Market Mechanisms and Incentives: Applications to Environmental Policy

A Workshop sponsored by U.S. Environmental Protection Agency's National Center for Environmental Economics (NCEE) and National Center for Environmental Research (NCER)

Resources for the Future
1616 P Street, NW, Washington, DC 20036
(202) 328-5000

Wednesday, April 29, 2009

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8:30 a.m. – 9:15 a.m. **Registration**

9:15 a.m. – 9:30 a.m. **Introductory Remarks:** *Julie Hewitt, Chief, Economic and Environmental Assessment Branch, Office of Water*

9:30 a.m. – 11:20 a.m. **Session I: Fuel Economy and Gasoline Prices**
Session Moderator: *Cynthia Morgan, EPA, National Center for Environmental Economics*

9:30 a.m. – 10:00 a.m. Imperfect Competition, Consumer Behavior, and the Provision of Fuel Efficiency in Vehicles
Carolyn Fischer, Resources for the Future

10:00 a.m. – 10:30 a.m. New Vehicle Characteristics and the Cost of the Corporate Average Fuel Economy Standard
Thomas Klier, Federal Reserve Bank of Chicago, and Joshua Linn, University of Illinois at Chicago

10:30 a.m. – 10:40 a.m. Discussant: *Gloria Helfand, University of Michigan, and EPA, Office of Transportation and Air Quality*

10:40 a.m. – 10:50 a.m. Discussant: *Winston Harrington, Resources for the Future*

10:50 a.m. – 11:20 a.m. Questions and Discussion

11:20 a.m. – 12:30 p.m. **Lunch** (On Your Own)

12:30 p.m. – 1:30 p.m. Panel Discussion: Role of Market Mechanisms and Incentives to Climate Change
Moderator: *Dick Morgenstern, Resources for the Future*
Panelist: *Joe Aldy, Special Assistant to the President for Energy and the Environment*
David McIntosh, Senior Counsel in the Office of Congressional and Intergovernmental Relations
Brian Murray, Duke University

1:30 p.m. – 1:40 p.m. **Break**

1:40 p.m. – 3:30 p.m. **Session II: Applications of Environmental Trading Programs**
Session Moderator: *Will Wheeler, EPA, National Center for Environmental Economics*

1:40 p.m. – 2:00 p.m. An Experimental Analysis of Compliance in Dynamic Emissions Markets: Theory and Experimental Design
John Stranlund, University of Massachusetts - Amherst, James Murphy, University of Alaska – Anchorage, and John Spraggon, University of Massachusetts - Amherst

	2:00 p.m. – 2:30 p.m.	Can Markets for Development Rights Improve Land Use and Environmental Outcomes? *Virginia McConnell, Elena Safirova, Margaret Walls, and Nick Magliocca, Resources for the Future*
	2:30 p.m. – 2:35 p.m.	Discussant: *Heather Klemick, EPA, National Center for Environmental Economics*
	2:35 p.m. – 3:05 p.m.	Preliminary Findings and Observations on Ohio's Great Miami River Water Quality Credit Trading Program *Richard Woodward, Texas A&M University*
	3:05 p.m. – 3:10 p.m.	Discussant: *Hale Thurston, EPA, National Risk Management Research Laboratory*
	3:10 p.m. – 3:30 p.m.	Questions and Discussion
3:30 p.m. – 3:40 p.m.	**Break**	
3:40 p.m. – 5:30 p.m.	**Session III: Winners and Losers in Cap and Trade** Session Moderator: *Charles Griffiths, EPA, National Center for Environmental Economics*	
	3:40 p.m. – 4:10 p.m.	Paving the Way for Climate Policy: Compensation for Electricity Consumers and Producers Under a CO_2 Cap and Trade Policy *Karen Palmer, Dallas Burtraw, and Anthony Paul, Resources for the Future*
	4:10 p.m. – 4:40 p.m.	When Does Cap-and-Trade Increase Regulated Firms' Profits? *Dave Evans, EPA, National Center for Environmental Economics; Ian Lange, University of Stirling; and Joshua Linn, University of Illinois at Chicago*
	4:40 p.m. – 4:50 p.m.	Discussant: *Ann Wolverton, EPA, National Center for Environmental Economics*
	4:50 p.m. – 5:00 p.m.	Discussant: *Terry Dinan, Congressional Budget Office*
	5:00 p.m. – 5:30 p.m.	Questions and Discussion
5:30 p.m.	**Adjournment**	

May, 2009

An Experimental Analysis of Compliance in Dynamic Emissions Markets: Some Preliminary Results

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Abstract: Whether pollution sources should be allowed to bank transferable emissions permits and what restrictions should be placed on this activity are fundamental design choices for market-based pollution control. Recent theoretical work examines compliance incentives and enforcement strategies for trading programs with banking provisions. This paper reports preliminary results from economic experiments to test hypotheses from this theoretical work. The experiments are designed to address questions about how to construct enforcement strategies to motivate truthful emission reporting and permit compliance in a dynamic trading environment. We also investigate the consequences of inadequate enforcement on compliance and banking behavior.

Keywords: Compliance, Enforcement, Emissions trading, Laboratory experiments, Permit markets, Permit banking

JEL Codes: C91, L51, Q58

Acknowledgements: The research is funded by the U.S. EPA – Science to Achieve Results (STAR) Program. Daniel Peterson and Ben Laine provided outstanding research assistance, Glenn Caffery and Emily Caffery programmed the software for this project, and Karen Pelto provided valuable administrative support.

