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The Dynamic Effects of Agricultural Subsidies in the United States

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This article analyzes the dynamic effects of the farm subsidies in the United States. The subsidies a farmer receives are based upon historical plantings, also called base acreage. It is sometimes optimal for a farmer temporarily not to participate in a program in order to increase future subsidies. The farmer's optimal policy is the solution to a deterministic dynamic program. Farmers with low base acreage opt out of these programs, whereas those with high base acreage participate in them. The article examines aggregate data involving corn, cotton, rice, and wheat during 1987. It shows that these programs increase the output of each of these crops and represent an annual deadweight loss of more than $2 billion.

Key words: agricultural subsidies, dynamic programming.

Introduction

> 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. . . .
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> [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)[1]

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

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

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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 the participation decision is left up to the farmer. Although some acreage is diverted and some farmers do restrict plantings, there is an incentive to expand current acreage in anticipation of future subsidies. Samuelson and Nordhaus recognize the dynamic aspect of these programs by explaining that this year's subsidies are based in part upon last year's planting. Since a forward-looking farmer may plant a large acreage in anticipation of next year's subsidies, the net effect of these programs is not obvious.

The purpose of this article is to pursue this insight more deeply. Our work makes a theoretical and an empirical contribution to the literature on agricultural policy in the United States. The theoretical contribution is to model the farmer's planting decisions as a deterministic dynamic program. Even though the farmer's reward is not continuous in the level of plantings, we show that the dynamic program has a value function and characterize the optimal policy it implies. The empirical contribution is to use data from 1987 to show that these subsidies increased the outputs of corn, cotton, rice, and wheat beyond a benchmark of static perfect competition. The intuition behind this empirical finding is that small farmers expand their plantings in anticipation of higher future subsidies.

The central feature of these farm policies is that participants in a program are limited by their base acreages, a fixed proportion of which must be left fallow in order to qualify for subsidies. The United States currently determines historical base acreage according to a five-year moving average of "considered plantings."[2] Farmers often find it in their long-run interest to opt out temporarily from the program and increase current planting, raising base acreage and future subsidies.[3] 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 name for these programs is "base acreage limitations" and participants in them are subject to the constraint of "acreage diversion." The U.S. 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. The first is "deficiency payments," and the second is "diversion payments." The deficiency payment is a per unit subsidy calculated as the difference between a target price and the maximum of the market price and a "loan rate."[4] It is based on an "official" level of production,[5] and the total number of acres planted. The diversion payment is for crops *not* planted. Further, for each subsidized crop, there is a maximum on the total subsidy payments that a farmer may receive in any year.

To the best of our knowledge, the only dynamic analysis of these subsidies is that of Fisher and de Gorter; that paper explores how these programs affect agricultural exports. These subsidies are typically analyzed using comparative statics. Both Wallace and Gardner (1984) model acreage diversion as a shift left of the supply curve, as does Gardner (1987) in his influential text. Lichtenberg and Zilberman give a static analysis of the welfare effects of environmental regulations on farmers who participate in these acreage restriction programs. Eckstein applies dynamic programming to the planting decisions of Egyptian cotton producers.

The remainder of the article is structured as follows. The second section describes the model and shows that the value function exists. The third section characterizes the implicit optimal policy. The next section presents simulated solutions to the dynamic program for the four major field crops in 1987, the only year for which complete data on the distribution of farm base acreages are available. The final section presents our conclusions. The data and their sources are detailed in appendix A, and the proofs of the four propositions describing the farmer's optimal policy are presented in appendix B.

The Model

Because we are interested in the decisions of an individual farmer, we study a model of price-taking behavior and assume that the farmer has perfect foresight. Then the farmer's decision is 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 the last 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 take covered positions by using forward contracts in order to ensure 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 making any planting decisions.

The net revenues of a farm facing price p and having cost $c(u_t)$ are:

(1) $$f(p, u_t) = pu_t - c(u_t),$$

where $f: \Re_+ \times \Re_+ \to \Re$ describes a farmer producing u_t units of output.

We make the following assumptions about the cost function $c(u_t)$:

Assumption 1: The function $c(u_t)$ is positive, nondecreasing, and continuous on $\Re_+$. Further, $c(0) > 0$.

The existence of a solution to the dynamic program is robust with respect to many specifications of costs, and in practice, we simulate the solution to the dynamic program using an arbitrary $c(u_t)$.

The number of bushels planted (and harvested under the assumption of perfect foresight) is the farmer's control variable. The analysis below assumes that there is a strict linear relationship between acres planted and the farmer's eventual harvest. This assumption entails that yields are fixed and exogenous for the representative farmer, and it limits the generality of the model. Still, the cost function does capture the idea that the farmer plants the most fertile land first since it allows for increasing marginal costs. The linear relationship between acres planted and output produced allows one to describe a simple transition rule for the farmer's considered plantings. Also, it makes the empirical applications of the model tractable.

The state variable is the farmer's five-year history of considered plantings denoted by the vector $\boldsymbol{x}_t = (x_{t-5}, \ldots, x_{t-1})'$, where x_{t-i} is the output equivalent of the farmer's base acreage in year $t - i$. The output equivalent of current base acreage is $b_t = .2x_{t-5} + \ldots + .2x_{t-1}$. Again, there is a linear relationship between land as an input and the crop as an output, justified in part by the fact that we are describing the long-run behavior of the farmer.

