Journal of Environmental Management 177 (2016) 192–201

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Dynamic adjustment in agricultural practices to economic incentives aiming to decrease fertilizer application

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ARTICLE INFO

Article history:
Received 10 December 2015
Received in revised form
27 March 2016
Accepted 3 April 2016
Available online 18 April 2016

JEL classification:
Q11
Q15
Q25
Q53
Q58

Keywords:
Dynamic adjustment
Fertilizer use
Land allocation
Water pollution

ABSTRACT

Input- and output-based economic policies designed to reduce water pollution from fertilizer runoff by adjusting management practices are theoretically justified and well-understood. Yet, in practice, adjustment in fertilizer application or land allocation may be sluggish. We provide practical guidance for policymakers regarding the relative magnitude and speed of adjustment of input- and output-based policies. Through a dynamic dual model of corn production that takes fertilizer as one of several production inputs, we measure the short- and long-term effects of policies that affect the relative prices of inputs and outputs through the short- and long-term price elasticities of fertilizer application, and also the total time required for different policies to affect fertilizer application through the adjustment rates of capital and land. These estimates allow us to compare input- and output-based policies based on their relative cost-effectiveness. Using data from Indiana and Illinois, we find that input-based policies are more cost-effective than their output-based counterparts in achieving a target reduction in fertilizer application. We show that input- and output-based policies yield adjustment in fertilizer application at the same speed, and that most of the adjustment takes place in the short-term.

1. Introduction

It is widely acknowledged that fertilizer (e.g., nitrogen and phosphorus) use in agricultural production and the associated runoff leads to high levels of water pollution in the surrounding watershed area, as well as downstream (Goolsby et al., 2001; Rabotyagov et al., 2010; Rebolledo et al., 2016; Yuan et al., 2013). The application rate of fertilizer on a certain area of land is one of the key factors influencing water pollution: all else equal, a higher fertilizer application rate leads to a larger amount of nutrient migrating from the soil into the water system (Angle et al., 1993; Jaynes et al., 2001). When fertilizer is overused the surplus of nutrition in the soil is more likely to cause water pollution (Andraski et al., 2000; Angle et al., 1993). Past research finds that farmers often overuse fertilizer to avoid potential loss in yield associated with uncertainty in weather and soil nutrition levels (Sheriff, 2005; Stuart et al., 2014). As a result, a major policy focus is on minimizing the impact of fertilizer application on environmental systems. We contribute to this policy discussion by shedding light on the dynamics and relative cost-effectiveness of input- and output-based policies that use financial incentives to influence farmer behavior.

Input- and output-based policies refer to policies that target the prices of inputs or outputs in production; for example, a policy that affects the prices of fertilizer used in production is an input-based policy and a policy that affects the price of crops grown on a parcel of land is an output-based policy. This definition is different from another definition in which an input refers to a variable in the polluter's choice set of variables that influence pollution runoff. In this latter case, an input-based policy is one that targets these choice variables, instead of directly targeting emissions or their proxies (see Shortle and Horan, 2013 for further discussion).

Different crops have different requirements for fertilizer application. Corn is a particularly fertilizer-intensive crop. According to data published by the Economic Research Service at the United States Department of Agriculture (USDA ERS), the average application rate of nitrogen for corn production in the United States in 2002 was 154 kg/hectare. The average rate of phosphate application

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http://dx.doi.org/10.1016/j.jenvman.2016.04.002
0301-4797/

was 67 kg/hectare. Conversely, soybeans is a fertilizer-saving crop with an average application rate of nitrogen and phosphate being only 24 and 55 kg/hectare. Not surprisingly the production of corn usually leads to higher levels of water pollution than soybeans. Research finds that continuous corn cultivation causes a higher level of nitrogen runoff than a corn-soybean rotation (Kanwar et al., 1997; Weed and Kanwar, 1996) because of its repeated high rate of fertilizer application year after year (Andraski et al., 2000). For these reasons, crop choice is another important factor influencing water pollution, and consequently, another channel through which policy can exact reductions.

Though a variety of policy options are available for targeting improvements in water quality via a reduction in fertilizer runoff, economists have long favored financial incentives. Financial incentives induce a change in farmer behavior in a manner consistent with environmental conservation without dictating the means of conservation. This allows each farmer to select his/her best option for reducing runoff, which renders financial incentives more efficient than command-and-control policies (Hahn, 2000; Whittaker et al., 2003). In the context of fertilizer application, financial incentives may increase the cost of fertilizer (input-based policies) or reduce the profitability of a fertilizer intensive crop, such as corn (output-based policies).

Input-based policies may operate as a tax on fertilizer use or a subsidy on fertilizer reduction, and have been implemented internationally. In the United States, Wisconsin, Iowa and Nebraska have levied taxes on fertilizer application (Larson et al., 1996; US EPA, 2001). In Europe, Austria, Denmark, Finland, Italy, Norway and Sweden have also implemented a fertilizer tax to reduce fertilizer application (Rougoor et al., 2001; Soderholm and Christiernsson, 2008; Vojtech, 2010).