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An Experimental Analysis of Compliance in Dynamic Emissions Markets: Some Preliminary Results

1. Introduction

Whether pollution sources should be allowed to bank transferable emissions permits, and what restrictions should be placed on this activity are fundamental design choices for emission trading policies. We report on the initial stages of efforts to design and conduct economic experiments to test hypotheses related to enforcement and compliance in emission trading programs with banking provisions. Several existing trading programs allow some form of permit banking.[1] Perhaps the most well known is the SO_2 Allowance Trading program, which allows unrestricted banking of permits, but not borrowing. Pollution sources have made good use of this feature. For example, for the 2006 compliance year banked allowances accounted for nearly 40% of available allowances. In addition, there have been only a few incidences of noncompliance since the inception of the program. By the measure of maintaining compliance, the enforcement apparatus of the SO_2 program has been very successful (US EPA 2007).

Policy analysts usually point to two features of the SO_2 program to explain its success in maintaining near-perfect compliance. First, if a source fails to hold sufficient allowances to cover its emissions in a compliance period it is automatically assessed a financial penalty at a rate which has usually been many times higher than going allowance prices.[2] Second, all facilities in the program are required to install a continuous emissions monitoring system or an approved alternative. These systems are fully automated, thereby minimizing the opportunities for submitting false emissions data. Two additional program features have received less attention, but are likely to be at least partially responsible for the high rate of compliance. Misreporting of emissions is a separate violation under the SO_2 program that is distinct from the failure to hold sufficient permits. The Clean Air Act authorizes the use of criminal sanctions for false or misleading reporting. Each source must identify a single individual who bears the responsibility of submitting truthful reports, and who faces criminal liability for misreporting (Tietenberg

[1] Including the EPA's SO_2 Allowance Trading program, its NO_x Budget Trading program, and the EU's Emissions Trading Scheme. Many proposals for carbon trading schemes include banking provisions (e.g., Stavins 2008).
[2] The penalty for excess emissions was set at $2,000 per ton in 1990, and is adjusted for inflation every year. In the 2005 compliance year the penalty was $3,152 (US EPA 2007). The penalty has always been many times higher than going allowance prices, except for a brief period near the end of 2005 when the allowance price spiked to about $1,600 (US EPA 2006).

2006). Finally, in addition to facing a high financial penalty, a firm's excess emissions in one period are offset by a one-to-one deduction from its allocation of permits in the next period.

Recent theoretical work by Stranlund *et al.* (2005) provides results about the relative contributions of these enforcement characteristics to maintaining compliance in trading programs with banking.[3] This work is motivated by emission trading programs that include permit banking provisions when regulators cannot rely on the perfect (or near-perfect) emissions monitoring provided by continuous emissions monitoring systems. Stranlund *et al.* highlight the importance of detecting and punishing under-reported emissions in these trading programs. Self-reporting of emissions is a necessary enforcement component when permits can be banked and monitoring is imperfect. If a firm is not monitored in a particular period its emissions report is the only piece of information available to a regulator to determine how many permits the firm is using for current compliance purposes and how many are carried into the future. Moreover, misreporting and the failure to hold sufficient permits must be distinct violations. This is so because a firm that holds enough permits to cover its emissions in a period may be motivated to under-report its emissions to increase the size of its permit bank.[4]

In addition, Stranlund *et al.* suggest that a high unit penalty for permit violations is not warranted. When permit borrowing is not allowed, a permit violation penalty has only limited deterrence value; in particular, increasing this penalty does not reduce the amount of monitoring necessary to maintain compliance. In contrast, a penalty for under-reported emissions allows regulators to maintain compliance with imperfect monitoring, and setting this penalty as high as is practicable conserves monitoring costs. This suggests that it is possible to maintain compliance in a dynamic emissions trading program with imperfect monitoring and low permit violation penalties, but doing so requires focusing on punishing reporting violations rather than on punishing permit violations.

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[3] The theoretical literature on compliance and enforcement in emissions trading is extensive (including contributions by Keeler 1991, Malik 1990, 1992, and 2002, vanEgteren and Weber 1996, Stranlund and Dhanda 1999, Stranlund and Chavez 2000, Chavez and Stranlund 2003, Stranlund 2007). However, only Innes (2003) and Stranlund *et al.* (2005) allow for noncompliance in models with bankable permits. Innes argues that giving sources the ability to bank and borrow permits eliminates the need to impose costly sanctions to maintain compliance in these programs. He does not, however, examine the design of monitoring and punishment strategies that is the focus of Stranlund *et al.*

[4] Requiring self-reporting and making misreporting a distinct violation is different from most of the literature on self-reporting in law enforcement. Malik (1993), Kaplow and Shavell (1994), Livernois and McKenna (1999), and Innes (1999, 2000, and 2001) all assume that self-reporting is a voluntary activity that can be encouraged by offering a lower penalty for self-reported violations. In fact, self-reporting is not necessary to achieve compliance in most of the models in this literature.