Farmers benefit from two explicit subsidies: deficiency payments and diversion payments. First, if a farmer participates in a subsidy program and plants sufficient land to yield u_t bushels, the deficiency payments are:

$$s_1(p, \tau, L, \psi; u_t) = \psi[\tau - \max\{p, L\}]u_t,$$

where τ is the target price, p is the market price, ψ is the ratio of program yield to actual yield, and L is the loan rate. We shall assume, of course, that $\tau > \max\{p, L\}$. Second, farmers receive a payment γ per unit of foregone output for the land they leave fallow. If the farmer's history is $\boldsymbol{x}_t$, then diversion payments are:

$$s_2(\psi, \gamma; \boldsymbol{x}_t, u_t) = \gamma\psi \max\{0, (b_t - u_t)\},$$

which are positive only if the farmer diverts acreage. This payment also depends upon the program yield.

Let the vector of parameters be $\boldsymbol{\theta} = (p, \tau, L, \psi, \gamma)'$. Then the total subsidies accruing to a participant in the program are:

$$s(\boldsymbol{x}_t, u_t; \boldsymbol{\theta}) \equiv \min\{s_1(\cdot) + s_2(\cdot), 50{,}000\},$$

which shows that a farmer receives a maximal total subsidy of \$50,000.[7] Finally, the farmer's revenues from the sale of crops on the market are $[\max\{p, L\}]u_t$, since output is sold at the maximum of market price and the loan rate, and these revenues are based upon actual yield.

We shall henceforth take $\boldsymbol{\theta}$ as fixed and suppress it as an argument in the functions below. A subsidized farmer having history $\boldsymbol{x}_t$ and planting acreage yielding u_t units receives:

$$h(\boldsymbol{x}_t, u_t) \equiv [\max\{p, L\}]u_t + s(\boldsymbol{x}_t, u_t; \boldsymbol{\theta}) - c(u_t). \tag{2}$$

Note that $h(\boldsymbol{x}_t, u_t)$ is continuous.

Let $\delta \in [0, 1)$ be the proportion of acreage that a farmer must leave fallow in order to qualify for subsidies. Since $\boldsymbol{x}_t$ is the state variable summarizing the farmer's five-year planting history, the reward is:

$$r(\boldsymbol{x}_t, u_t) = \begin{cases} h(\boldsymbol{x}_t, u_t) & \text{if } u_t \le (1 - \delta)b_t \\ f(p, u_t) & \text{otherwise,} \end{cases}$$

where again b_t is the simple average of the elements of $\boldsymbol{x}_t$. Consider $r(\boldsymbol{x}_t, u_t)$ as a function of u_t; it may have a point of discontinuity occurring at $(1 - \delta)b_t$. Still, it can be shown that $r(\boldsymbol{x}_t, u_t)$ is upper semi-continuous[8] since $\tau > \max\{p, L\}$.

The transition rule is

$$\boldsymbol{x}_{t+1} = \begin{cases} (x_{t-4}, x_{t-3}, x_{t-2}, x_{t-1}, \delta b_t + u_t)' & \text{if } u_t < (1 - \delta)b_t \\ (x_{t-4}, x_{t-3}, x_{t-2}, x_{t-1}, b_t)' & \text{if } (1 - \delta)b_t \le u_t \le b_t \\ (x_{t-4}, x_{t-3}, x_{t-2}, x_{t-1}, u_t)' & \text{if } b_t < u_t, \end{cases} \tag{3}$$

where $\boldsymbol{x}_{t+1}$ is the farmer's history at time $t + 1$ and b_t is as above.[9]

The discount factor satisfies $0 \le \beta < 1$. Let $\boldsymbol{X}$ be the state and U the control space. Then the farmer's dynamic program is a four-tupel $\langle \boldsymbol{X}, U, z, \beta \rangle$, where z: $\boldsymbol{X} \times U \rightarrow \boldsymbol{X}$ is the transition rule. A policy is a function π: $\boldsymbol{X} \rightarrow U$, and the expected discounted return from π is

$$I(\pi)(\boldsymbol{x}_t) = \sum_{s=t}^{\infty} \beta^{s-1} r(\boldsymbol{x}_s, \pi(\boldsymbol{x}_s)),$$

where $I(\pi)(\boldsymbol{x}_t)$ is the value of following π when the state is $\boldsymbol{x}_t \in \boldsymbol{X}$. An optimal policy is a plan π^* such that $I(\pi^*)(\boldsymbol{x}_t) \ge I(\pi)(\boldsymbol{x}_t)$ for all π and $\boldsymbol{x}_t \in \boldsymbol{X}$. We are interested in describing this function.

If there is an optimal policy, then the value function is

$$V(\boldsymbol{x}_t) = \max_{u_t \in U}[r(\boldsymbol{x}_t, u_t) + \beta V(\boldsymbol{x}_{t+1})], \tag{4}$$

where u_t is chosen according to π^* and $\boldsymbol{x}_{t+1}$ is given by (3). Equation (4) has the interpretation that a farmer with base acreage history $\boldsymbol{x}_t$ who follows an optimal plan will have $V(\boldsymbol{x}_t)$ as the present discounted value of the subsidy program.

We impose:

Assumption 2: The state space $\boldsymbol{X}$ and the control space U are compact.

This postulate is innocuous enough: yields are not infinite, a farmer has a finite base acreage, and only a finite plot of land is planted. We now state:

Theorem: There is a solution to the farmer's dynamic program.

