Appendix A
Modeling the Farm Level

Linear Program To Calculate Dual Values

Positive mathematical programming (PMP) is used to calibrate the farm-level model to base year data without having to add constraints that cannot be justified by economic theory. PMP takes advantage of the fact that it is easier to collect information about outputs and inputs at the farm level than information about costs. The observed output and input levels result from a complicated decision process based in part on a cost function that is known to the farmer but difficult or impossible to observe directly. Some costs—perhaps associated with the environment, risk, or technology—may be hidden to the researcher even when a detailed survey instrument is available. PMP incorporates information about unobservable costs by using a quadratic cost function that approximates the true underlying cost function.

There are three steps to the PMP calibration (Howitt, 1995). In the first step, a constrained linear programming model is used to derive dual values associated with the "calibration constraints." In the second step, the dual values are used to parameterize a calibrated quadratic objective function. In the third step, the calibrated model is used for economic analysis, by imposing environmental policy constraints.

In the first step, the linear objective is to maximize total net revenues:

$$(1) \qquad \max_{X1_{ir}} \sum_{r} \sum_{i} X1_{ir}(P_{ir} - C_{ir}),$$

where $X1_{ir}$ is the level of each output i in region r. The cost of producing each output is $C_{ir} = \sum_{j} A_{ijr} W_{jr}$, where A_{ij}r is the amount of input j required to produce a unit of output and W_{jr} is the input price. The optimization is subject to $j \times r$ resource constraints:

$$(2) \qquad \sum_{i} A_{ijr} X_{ir} \leq \sum_{i} A_{ijr} X0_{ir}, \forall\ j, r$$

where $X0_{ir}$ is the initial observed activity level, so that $\sum_{i} A_{ijr} X0_{ir}$ is the initial level of input j.

Inputs include land, capital, feeder pigs, feed corn, feed soy, and chemical nitrogen fertilizer. Outputs include hogs, corn, soybeans, and "other crops" (defined as the value of all other crops produced). All three crops can be produced under three fertilization regimes: (1) chemical fertilizer, (2) manure fertilizer applied to the surface, or (3) manure fertilizer injected into the soil. We use the extension of PMP developed by Röhm and Dabbert (2003) to allow for a greater policy response between crop fertilization regimes than between crops. To do so, we define three "variant activities" (chemical fertilizer, manure-spread, and manure-injected) for each crop and impose calibration constraints that distinguish between variant activities and the total activity for each crop. In practice, this approach results in greater substitution between, for example, corn fertilized by spreading manure and corn fertilized by injecting manure, than between corn and "other crop" production.

The calibration constraints for each activity are:

$$(3) \qquad X1_{ir} \le X0_{ir}(1+\xi_1), \forall\ i,r \quad dual{:}\hat{\lambda}_{i,r}$$

where ε_1 is a small perturbation (see Howitt, 1995). Following Röhm and Dabbert, we include three additional calibration constraints corresponding to each set of variant activities. For corn activities, the additional calibration constraint is:

$$(4) \qquad \sum_{i \in cv} x1_{ir} \le \sum_{i \in cv} x0_{ir}(1+\xi_2), \forall\ i,r \quad dual{:}\ \hat{\lambda}_{corn,r}$$

where *cv* is the set of corn variant activities: *cv* = {corn - chemical fertilizer, corn - spread manure, corn - injected manure}. There are two additional constraints analogous to equation 4 corresponding to soybean variant activities, sv, and other crops variant activities, *ov*.

From the 1998 ARMS survey and other sources, we observe prices P_{ir}, W_{ir}, the output levels $X0_{ir}$, and most of the input-output coefficients A_{ijr} (see Appendix tables A1-A4 for details). It would be desirable to include manure nitrogen as an input. However, we do not observe manure application rates, only the amount of land on which manure is applied.

