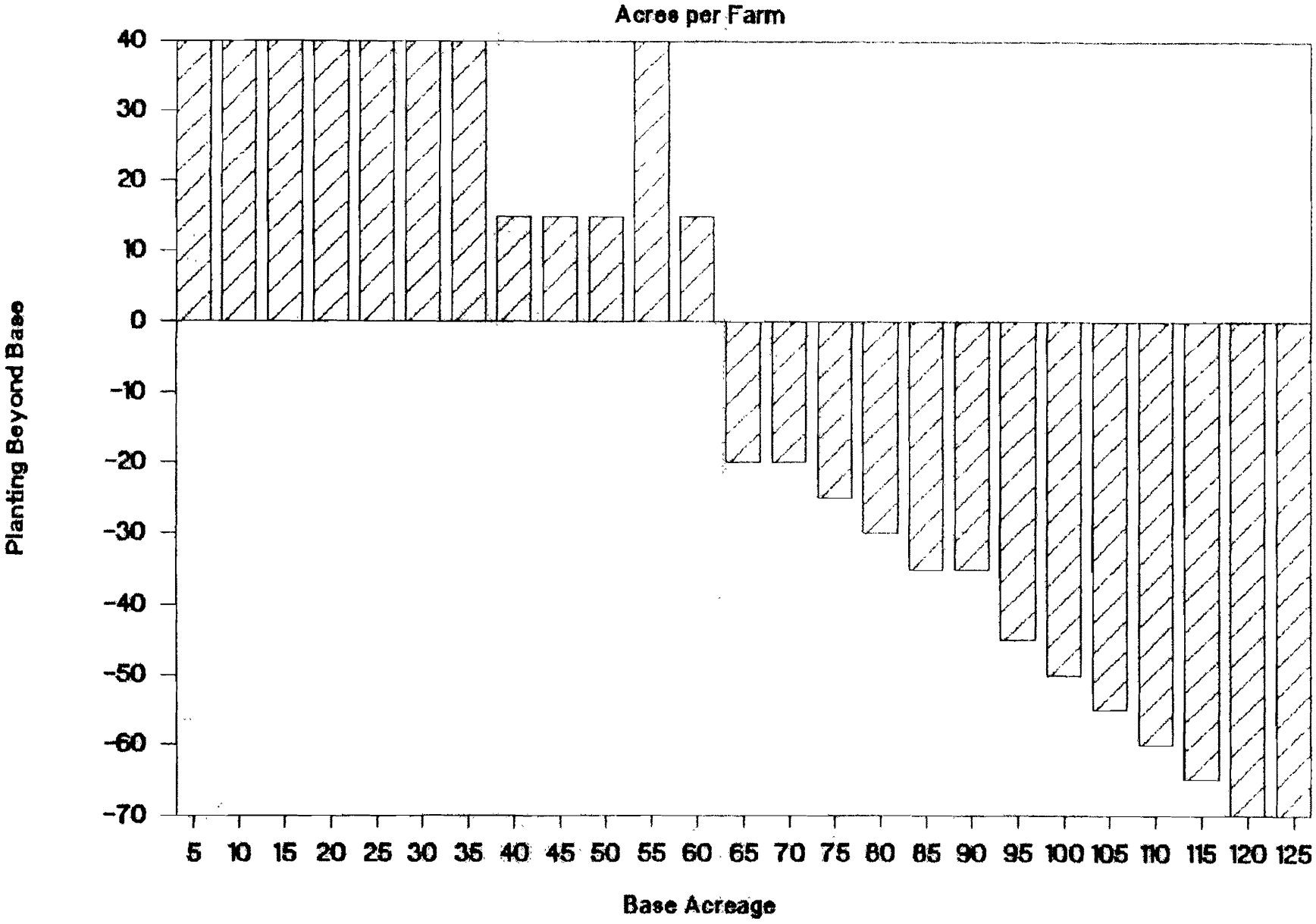


Fig. 2: Optimal Policy for Corn

