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Regulated Firm Strategy under Uncertainty about Regulatory Status

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Abstract. The effectiveness of environmental regulation is limited by the extent to which those regulations are enforced. Profit-maximizing firms will comply with a regulation if the expected net benefits of compliance are greater than the expected net benefits of non-compliance given the limited enforcement capabilities regulators have at their disposal. Analyses in the literature usually assume that firms know their regulatory status, specifically, whether specific regulatory provisions apply to them or even whether they are subject to regulation at all. But uncertainty about regulatory status is not uncommon. This paper conducts a theoretical and empirical analysis of firms' compliance strategy when they face uncertainty about their regulatory status. Our theoretical analysis indicates that the optimal strategy for a firm with a sufficiently low probability of being subject to enforcement action will be to delay developing a protocol until warned and then delay implementation until being inspected and warned. We analyze the effect of this kind of regulatory uncertainty on the compliance protocol development component of regulations empirically within the context of the Maryland Water Quality Improvement Act (WQIA) of 1998, which requires farms meeting certain criteria to develop, file, and implement a nutrient management plan. The Maryland Department of Agriculture (MDA), which enforces this regulation, has a registry of farms that includes less than half of the farm operations in Maryland. We conduct an econometric analysis using farm level data from a University of Maryland survey combined with county-level enforcement data from MDA. Our econometric model indicates that the probability of being included in the MDA farm registry is associated with a statistically significant and economically meaningful increase in the probability of being in compliance with nutrient management regulations. Further, the probability of being in compliance is increasing in farm size while the marginal effect of being included in the MDA farm registry is decreasing in farm size; both results are consistent with the predictions of our theoretical model.

Keywords. Environmental regulation, enforcement, nutrient management, water quality.

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1. Introduction

The effectiveness of environmental regulation is limited by the extent to which those regulations are enforced. Profit-maximizing firms will comply with a regulation if the expected net benefits of compliance are greater than the expected net benefits of non-compliance. That calculation depends on the regulator's enforcement strategy. Regulators typically have limited resources for enforcement. Efficient allocation of those resources depends on how firms react to different enforcement measures. There is evidence that a wide variety of instruments—including inspections, warnings, penalties, and sanctions—can be effective in increasing compliance (for reviews see Cohen 1999; Polinsky and Shavell 2007; Gray & Shimshack 2011; and Shimshack 2014).

Analyses in the literature usually assume that firms know their regulatory status, specifically, whether specific regulatory provisions apply to them or even whether they are subject to regulation at all.¹ But uncertainty about regulatory status is not uncommon. For example, a recent study by the United States Environmental Protection Agency's (EPA's) Office of Inspector General found significant gaps in the Agency's knowledge of entities regulated under such core legislation as the Clean Air Act (CAA), the Clean Water Act (CWA), the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the Toxic Substances Control Act (TSCA), the Safe Drinking Water Act (SDWA), and the Resource Conservation and Recovery Act (RCRA) (USEPA 2005), suggesting that many

¹ When regulatory uncertainty is considered, the literature generally focuses errors that occur during an inspection (McClelland and Horowitz 1999, Alberini et al. 2008, Rousseau 2009, Malik 2014) rather than uncertainty in the threat of inspection itself.

firms that should be regulated under these statutes face significant uncertainty about their regulatory status.

This paper conducts a theoretical and empirical analysis of firms' compliance strategy when they face uncertainty about their regulatory status. We develop a theoretical model of a firm's compliance decision in a setting typical of environmental and health and safety regulations, where the compliance decision consists of two components: (1) developing an initial compliance protocol (including installation of required pollution control equipment) and (2) implementing and adhering to that compliance protocol (including maintaining pollution control equipment in good working order). Determining whether a firm has developed a compliance protocol is straightforward as it involves checking to see if a compliance protocol has been filed for every firm in the regulator's database. Failure to comply with either component initially results in a warning, with subsequent violations resulting in fines. We show that when there is no regulatory uncertainty (e.g., if the regulator has a complete census of the regulated industry), the firm's optimal strategy will be to develop a compliance protocol but not implement it until inspected and warned. However, the optimal strategy for a firm believing it has a sufficiently low probability of being subject to enforcement will be to delay developing a protocol until warned and then delay implementation until being inspected and warned.

We analyze the effect of this kind of regulatory uncertainty on the compliance protocol development component of regulations empirically within the context of the Maryland Water Quality Improvement Act (WQIA) of 1998. The WQIA requires farms meeting certain criteria to develop, file, and implement a nutrient management plan

(NMP). The registry of farms used by the Maryland Department of Agriculture (MDA), which enforces this regulation, includes only a subset of the farm operations in Maryland that are required to comply with this regulation. Our econometric model indicates that the probability of being included in the MDA farm registry is associated with a statistically significant and economically meaningful increase in the probability of filing a NMP for farms required to have a NMP. This result is robust to a variety of specifications of the probability of inclusion in the MDA farm registry and the inclusion of covariates. Additionally, we present suggestive evidence that farms delay compliance with the implementation requirement of the WQIA until inspected and warned.

The rest of the paper is organized as follows. In section 2, we review the relevant literature. We develop a theoretical model in section 3 and propose testable hypotheses. Then, in section 4, we discuss the institutional background of the WQIA and in section 5, our data. In section 6, we develop an econometric model to test the hypotheses proposed in section 3. In section 7, we present and discuss the results of our econometric model. Section 8 concludes.

2. Literature Review

Most regulations are not self-enforcing, so compliance can only be achieved when regulated firms are monitored for compliance and penalized for non-compliance (see for example, Shimshack 2014). Monitoring and enforcement actions are typically rationed because they are costly and because regulatory agencies have limited resources. Thus, firms' compliance strategies are shaped by their beliefs about the likelihood of being detected in a state of non-compliance and about the sanctions they will incur upon

detection. Specifically, economic theory suggests firms will comply with an environmental regulation so long as the expected costs of non-compliance exceed the expected benefits. The expected benefits of non-compliance include avoiding the direct and indirect costs associated with compliance. Those direct costs of compliance may be comprised of internal and external costs associated with developing a compliance protocol, purchasing any equipment required by the protocol, keeping that equipment running and in good working order, etc. Indirect costs include higher expenses due to redesign of production processes, reductions in productivity, and lost output when the compliance protocol is implemented. The costs of non-compliance include fines, penalties, expenses associated with more intensive regulatory scrutiny, financial impacts arising from a tarnished public image, and negative spillovers onto other aspects of a firm's operations due to a poor relationship with various levels of government.