While there is a substantial body of economic theory about compliance and enforcement in emissions trading programs, and readily available information about how existing emissions trading programs are enforced, to our knowledge there are no empirical analyses of the determinants of compliance decisions in emissions trading programs with real world data. To fill this empirical gap, some authors have turned to data generated by economic experiments. Cason and Gangadharan (2006) conducted emissions trading experiments with stochastic emissions, bankable permits, and noncompliant subjects. They identified interesting interactions among random emissions shocks, permit banking, and compliance, but they did not attempt to draw conclusions about the appropriate design of enforcement strategies. Murphy and Stranlund (2006 and 2007) examined compliance behavior under several combinations of monitoring and penalties, but their design was based on a static model of emissions trading that did not allow for permit banking.[5]

In this paper we report preliminary results from experiments designed to address questions about how to construct enforcement strategies for emission trading programs that feature imperfect emissions monitoring and bankable emissions permits. In particularly we test the hypothesis that it is possible to motivate truthful emissions reporting and permit compliance with imperfect monitoring and permit violation penalties that are lower than predicted permit prices. Our preliminary results suggest qualified support for this hypothesis. Moreover, it appears that the main consequence of weak enforcement is to increase aggregate emissions through reporting violations rather than permit violations.

2. A Sketch of the Theory of Compliance in Dynamic Emissions Trading Programs

In this section we provide a brief sketch of the theory of compliance in a dynamic emission trading program developed by Stranlund et al. (2005). While they allowed for the possibility that firms could borrow against future permit allocations, we do not allow borrowing in our initial experimental design. Therefore, in this section we focus on compliance incentives in programs that allow permit banking but not borrowing.

Consider a risk-neutral firm in a dynamic emissions trading program that lasts T periods. Let x_t be the number of emissions permits the firm holds at the beginning of period t. Each

[5] Muller and Mestelman (1998) review a number of emission trading experiments that include banking provisions. None of them deal with the problem of noncompliance.

permit allows the release of one unit of emissions. During t the firm chooses how many permits l_t to purchase ($l_t > 0$) or sell ($l_t < 0$). Permits trade in period t at a competitive price p_t. A system is in place to track emissions permits so that at any point in time the regulator has perfect information about the number of permits held by each firm. During period t the firm also chooses its emissions e_t. The firm has an abatement cost function, $c(e_t)$, which is strictly decreasing and convex and does not vary over the life of the program.

The firm's emissions are unknown to the regulator unless it conducts an audit of the firm. Because a trading program with bankable permits but imperfect emissions monitoring must include a self-reporting provision, the firm is required to submit a report, r_t, of its emissions in t. The firm can commit two types of violations. A *reporting violation* occurs in period t if the firm under-reports it emissions; that is, $e_t > r_t$. A *permit violation* occurs when the firm does not hold enough permits to cover its emissions; that is, $e_t > (x_t + l_t)$. Because borrowing against future permit allocations is not allowed, a permit violation can occur in any period.

The firm's emissions report is also its report of its compliance status and whether it is banking permits. If $r_t > (x_t + l_t)$, then the firm is reporting a permit violation. If $r_t \leq (x_t + l_t)$, then the firm is reporting that it is permit compliant and banking permits if $r_t < (x_t + l_t)$. Of course, we must distinguish reported permit violations, permit compliance, and permit banking from their actual values. If actual emissions exceed permit holdings, $e_t > (x_t + l_t)$, then there is an actual permit violation. If $e_t < (x_t + l_t)$ the firm has excess permits to bank, and if $e_t \leq (x_t + l_t)$, then the firm is permit compliant.

Monitoring for compliance by authorities is potentially imperfect in the sense that the probability that the authority is able to make a determination of a firm's compliance status is $\pi_t \in [0,1]$. Permit violations in period t (whether they are revealed in a firm's emissions report or discovered by the authorities) are penalized at ϕ_t per unit. This penalty corresponds to the permit violation penalty in the SO_2 program. Reporting violations that are discovered through an audit are penalized at γ_t per unit. Both ϕ_t and γ_t are constants known by all parties.

Bringing the enforcement features together, the expected penalty for a firm that is violating its permits and under-reporting its emissions is

$$f(e_t, l_t, r_t) = \phi_t(r_t - (x_t + l_t)) + \pi_t\{\gamma_t(e_t - r_t) + \phi_t[(e_t - (x_t + l_t)) - (r_t - (x_t + l_t))]\}$$

$$= \phi_t(r_t - (x_t + l_t)) + \pi_t(\gamma_t + \phi_t)(e_t - r_t). \qquad [1]$$

To understand how $f(e_t, l_t, r_t)$ is constructed, note that a firm that reports a part of its permit violation faces an automatic penalty of $\phi_t(r_t - (x_t + l_t))$. If the firm is audited so that its reporting violation is discovered (this occurs with probability π_t) the penalty for this violation, $\gamma_t(e_t - r_t)$, is assessed. Of course, if a firm does not hold enough permits to cover its emissions and also under-reports its emissions, it has not reported the full extent of its permit violation. If this is discovered the firm is liable for its unreported permit violation, $\phi_t(e_t - r_t)$.