Proof: Since $\tau > \max\{p, L\}$, it is easy to check that $r(\boldsymbol{x}_t, u_t)$ is upper semi-continuous in u_t. The transition function given in equation (3) is continuous in u_t and it is degenerate; hence, it is trivially continuous in the sense of the weak convergence of measures. Since $\boldsymbol{X}$ and U are compact, Maitra's theorem applies. □

Characterizing the Farmer's Optimal Policy

It will be useful to characterize the farmer's optimal planting program. Define $K \equiv \{(\boldsymbol{x}_t, u_t) \in \boldsymbol{X} \times U: u_t \leq (1 - \delta)b_t\}$, where again b_t is the average of the elements of $\boldsymbol{x}_t$. The set K gives the base acreage histories and current plantings for which a farmer is a participant in the subsidy program. Since K is a closed subset of a compact set, it is compact itself. Since both (1) and (2) are upper semi-continuous and U and K are compact, neither $\text{argmax}_{u_t \in U} f(p, u_t)$ nor $\text{argmax}_{(\boldsymbol{x}_t, u_t) \in K} h(\boldsymbol{x}_t, u_t)$ is empty. Let u_p be the smallest u_t in $\text{argmax}_{u_t \in U} f(p, u_t)$, and let u_θ be the smallest u_t in $\text{argmax}_{(\boldsymbol{x}_t, u_t) \in K} h(\boldsymbol{x}_t, u_t)$. The maximal values of these functions are denoted by $f^*(p)$ and $h^*(\boldsymbol{\theta})$, respectively. It is convenient to let b_θ be the minimal five-year average of the $\boldsymbol{x}_t$ in $\text{argmax}_{\boldsymbol{x}_t \in \boldsymbol{X}} h(\boldsymbol{x}_t, u_\theta)$. This quantity is the lower bound on the base acreage needed to obtain $h^*(\boldsymbol{\theta})$ when planting u_θ. Finally, let $\boldsymbol{b}_\theta$ be the vector, each of whose five elements is b_θ. The quantities u_p and u_θ are the smallest static profit-maximal outputs for a farmer with sufficiently large acreage history facing price p and policy parameters θ.

We can now state:

Proposition 1: (i) If $h^*(\boldsymbol{\theta}) \leq f^*(p)$, then $\pi^*(\boldsymbol{x}_t) = u_p$; and
(ii) If $h^*(\boldsymbol{\theta}) > f^*(p)$, then $\pi^*(\boldsymbol{x}_t) = u_\theta$ for all $\boldsymbol{x}_t \gg \boldsymbol{b}_\theta$.

Proof: See appendix B.

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 the marginal cost of production equals price if the maximal subsidy payments are sufficiently low. If the maximal subsidy payments are large enough, part (ii) of Proposition 1 states that farmers with sufficiently large historical base acreage in each of the five prior years will plant the one-period profit-maximal acreage.

The following is also true.

Proposition 2: The value function $V(\boldsymbol{x}_t)$ is not decreasing.

Proof: See appendix B.

The intuition behind Proposition 2 is straightforward. It states that it never hurts to have a larger history of base acreage in the last five years. Indeed, if a farmer's base acreage $\boldsymbol{x}_t$ has been sufficiently large, then it is not costly to plant $u_t < (1 - \delta)b_t$, where b_t is the average of $\boldsymbol{x}_t$.

In the remainder of the article, we assume that $h^*(\boldsymbol{\theta}) > f^*(p)$; this states simply that there is some base acreage history for which it is profitable to participate in the subsidy program. Then Proposition 2 describes the optimal policy function and the value function more precisely.

Proposition 3: If $\boldsymbol{x}_t \gg \boldsymbol{b}_\theta$, then $\pi^*(\boldsymbol{x}_t) = u_\theta$ and $V(\boldsymbol{x}_t) = (1 - \beta)^{-1}h^*(\boldsymbol{\theta})$. Further, there is $\boldsymbol{x}'' \ll \boldsymbol{b}_\theta$ such that, for all $\boldsymbol{x}_t$ satisfying $\boldsymbol{x}'' \leq \boldsymbol{x}_t \leq \boldsymbol{b}_\theta$, $\pi^*(\boldsymbol{x}_t) = (1 - \delta)b_t$ and $V(\boldsymbol{x}_t) = (1 - \beta)^{-1}h(\boldsymbol{x}_t, (1 - \delta)b_t)$.

Proof: See appendix B.

The intuition behind Proposition 3 is simple. It is never optimal for a farmer with sufficiently large base acreage history to opt out of the subsidy program because the present

value of the gains from increased base acreage do not offset the current loss in profits owing to opting out of the program. Hence, the value of the subsidy program for sufficiently large farms is the present discounted value of maintaining the current base acreage.

The optimal plan also satisfies:

Proposition 4: Assume that $f^*(p) > 0$. Then there is an $\mathbf{x}' \gg \mathbf{0}$ such that, for all $\mathbf{x}_t$ satisfying $\mathbf{0} \leq \mathbf{x}_t \leq \mathbf{x}'$, $\pi^*(\mathbf{x}_t) > (1 - \delta)b_t$.

Proof: See appendix B.

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

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 output u_t that is greater than 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 (4) is given by

$$p - c'(u_t) + .2\beta\, \partial V(\mathbf{x}_{t+1})/\partial x_t = 0,$$

where we have assumed that $u_t > b_t$ and have used the transition rule (3). Since $\partial V(\mathbf{x}_{t+1})/\partial x_t \geq 0$, we may conclude that $u_t \geq u_p$, the static profit-maximal output choice when a farmer faces price p. Hence, the subsidies cause even nonparticipants to produce inefficiently.

Simulation Results for the Four Major Field Crops

In this section, we use data from 1987 to simulate the dynamic program for the four major field crops: corn, cotton, rice, and wheat. It is worth repeating here that we are modeling representative farmers' decisions under certainty in order to make predictions about national outputs for these crops. Of course, farms produce several products under conditions of uncertainty, and the empirical implications of our model are not as general as we might like.