It is well established in the theoretical literature on firms' responses to regulatory enforcement that inspections and penalties are close substitutes, as the expected cost of non-compliance is simply the product of the probability of detection and the penalties incurred upon detection. When penalties are limited, compliance can be influenced by altering the frequency with which firms are inspected (Becker 1968, Polinsky and Shavell 2000). Firms may respond by undertaking avoidance activities that make detection more difficult (Malik 1990, Bebchuk and Kaplow 1993, Heyes 1994). When firms may invest in technologies that serve to reduce the probability a violation is detected during an inspection, regulators may need to respond by making inspections more thorough (Heyes 1994). Conversely, firms may choose to heighten compliance effort when inspections are subject to measurement error (McClelland and Horowitz 1999, Alberini et al. 2008,

Malik 2014). Regulators can also reduce enforcement costs by creating incentives for regulated firms to self-report rather than waiting to be inspected (Malik 1993, Kaplow and Shavell 1994). The desirability of incentives for self-reporting are especially great when firms engage in avoidance behaviors (Innes 1999a, 1999b, 2001).

The empirical literature provides evidence that, as expected, fines are effective in inducing compliance (Earnhart 2004; Glicksman & Earnhart 2007). There is also evidence that the threat of a penalty induces compliance; within the context of the US pulp and paper industry, for example, Shimshack and Ward (2005) find that while fines imposed on a single plant have minimal impact, the “regulator reputation” spillover effect from a regulator imposing a fine on plants within a regulatory jurisdiction has a positive, statistically significant, and economically meaningful effect on the likelihood of compliance by other plants within the same regulatory jurisdiction. As previously discussed, an increase in the magnitude of a fine increases the expected cost of non-compliance. Consistent with this finding, Stafford (2002) found that a federally mandated increase in the allowable financial penalties for noncompliance significantly reduced firms' violation probabilities, though the increase in compliance was small relative to the increase in the allowable penalties.

Adverse effects of non-compliance other than fines have also been shown to increase the likelihood of compliance. In some cases, the prospect of standing trial by itself has been found to be more of a deterrent than the probability of conviction or the magnitude of the fine (Almer and Goeschl 2010). Being sued for mismanagement of hazardous waste under the Resource Conservation and Recovery Act (RCRA) or the Comprehensive Environmental Response Compensation and Liability Act (Superfund)

has similarly been shown to result in de facto penalties in terms of loss of market value (Muoghalu et al. 1990).

While fines and sanctions seem to be effective at deterring violations, they are costly and are imposed relatively rarely (Esworthy 2014). As noted above, inspections have been shown to be close substitutes for financial and non-financial penalties. There is extensive evidence that the threat of inspection reduces the likelihood of a violation. This result has been observed in a variety of contexts, including water pollutant emissions from the pulp and paper industry (Magat & Viscusi 1990; Laplante & Rilstone 1996; Helland 1998) and municipal wastewater treatment plants (Earnhart 2004); air pollutant emissions (Telle 2009); compliance with food safety regulations in seafood processing plants (Alberini et al. 2008), hazardous substance regulations in Norwegian manufacturing plants (Telle 2013); and petroleum storage regulations at storage sites in Manitoba (Eckert 2004).

After detecting a violation, regulators may issue a warning rather than a fine. Warnings are used extensively in the enforcement of environmental regulations; most of the EPA's audits result in a notice of violation rather than an immediate penalty (Harrington 1988) and several states impose a penalty only when firms refuse to correct violations or prove to be uncooperative (Russell 1990). Theoretical arguments suggest that warnings can deter future violations through the threat of stronger enforcement. (Malik 2014). Empirical evidence provides confirmation. Using data on the enforcement of environmental regulations of petroleum storage in the province of Manitoba, Eckert (2004) finds that a warning at last inspection increases the probability of an inspection. This result suggests that firms who received a warning in the previous period are more

likely to be inspected in the current period, consistent with the idea that a firm may face a more stringent enforcement regime in the current period if it was found to be out of compliance in the previous period. Therefore, assuming that firms are not myopic, warnings may deter future violations through the associated threat of a more stringent enforcement regime.

Theoretical and empirical studies to date all treat the threat of inspection as common knowledge. There is often, however, uncertainty about the threat of inspection, i.e., the probability of being inspected is itself random rather than known with certainty. For example, a regulatory agency's priorities may change over time due to changes in the political party in power, budgetary changes, recent scandals, or other unforeseen events. Uncertainty about regulatory enforcement strategy can also arise from a regulator's inability to identify *all* of the relevant agents. This latter source of uncertainty arises from a regulatory error and is not uncommon. For example, the US EPA's Office of Inspector General found that the EPA's Office of Enforcement and Compliance Assurance (OECA) had limited knowledge of the size and composition of the regulated agents within the purview of such major regulations as the Clean Air Act (CAA), the Clean Water Act (CWA), the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the Toxic Substances Control Act (TSCA), the Safe Drinking Water Act (SDWA), and the Resource Conservation and Recovery Act (RCRA) (USEPA 2005). A comparison of current data with OECA's data showed that the number of entities that ought to have been regulated under these programs was 35% greater than the number in OECA's enforcement database. Smaller entities in particular were more likely to have been overlooked by OECA.

The effects of this latter kind of uncertainty about enforcement have not been investigated in the literature to date. In what follows, we examine theoretically a firm's compliance strategy in a setting where the enforcement agency has limited information on the number and identities of the regulated agents. We then test the predictions of that theoretical analysis using data on enforcement of Maryland's regulations governing nutrient management in agriculture.