Estimate Calibrated Quadratic Cost Function

In step 2 we define quadratic total variable costs as $\frac{1}{2}\hat{Q}_{ir}X_{ir}^2$, where $\hat{Q}ir = (\hat{\lambda}_{ir} + \hat{\lambda}_{crop,r} + C_{ir}) / X0_{ir}$, $\hat{\lambda}_{ir}$, are the estimated dual values associated with equation 3 the calibration constraints, and $\hat{\lambda}_{crop,r}$, are the estimated dual values associated with equation 4 the calibration constraints for each crop activity: crop $\in \{corn,\ soybean,\ other\}$. Since equation 4 applies only to crops, $\hat{Q}_{ir} = (\hat{l}_{ir} + C_{ir}) / X0_{ir}$ for *i=hogs*. The objective in step 2 is to maximize total net revenues:

$$(5) \qquad \max_{x2_{ir}} \sum_r \sum_i P_{ir} X2_{ir} - \frac{1}{2}\hat{Q}_{ir} X2_{ir}^2$$

subject to the resource constraints:

$$(6) \qquad \sum_i A_{ijr} X2_{ir} \le \sum_i A_{ijr} X0_{ir}, \forall\ j,r$$

Solution of the non-linear optimization problem defined by equations 5 and 6 results in the initial output levels $X0_{ir}$.

Estimate Activity Levels for Policy Scenarios Using Calibrated Cost Function

Having characterized the farmer's non-linear optimization problem that results in the observed initial values, the final step is to impose policy constraints and compare solutions to the initial values. The policies we consider are the CAFO nitrogen application constraint and a hypothetical ammonia emission constraint. Farms can respond to policy constraints by adjusting input and output levels. Pit storage operations can vary the amount of land on which they inject versus surface-apply manure slurry in order to alter the ammonia emitted to the air and the nutrients available to plants. Lagoon operations can cover their lagoons to reduce air ammonia emissions. EQIP payments can enter the farmer's decision problem by reducing costs of abiding by the CAFO rules.[1]

First we incorporate into the optimization a manure transportation cost that depends on how the manure is stored and handled. Prior to implementation of the CAFO manure application rules, farmers had little incentive to transport manure off-farm, and few did. According to the 1998 survey, fewer than 2 percent of farms transported manure off-farm. The CAFO manure application rules require farmers to apply manure at a rate that plants can absorb. In response to the CAFO rules, farmers without adequate cropland will need to transport some manure off-farm (Ribaudo et al., 2003).

For the policy analysis, the farmer's objective is:

$$(7) \quad \max_{x3_{ir}\,\mathrm{cov}_r} \sum_r \sum_i P3_{ir} X3_{ir} - \frac{1}{2}\hat{Q}_{ir} X3_{ir}^2 - (1 - EQIP)MTC_r - COV_r \cdot \kappa \cdot X3_{hogs,r}$$

where MTC_r is the cost of transporting manure off-farm, which is a function of technology choices that affect that nutrient availability to the crop—and consequently the amount of land on which the manure must be spread. Farms eligible for EQIP payments receive a share of the manure transportation costs and receive a per acre subsidy for land on which they apply manure at the agronomic rate. *EQIP* is defined as the share of manure transportation costs financed by EQIP. The per-acre EQIP subsidy is expressed as a per-unit subsidy and appears in the optimization as a higher price *P3*. The decision by lagoon farms to cover their lagoon is reflected in the binary choice variable COV_r (1 if covered, 0 otherwise). The cost of covering a lagoon is simply a cost κ per unit of hog output.

Manure transportation costs depend on the nutrient content of the manure (how it was stored), how it is applied (injected or spread), the availability of land on which to apply the manure, and what crops it is applied to. Estimates for the transportation costs per hundredweight of hog are based on a transportation cost model proposed by Fleming et al. (1998) (see Appendix table A-5 for details). Manure transportation costs equal the quantity of hogs used to produce manure transported off-farm, $hogs\_off_r$, multiplied by the manure transportation costs per hundredweight of hog. Manure transportation costs are distinguished for lagoon operations, which may or may not cover their lagoons:

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[1] We assume for this analysis that CAFOs do not receive EQIP payments.

$$(8) \qquad MTC_r = hogs\_off_r(COV_r * T_{cover,r} + (1 - COV_r) * T_{uncov,r}),$$

and for pit storage operations which may inject (versus surface-apply) manure into some portion of the land on which manure is applied:

$$(9) \qquad MTC_r = hogs\_off_r(INJ_r * T_{inject,r} + (1 - INJ_r) * T_{surf,r}),$$

where transportation costs per hundredweight of hog produced, $T_{e.r}$, depend on the manure storage and handling technology $e \in$ {covered, uncovered, surface-applied, injected}.