The first step in the simulation involves the farmers' cost function. It is assumed to have the form:

$$c(u_t) = F + \alpha u_t^{(\eta+1)/\eta}, \tag{5}$$

where η is the elasticity of supply for the crop in question. The fixed cost F and the parameter α are derived from *national* data on fixed and variable costs per unit of output.[10] Since there was some difficulty in determining individual farm supply elasticities from the literature in agricultural economics, three values of the parameter η were considered: .25, .5, and 1. They correspond, respectively, to the low, medium, and high cases of individual farm responsiveness.

Table 1 summarizes the aggregate data used to simulate (5). These data allowed one to compute average output per farm, and then one can recover the fixed cost for each farm. Each value of η then determines α, using the data on average variable cost.

The policy parameters and market prices are presented in table 2. Data on the distribution of farms are not published. We obtained data for the year 1987 from the U.S. Department of Agriculture (USDA), Agricultural Stabilization and Conservation Service, Commodity Analysis Division, National Agricultural Statistical Services, and they are dated 30 December 1988. Since we did not have histories of base acreages, we were forced to assume that $x_{t-5} = \ldots = x_{t-1} = x_{1987}$ for each farm. This is a limitation of our analysis, and a fully dynamic specification of the evolution of farm sizes is a fertile area for future research.

The state space was divided into 40 discrete points, using increments of 10 acres. The first group contained all farms between five and 14 acres, the second those between 15

Table 1. Data Used in Simulating the Cost Functions (1987 dollars per unit, except for number of farms and total output)

	Fixed Costs	Variable Costs	Number of Farms	Total Output (billions)
Corn	.40	.99	1,081,625	7.0721
Cotton	.11	.37	117,894	6.9498
Rice	1.05	4.65	19,493	.1296
Wheat	.75	1.41	836,397	2.1070

Notes: The costs are in 1987 dollars per unit. The units are all in bushels, except for cotton and rice. In these cases, it is pounds and cwt., respectively.
Sources: The number of farms represent all farms with greater than four base acres in 1987; the data on the national distribution of base acreages were provided by the USDA, Agricultural Stabilization and Conservation Service, Commodity Analysis Division, National Agricultural Statistical Services. The output data are from various USDA publications; see appendix A for details.

and 24, and so on, with the last group containing all farms with at least 400 base acres. The within-group average output was the representative state for that group, and the control space was set equal to the state space. We used a discrete approximation to the rule (3) and the discount factor 1.05^{-1} in all simulations.

Figure 1 gives an example of an optimal policy for a corn farmer whose cost function has elasticity .5;[11] the policies for other crops and other elasticities are largely similar. The optimal policy is graphed to show planted acreage. Any farmer planting more than his or her historical base is not a participant in the program. Otherwise, a farmer diverts at least the requisite base acreage and may even plant a lower acreage than required.

It is striking 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 shows that these policies benefit big farms more than small ones. This theoretical result is corroborated by an analysis of aggregate data on the participation rates for the four crops. The average base acreage in 1987 of participants in the programs for corn, cotton, rice, and wheat was 83.7, 121.9, 200.7, and 137.6, respectively; the equivalent figures for nonparticipants in that year were 14.1, 39, 54.2, and 20.[12]

We use the historical distribution of base acreage in 1987 for all farms in the United States to determine the supply of each crop in 1987. Figure 2 presents that distribution for corn; the other crops have the same skewed shape for their distributions. In order to contrast the results with the output that would prevail in the absence of these programs,

Table 2. The Parameters in 1987

	Market Price	Target Price	Loan Rate	Diversion Factor	Diversion Payments	Ratio of Program Yield to Actual Yield
Corn	$1.94	$ 3.03	$1.82	.314	$.59	.857
Cotton	$ .64	$ .79	$ .52	.286	$.00	.873
Rice	$6.95	$11.66	$6.84	.392	$.00	.898
Wheat	$2.57	$ 4.38	$2.28	.312	$.00	1.106

Notes: Prices are dollars per bushel, pound, or cwt., as relevant. Diversion payments are in dollars per bushel, pound, or cwt., *not planted.* The actual yields per acre for corn, cotton, rice, and wheat were 122.49, 679.32, 54.67, and 31.64, respectively.
Sources: See appendix A for a full description.