3. Theoretical Framework

This section develops a theoretical model of the optimal response of the firm when it is uncertain about its regulatory status. We use a standard model with costly enforcement and limited liability. We present a model of a firm's compliance decision in a setting typical of environmental and health and safety regulations, where the compliance decision consists of two components: (1) developing an initial compliance protocol (e.g., installing pollution control equipment and/or establishing a set of safety procedures) and (2) implementing and adhering to that compliance protocol. Failure to install the proper equipment or establish adequate safety procedures initially results in a warning, with subsequent violations resulting in a penalty, P_f . Once a protocol has been developed, inspections are used to determine whether implementation of the compliance protocol is adequate. Firms that complied with the protocol development component of the regulation are inspected with probability q_i while firms that did not are inspected with probability q_n . Given a limited budget, a regulator may find it optimal to target inspections towards firms that have not complied with the requirement to develop a plan. This is because such firms may be more likely to not implement their plan after they have

developed it. Therefore, we assume $q_i > q_i$. Again, non-compliance initially results in a warning with subsequent violations resulting in a fine, P_c . Compliance is costly to the firm; firms incur a cost F in developing and a cost C in implementing the compliance protocol. Assume $0 < P_f < P_c$, $P_f > F$, and $P_c > C$.

In our model, regulatory uncertainty arises from the regulator's incomplete information on the identities of all of the relevant agents. This means there is a probability, k , that the firm is known to the regulator, and for some firms, this probability is strictly less than 1. The representative firm's decision tree is presented in Figure 1. At the first decision node, the firm faces three options: develop a protocol and implement it, develop a protocol and do not implement it, or do not develop a protocol and do not implement it. If a firm chooses to develop a protocol and implement it, then it will incur a cost of $F+C$. Suppose a firm chooses to devise a compliance protocol, but then not implement it. Such a firm will be inspected with probability q_i . If inspected, the firm will be warned and must then decide to comply or disregard. If it complies, it will incur a cost of $F+C$ and if it disregards, it will incur a cost of $F+P_c$. If an inspection does not occur, it will only incur F . If warned, it is easy to see that a firm will comply rather than disregard because $F+C < F+P_c$.

Next, consider a firm that initially does not develop a compliance protocol and, therefore, does not implement it. Then, with probability k , such a firm will receive a warning from the regulator to develop a compliance protocol. After the warning, the firm is faced with the same choices as in the first decision node. Again, if it develops a compliance protocol and implements that protocol, it will incur a cost of $F+C$. If it does not develop a compliance protocol and thereby does not implement one, it will have to

pay both penalties, $P_v + P_c$.² If the firm does not receive a warning for failing to develop a compliance protocol, then it will incur no costs. Suppose the firm develops a protocol, but does not implement it. Such a firm will be inspected with probability q_1 , and if inspected, will receive a warning. The firm must then decide to either comply with or disregard the warning. As before, it will comply with the warning because $F+C < F+P_c$.

It is clear from Figure 1 that it is never optimal for a firm to “develop and implement” at the first decision node because both “develop and do not implement” and “do not develop and do not implement” strictly dominate “develop and implement” ($F+q_1C < F+C$ and $k(F+q_1C) < F+C$, respectively). Whether or not “develop and do not implement” dominates “do not develop and do not implement” depends on the value of k . For sufficiently small uncertainty about regulatory status, the firm will behave as if it knows with certainty that it is being regulated (i.e. $k = 1$). More specifically, for values of k such that $\frac{F+q_1C}{F+q_2C} < k \leq 1$, the firm will choose to develop a protocol, but only implement it if inspected and warned. This is identical to the strategy a firm would choose when $k = 1$, i.e., when the firm knows with certainty that it falls under regulatory purview. For sufficiently large uncertainty about regulatory status, though, it will be optimal for the firm to delay the development of a compliance protocol until it is inspected and found to be non-compliant. In particular, for $k < \frac{F+q_1C}{F+q_2C} < 1$, the firm will choose to not develop a compliance protocol and then, if warned, develop one but not implement it until inspected and warned. Thus, the greater the uncertainty about regulatory status, the greater the likelihood a firm will fail to comply with the protocol development component of the regulation.

² We are ruling out the case where a farmer does not file but complies with a plan.

This analysis suggests that: (1) firms that are subject to regulation and face less uncertainty about their regulatory status are more likely to develop an initial protocol and (2) firms will tend to delay implementation until inspected and warned.

With respect to the first result, a decrease in uncertainty about regulatory status essentially reduces the expected cost of non-compliance. The firm's expected cost of noncompliance when it chooses to not develop a protocol is $k(F + q_2C)$. It is clear that an increase in the magnitude of uncertainty about regulatory status, i.e., a decrease in k , serves to reduce the expected cost of noncompliance. The greater the uncertainty about regulatory status, the lower the value of k and the greater the incentive for firms to delay the development of a compliance protocol until discovered. In the case where $k = 1$, i.e., when there is no uncertainty about regulatory status, firms do not have the incentive to delay the development of an initial protocol because, with certainty, they will face higher implementation inspection probabilities and therefore, higher expected costs. For the firm's compliance decision, the relevant inspection probability is the conditional probability of inspection given that the regulator is aware of the firm's existence. Since a regulator must be aware of a firm in order to inspect it, it must be the case that, if the probability of being known is strictly less than 1, then the firm's conditional probability of inspection given that it is known to the regulator is strictly greater than the unconditional probability of inspection. Additionally, this probability of inspection conditional on being known approaches the unconditional probability of inspection as the uncertainty decreases (i.e., as k approaches 1).

With respect to the second result, even if a firm knows the regulator is aware of its existence, it will have an incentive to delay compliance until warned. The firm knows

that, before the regulator determines whom to inspect, there is a possibility that it can choose to not comply and face no penalty. Additionally, if inspected, the firm knows it will initially only receive a warning. If receiving a warning is costless to the firm, then the firm has an incentive to delay compliance until inspected and warned. At that point, the firm knows for certain that a continuing violation will result in a penalty. Therefore, if the detection of a violation results in a warning that is costless to the firm, then the firm is better off waiting to come into compliance until inspected. Because this second result only depends on warnings being costless to the firm, it will hold for all values of k .