Combining the elements defined thus far yields the firm's single-period expected costs,

$$v(e_t, l_t, r_t, x_t) = c(e_t) + p_t l_t + \phi_t(r_t - (x_t + l_t)) + \pi_t(\gamma_t + \phi_t)(e_t - r_t). \qquad [2]$$

Let us now characterize the evolution of the firm's stock of permits. Let the firm's expectation in period t of the number of permits it starts the next period with be $E_t(x_{t+1})$. The subscript on the expectation operator indicates that the expectation is from the perspective of period t. From this perspective, x_{t+1} is potentially a random variable because of incomplete monitoring and the possibility of under-reporting of emissions in t. $E_t(x_{t+1})$ is also determined by rules about the rate at which permits trade across time, and possible offset penalties for permit violations. In our experiments we focus on the simple case of programs that allow banking permits across time on a one-to-one basis, and permit violations in a period are offset by a one-to-one reduction in next period's endowment of permits. Assuming that the firm receives a predetermined endowment of permits in $t + 1$ of $\overline{l}_{t+1}$,

$$E_t(x_{t+1}) = \overline{l}_{t+1} + [\pi_t(x_t + l_t - e_t) + (1 - \pi_t)(x_t + l_t - r_t)]. \qquad [3]$$

Note that if an audit is conducted in t the firm's actual permit shortfall, $(x_t + l_t) - e_t < 0$, or bank, $(x_t + l_t) - e_t > 0$, is carried into the next period. If an audit is not conducted the firm's reported permit shortfall, $(x_t + l_t) - r_t < 0$, or reported bank, $(x_t + l_t) - r_t > 0$, is carried forward.

We can now specify a firm's decision problem in its entirety. Its objective is to choose a time path of emissions, permit transactions, and emissions reports to minimize its discounted sum of expected costs, subject to [3], and non-negativity constraints for emissions, reported emissions, and permit holdings in every time period. In the final period the firm will never find it advantageous to hold excess permits or report that it holds excess permits, because excess permits at the end of T have no value. Therefore, we impose the constraint that $e_T - (x_T + l_T) \geq 0$. Formally, the firm's problem is to choose $\{e_t, l_t, r_t\}$, $t = 0, \ldots, T$, to solve:

$$
\begin{aligned}
& min\ E\left[\sum_{t=0}^{T} \beta^t \left(c(e_t) + p_t l_t + \phi_t(r_t - (x_t + l_t)) + \pi_t(\gamma_t + \phi_t)(e_t - r_t)\right)\right] \\
& s.t.\quad x_{t+1} = \begin{cases} \overline{l}_{t+1} + (x_t + l_t - e_t) & \text{with probability } \pi_t \\ \overline{l}_{t+1} + (x_t + l_t - r_t) & \text{with probability } 1 - \pi_t, \end{cases} \quad t = 0, 1, \ldots, T-1, \\
& \qquad e_t \geq 0,\ r_t \geq 0,\ x_t + l_t \geq 0,\ t = 0, 1, \ldots, T, \\
& \qquad e_T - (x_T + l_T) \geq 0, \\
& \qquad x_0 = \overline{l}_0. \qquad\qquad [4]
\end{aligned}
$$

In the objective function β is the discount factor, which is assumed to be constant over the life of the program.

The objective function and constraints specified in [4] define a discrete-time stochastic dynamic programming problem. The uncertainty in our problem stems from incomplete monitoring: there are no other stochastic elements in the problem. In particular, we assume that each firm can accurately forecast equilibrium permit prices over the life of the policy. Define $J_t(x_t)$ as minimum expected discounted costs from period t on through the last period, given that the firm has x_t permits at the beginning of t. Stranlund *et al.* show that the stochastic dynamic programming equation associated with [4] in periods $t = 0, \ldots, T-1$ is

$$
\begin{aligned}
J_t(x_t) = & \min_{e_t, l_t, r_t} c(e_t) + p_t l_t + \phi_t(r_t - (x_t + l_t)) + \pi_t(\gamma_t + \phi_t)(e_t - r_t) + \beta E_t[J_{t+1}(x_{t+1})] \\
s.t. \quad & E_t[J_{t+1}(x_{t+1})] = -p_{t+1}[\pi_t(x_t + l_t - e_t) + (1 - \pi_t)(x_t + l_t - r_t)] + \tilde{C}_{t+1} \\
& e_t \geq 0,\ r_t \geq 0,\ x_t + l_t \geq 0,
\end{aligned}
$$

for some constant $\tilde{C}_{t+1}$. The dynamic programming equation balances the effects of decisions e_t, l_t, and r_t on period t expected costs against the effects of these decisions through the state equation [3] on minimum discounted expected costs from $t + 1$ on through the last period. In the last period, there are no future costs to consider so the dynamic programming equation is

$$J_T(x_T) = \min_{e_T, l_T, r_T} \quad c(e_T) + p_T l_T + \phi_T(r_T - (x_T + l_T)) + \pi_T(\gamma_T + \phi_T)(e_T - r_T)$$

$$s.t. \qquad e_T \geq 0, r_T \geq 0, x_T + l_T \geq 0, \text{ and } e_T - (x_T + l_T) \geq 0.$$

This model provides the compliance incentives of the firm. Let us first deal with the firm's reporting incentives. A firm that is violating its permits truthfully reports its emissions in any $t = 0,...,T-1$ if $\pi_t(\gamma_t + \phi_t) \geq (1-\pi_t)\beta p_{t+1} + \phi_t$. To interpret this condition, note that there are two reasons a firm may choose to under-report its emissions. One is to cover up a permit violation while the other is to carry additional permits into the next period. Thus, $\pi_t(\gamma_t + \phi_t)$, is the expected marginal penalty for a reporting violation and the undisclosed part of a permit violation. The expected marginal benefit of under-reporting emissions is $(1-\pi_t)\beta p_{t+1} + \phi_t$, in which $(1-\pi_t)\beta p_{t+1}$ is the expected discounted marginal benefit of carrying additional permits into the next period because emission are under-reported, and ϕ_t is the certain unit penalty for the part of the permit violation that the firm avoids by under-reporting its emissions.