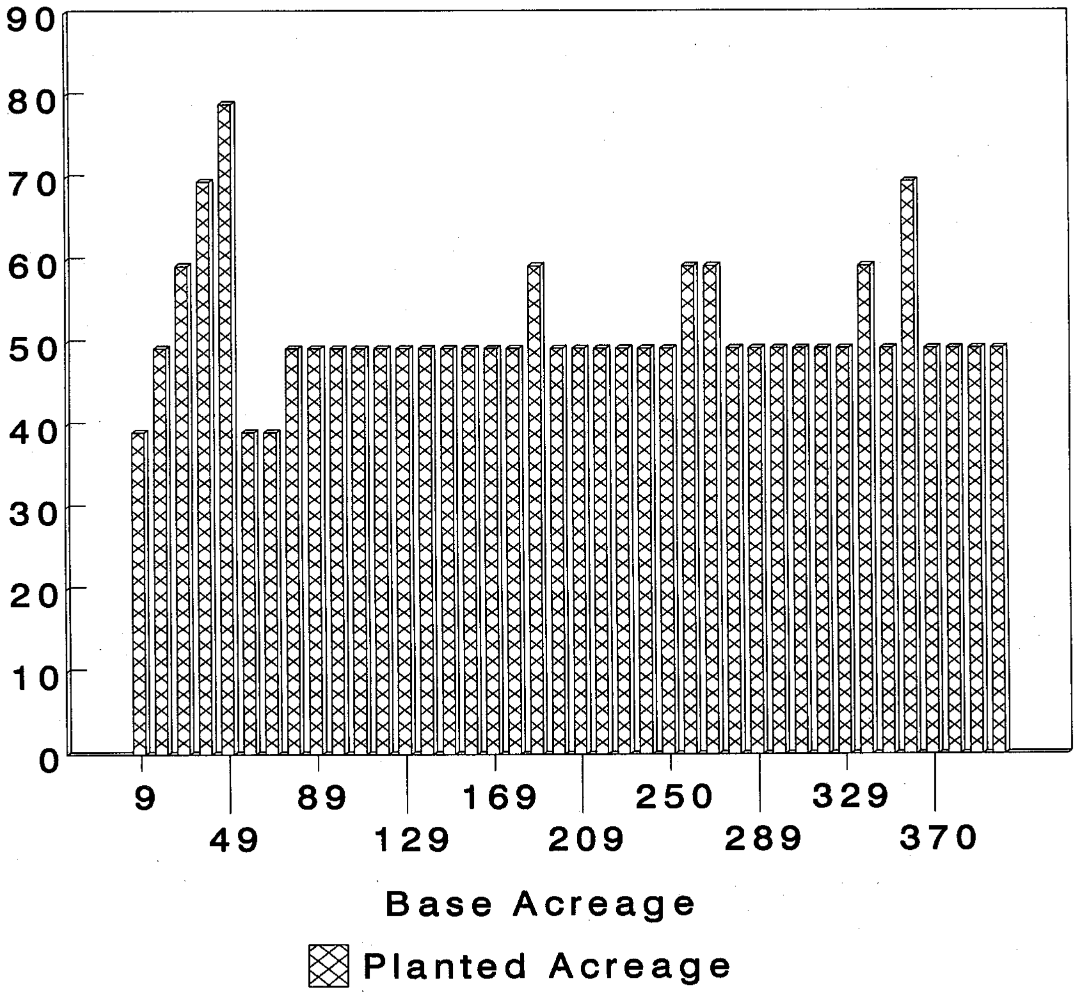

Figure 1. Optimal policy for corn

we calculated the perfectly competitive aggregate outputs corresponding to the total number of farmers with more than four base acres in 1987 and to the market prices given in table 2.[13] The model's predictions appear in table 3.

The predictions on the relative effects of the programs on aggregate outputs are apt to be accurate because any bias in the determination of the cost functions affects the simulation results of the dynamic program and the predicted perfectly competitive outputs symmetrically. It is remarkable that these crop restriction programs increased output in 1987. Of course, this result is valid only if our simplifying empirical assumption about the historical distribution of base acreage is valid for that year. It is quite possible that the long-run effect of these programs would be to restrict output with respect to the appropriate invariant distribution of the state space. Indeed, aggregate base acreage has decreased for some of these crops in the latter part of the last decade.

It is also interesting to analyze the effect that these crop restriction programs have on producer surplus. The solutions to the dynamic programs are the present values of producer surplus. Although the value functions are not reported here, it is easy to calculate producer surplus for each crop by using the distributions of base acreages. Further, producer surplus under perfect competition is the present value of the static quasi-rents corresponding to

