Inferring the Effects of Nitrogen Management Policies Using a Fully Calibrated Programming Model of California Agriculture

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Executive summary: Our work addresses *ex ante* policy evaluation as it relates to nitrogen management in agriculture, in particular the reduction of nitrogen losses from field crops. We build a bio-economic model of crop production at the regional scale to predict the effects of nitrogen-related policies on agriculture and the environment. The model is calibrated against economic data on observed crop acreages and yields, as well as predetermined supply responses. In addition, crop-specific production functions are calibrated to exogenous agronomic information on yield responses to nitrogen and irrigation. Environmental outcomes are tracked using the biophysical model DAYCENT.

The model is applied to the study of a nitrogen tax in Yolo County, California, intended to mitigate non-point source nitrogen pollution from field crops. At low tax levels, the behavioral and environmental responses to the nitrogen tax appear to be largely due to the reduction in fertilizer use and irrigation on each crop. However, as the tax level increases, reductions in input intensities start to level out due to unfavorable yield effects, and acreage reallocation among crops begins to play a sizable part in the total response.

From a methodological standpoint, our study illustrates the need to accurately model input intensity adjustments in regional models of crop supply intended for agri-environmental policy analysis. From a policy standpoint, our study shows that sizable reductions in nitrogen application, and attendant reductions in nitrogen losses, can be achieved at the regional scale at a moderate social cost. Overall, the induced reduction in nitrate leaching appears larger than the reduction in nitrous oxide emissions.

Specific results: The study develops an economic model of nitrogen use at the regional scale, for use in *ex ante* agri-environmental policy evaluation. The model is based on the principles of positive mathematical programming (PMP), as outlined in Howitt (1995) and, more recently, Mérel et al. (2011). As such, the model exactly replicates an observed acreage

allocation among activities, as well as an exogenous set of crop supply elasticities. The novelty of our approach lies in the fact that the model is also calibrated so as to replicate crop yield responses to irrigation and nitrogen application consistent with agronomic information obtained from the biophysical soil process model DAYCENT (Del Grosso et al., 2008). Consequently, our fully calibrated model is particularly fit for the analysis of policies that are likely to affect both acreage allocation and input intensity in multi-crop agricultural systems.
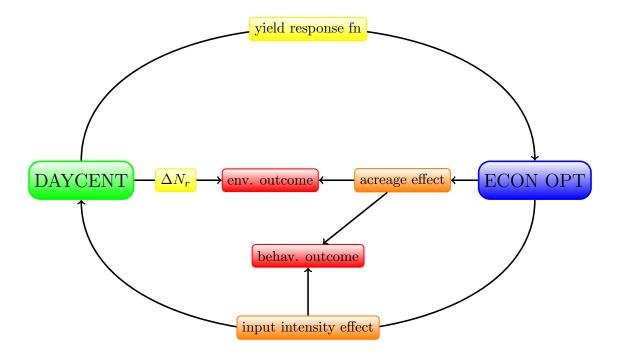
This paper is not the first one to recognize the need to better represent farmers' input adjustment opportunities in programming models of agricultural supply, but it is the first one to propose a solution to the yield response calibration problem in the context of positive mathematical programming. Before us, Godard et al. (2008) have used local yield response curves derived from the biophysical model STICS (Brisson et al., 2003) to represent farmers' nitrogen fertilizer application choice as a first stage to a linear programming representation of crop choice. Graveline and Rinaudo (2007) have exploited a yield response curve for corn to specify a discrete set of corn production activities in a pure linear programming framework. Our approach is different from these, as we focus on exact replication of observed economic behavior through non-linear PMP calibration, as opposed to constrained linear optimization. We also calibrate crop yield responses not only to nitrogen, but also irrigation, an important margin for the assessment of certain environmental outcomes such as nitrate leaching. Finally, we use the biophysical model to derive regional-level—as opposed to farm-level—yield response curves.

Our model is applied to field crop agriculture in Yolo County, California, to evaluate the economic and environmental effects of an exogenous increase in the price of nitrogen. A nitrogen tax represents a possible market-based instrument to help mitigate non-point source nitrogen pollution from agriculture. The effects of the tax on nitrate leaching and nitrous oxide (N_2O) fluxes are tracked. The linkages between the agronomic model DAYCENT and the economic optimization model are depicted in figure 1.