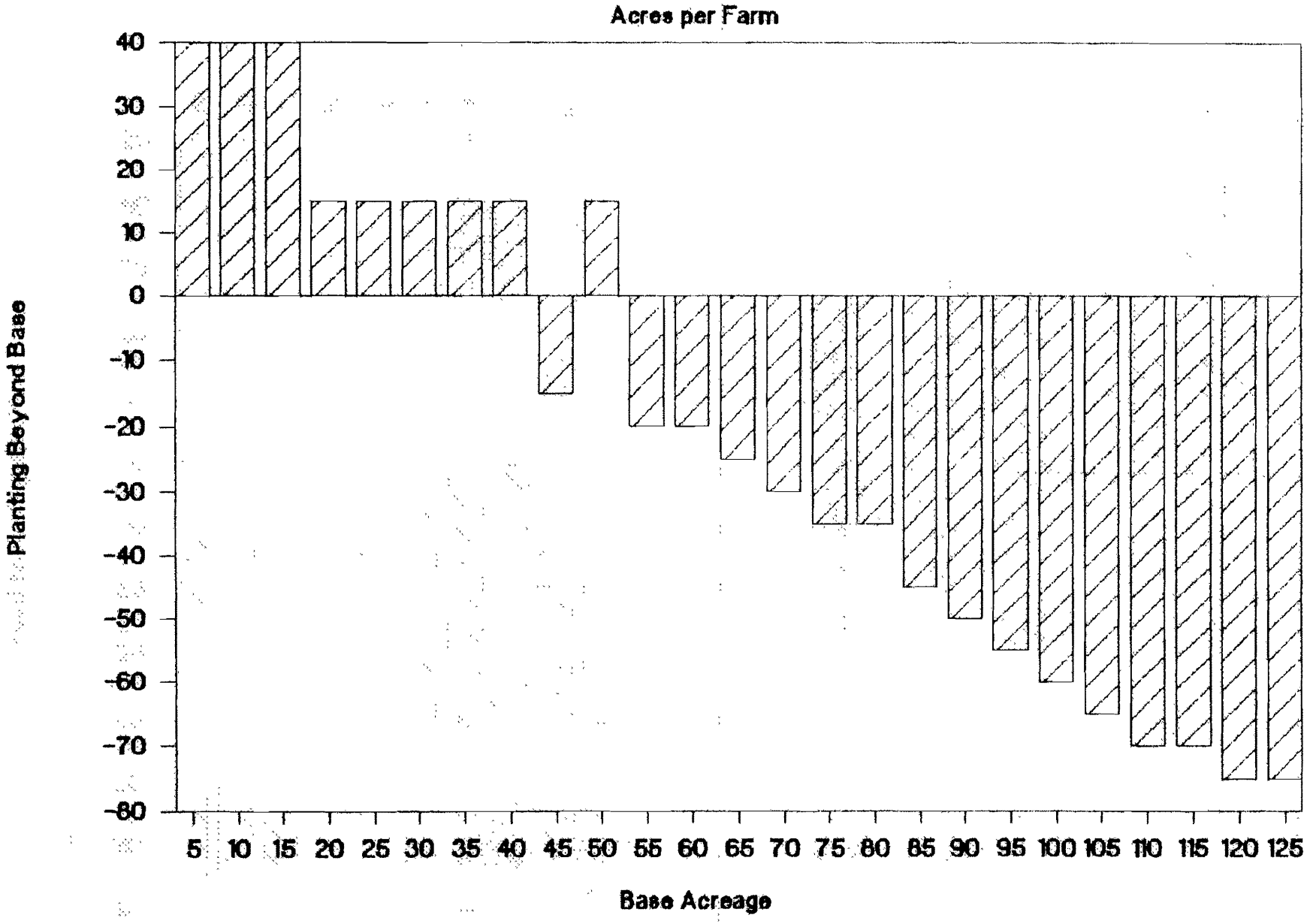


Fig. 3: Optimal Policy for Cotton