On the other hand, if the firm is permit compliant, and perhaps has a positive permit bank, its only incentive to under-report its emissions is to increase the size of its permit bank. Thus, a permit compliant firm provides a truthful emission report in any $t = 0,...,T-1$ if and only if $\pi_t \gamma_t \geq (1-\pi_t)\beta p_{t+1}$.

Given some γ_t, ϕ_t and βp_{t+1}, it is straightforward to demonstrate that the monitoring required to induce truthful emissions reporting is higher when the firm is permit compliant than when it is violating its permits. However, a regulator does not know if a firm is complying with its permits unless it audits the firm. Therefore, it cannot choose a different monitoring strategy for permit compliant firms than for firms that are violating their permits. This suggests that

inducing truthful reporting by all firms requires $\pi_t(\gamma_t + \phi_t) \geq (1-\pi_t)\beta p_{t+1} + \phi_t$, which further suggests a monitoring probability of

$$\pi_t \geq (\phi_t + \beta p_{t+1})/(\gamma_t + \phi_t + \beta p_{t+1}) \qquad [5]$$

in all periods $t = 0,...,T-1$. In the last period, a firm is motivated to under-report its emissions only to cover up a permit violation. Thus, under-reporting in the last period is deterred by monitoring so that

$$\pi_T \geq \phi_T/(\gamma_T + \phi_T). \qquad [6]$$

Now let us turn to a firm's decision to hold permits, given that it has the proper incentive to truthfully report its emissions. In $t = 0,...,T-1$, the firm holds enough permits to cover its emissions (and perhaps banks permits) if

$$\phi_t \geq p_t - \beta p_{t+1}. \qquad [7]$$

In the last period the firm is permit compliant if

$$\phi_T \geq p_T. \qquad [8]$$

Under the assumption that permit borrowing is not allowed, previous work has shown that intertemporal equilibrium in a permit market under certainty requires that real permit prices be non-increasing across time periods, and that firms will bank permits only when real permit prices are expected to remain constant (Cronshaw and Kruse 1996; Rubin 1996, Kling and Rubin 1997).[6] In all periods but the last, [7] indicates that the permit violation penalty serves no

[6] Whether a firm is permit compliant or not, $p_t < \beta p_{t+1}$ implies that all firms would demand an unbounded number of permits in *t*, because they are more valuable in the future. Since this cannot be true in equilibrium, we must have $p_t \geq \beta p_{t+1}$. If $p_t > \beta p_{t+1}$ firms will not hold excess permits because they are less valuable in the future. Thus, firms bank permits only if $p_t = \beta p_{t+1}$. When $p_t > \beta p_{t+1}$ the only reason to hold permits is for compliance purposes.

deterrence role when real permit prices are expected to remain constant across periods. When real permit prices are falling and firms are not banking permits, the permit violation penalty needs to only make up the difference between real prices across time periods. Finally, in the last period the permit violation penalty only needs to cover the equilibrium permit price.

Examining the role of the permit violation penalty in determining the monitoring requirements [5] and [6] suggests that increasing this penalty cannot conserve monitoring costs. In fact, [5] and [6] are both increasing in ϕ_t, $t = 0,...,T$. In contrast, increasing the reporting violation penalty γ_t, $t = 0,...,T$, reduces the monitoring required to induce truthful emissions reporting. From these results Stranlund *et al.* (2005) conclude that enforcement of an emissions trading program with a banking provision and imperfect monitoring should focus primarily on inducing truthful emissions reporting and punishing misreporting with as high a penalty as is practicable to conserve monitoring effort. A testable hypothesis that emerges from Stranlund *et al.* is that using an enforcement strategy that satisfies [5] through [8] should achieve compliance in an emissions trading program with bankable permits despite imperfect monitoring and a permit violation penalty that is lower than predicted permit prices. Our experiments were designed primarily to test this hypothesis.

3. Experimental Design

Our experimental design extends the static model of permit market enforcement used in Murphy and Stranlund (2006 and 2007) to the case in which permits can be banked into the future. Subjects were given a predetermined endowment of production permits at the beginning of each market period. The permit endowment for all periods was known at the beginning of the session. During each market period subjects simultaneously chose to produce units of a fictitious good and trade in a continuous double auction for permits that conveyed the right to produce. The experiments were framed as a production decision in which permits were a license to produce, rather than an emissions decision, to avoid introducing potential biases due to individual attitudes about the environment or emissions trading.[7]

Subjects received a benefit from their choice of production according to the "Earnings from Production" schedules shown below in Table 1. Each experiment consisted of two subjects of each type A through D for a total of eight subjects in each group. These marginal benefit

[7] The experiment instructions are available upon request.

schedules are similar to those used by Cason and Gangadharan (2006). From these data the aggregate marginal benefit function in a period is presented in Figure 1. Individual and aggregate marginal benefit functions were stationary across time periods and stages in an experiment.