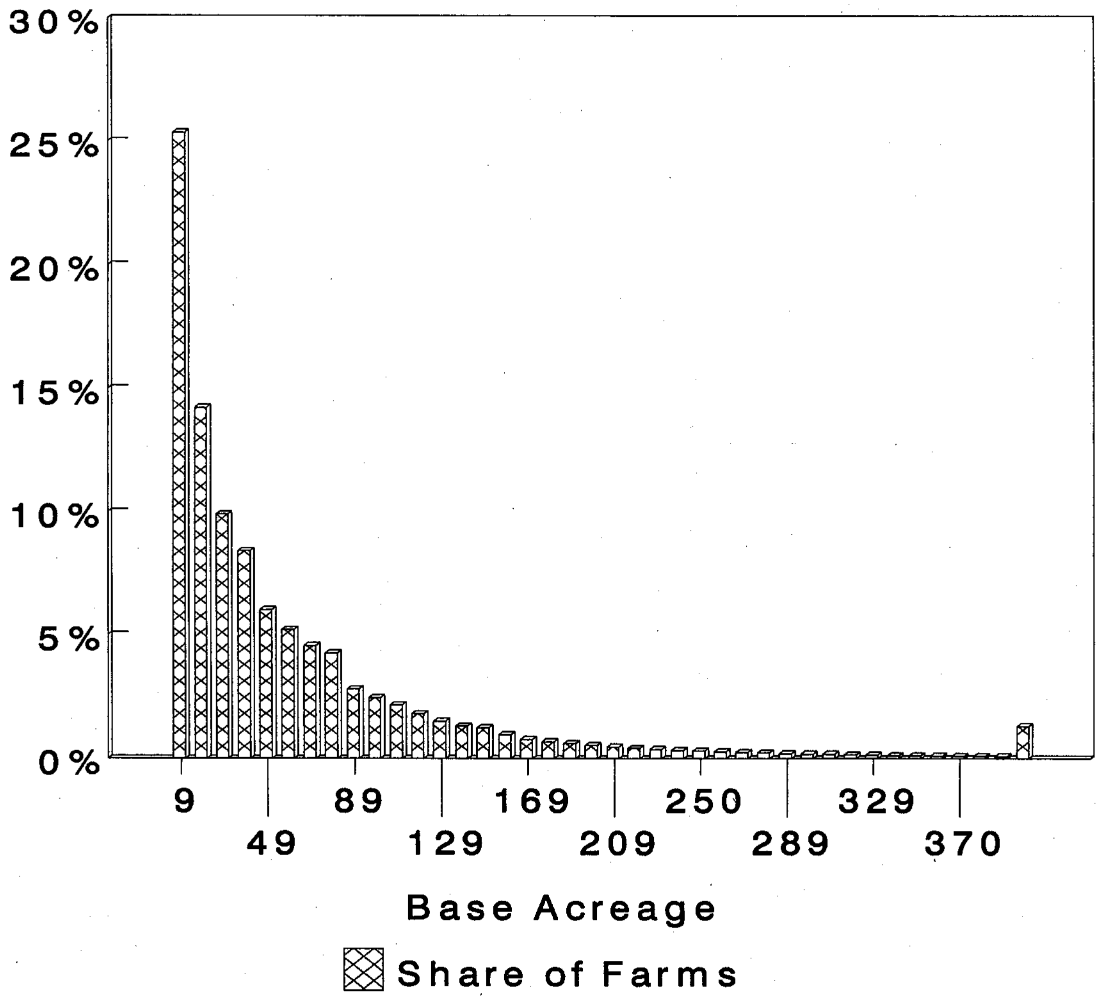

Figure 2. Distribution of farm size: Corn in 1987

the price in table 2. The calculations concerning producer surplus are reported in the second half of table 3. The existence of crop restriction programs typically doubles producer surplus. Indeed, using the supply parameters that best fit the actual output, we see that these programs raise the present value of producer surplus for these four crops by $207.2 billion, representing a transfer of $10.4 billion or .2% of the United States' gross national product.

The model also has positive implications for the change in the distribution of base acreage from 1987 to 1988. Although we were unable to obtain data on the complete distribution of base acreage in 1988, we did receive aggregate data on base acreage in those two years. Base acreage increased for each of the four crops between 1987 and 1988. The model predicts that base acreage increases for all of the crops, but the predicted increases tend to be more conservative than the actual ones. Table 4 reports these results.

We conclude with a calculation of the production deadweight loss that these programs entail.[14] We are in a second-best world, and these subsidies may be an inevitable part of the political process. It is still interesting to calculate their deadweight loss as a proportion of the total economic transfer to farmers. This is the incremental cost, net of the value of increased output, that the induced excess production for each crop entails. These

Table 3. Predicted Aggregate Outputs and Producer Surplus

	Output (billions)		Producer Surplus (billions)	
	Perfect Competition	Crop Restrictions	Perfect Competition	Crop Restrictions
Corn, low	5.6	6.4	123.0	232.1
Corn, medium*	5.7	6.7	95.8	231.9
Corn, high	6.9	10.8	81.7	248.8
Cotton, low	5.3	5.9	41.3	47.2
Cotton, medium	5.3	5.9	31.2	40.7
Cotton, high*	6.0	7.6	24.3	36.0
Rice, low	.10	.11	8.3	13.6
Rice, medium*	.09	.12	6.0	12.1
Rice, high	.10	.16	4.2	11.7
Wheat, low	1.6	1.8	37.5	81.4
Wheat, medium*	1.6	2.2	25.9	79.2
Wheat, high	1.9	3.3	18.6	88.6

Notes: Output for corn and wheat is in bushels, that for cotton is in pounds, and that for rice is in cwt. Producer surplus is in present value dollars. An asterisk (*) denotes the simulated supply elasticity that gives rise to the best fit to the actual data on market supply in table 1.

calculations are presented in table 5. The United States could save $48 billion in present value of wasted resources simply by giving these farmers a lump-sum transfer of $207.2 billion and then abolishing all of these programs.

Conclusion

This article develops a dynamic analysis of the crop restriction programs of the United States. The decision to participate in these programs is voluntary, and we solve the dynamic program that the farmer faces. The optimal policy for small farmers is to build up base acreage; this is akin to rent-seeking behavior by producers who are not currently participating in these programs. Acreage diversion, the target price, the loan rate, the difference

Table 4. Aggregate Base Acreage in 1987 and 1988

	1987		1988	
	Actual	Model Basis	Actual	Model Prediction
	(Millions of acres)			
Corn	66.8	69.1	68.5	69.5
Cotton	11.2	12.3	12.9	12.7
Rice	2.9	3.4	3.2	3.4
Wheat	71.6	74.3	72.5	77.0

Notes: Model basis represents the aggregate acreage of all farms with base greater than four acres. The predicted aggregate base acreage for 1988 is calculated using the optimal policy function that best fits the actual 1987 output and the transition function given in equation (3).
Sources: The source of the data for actual base acreage is described in the last paragraph of appendix A. The source for model basis in 1987 was a USDA tape consisting of fully disaggregated data on the distribution of base for each crop; see the text for a full description. This tape is dated earlier than the source for the "actual" data, and this may be the reason for the discrepancy in the two columns concerning 1987.

Table 5. Social Cost of the Crop Restriction Programs

	Annual Deadweight Production Loss (billions 1987 dollars)	Deadweight Loss as a Percentage of Increased Farmer Surplus
Corn	1.3	21
Cotton	.2	37
Rice	.1	27
Wheat	.8	32

Notes: The first column is the incremental production costs owing to the crop restriction programs net of the increased value of farm output, both measured at 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 3 for the cases which best fit the actual output in 1987.

between actual and program yields, and diversion payments all affect the incentives of both participants and nonparticipants.

We have not explored the implications of this model on the long-run distribution of farm sizes, but we showed that small farms tend to increase 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, in 1987, these crop restriction programs resulted in higher output than would have occurred in their absence. The present value of resources wasted in this rent-seeking behavior was $48 billion.

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Notes

[1] Farm subsidies in the United States have never included alfalfa; still, we hope the reader indulges Mr. Heller his poetic license. Farmers producing barley, oats, and sorghum have received subsidies; de Gorter and Fisher describe the effects of these programs on those feed grains.