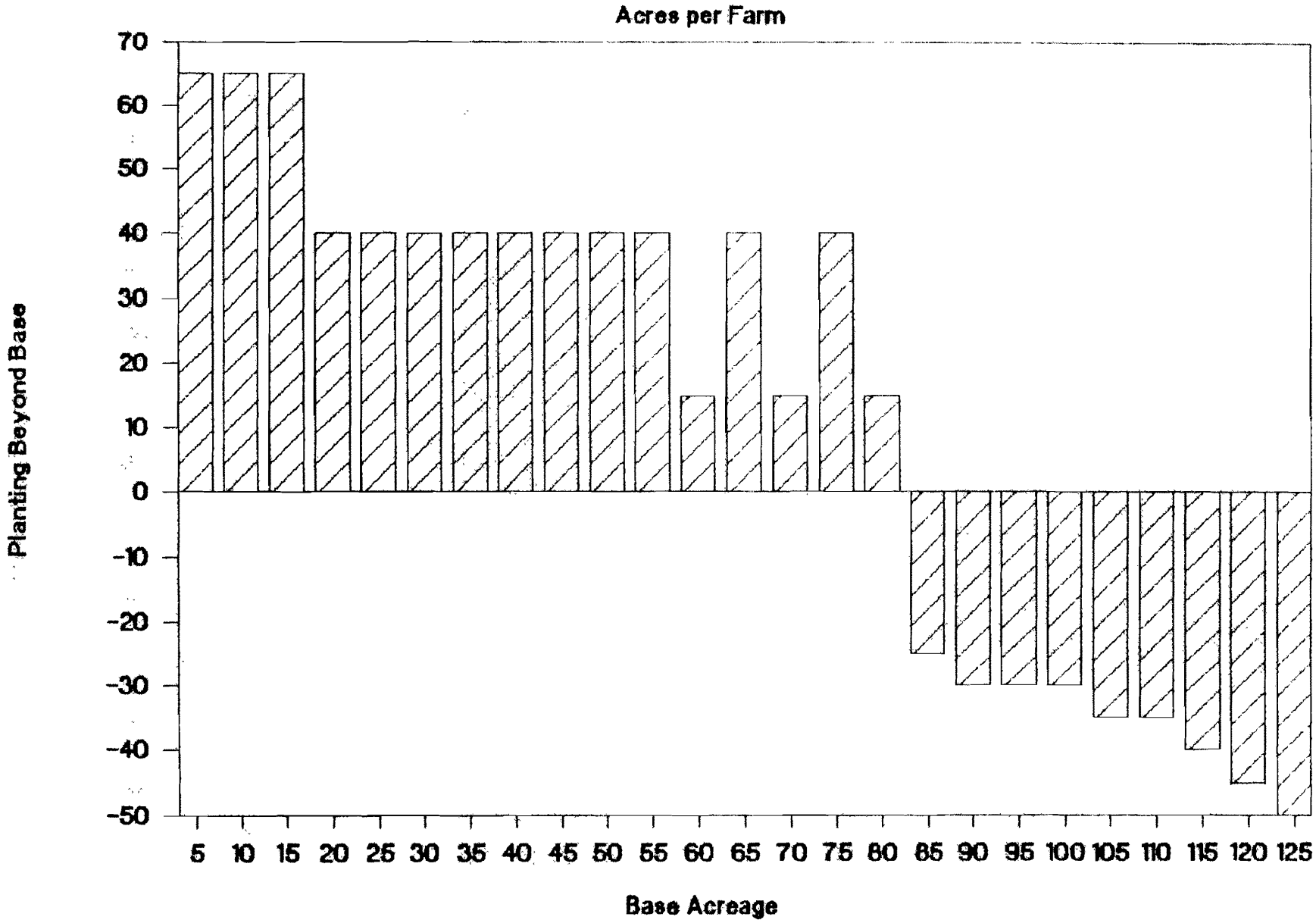


Fig. 4: Optimal Policy for Oats