4. Institutional Background

We examine the consequences of uncertainty about regulatory status in the context of nutrient management regulations imposed under the Maryland Water Quality Improvement Act (WQIA) of 1998. The WQIA was passed to protect the Chesapeake Bay from agricultural nutrient loading that could contaminate both surface water and groundwater. About 40% of the nitrogen and 50% of the phosphorus polluting the Bay comes from agricultural runoff (Chesapeake Bay Foundation 2017). Nutrient runoff from agriculture may result in eutrophication, decreased biodiversity, and altered species composition/dominance (Chislock et al. 2013). The Chesapeake Bay is an important part of the economy of several states. In 2009 alone, the Bay region generated benefits valued at \$107.2 billion (Phillips and McGee 2016). The State of Maryland has a longstanding commitment to improving water quality in the Bay and its tributaries. The WQIA is intended to help the State achieve this goal by reducing nutrient runoff from farms

through improved management of fertilizers and manure, the sources of agricultural nutrient emissions.

Under the WQIA, agricultural operations that use commercial fertilizer and have a annual farm sales of \$2,500 or more *or* eight or more animal units are required to develop and implement a nitrogen- or phosphorus-based NMP.³ The goal of nutrient management planning is to balance soil nutrient inputs with crop nutrient uptake requirements in order to reduce nutrient runoff into water bodies. Components of nutrient management plans include chemical analysis of soil and manure, assessment of the nutrients contributed by leguminous crops, evaluation of past management practices, determination of fertilizer application and timing, and establishment of yield goals. Additionally, agricultural operators must submit Annual Implementation Reports (AIRs) every year that include information about the amounts of fertilizers applied to each crop as well as other relevant information about the farm operation. The MDA uses the AIR submitted to evaluate each operator's implementation of his or her plan. The environmental benefits gained from nutrient management planning are a function of the extent of compliance with NMPs, which in turn is determined by the incentives for compliance faced by firms.

The WQIA specifies measures MDA must take in enforcing nutrient management plan regulations. An operator that fails to *file* a NMP by the deadline is subject to a written warning for a first violation and an administrative penalty of no more than \$250 for any subsequent violations (WQIA §15.20.07.07A). An operator who fails to *implement* a plan by the implementation deadline is subject to a written warning for a

³ In terms of animal units, 1 beef cow=1 animal unit, 1 bird=0.008 animal units, 1 dairy cow=1.25 animal units, 1 pig=0.4 animal units, 1 sheep/goat/lamb=0.1 animal units, and 1 horse=2 animal units.

first violation. If an operator fails to comply with the plan implementation requirements after a reasonable period of time following the warning (90 days), an operator is subject to an administrative penalty for any subsequent violation of no more than \$100 per violation per day up to a yearly maximum of \$2,000 per operation per NMP. Daily penalties do not continue to accrue as long as the operator takes reasonable steps to correct the violation (WQIA §15.20.07.07D). In addition to the fines, farms may also incur indirect costs by not complying. The Maryland Agricultural Water Quality Cost-Share Program (MACS) provides farmers with grants that cover up to 87.5% of the installation costs of certain conservation practices. If an operator violates the law, the MDA may require repayment of MACS funds already disbursed to the operator and may deny or restrict future cost-share payments to the operator (WQIA §15.20.07.07F).

Given its limited budget, the MDA cannot inspect every farm to determine the adequacy of its implementation of a NMP. Therefore, it sends nutrient management specialists to perform a comprehensive on-site inspection of about 10 to 15% of farms every year (Maryland Department of Agriculture 2014). While MDA estimates that roughly 95% of farmers are in compliance with the nutrient management planning regulations, an independent estimate based on farmers' self-reports indicate a compliance rate of only 63% (Lichtenberg, Parker, & Lane 2010). A likely reason for the discrepancy is MDA's lack of full information about which farms are required to comply with the regulation. MDA's registry of farms consists of operations that have filed for agricultural use assessments for property tax purposes. Since having land that is assessed for agricultural use generates substantial tax savings, farmers have an incentive to obtain agricultural use assessments. But figures from the Census of Agriculture indicate that less

than half the operations classified by the US Department of Agriculture as farms apply for agricultural use assessments. In 2007, for instance, MDA had a total of 6,567 farms in its database of farm operations while the USDA Census of Agriculture had 12,834.

Farmers who have not applied for agricultural use assessments and know that MDA only inspects farms that have such assessments are still subject to uncertainty about their regulatory status. Environmental groups with an interest in improving water quality in the Chesapeake Bay have taken farmers to court for supposed violations of nutrient management regulations (Farenthold 2012). People living in residential areas near poultry farms or fields to which manure has been applied may also seek to use violations of nutrient management regulations as a reason for bringing nuisance suits that would be otherwise ruled out by Maryland's right to farm law (Goeringer 2013). Defending lawsuits of these kinds can be quite costly. Being in compliance with an approved nutrient management plan on public record can deter filings of such lawsuits and thus protect farms against incurring legal expenses, giving them an incentive to comply even if they believe that they are not included in MDA's registry of farms.

5. Data

We examine the implications of uncertainty about by nutrient management plan regulatory status using a combination of survey data about individual farm operations, county-level enforcement data from the MDA and data from the 2007 United States Census of Agriculture. In 2010, the University of Maryland conducted a survey of Maryland farmers' use of best management practices (BMPs), including NMPs. The survey was administered by the National Agricultural Statistical Service (NASS) of the

US Department of Agriculture. NASS employed a stratified sampling design in order to ensure a sufficient number of observations of the high-revenue farm operations that account for the majority of farming activity in Maryland. For computing population estimates, NASS provided a revenue-based expansion factor. The survey was sent to 1,000 farms in the NASS database, which is based on the Census of Agriculture. Of those receiving the survey, 523 responded.