Table 1: Earnings from Production

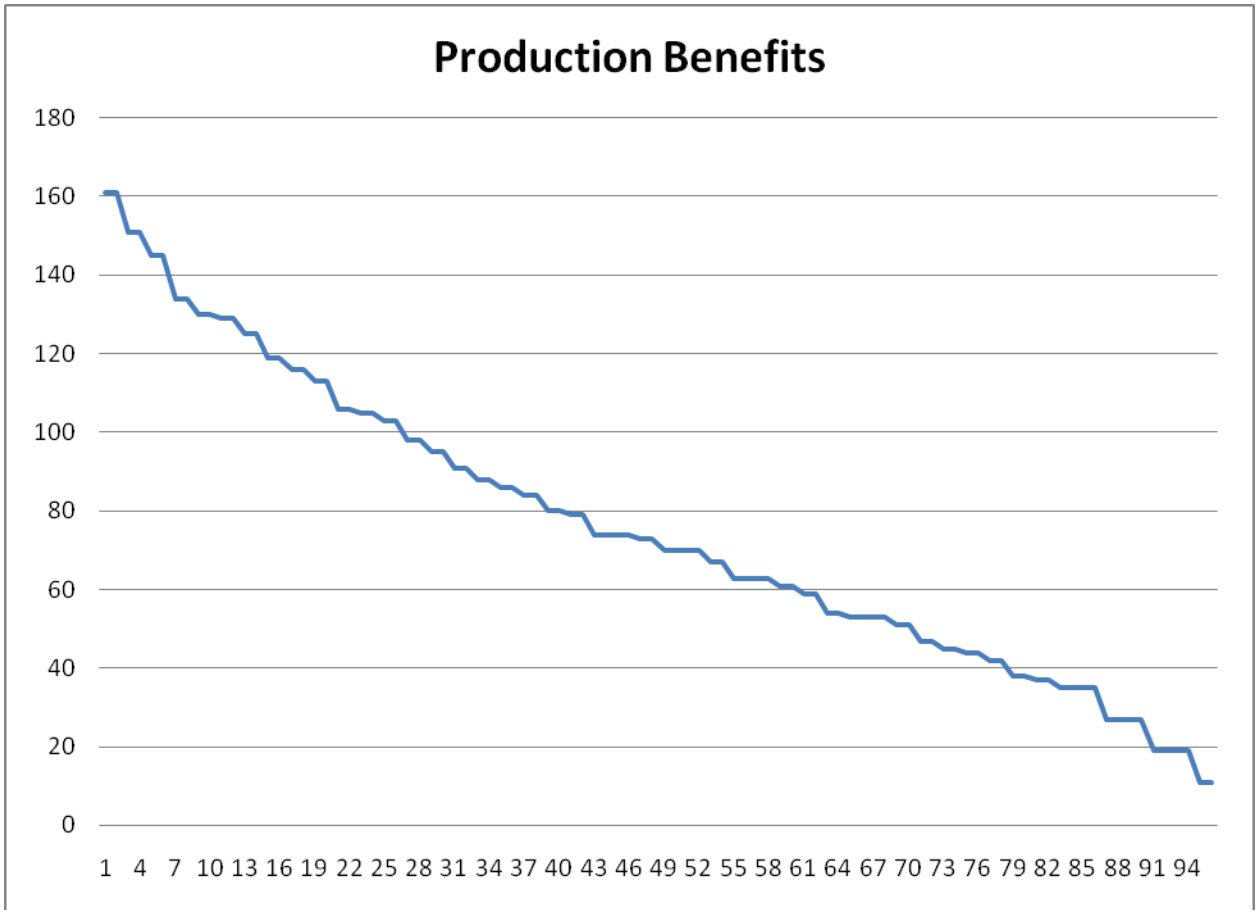
	Subject Type			
Production	**A**	**B**	**C**	**D**
1	161	151	129	125
2	145	134	113	105
3	130	119	98	88
4	116	106	84	74
5	103	95	73	63
6	91	86	63	54
7	80	79	53	47
8	70	74	44	42
9	61	70	35	38
10	53	67	27	35
11	45	59	19	27
12	37	51	11	19

At the end of each market period each subject was required to submit a report of his or her production for the period. After all reports were submitted, subjects' production choices were audited with a known probability. Permit shortfalls that were either self-reported or uncovered by an audit were punished with a constant unit financial penalty. In addition, a subject's permit shortfall in any period but the last was offset by a one-for-one reduction in the subject's endowment of permits in the next period. If a subject's reported or discovered permit shortfall ever exceeded his endowment in the next period, the subject was declared bankrupt and was not allowed to participate in the remainder of the stage. Finally, if an audit revealed that a subject had under-reported his or her production, he or she was assessed an underreporting penalty that is different from the permit shortfall penalty.

With inter-temporal experiments such as these, learning in earlier periods can affect outcomes in the remainder of a session. To minimize learning effects, sessions were organized into three separate stages each of which contained six market periods, similar to the design used

by Anderson and Sutinen (2006) in their study of trading in fishery quota markets. This provided subjects with an opportunity to gain experience in a short six-period setting, adapt, and try again.

Figure 1: Aggregate Marginal Benefit of Production.



Since marginal benefits were stationary for all six periods of a session and production was non-stochastic, we induced permit banking by reducing the aggregate supply of permits for the last three trading periods of each stage. In particular, we distributed a total of 68 production permits for each of the first three periods of a stage, and a total of 16 for each of the last three periods. The perfect foresight and perfect compliance equilibrium consists of 42 units of total production and an equilibrium permit price of about $79 in each period.

Treatments

Our initial experimental design consists of three treatments. In all treatments, individuals were allowed to bank permits and were motivated to do so because of the reduction in the aggregate supply of permits in the middle of each stage. Individual permit endowments were allocated in the following way. In the first three periods, five permits were allocated to each of subject types A and B and twelve permits were allocated to each of subject types C and D. In the last three periods, subject types A and B received 1 permit and subject types C and D received three permits. These permit endowments were the same for each treatment. The three treatments differ according to enforcement aspects.