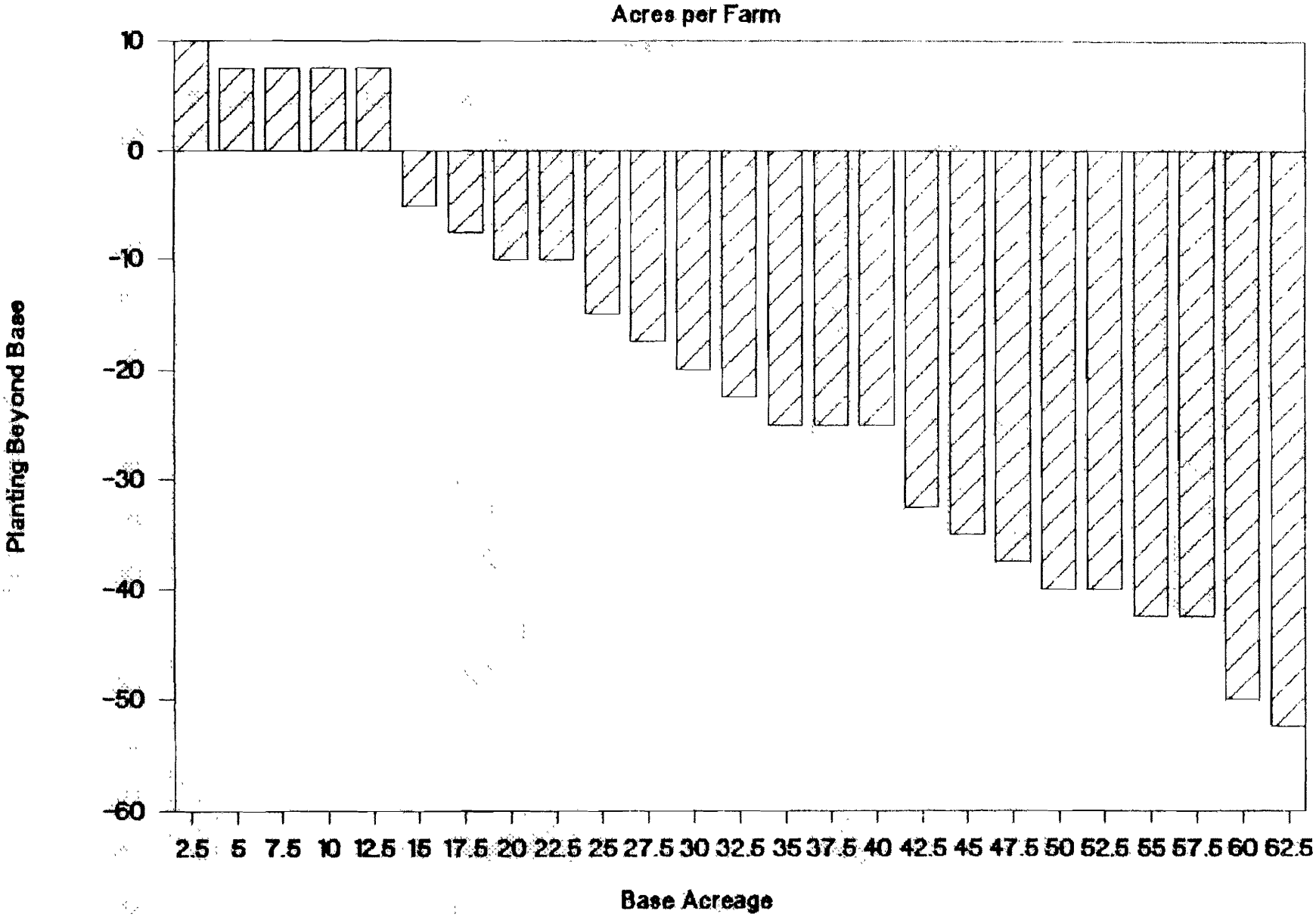


Fig. 5: Optimal Policy for Rice