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

[3] See Ericksen and Collins.

[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.

[5] This "official" level of production is determined from a five-year rolling average in which the years with the highest and lowest yields per acre are eliminated. This is called "program yield," and it is often, though not always, lower than actual yield. A farmer's program yield is known at the time of planting.

[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 the penultimate section, we cannot hope to analyze individual yield per farmer with aggregate data.

[7] 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. Farmers have also leased their land to employees, charging rents high enough to capture a substantial part of the implicit government benefits. Sumner provides a good discussion of this issue.

[8] Let $f: X \rightarrow \Re$, and consider a sequence $\{x_n\}$, each of whose elements is in X, such that $x_n \rightarrow x_0$. Then $f(x)$ is upper semi-continuous at x_0 if $\lim_{n \to \infty} f(x_n) \leq f(x_0)$. The function $f(x)$ is upper semi-continuous if it is upper semi-continuous at each element in its domain.

[9] If a farmer diverts exactly the required acreage, then historical base does not diminish; however, if one wishes to decrease historical base, we assume that the required acreage diversion is part of one's considered plantings in year t.

[10] Since we are using a smooth cost function, we are assuming that the farmer faces no acreage limitations over the relevant ranges of planting. This is not unreasonable for small increases in plantings, but it may not be appropriate for farms that expand their base acreages radically.

[11] In figure 1, we have converted the state and control variables into acres for ease of exposition.

[12] Because data on the participation decisions of individual farms were not available, we used aggregate data on the number of participants and nonparticipants to calculate these averages. These data were provided by the USDA, Agricultural Stabilization and Conservation Service (via correspondence dated 30 December 1988); they are not published.

[13] We are assuming for simplicity that the price of each of these crops is fixed by conditions in the world market, and we are also assuming implicitly that the total number of farms is unchanged under conditions of perfect competition. The aggregate output is thus the total output of a fixed number of identical farmers.

[14] Since output prices are fixed by assumption, there is no consumption deadweight loss.

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Appendix A: Data

The data on costs of production are reported in McElroy et al. 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 on the number of farms in the United States refer to farms that have at least five base acres in 1987. These farms may or may not be participants in the relevant programs in that year. The source is USDA, Agricultural Stabilization and Conservation Service, Commodity Analysis Division, National Agricultural Statistical Services.

The data for total output of these crops are obtained from U.S. Department of Agriculture/Economic Research Service (USDA/ERS) publications: *Wheat Situation and Outlook Report* (August 1989), *Feed Situation and Outlook Report* (August 1989), *Rice Situation and Outlook Report* (April 1989), and *Cotton and Wool Situation*

and Outlook Report (May 1989). The yield per acre refers to planted acres, and these data are again from McElroy et al.

Market prices, target prices, and loan rates are from the USDA/ERS *Situation and Outlook Report* for the relevant crop. The diversion requirements are calculated as the ratio of acres diverted to total base acreage. 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 unpublished source for these data is the USDA's Agricultural Stabilization Conservation Service, Commodity Analysis Division. The data for corn are dated July 1989, those for wheat are dated 10 May 1989, and those for rice are dated October 1989. The corresponding data about acreage diverted for cotton are from the USDA, Office of Information, *News,* dated 10 March 1989, and the data on cotton base acreage are found in Stults et al. (pp. 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 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 et al. (p. 79).

The data on actual aggregate base acreage in 1987 and 1988 do not include acreage placed in long-term conservation reserve programs. They were obtained by private correspondence with the USDA's Agricultural Stabilization and Conservation Service, Commodity Analysis Division; this correspondence is dated 23 October 1990.

Appendix B: Proofs

Proof of Proposition 1: If $h^*(\theta) \le f^*(p)$, then the static profit-maximal choice of output is u_p, even for farms with sufficiently large base acreage. Hence, for any state $\boldsymbol{x}_t$, $\pi^*(\boldsymbol{x}_t) = u_p$. This proves (i).

If $h^*(\theta) > f^*(p)$, the static profit-maximal output for a participant with sufficiently large base acreage is u_θ. Hence, a farmer with base acreage history $\boldsymbol{x}_t \gg \boldsymbol{b}_\theta$ may plant u_θ and earn no less than $h^*(\theta)$ per period. Since $\boldsymbol{x}_t \gg \boldsymbol{b}_\theta$, $b_{t+1} > b_\theta$, the lower bound for the five-year average of $\boldsymbol{x}_t$. This implies that the state next period will be such that the one-period profit-maximal choice of acreage will again be possible. □

Proof of Proposition 2: Let $\boldsymbol{x}_t \le \boldsymbol{y}_t$, where this is a vector inequality. Let $u_t^* \in \operatorname{argmax} r(\boldsymbol{x}_t, u_t)$ and $v_t^* \in \operatorname{argmax} r(\boldsymbol{y}_t, u_t)$, where the dependence of u_t^* on $\boldsymbol{x}_t$ and that of v_t^* on $\boldsymbol{y}_t$ has been suppressed for convenience. Since $\boldsymbol{x}_t \le \boldsymbol{y}_t$, $r(\boldsymbol{x}_t, u_t^*) \le r(\boldsymbol{y}_t, v_t^*)$. Further, since each element of $\boldsymbol{x}_t$ is not greater than the corresponding element of $\boldsymbol{y}_t$, we may always choose u_t^* and v_t^* such that $u_t^* \le v_t^*$. This implies that $\boldsymbol{x}_{t+1} = \boldsymbol{z}(\boldsymbol{x}_t, u_t^*) \le \boldsymbol{z}(\boldsymbol{y}_t, v_t^*) = \boldsymbol{y}_{t+1}$, again a vector inequality. Hence, $r(\boldsymbol{x}_{t+1}, u_{t+1}^*) \le r(\boldsymbol{y}_{t+1}, v_{t+1}^*)$, 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 $I(\pi^*)(\boldsymbol{x}_t) \le I(\pi^*)(\boldsymbol{y}_t)$, and thus $V(\boldsymbol{x}_t) \le V(\boldsymbol{y}_t)$. □