Full Compliance: This treatment was designed to induce full compliance using an enforcement strategy derived from equations [5] through [8] and the distribution of production permits described above. We decided to over-enforce somewhat so we assumed a monitoring probability of $\pi_t = 0.7$, $t = 1, 2, ..., 6,$ and assessed permit and reporting violation penalties that are about $20 higher than they need to be to satisfy [5] through [8]. Since our perfect foresight and perfect compliance equilibrium produces the permit price $p_t = \$79$ for each $t = 1, 2, ..., 6,$ [7] and [8] suggest that the permit violation penalty can be set to zero for periods 1 through 5 and $79 for period six. Therefore, we chose $\phi_t = \$20$ for t = 1, …, 5 and $\phi_6 = \$100$.

Next we chose the reporting penalty. For $t = 1, 2, ..., 5,$ [5] implies that γ_t needs to be set so that $\gamma_t \geq (1-\pi_t)(\phi_t + p_{t+1})/\pi_t$ to induce truthful reporting. With $\pi_t = 0.7$, $\phi_t = \$20$, and $p_{t+1} = \$79,$ $\gamma_t \geq \$42.43$. Setting this penalty about $20 higher led us to choose $\gamma_t = \$60$, $t = 1, 2, ..., 5.$ We set $\gamma_6 = \$60$ in the last period as well, because from [6], $\gamma_6 = \$60$ and $\phi_6 = \$100$ implies that a monitoring probability of at least 0.625 should be sufficient to induce truthful reporting in the last period. Therefore, $\gamma_6 = \$60$ with $\pi_6 = 0.7$.

This treatment was designed to test the hypothesis that compliance can be maintained in dynamic trading programs with imperfect monitoring and low permit violation penalties. Note that we set the permit violation penalty at about ¼ of the predicted permit price for all periods but the last. Note as well that the theoretical model allows us to set the reporting violation penalty below the predicted permit price.

Weak Enforcement: This treatment is the same as the Forced Compliance treatment except that the monitoring probability was reduced by half to $\pi_t = 0.35,\ t = 1,...,6.$ In this treatment we expected significant noncompliance. Weak enforcement reduces the aggregate demand for permits in every period so we expected that permit prices would be significantly lower than in the Forced Compliance and Full Compliance treatments. However, we still expected individuals to bank permits to smooth the effects of the decrease in the aggregate supply of permits.

Forced Compliance: In this treatment, we did not allow subjects to violate their permits or to submit false production reports. This treatment is a baseline treatment against which we will judge the effects of allowing noncompliance.

Subject Recruitment

Participants were recruited from the student population at the University of Massachusetts, Amherst. Subjects were told that to be eligible they had to participate in four two-hour sessions (two days a week for two consecutive weeks). Subjects were paid $5 for agreeing to participate and showing up on time for the first session, and were then given an opportunity to earn additional money in each experiment.

Experiment procedures

Table 2 summarizes the key aspects of the experiments. The experiments were conducted in a computer lab at the University of Massachusetts-Amherst using software designed in Visual Basic specifically for this research. To familiarize subjects with the experiments the first of the four sessions were for training purposes. During the training session, subjects first reviewed the instructions which included interactive questions to ensure that they understood the instructions before proceeding. Subjects then participated in a two-stage experiment. Stage 1 of the trainer followed the same rules as the Forced Compliance treatment (but with different parameters), and Stage 2 followed the rules of the Full Compliance treatment (again with different parameters). The data from the training sessions were not included in the analysis. Prior to the start of the real data sessions, subjects read a summary of the instructions. To mitigate possible order and experience effects, we varied the order of the treatments as shown in Table 3. A total of 72 subjects participated in nine real data sessions, with eight subjects per group.

Table 2. Experiment Summary

- Subjects
  - All subjects participated in a 2-hour training session prior to participating in real data sessions.
  - 72 University of Massachusetts-Amherst students participated in real data sessions.
  - Paid $5 for participating, plus experiment earnings (mean about $23 per session).
- Number and Type of Subjects
  - 8 subjects, 2 of each of four types described in Table 1
- Sessions
  - 3 Stages of 6 four-minute periods during which subjects produced a fictitious good and traded production permits for the right to produce the good.
- Production
  - Production generates "Earnings from Production".
  - Production allowed only during first three minutes of the period.
  - Each unit produced sequentially; production takes 10 seconds per unit.
  - Each subject could produce a maximum of 12 units.
- Permit Market
  - Permit market open for entire four-minute period.
  - Permits traded in a continuous double auction.
  - Permits could be banked for future periods.
- Reporting (for the Full Compliance and Weak Enforcement treatments)
  - After the market closed subjects were asked to report their production.
  - If they reported more production than they had permits they were charged a permit shortfall penalty for each unit they produced without a permit. Also, reported excess emissions were subtracted from next period's endowment.
- Auditing (for the Full Compliance and Weak Enforcement treatments)
  - Within a session, each individual faced the same probability of being audited.
  - Random audits occurred after production and market trading period was over.
  - Permit shortfall penalty applied if an audit revealed production exceeded permit holdings. The permit shortfall penalty is a constant penalty per unit of permit violation. In addition, uncovered excess emissions were subtracted from next period's endowment.
  - Reporting penalty applied if an audit revealed production report less than actual production. The reporting penalty is a constant penalty per unit of underreported production.
  - Subjects could become bankrupt if they required more permits to cover current production than they would be allocated in the next period. Bankrupt subjects were excluded from the remainder of the stage.