Output-based policies encourage farmers to substitute to less fertilizer-intensive crops by either taxing fertilizer-intensive crops or subsidizing fertilizer-saving crops. Florida has levied a tax on fertilizer-intensive crop acreage to reduce phosphorus loadings from cropland (Ribaudo, 2001). Another policy that has been suggested is to couple an environmental standard with federal commodity program payments (Claassen, 2007; Ribaudo, 2011). Such a policy might affect the profitability of different crops, and lead to the reduction in fertilizer use. In the Corn Belt, corn and soybeans are the main crops that receive government payments. For example, in Iowa, corn and soybeans account for 69 and 30 percent respectively in the total base acres of covered commodities by the payment programs (Plastina et al., 2016). Given the differences in the production practices of corn and soybeans, imposing an environmental standard as a condition for commodity program payments would increase the compliance costs of corn production relative to soybean production, which in turn would decrease the relative profitability of corn.

Several studies evaluate the relative efficiency of both input- and output-based policies. The findings from these studies are mixed. In terms of a reduction in net farm income, Huang and Lantin (1993) find that the cost per pound of reducing excess nitrogen fertilizer application is lower for input-based policies relative to output-based policies. Wu and Tanaka (2005) find that a fertilizer-use tax is more cost-effective than incentive payments. Using a general equilibrium model of the United States economy, Taheripour et al. (2008) find that output-based policies are more efficient for lower nitrogen reduction goals, but input-based policies become more efficient when higher levels of nitrogen reduction are targeted. In contrast, Bourgeois et al. (2014) find that mixed policies that combine both input- and output-based policies are more cost-effective than any single policy.

The literature that evaluates the relative merits of economic policies targeting water quality and fertilizer runoff typically does so on the grounds of relative cost-effectiveness (Hahn, 2000; Shortle and Horan, 2001, 2013). Comparing policies from a Pareto-efficiency point of view that considers all social costs and benefits of the policy is often impractical because of the informational requirements associated with the Pareto criterion. The cost-effectiveness criterion does not attempt to identify policies capable of attaining the optimal level of pollution that maximizes social welfare as does the Pareto-efficiency criterion. Instead, it identifies the policy instrument that attains an exogenously given environmental target (optimal or not) at minimum cost. The cost-effectiveness criterion has been applied to evaluate command-and-control policies as well as financial incentives. The former include policies encouraging best management practices or land retirement (Khanna et al., 2003; Rabotyagov et al., 2010; Wu and Tanaka, 2005). The latter include tax/subsidy policies based on agricultural input usage or ambient pollution concentration levels (Bourgeois et al., 2014; Kampas and White, 2002; Wu and Tanaka, 2005). Following this literature, we use the cost-effectiveness criterion.

One limitation in the scope of existing research that we address in this paper is that previous research focuses on the overall long-term effectiveness of the policy – i.e., how much water pollution reduction is achieved once the effect of the policy is fully realized. Past research provides valuable insight; yet, an important, practical aspect of this policy discussion is the speed at which each type of policy takes effect, or how long each policy takes to achieve these (previously estimated) goals. Understanding the dynamics of full adjustment is a crucial factor in assessing the relative cost-effectiveness of input- and output-based policies. If a particular type of policy is known to be more effective, yet takes a substantially longer time to yield these effects, then that policy may in fact be less desirable from a policy vantage.

Decreasing the application rate of fertilizer on a certain area of land or switching land allocation from a fertilizer-intensive crop to a fertilizer-saving crop are both able to reduce fertilizer use. While the adjustment of the application rate of fertilizer can be rapid, the adjustment of land allocation across different crops may be sluggish and require a long time to be fully realized. Because of crop rotational effects and quasi-fixed capital constraints (Arnberg and Hansen, 2012; Orazem and Miranowski, 1994), farmers respond slowly to policies targeting adjustments in land allocation. Vasavada and Chambers (1986) find that it takes two years for total agricultural land to adjust to its optimal level when land is treated as one single input. When land is divided across different crops, Lansink and Stefanou (1997) find that it takes more than twelve years to adjust land allocation between root crops and other crops. This sluggishness in the adjustment of land allocation affects the speed at which economic policies affect fertilizer application.

To simultaneously assess both the magnitude of input- and output-based policy effects and the speed at which the policies take effect, we deploy an empirical dynamic adjustment model of corn production that takes fertilizer as one of several inputs into production. We estimate the dynamic response of fertilizer use to changes in the price of both fertilizer (input-based policy) and corn (output-based policy). By estimating the response of fertilizer use to changes in the prices of fertilizer and corn, we are able to measure the effect of each type of policy on fertilizer use. By estimating the adjustment rate of the quasi-fixed inputs (capital and land allocated to corn), we can measure the total time required for the policy to take full effect.

We use county-level data because it is more policy-relevant than farmer level data, as policymakers are interested in affecting change over a relatively large area. This focus is advantageous when we consider the possibility that, while individual farmers may respond to policy-induced incentives slowly, the aggregate