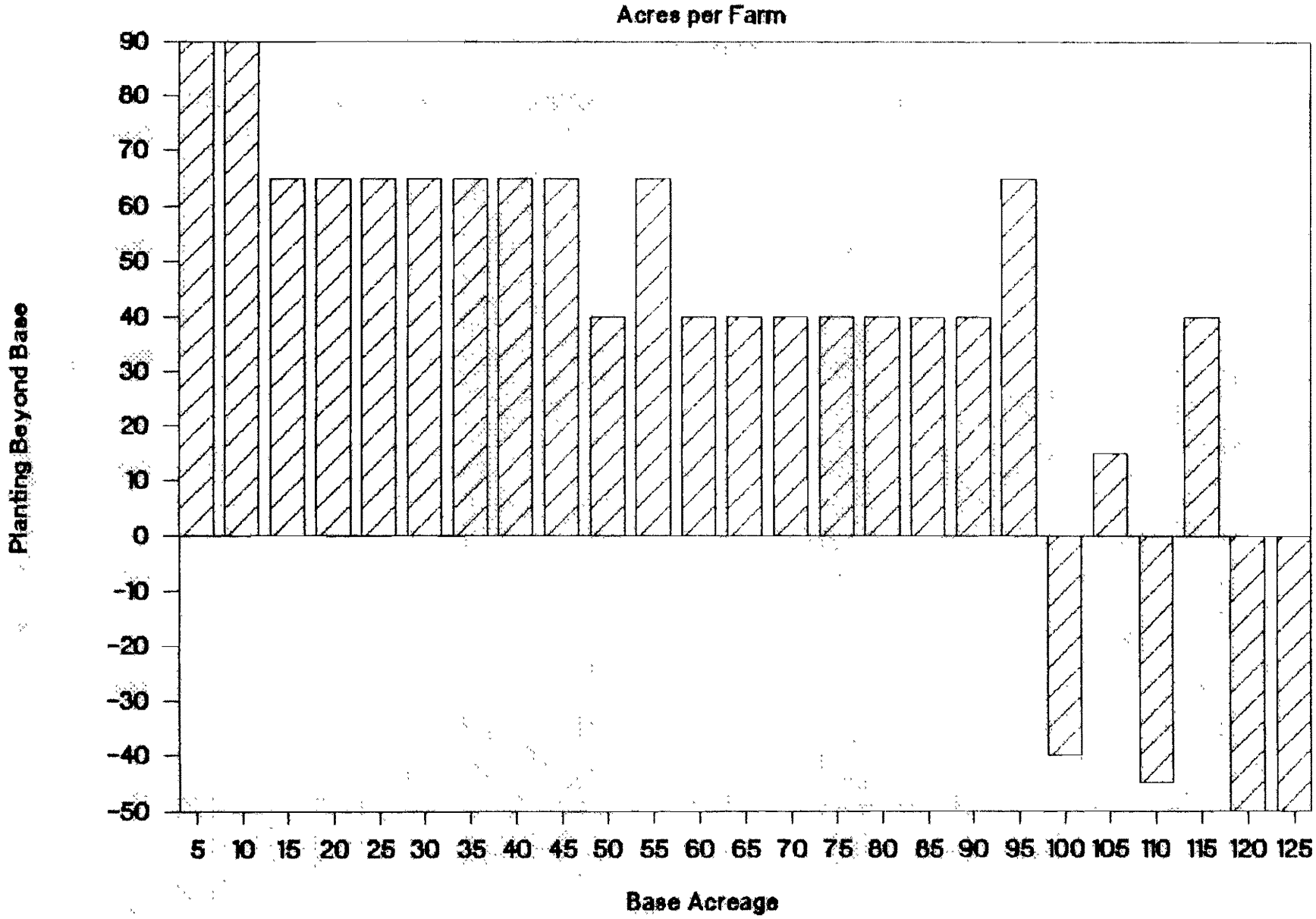


Fig. 6: Optimal Policy for Sorghum