The survey gathered data on the use of 13 different classes of best management practices (BMPs) and on the adoption of NMPs. If the operator used a given BMP, the survey asked whether or not cost-sharing was received for that BMP. If the operator adopted a NMP, details on the preparation of the plan were collected. NMP preparation details include: (1) if it is primarily phosphorus- or nitrogen-based, (2) the percentage of land it covers, and (3) the identity of the plan preparer. The survey also collected information on several aspects of the farmer's operation including questions on land ownership, farm income and finance, crop operations, and livestock operations. Information about land ownership included the number of acres the farm operator owned, rented from others, rented to others, and used for free. Information about farm income and finance includes annual sales (measured categorically) and the share of household income obtained from farming. Information about crops included acreage of land harvested for corn, soybeans, small grains, vegetables, hay, pasture, and other crops. Information about livestock included the total number of cattle/calves, milk cows, hogs/pigs, poultry, sheep/lamb/goats, and horses present on the operated acres.

We use the survey data to construct an indicator variable for being required to have a NMP under the WQIA. The “required” variable is equal to 1 if the farm has

cropland and has either eight or more animal units or annual sales of \$2,500 or more. The “required” variable is equal to 0 if the farm has no cropland or has cropland but earns less than \$2,500 and has fewer than eight animal units. Some respondents with fewer than eight animal units did not report annual sales; we are not able to determine whether those farms are required to have NMPs and therefore exclude them from the analysis. The resulting sample size is 486.

Enforcement data was provided by the MDA for years 2006 through 2010. Due to privacy concerns, the MDA was only able to provide county-level data on enforcement as opposed to farm-level. The enforcement data included the number of farms subject to the regulation in each county (by MDA’s count), the number of acres required to have a NMP, the number of inspections conducted, the number of warnings issued, and the number and amount of administrative fines levied. We use these data to construct county-level estimates of the probability that a farm is inspected, given that it is known to the MDA. We use enforcement data from 2008, the first year MDA issued fines rather than warnings, i.e., the first year that enforcement was truly in effect.

We use the 2007 Census of Agriculture to determine the total number of farms in a county. The Census of Agriculture provides the total number of farms and the total number of farms with cropland in each county. Since a farm must have cropland in order to use fertilizer, the number of farms with cropland is an upper bound on the number of farms within the purview of the WQIA as farms may have cropland and use fertilizer but earn less than \$2,500 and have fewer than eight animal units, and therefore, be outside of the purview of the WQIA. Table 1 presents descriptive statistics weighted to give population estimates. On average, there is a 70.4% chance that the MDA is aware of the

farm, which is, again, quite a substantial regulatory error. The probability that MDA inspects a farm included in its registry is about a 10%.

6. Specification and Estimation of the Econometric Model

This section develops an econometric model of a farmer's decision to file a NMP under the presence of uncertainty about her regulatory status. We assume that the net benefits of filing a NMP for farm i in county c , $File_{ic}^*$, is a function of the probability of being included in MDA's registry of farms, $\tilde{k}_{ic}$:

$$File_{ic}^* = \beta_0 + \beta_1 \tilde{k}_{ic} \times 1(Required_{ic}) + \mathbf{X}_i \boldsymbol{\beta}_2 + \varepsilon_{ic} \quad (1)$$

where $1(Required_{ic})$ is an indicator for whether farm i in county c is required to have a NMP under the WQIA, $\mathbf{X}_i$ is a vector of controls, and ε_{ic} is the error term. However, the latent net benefits of filing a NMP for farm i in county c are unobserved; we can only observe whether or not they have filed. Thus, the mapping is as follows:

$$File_{ic} = \begin{cases} 1, & File_{ic}^* \geq 0 \\ 0, & File_{ic}^* < 0 \end{cases} \quad (2)$$

where $File_{ic}$ is an indicator for whether or not a farm has filed a NMP. We assume that $\varepsilon_{ic} \sim N(0,1)$ and thus estimate the coefficients in equation (1) using probit.

Our theoretical model indicates that a farm with a high probability of being included in the MDA farm registry faces a higher expected cost of noncompliance, and hence, we expect the probability of being included in MDA's registry of farms to have a

positive effect on the probability of filing a NMP. We proxy for the probability of being included in MDA's registry of farms by dividing the number of farms in county c in MDA's database by the number of farms in county c with cropland in the census. Additionally, farms that have received cost share funds for adoption of conservation practices are assumed to be included in MDA's registry since the overwhelming majority of such spending comes from MDA's Maryland Agricultural Cost Share Program. We therefore adjust the probability of being included in the MDA farm registry to 1 for farms that report having received cost sharing. We use alternate calculations of the probability of being known in our robustness checks, discussed below.

The vector of covariates $\mathbf{X}_i$ includes the total operated acres and indicator variables for various farm operation characteristics including: (1) grain crops (corn, soybean, small grains), (2) hay or pasture, (3) cattle and calves, (4) sheep, lamb, and goats, (5) horses, and (6) annual sales, which are reported categorically. The coefficient of total operated acres captures the economies of scale associated in the adoption of NMPs (McCann 2009). It may also reflect a farmer's perception of being regulated since larger farms interact more with MDA and are also more prominent in the public eye. Accordingly, we expect the coefficient of total operated acres to be positive. Similar considerations suggest that farms with greater annual sales are more likely to believe that NMP regulations apply to them.

There may be benefits to adopting a NMP that are unrelated to the benefits derived from complying with the WQIA. Nutrient management planning is often thought to be win-win, since (in principle at least) it allows farmers to economize on fertilizer purchases while meeting yield goals and reducing runoff simultaneously through such

measures as crediting manure nutrients and adjusting fertilizer recommendations for soil fertility status. Farms growing grain crops (corn, soybeans, and/or small grains) and farms raising livestock are most likely to find nutrient management planning profitable and were more likely to have NMPs prior to 1998 (Lawley, Lichtenberg, & Parker 2009). Since one would expect that the determinants of adoption when NMPs were voluntary would also be determinants of adoption when NMPs are mandatory, we include crop and livestock indicators as well as total operated acres in our regressions. We expect the coefficients on all of these variables to be positive.

7. Results and Discussion

Table 2 reports the marginal effect of the probability of being known to MDA estimated under a variety of specifications. That marginal effect is positive and significantly different from zero in all specifications. Our preferred specification includes the full set of covariates and is reported in the fifth column of Table 2.