Proof of Proposition 3: If $\boldsymbol{x}_t \gg \boldsymbol{b}_\theta$, then Proposition 1 implies that $\pi^*(\boldsymbol{x}_t) = u_\theta$. This implies that $\boldsymbol{x}_{t+1} \ge \boldsymbol{b}_\theta$ and $\pi^*(\boldsymbol{x}_{t+1}) = u_\theta$ again. Hence, even though $\boldsymbol{x}_t$ and $\boldsymbol{x}_{t+1}$ may be different, they both entail the same optimal level of planting. But then $V(\boldsymbol{x}_t) = (1 - \beta)^{-1} h^*(\theta)$.

Now let $\boldsymbol{x}_t$ be such that $\boldsymbol{x}'' \le \boldsymbol{x}_t \le \boldsymbol{b}_\theta$, where $\boldsymbol{x}''$ is sufficiently close to $\boldsymbol{b}_\theta$. Assume that for some $\boldsymbol{x}_t$ satisfying $\boldsymbol{x}'' \le \boldsymbol{x}_t \le \boldsymbol{b}_\theta$, it is the case that $u_t = \pi^*(\boldsymbol{x}_t) > (1 - \delta)b_t$. Then:

$$V(\boldsymbol{x}_t) = f(p, u_t) + \beta V(\boldsymbol{x}_{t+1}) \le f(p, u_t) + \beta(1 - \beta)^{-1} h^*(\theta) \le f^*(p) + \beta(1 - \beta)^{-1} h^*(\theta)$$
$$= f^*(p) + \beta(1 - \beta)^{-1} h^*(\boldsymbol{b}_\theta, u_\theta),$$

where the first inequality follows from $V(\boldsymbol{x}_{t+1}) \le V(\boldsymbol{x}_\theta) = (1 - \beta)^{-1} h(\boldsymbol{x}_\theta, u_\theta)$, the second since $u_p \in \operatorname{argmax} f(p, u_t)$, and the equality from $h^*(\theta) = h(\boldsymbol{b}_\theta, u_\theta)$. Since π^* is an optimal plan, planting $u_t = (1 - \delta)b_t$ may not be optimal. Then it follows that $(1 - \beta)^{-1} h(\boldsymbol{x}_t, (1 - \delta)b_t) \le V(\boldsymbol{x}_t)$. But this implies that

$$(1 - \beta)^{-1} h(\boldsymbol{x}_t, (1 - \delta)b_t) \le f^*(p) + \beta(1 - \beta)^{-1} h(\boldsymbol{b}_\theta, u_\theta)$$
$$\Leftrightarrow h(\boldsymbol{x}_t, (1 - \delta)b_t) \le (1 - \beta) f^*(p) + \beta h(\boldsymbol{b}_\theta, u_\theta).$$

This inequality is contradicted because $h(\boldsymbol{x}_t, (1 - \delta)b_t)$ is continuous in $\boldsymbol{x}_t$, and $p < \tau$ implies that, for $\boldsymbol{x}_t$ in a neighborhood of $\boldsymbol{b}_\theta$, $f^*(p) < h(\boldsymbol{x}_t, (1 - \delta)b_t)$. This establishes that $\pi^*(\boldsymbol{x}_t) = (1 - \delta)b_t$.

Then, for $\boldsymbol{x}_t$ satisfying $\boldsymbol{x}'' \le \boldsymbol{x}_t \le \boldsymbol{x}_\theta$, $V(\boldsymbol{x}_t) = (1 - \beta)^{-1} h(\boldsymbol{x}_t, (1 - \delta)b_t)$ from the definition of the value function. □

Proof of Proposition 4: Let $\boldsymbol{x}_t$ satisfy $0 \le \boldsymbol{x}_t \le \boldsymbol{x}'$, where $\boldsymbol{x}'$ is sufficiently near 0. Since $\{(\boldsymbol{x}_t, u_t): 0 \le \boldsymbol{x}_t \le \boldsymbol{x}'$ and $0 \le u_t \le b_t\}$ is closed, there is a pair $(\tilde{\boldsymbol{x}}, \tilde{u})$ that maximizes $h(\boldsymbol{x}_t, u_t)$ on this set. Now assume that $\pi^*(\boldsymbol{x}_t) \le (1 - \delta)b_t$; hence, $\boldsymbol{x}_{t+1} \le \boldsymbol{x}'$. Then

$$V(\boldsymbol{x}_t) = h(\boldsymbol{x}_t, \pi^*(\boldsymbol{x}_t)) + \beta V(\boldsymbol{x}_{t+1}) \le h(\tilde{\boldsymbol{x}}, \tilde{u}) + \beta V(\boldsymbol{x}_{t+1}) \le h(\tilde{\boldsymbol{x}}, \tilde{u}) + \beta V(\boldsymbol{x}'),$$

where the second inequality follows from the fact that the value function is not decreasing. Hence, $V(\boldsymbol{x}_t) \le (1 - \beta)^{-1} h(\tilde{\boldsymbol{x}}, \tilde{u})$. But $\lim_{\boldsymbol{x}' \downarrow 0} h(\tilde{\boldsymbol{x}}, \tilde{u}) \le 0$.