For lagoon operations, COV_r is a binary choice variable. For pit storage operations, INJ_r is the share of manure-applied cropland on which manure is injected:

$$(10) \qquad INJ_r = \sum_{i \in mi} A3_{i,land,r} X3_{i,r} \Big/ \sum_{i \in m} A3_{i,land,r} X3_{ir},$$

where *m* is the set of manure crop activities (corn, soybean and other crops, either spread or injected) and *mi* is the set of all cropping activities on which manure is injected.

The quantity of hogs that produce manure applied off-farm equals the total hogs produced minus the number of hogs required to produce the nitrogen from manure applied on-farm:

$$(11) \qquad hogs\_off_r = X3_{hogs,r} - \left(manrate_r \sum_{i \in m} X3_{ir} A_{i,ferN,r}\right)\left(\frac{COV_r}{NH_{cov}} + \frac{1 - COV_r}{NH_{uncov}}\right).$$

The number of hogs required to produce the nitrogen from manure applied on-farm equals the manure nitrogen used on-farm divided by the manure nitrogen available to crops per hundredweight of hogs, NH_e (which depends on the cover technology). The manure nitrogen used on-farm equals the pounds of manure nitrogen applied on - farm if it were applied at an agronomic rate $\sum_{i,m} X3_{ir}A_{i,fertN,r}$ (the rate at which chemical fertilizers are applied) multiplied by the factor $manrate_r$. From the survey we observe the average rate at which manure is applied to receiving land, but we do not know the rate applied to individual crops. Consequently, we assume that farmers apply manure at the same observed factor, $manrate_r$, above the agronomic rate for all crops.

There is an analogous equation for pit storage operations.

$$(12) \quad hogs\_off_r = X3_{hogs,r} - \left(manrate_r \sum_{i \in m} X3_{ir} A_{i,fertN,r}\right)\left(\frac{INJ_r}{NH_{inject}} + \frac{1 - INJ_r}{NH_{surf}}\right)$$

Policy 1: Nitrogen application constraint. CAFO rules require a nutrient management plan that requires growers to apply manure nitrogen at or below the rate at which plants can absorb (the agronomic rate). This policy is imposed by constraining $manrate_r$ to be less than or equal to 1.

Policy 2: EQIP payments. The effect of EQIP payments can be modeled by adjusting the share of off-farm manure transportation costs borne by EQIP and by adjusting the per-unit subsidy for crops produced in accordance with CAFO application guidelines.

Policy 3: Ammonia nitrogen emission constraint. Hypothetical ammonia emissions regulations are modeled by imposing a limit, *Amlimit*, on the quantity of nitrogen from ammonia per-unit of hog produced. Nitrogen emissions per unit of hog produced, AmN_e, depend on manure storage and handling technologies. The ammonia emission constraint is:

$$COV_r * AmN_{Cover} + (1 - COV_r) * AmN_{Un\mathrm{cov}er} \leq Amlimit \tag{13}$$

for lagoon operations and:

$$INJ_r * AmN_{Inject} + (1 - INJ_r) * AmN_{Surface} \leq Amlimit \tag{14}$$

for pit storage operations. Note that the ammonia emission constraint does not depend on the quantity of manure transported off-farm. The application method (spread/inject) is assumed to be the same on-farm and off-farm.

Appendix table A-1

Initial production, $X0_{ir}$

Outputs	Units	Value	Source
Corn fertilizer	100 bushels	*	USDA ARMS Survey 1998
Corn manure surface	100 bushels	*	USDA ARMS Survey 1998
Corn manure inject	100 bushels	*	USDA ARMS Survey 1998
Soy fertilizer	100 bushels	*	USDA ARMS Survey 1998
Soy manure surface	100 bushels	*	USDA ARMS Survey 1998
Soy manure inject	100 bushels	*	USDA ARMS Survey 1998
Other fertilizer	$ (value of production)	*	USDA ARMS Survey 1998
Other manure surface	$ (value of production)	*	USDA ARMS Survey 1998
Other manure inject	$ (value of production)	*	USDA ARMS Survey 1998
Hogs	cwt	*	USDA ARMS Survey 1998

* Estimated mean value varies by region and size of operation.