To comprehend the effect of a nitrogen tax on behavioral and environmental outcomes, it is useful to decompose the total effect into its two elementary economic responses: an *extensive margin* effect, that is, the reallocation of acreage among crops, and an *intensive margin* effect, that is, the change in input intensity per acre, for a given crop. Both effects are operating simultaneously, and in our application the intensive margin effect, which has been overlooked in existing PMP studies (Helming, 1998), is likely to be large. Hence, to anticipate the full effect of a nitrogen tax policy, it is necessary to accurately model the intensive margin response, in addition to the extensive margin response.

Indeed, we find that at low to moderate tax levels, most of the environmental benefits of the policy arise from reductions in nitrogen and water application on each crop, with acreage reallocation playing a minor role. However, as tax levels rise, input intensity adjustments start to level out due to adverse yield effects, and acreage reallocation among crops starts to play a more significant role in the behavioral and environmental responses.

Table 1 reports the contributions of the input intensity and acreage reallocation effects to the total behavioral response, that is, the reduction in nitrogen application at the regional

Note: ΔN_r denotes the change in nitrogen emission factors per activity due to the change in input intensity.

Figure 1: Linkages between the economic and agronomic models

level. At the tax level of ¢4/lb N, the total reduction in nitrogen applied in Yolo is predicted to be 3.9%, and 3.3% is due to the input intensity effect. At the higher tax level of ¢16/lb N, the total effect is a reduction of N application by 12.8%, the contribution of the input intensity effect being 8.3%. As such, the relative importance of the acreage reallocation effect to the total effect is increasing with the tax level.[1]

Table 1: Decomposition of the behavioral response

Effect		Increase in nitrogen price			
		¢4/lb N	¢8/lb N	¢12/lb N	¢16/lb N
acreage reallocation	(%)	-0.54	-1.03	-2.48	-4.93
input intensity	(%)	-3.34	-5.66	-7.29	-8.30
Total	(%)	-3.87	-6.68	-9.65	-12.81

Our analysis also allows for the calculations of the private and social costs of the tax policy. The reduction in regional returns to land ownership is calculated to be 2.4% at the highest tax level considered, ¢16/lb N. The economic surplus loss of the policy is moderate, about 0.2% at the highest tax level considered.

Table 2: Returns to land ownership and tax revenue

Scenarios	Returns to land ownership		Tax revenue	Economic surplus loss
	(million dollar)	% change	(1,000 dollar)	(1,000 dollar)
Base case	124.79	-	-	-
¢4/lb N	124.00	-0.63	771.65	-14.01
¢8/lb N	123.24	-1.24	1498.13	-47.61
¢12/lb N	122.50	-1.83	2175.80	-107.92
¢16/lb N	121.79	-2.40	2799.60	-196.47

Environmental effects are not perfectly correlated with the behavioral response. This is because nitrogen-saving crops are not necessarily the ones with the lowest emission factors. As such, when it comes to environmental outcomes, the acreage reallocation effect may either reinforce or counteract the input intensity effect. Table 3 reports the total environmental effects for nitrate leaching and N_2O emissions. It shows that sizable benefits may indeed arise from the nitrogen tax. The induced reduction in nitrate leaching is larger than that in nitrous oxide emissions.

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[1]The decomposition of the total effect into the input intensity effect and the acreage reallocation effect holds at the margin only. Hence, the percentage reductions indicated in table 1 need not add up exactly to the total effect.

Table 3: Aggregate environmental outcomes, total effect

Scenarios	Nitrate leaching		N$_2$O flux	
	Quantity (tonne N/yr)	% Change from base case	Quantity (tonne N/yr)	% Change from base case
Base case	4659.66	-	166.00	-
4 ¢/lb N	4433.82	-4.85	162.28	-2.24
8 ¢/lb N	4294.50	-7.84	159.37	-3.99
12 ¢/lb N	4164.28	-10.63	156.06	-5.99
16 ¢/lb N	4029.96	-13.51	152.21	-8.31

Potential Impacts: This study is targeted at policy makers in California and elsewhere interested in investigating market-based incentives for nitrogen pollution reduction in cropping. The calibration methodology developed in the study is novel and has the potential to be replicated in other settings. I can also be scaled up to the entire state to investigate issues related to the participation of agriculture in carbon markets.

The study resulted in a manuscript, that was sent for review in September 2011.

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