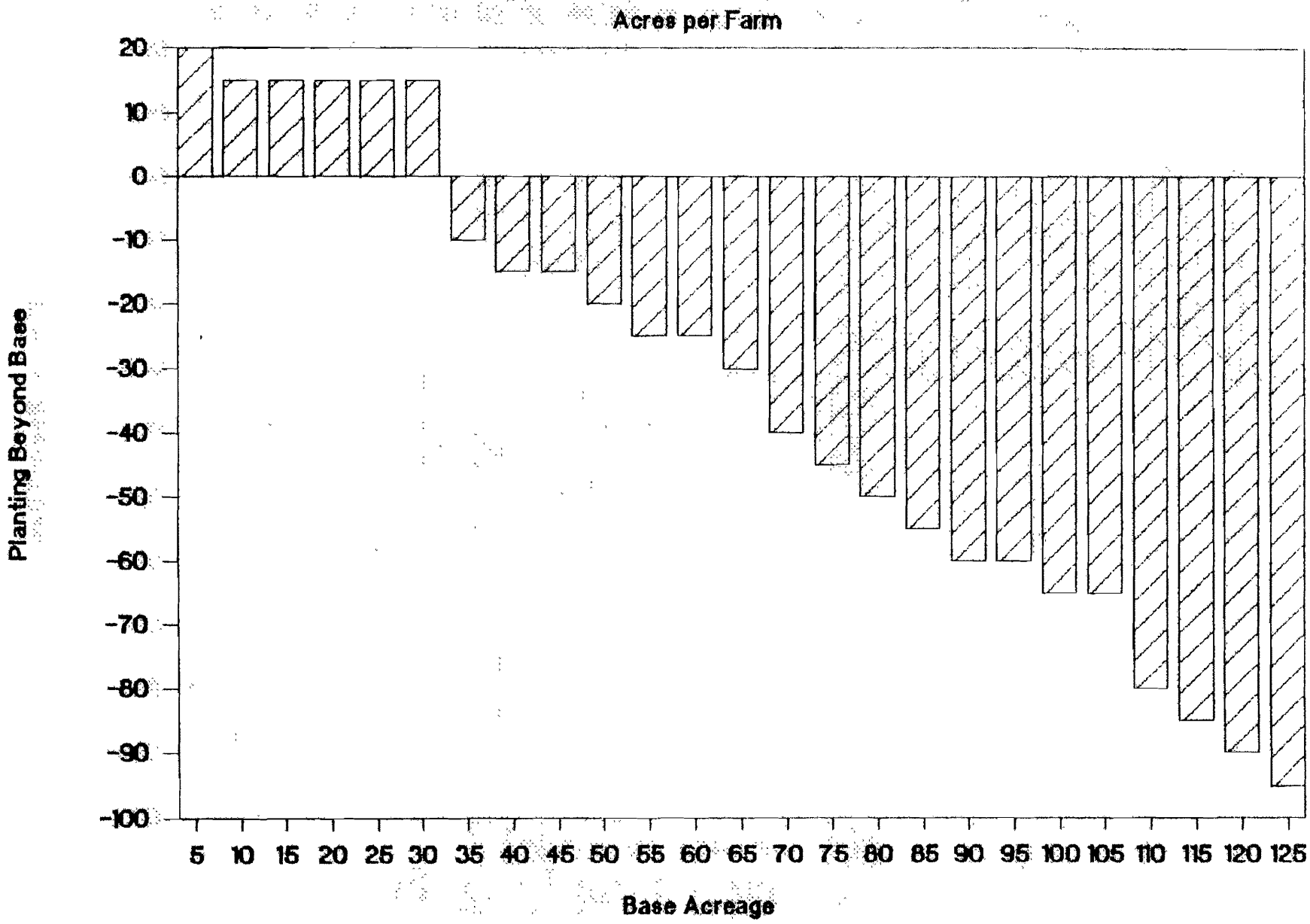


Fig. 7: Optimal Policy for Wheat