7.A. Main Results

Consistent with our theoretical analysis, the marginal effect of the probability of being included in MDA's farm registry is positive and significantly different from zero for farm operations required to have a NMP. It is also economically meaningful: in our preferred specification, a one percentage point increase in the probability of being included in MDA's farm registry is associated on average with about a quarter of a percentage point increase in the likelihood of filing a NMP. Since the average probability of having a NMP is 70%, this estimate implies that a one percent change in the perceived

probability of being regulated is associated with a 17.5% increase in the likelihood of having an NMP.

One would expect that commercial scale farms are more likely to file for agricultural use property tax assessments, making them more likely to believe they are included in MDA's enforcement database and thus more likely to file a NMP. One would similarly expect that farm operations that are smaller than commercial scale are less likely to file for agricultural property use tax assessments, suggesting that they are less likely to believe they are subject to nutrient management regulation under the WQIA. Our farm-size specific estimates of the probability of having a NMP and of the marginal effect of being included in the MDA registry, reported in Table 3, are consistent with these predictions. The probability of being in compliance with nutrient management regulations (by having a NMP) is increasing in farm size (as measured by revenue category). Compliance rates for very small operations with less than \$5,000 in farm sales annually are only on the order of 40-50%. Compliance rates are increasing in farm size and non-compliance is virtually non-existent among commercial scale farms: 98-99% of farms with annual sales of \$40,000 or more report having a NMP.

Our theoretical analysis similarly predicts that the marginal effect of regulatory uncertainty decreases as the level of uncertainty falls. In terms of compliance with nutrient management regulations under the WQIA, that prediction corresponds to a prediction that the marginal effect of being included in the MDA farm registry decreases with farm size, as large farms are far more likely to have filed for agricultural use assessments, to have ongoing relationships with MDA, and to be more prominent in the public eye. Consistent with this prediction, the marginal effect of being included in the

MDA registry is decreasing in farm size. Moreover, for commercial scale farms the marginal effect of a 1 percent increase in the probability of being included in the MDA registry is extremely small (less than a tenth of a percentage point) and not significantly different from zero. Recall that our theoretical analysis indicates that developing a compliance protocol (but not implementing it) is the optimal strategy for a firm whose probability of being known to the regulator is close to 1. In our case, that strategy corresponds to filing a NMP. Our empirical finding is thus consistent with that theoretical prediction.

Maryland has three types of major commercial farm operations: Crop farms producing grain crops (corn, soybeans, wheat) primarily for sale to poultry producers; poultry farms, many of which also grow grain; and dairy farms, many of which also grow corn for grain and silage as feed for their animals. One would thus expect MDA enforcement efforts to concentrate on these types of farms. Grain producers use both chemical fertilizers and manure. Poultry and dairy operations produce manure; those with crop operations typically apply that manure to their fields. Consistent with the expectation that these kinds of operations are more likely to be targets of MDA enforcement efforts, we find that estimated compliance is quite high for all three kinds: between 80 and 90 percent of these types of farms have NMPs (Table 3).

Lastly, our theoretical model indicates that warnings provide firms with an incentive to delay the implementation of a compliance protocol, which in our case is the implementation of a NMP, until inspected and warned. Recall that under the WQIA, if a farm fails to implement a NMP by the implementation deadline, then the farm is initially issued a warning with subsequent violations resulting in a fine. We do not have farm-

level information about receipt of warnings. But MDA's county-level data suggest that warnings are effective: Warnings were issued in about 38% of inspections conducted in 1998 but only 2% of subsequent inspections result in fines.

7.2 Robustness Checks

In order to assess the robustness of our preferred calculation of the probability of being known, we employ two alternative calculations of the probability of being included in the MDA farm registry. The first one is similar to the definition in our preferred specification but does not make the cost-share adjustment; it simply is the number of farms in county c in MDA's database divided by the number of farms in county c with cropland in the census. The second calculation divides the number of farms in county c in MDA's database by the number of farms in county c earning \$2,500 or more as reported by the 2007 Census of Agriculture, since nutrient management regulations under the WQIA exempt all farms with less than \$2,500 in annual sales.

Table 4 presents the marginal effects averaged across all observations under these alternative definitions of the probability of being included in the MDA farm registry. The estimated marginal effects of being included in the MDA farm registry are quite similar to the estimates in Table 2.

8. Conclusion

A common assumption in the literature on regulatory compliance is that firms are aware of their regulatory status. This assumption does not always hold; in fact, regulatory agencies frequently lack information about the identities of firms to which regulations

apply, and therefore, firms may face uncertainty with respect to their regulatory status. This uncertainty is likely to alter firms' compliance strategies.

We examine theoretically how the optimal compliance strategy of a firm compares to the standard case where firms face no uncertainty with respect to their regulatory status. We examine the firm's compliance decision in a setting common to environmental regulations where compliance has two components: the development of an initial compliance structure and the implementation of that compliance structure. In the standard case where firms operate under the assumption of perfect information, their optimal strategy is to develop an initial compliance protocol but then delay the implementation of that compliance protocol until inspected and warned. However, when the perfect information assumption is relaxed, we show that, for sufficiently low values of the probability of being known to the regulator, it is optimal for firms to delay the development of an initial compliance protocol until warned in addition to delaying the implementation of that compliance protocol until inspected and warned.

We then conduct an empirical analysis of the effect of the uncertainty in regulatory status within the context of the Maryland Water Quality Improvement Act, which requires most farms to file and implement a nutrient management plan. The database used by the Maryland Department of Agriculture in enforcing the NMP requirement consists only of farms that have filed for agricultural use assessments for property tax purposes; that set of farms comprises only about half the farms in the state. We estimate a probit model of the farmer's decision to file a NMP using farm-level data from a 2010 survey of Maryland farms, county-level enforcement data from the MDA, and county-level data from the 2007 Census of Agriculture. Our estimates indicate that

the probability of being included in the MDA list of farms subject to regulation has a positive and statistically significant effect on the farm's decision of whether to file a nutrient management plan. The probability of being in compliance with the regulation increases with farm size while the marginal effect of being included in the MDA farm registry declines with respect to farm size; both results are consistent with the predictions of the theoretical analysis.