Appendix table A-2

Output price, P_{ir}

Outputs	Units	Value	Source
Corn (all)	$/100 bushels	284	NASS - (average price 1997-99)
Soy (all)	$/100 bushels	700	NASS - (average price 1997-99)
Other (all)	-	1	-
Hogs	$/cwt	46.92	NASS -(average price 1997-99)

Appendix table A-3

Input price, W_{jr}

Inputs	Units	Value	Source
Land	$/acre	68.2	NASS Agricultural Land Values Final Estimates 1998, Statistical Bulletin Number 957 (national average) (use 7% of land value as rental rate)
Capital	$	1	(by definition)
Feeder pigs	$/cwt	80.25	NASS - (average price 1997-99)
Feed corn	$/100 bushels	284	NASS - (average price 1997-99)
Feed soy	$/100 bushels	700	NASS - (average price 1997-99)
Fertilizer - N	$/lb.	0.185	Ribaudo et al., 2003

Appendix table A-4

Resource use, A_{ijr}

Input-output	Units	Value	Source
Land-corn	acres/100 bushels	*	USDA ARMS Survey 1998
Land-soy	acres/100 bushels	*	USDA ARMS Survey 1998
Land-other	acres/$	*	USDA ARMS Survey 1998
Capital-corn	$/100 bushels	49.3	Foreman, 2001
Capital-soy	$/100 bushels	127	Foreman, and Livezey, 2002
Capital-other	Share of value	0.17	Same share as corn
Capital-hogs	$/CWT.	*	USDA ARMS Survey 1998
Feed corn-hogs	100 bushels /CWT.	*	USDA ARMS Survey 1998
Feed soy-hogs	100 bushels /CWT.	*	USDA ARMS Survey 1998
Feeder pigs-hogs	CWT/CWT	*	USDA ARMS Survey 1998
Fertilizer-N-corn	lbs./ 100 bushels	80.0	Kellogg et al., 2000.
Fertilizer-N-soy	lbs./ 100 bushels	236.7	Kellogg et al., 2000.
Fertilizer-N-other	lbs./ $	0.282	Same rate as corn

* Estimated mean value varies by region and size of operation.

Appendix table A5

Manure off-farm transportation net costs by region and manure storage and handling technology, T_{re}

Manure storage /handling technology	Eastern Cornbelt	Western Cornbelt	Mid-Atlantic	South and West
	Dollars/cwt of hogs			
Lagoon				
Uncover	1.33	1.36	2.01	2.15
Cover	5.32	5.38	6.57	6.83
Pit				
Surface	1.20	1.25	2.29	2.53
Inject	1.61	1.66	2.82	3.08

Source: Estimated. Base manure handling costs from Fleming et al. 1998. Unit mile cost from USDA, NRCS, 2003 C*osts Associated with Development and Implementation of Comprehensive Nutrient Management Plans*. Lagoon cover costs from Massey, et al. *Agronomic and economic impacts of lagoon based swine operations complying with the proposed EPA zero discharge rule*.

Appendix table A-6

Nitrogen available to crops and nitrogen ammonia emissions by manure storage and handling technology

Manure storage/ handling techology	Soil nitrogen available to plants, $Npercwt_e$	Air ammonia emissions from house and storage	Air ammonia emissions from land application	Total air ammonia emissions, AmN_e
	Lbs/cwt			
Lagoon				
Uncover	1.53	7.21	0.42	7.62
Cover	5.07	2.69	1.39	4.08
Pit				
Surface	4.83	3.00	1.32	4.32
Inject	5.95	3.00	0.20	3.20

Source: US EPA *National Emission Inventory--Ammonia Emission from Animal Husbandry Operations*, 2004.

Appendix table A-7

EQIP payments per unit of output by crop and region

Crop	Uni	Eastern Cornbelt	Western Cornbelt	Mid-Atlantic	South and West
Corn	$/100 bu	8.87	8.28	53.00	49.70
Soybean	$/100 bu	27.44	24.44	85.62	86.92
Other	Share of value	0.05	0.11	0.13	0.17

Source: Estimated using EQIP program data, Farm Service Agency, USDA.