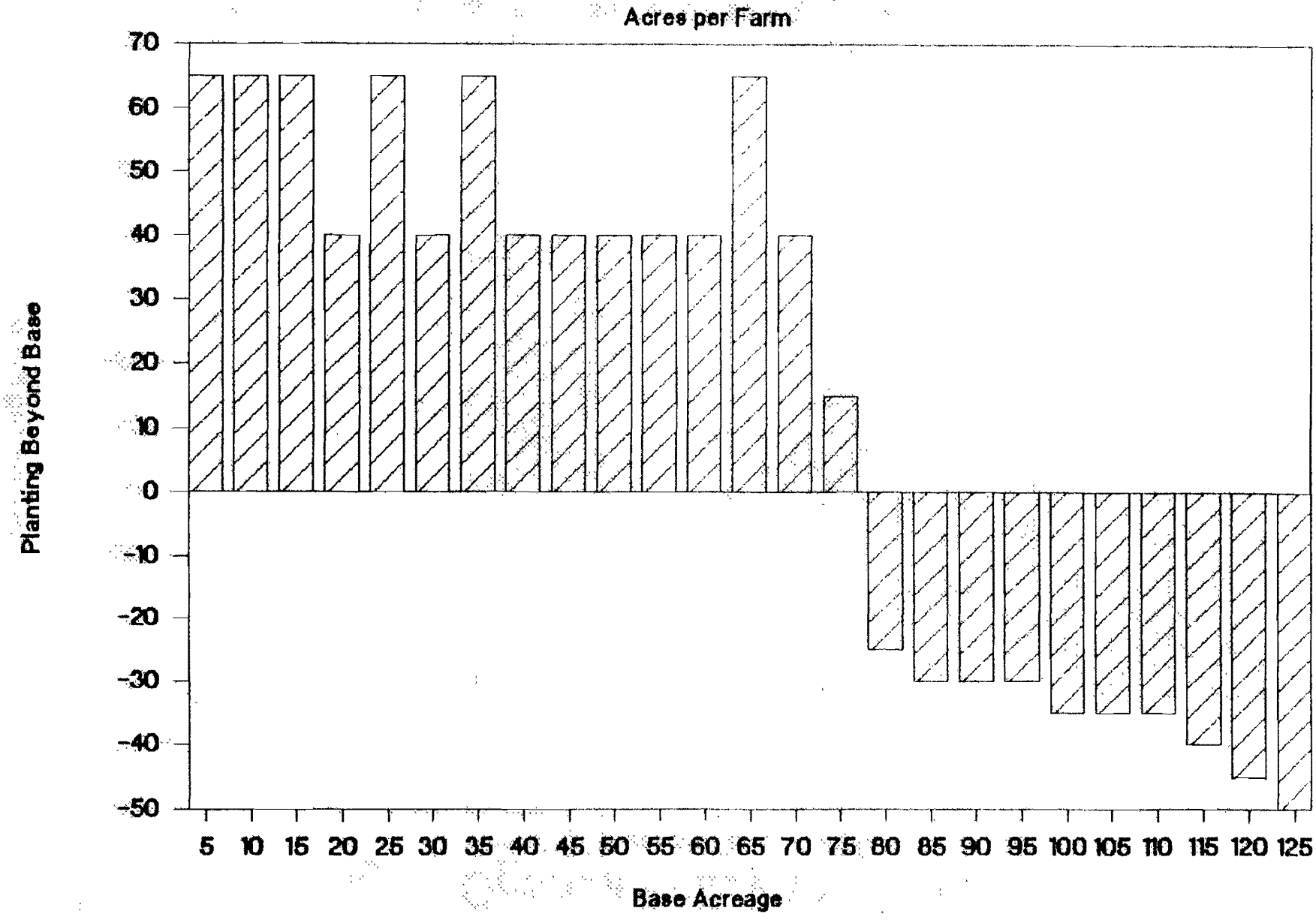
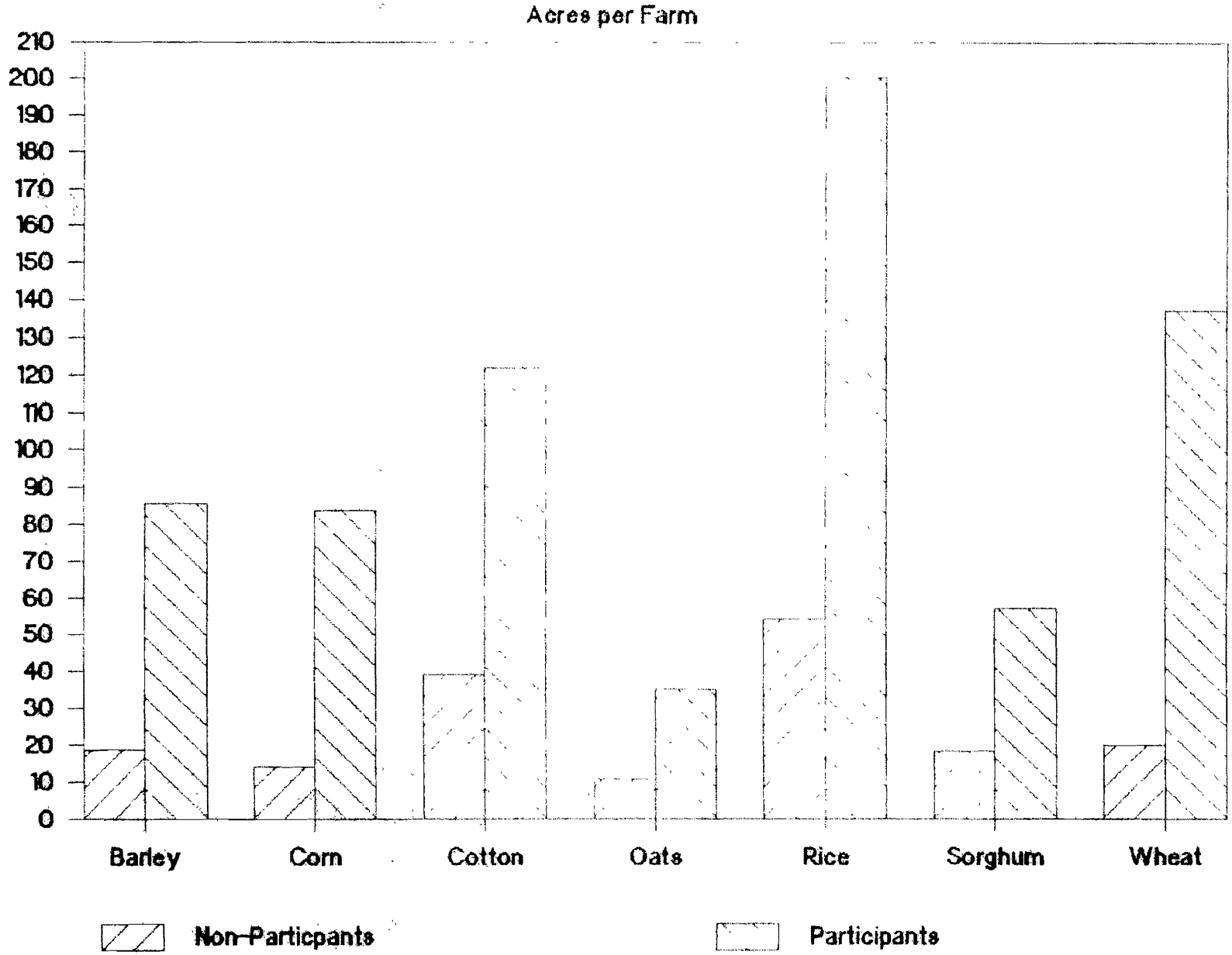


Fig. 8: Average Base



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