More broadly, our results suggest that firms' uncertainty about their regulatory status (due, for example, to regulators' incomplete information about the size and composition of a regulated industry) can have a significant effect on firms' regulatory compliance strategies and thus on the extent to which regulations achieve their aims. Examining the extent to which such a lack of information affects compliance with other regulations (e.g., major national level environmental regulations in the US, which, as noted earlier, suffer from the same problems as the Maryland WQIA) would thus seem to be a topic worthy of further research, as would the extent to which that lack of information affects achievement of regulatory goals.

References

- Maryland Department of Agriculture (MDA). (2014). *AgBrief nutrient management programs*. Retrieved from http://mda.maryland.gov/Documents/ag_brief/AgBrief_NM.pdf
- Alberini, A., Lichtenberg, E., Mancini, D., & Galinato, G. I. (2008). Was it something I ate? Implementation of the FDA seafood HACCP program. *American Journal of Agricultural Economics*, 90(1), 28-41.
- Almer, C., & Goeschl, T. (2010). Environmental crime and punishment: empirical evidence from the German penal code. *Land Economics*, 86(4), 707-726.
- Bebchuk, L. A., & Kaplow, L. (1993). Optimal sanctions and differences in individuals' likelihood of avoiding detection. *International Review of Law and Economics*, 13(2), 217-224
- Becker, G.S. (1968). "Crime and Punishment: An Economic Approach," *Journal of Political Economy* 76(2), 169-217.
- Chesapeake Bay Foundations (CBF). (2017). The history of Chesapeake Bay cleanup efforts. Retrieved from <http://www.cbf.org/how-we-save-the-bay/chesapeake-clean-water-blueprint/the-history-of-bay-cleanup-efforts.html>
- Chislock, M. F., Doster, E., Zitomer, R. A. & Wilson, A. E. (2013). Eutrophication: Causes, Consequences, and Controls in Aquatic Ecosystems. *Nature Education Knowledge*, 4(4), 10.
- Cohen, M. (1999). Monitoring and enforcement of environmental policy. *International Yearbook of Environmental and Resource Economics*, 3, 44-106.
- Earnhart, D. (2004). Regulatory factors shaping environmental performance at publicly-owned treatment plants. *Journal of Environmental Economics and Management*, 48(1), 655-681.
- Eckert, H. (2004). Inspections, warnings, and compliance: the case of petroleum storage regulation. *Journal of Environmental Economics and Management*, 47(2), 232-259.
- Esworthy, R. (2014). *Federal pollution control laws: how are they enforced?* Retrieved from Congressional Research Service website: <https://fas.org/sgp/crs/misc/RL34384.pdf>
- Farenthold, D.A. (2010). Perdue, poultry farms sued for polluting Chesapeake Bay. *Washington Post*, March 2.

- Glicksman, R. L., & Earnhart, D. H. (2007). The comparative effectiveness of government interventions on environmental performance in the chemical industry. *Stanford Environmental Law Journal*, 26, 317.
- Gray, W. B., & Shimshack, J. P. (2011). The effectiveness of environmental monitoring and enforcement: A review of the empirical evidence. *Review of Environmental Economics and Policy*, 5(1), 3-24.
- Goeringer, P. (2013). Understanding agricultural liability: Maryland's right to farm law. Center for Agricultural and Natural Resource Policy Fact Sheet, University of Maryland, College Park.
- Harrington, W. (1988). Enforcement leverage when penalties are restricted. *Journal of Public Economics*, 37(1), 29-53.
- Helland, E. (1998). The enforcement of pollution control laws: Inspections, violations, and self-reporting. *Review of Economics and Statistics*, 80(1), 141-153.
- Heyes, A. G. (1994). Environmental enforcement when 'inspectability' is endogenous: A model with overshooting properties. *Environmental and Resource Economics*, 4(5), 479-494.
- Innes, R. (1999a). Remediation and self-reporting in optimal law enforcement. *Journal of Public Economics* 72(3), 379-393.
- Innes, R. (1999b). Self-policing and optimal law enforcement when violator remediation is valuable. *Journal of Political Economy* 107(6), 1305-1325.
- Innes, R. (2001). Violator avoidance and self reporting in optimal law enforcement. *Journal of Law and Economic Organization* 17(1), 239-256.
- Kaplow, L., & Shavell, S. (1994). Optimal law enforcement with self-reporting of behavior. *Journal of Political Economy*, 102(3), 583-606.
- Laplante, B., & Rilstone, P. (1996). Environmental inspections and emissions of the pulp and paper industry in Quebec. *Journal of Environmental Economics and Management*, 31(1), 19-36.
- Lawley, C., Lichtenberg, E., & Parker, D. (2009). Biases in nutrient management planning. *Land Economics*, 85(1), 186-200.
- Lichtenberg, E., Parker, D., Lane, S. (2010). Best Management Practice Use and Nutrient Management in Maryland: A 2010 Snapshot. Center for Agricultural and Natural Resource Policy, University of Maryland, College Park.
- Magat, W., & Viscusi, W. (1990). Effectiveness of the EPA's regulatory enforcement: the case of industrial effluent standards. *The Journal of Law & Economics*, 33(2), 331-360.

- Maryland Water Quality Improvement Act of 1998, 15 MD §8-801–8-806 (1998).
- Malik, A. S. (1990). Avoidance, screening and optimum enforcement. *The RAND Journal of Economics*, 341-353.
- Malik, A. S. (1993). Self-reporting and the design of policies for regulating stochastic pollution. *Journal of Environmental Economics and Management*, 24(3), 241-257.
- Malik, A. (2014). The desirability of forgiveness in regulatory enforcement. *Journal of Regulatory Economics* 46(1), 1-22.
- McCann, L. M. (2009). Transaction costs of environmental policies and returns to scale: the case of comprehensive nutrient management plans. *Review of Agricultural Economics*, 31(3), 561-573.
- McClelland, J.D. and J.K. Horowitz, J.K. (1999). The costs of water pollution regulation in the pulp and paper industry. *Land Economics* 75, 220-232.
- Muoghalu, M. I., Robison, H. D., & Glascock, J. L. (1990). Hazardous waste lawsuits, stockholder returns, and deterrence. *Southern Economic Journal*, 357-370.
- Phillips, S., & McGee, B. (2016). Ecosystem Service Benefits of a Cleaner Chesapeake Bay. *Coastal Management*, 44(3), 241-258.
- Polinsky, A. M., & Shavell, S. (2000). The economic theory of public enforcement of law. *Journal of Economic Literature*, 38(1), 45-76.
- Polinsky, A. M., & Shavell, S. (2007). The theory of public enforcement of law. *Handbook of Law and Economics*, 1, 403-454.
- Russell, C.S. (1990). Monitoring and enforcement, in: P.R. Portney eds., *Public Policies for Environmental Protection*. Resources for the Future, Washington, D.C.
- Rousseau, S. (2009). The use of warnings in the presence of errors. *International Review of Law and Economics*, 29(3), 191-201.
- Shimshack, J. P., & Ward, M. B. (2005). Regulator reputation, enforcement, and environmental compliance. *Journal of Environmental Economics and Management*, 50(3), 519-540.
- Shimshack, J. P. (2014). The economics of environmental monitoring and enforcement. *Annual Review of Resource Economics*, 6(1), 339-360.
- Stafford, S. L. (2002). The effect of punishment on firm compliance with hazardous waste regulations. *Journal of Environmental Economics and Management*, 44(2), 290-308.

- Telle, K. (2009). The threat of regulatory environmental inspection: impact on plant performance. *Journal of Regulatory Economics* 35(2), 154-178.
- Telle, K. (2013). Monitoring and enforcement of environmental regulations: Lessons from a natural field experiment in Norway. *Journal of Public Economics*, 99, 24-34.
- US EPA. Office of the Inspector General. (2005). *Limited knowledge of the universe of regulated entities impedes EPA's ability to demonstrate changes in regulatory compliance*. Washington, D.C.: United States Environmental Protection Agency, Office of Inspector General.

Table 1. Descriptive Statistics

Variable	Mean	Standard Deviation
Indicator for NMP	0.579	0.0275
Total Operated Acres	255.4	19.39
Number of Animal Units	128.6	27.38
Required under WQIA	0.698	0.0272
1(Corn, Soybean, or Small Grains)	0.433	0.0252
1(Hay or Pasture)	0.616	0.0259
1(Cattle and calves)	0.340	0.0236
1(Sheep, lamb, goats)	0.112	0.0173
1(Horses)	0.246	0.0241
1(Revenue Class 1: \$1,000 - 2,499)	0.222	0.0253
1(Revenue Class 2: \$2,500 - 4,999)	0.0892	0.0160
1(Revenue Class 3: \$5,000 - 9,999)	0.0984	0.0160
1(Revenue Class 4: \$10,000 - 19,999)	0.0904	0.0141
1(Revenue Class 5: \$20,000 - 39,000)	0.0670	0.0124
1(Revenue Class 6: \$40,000 - 99,999)	0.0580	0.0101
1(Revenue Classes 7 & 8: \$100,000 - 499,999)	0.153	0.0147
1(Revenue Classes 9 & 10: \$500,000 or more)	0.0529	0.00767
Pr(Included in MDA's farm registry)	0.704	0.250
Pr(Inspection k=1)	0.0956	0.0450
Number of Observations	486	

Table 2. Marginal Effects from a Probit Model of the Decision to File a NMP

Dependent Variable: 1(File a NMP)	(1)	(2)	(3)	(4)	(5)
Adjusted Pr(Known) x Required	0.578*** (0.0263)	0.474*** (0.0519)	0.351*** (0.0467)	0.348*** (0.0474)	0.249*** (0.0524)
Observations	486	486	486	486	486
Crop Indicators	No	No	Yes	Yes	Yes
Livestock Indicators	No	No	No	Yes	Yes
Revenue Indicators	No	No	No	No	Yes

Standard errors in parentheses
 *** p<0.01, ** p<0.05, * p<0.1

Table 3. Average Marginal Effect and Predicted Probability by Revenue Category and Type of Operation

Dep. Var.: 1(File a NMP)	Average Marginal Effect	Average Predicted Probability	N
<i>Panel A: By Revenue Category</i>			
\$1,000 - 2,499	0.413*** (0.092)	0.296 (0.025)	62
\$2,500 - 4,999	0.501*** (0.112)	0.561 (0.031)	32
\$5,000 - 9,999	0.456*** (0.102)	0.623 (0.034)	37
\$10,000 - 19,999	0.387*** (0.102)	0.742 (0.029)	41
\$20,000 - 39,000	0.308*** (0.092)	0.816 (0.030)	32
\$40,000 - 99,999	0.075 (0.062)	0.971 (0.010)	36
\$100,000 - 499,999	0.031 (0.026)	0.99 (0.002)	125
\$500,000 or more	0.059 (0.047)	0.978 (0.007)	59
<i>Panel B: By Type of Operation</i>			
Grain Crop	0.194*** (0.049)	0.878 (0.013)	294
Cattle	0.274*** (0.067)	0.778 (0.022)	202
Poultry	0.165*** (0.051)	0.82 (0.068)	21

Standard errors in parentheses.
 *** p<0.01, ** p<0.05, * p<0.1

Table 4. Marginal Effects using Alternative Definitions of the Probability of Being Known

Dependent Variable: 1(File a NMP)	(1)	(2)	(3)	(4)	(5)
<i>Panel A: Pr(Known) defined as the number of farms in county c divided by the number of farms in county c with cropland:</i>					
Pr(Known) x Required	0.780*** (0.0422)	0.593*** (0.0790)	0.412*** (0.0681)	0.412*** (0.0683)	0.263*** (0.0746)
<i>Panel B: Pr(Known) defined as the number of farms in county c divided by the number of farms in county c earning \$2,500:</i>					
Pr(Known) x Required	0.608*** (0.0310)	0.469*** (0.0582)	0.340*** (0.0489)	0.340*** (0.0489)	0.240*** (0.0551)
Observations	486	486	486	486	486
Total Operated Acres	No	Yes	Yes	Yes	Yes
Crop Indicators	No	No	Yes	Yes	Yes
Livestock Indicators	No	No	No	Yes	Yes
Revenue Indicators	No	No	No	No	Yes

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1