Table 3. Sequence of Treatments

Cohort	Session 1	Session 2	Session 3	Session 4
1	Trainer	Weak Enforcement	Forced Compliance	Full Compliance
2	Trainer	Forced Compliance	Full Compliance	Weak Enforcement
3	Trainer	Full Compliance	Weak Enforcement	Forced Compliance

Because individual risk attitudes may have played an important role in the outcomes of our experiments, we conducted a Holt-Laury risk test (Holt and Laury 2002) with all subjects after the training session was completed. The analysis of individual compliance behavior, including how results from the Holt-Laury test are correlated with individual choices, will be conducted at a later date.

Each experiment consisted of three identical six-period stages. At the start of each period, the eight subjects were each given an initial allocation of permits. Each permit conveyed the right to produce one unit of output. During the experiment, subjects earned experimental dollars (E$) that were converted to US dollars at a pre-announced exchange rate.

Subjects produced each unit of the good sequentially by clicking on a button that initiated the production process. Production of a single unit took 10 seconds. After production of the unit was completed the "Earnings from Production" were immediately added to the individual's cash balance. Subjects were able to "plan" future production within the period by indicating the total number of units to produce. Once production of a unit was completed, if there were any "planned" units, the 10-second production process for the next began automatically. Subjects could increase or decrease their "planned" production, but units that were "in progress" or "completed" were committed and could not be changed. That is, subjects could alter planning decisions about units not yet produced, but they could not reverse production of a good after the 10-second production process begins.

During a market period, and concurrent with the production decision, subjects could alter their permit holdings by trading in a continuous double auction (CDA). In the CDA, individuals could submit bids to buy or asks to sell a single permit (provided that they had a permit available to sell). The highest bid and lowest ask price were displayed on the subjects' computer screens. A trade occurred whenever a buyer accepted the current ask or a seller accepted the current bid.

After each trade, the current bid and ask were cleared and the market opened for a new set of bids and asks. The trading price history was displayed on the subjects' screens.

Each period lasted a total of four minutes. The permit market was open for the entire period, but production had to be completed in three minutes. The three-minute production time was more than sufficient for a subject to produce up to his or her capacity constraint. We provided the additional minute of permit trading after production was completed to give subjects a final opportunity to adjust their permit holdings. The computer screen displayed the time remaining for both the production and the permit markets.

Since it was possible for individuals to lose money either through permit trading or penalties, we implemented two bankruptcy rules. If an individual's cash balance ever fell below negative E$800, he or she was declared bankrupt and no longer allowed to participate. A subject was also bankrupt if the permit offset penalties for reported and uncovered permit violations exceeded his or her permit allocation in the next period. We also instituted a price ceiling of E$400 above which offers to trade permits were not allowed. This ceiling set well above the highest possible marginal benefit from production so there was little chance that it would ever be reached.

To help subjects understand how to optimally allocate their permits across time periods, in all treatments we explained in the instructions that the best way to use their permits was to spread them out evenly over time. In addition to this we also provided an 'Even use' calculation that indicated how an individual would "even out" the number of permits he or she owned plus all their future allocations. This is consistent with the planner used by Godby et al. (1997). Providing this information to the subjects did not reveal their optimal paths of production and permit demands. It suggested to them that these should be spread evenly through time, but it did not tell them what their aggregate production and permit demands should be. In general these are functions of their Earnings from Production, the enforcement parameters, and the behavior of the others in their session.

As soon as a market period ended in the Full Compliance and Weak Enforcement treatments, each subject was required to submit a report of its production for the period. Subjects could not over-report their production. Subjects were told the probability of random audits prior to each market period. Recall that the Full Compliance and Weak Enforcement treatments are the same except the probability of an audit after each period was 0.7 in the Full Compliance

treatment and 0.35 in the Weak Enforcement treatment. After audits were conducted for a period, all penalties were assessed. At the end of each period, subjects were given their production earnings, receipts or expenditures from permit trades, and any penalties for the period, along with a running tally of their cumulative cash balance.

4. Preliminary results

In this section, we present some preliminary results from the experiments. At this date, the results have not been subjected to rigorous statistical tests; therefore, they should not be taken as conclusive. Moreover, the results presented are highly aggregated; we will examine individual compliance and banking behavior in the future.

We begin by noting that subjects made good use of the banking provision in all treatments. Figures 2a, 2b, and 2c contain average production and permit banks across the nine groups in stage 3 of each treatment. We present only the third stage results to conserve space and because the subjects' understanding of each treatment was at its highest in the third stage. The blue bars in the figures represent the supply of permits in each period, 68 in the first three periods and 16 in the last three. The green line indicates average production and the yellow bars represent the average size of the permit bank at the start of periods 2 through 6. Recall that the perfect foresight/perfect compliance equilibrium results in total production of 42 units in each period. This path of production and the distribution of permits reveal that the equilibrium path of banked permits at the start of periods 2 through 6 is 26, 52, 78, 52, and 26.

Although these results may mask important differences across the nine groups in each treatment, it is clear that on average the groups smoothed production across the six periods by building up a permit bank in the first three periods when the supply of permits was high, and then drawing the bank down in the last three periods when the permit supply was low. Note that it is hard to detect differences in average group production and permit banks between the Full and Forced Compliance treatments. This is to be expected because subjects were predicted to be fully compliant in the Full Compliance treatment. Note also that the mean production and bank values tended to be close to the perfect foresight/perfect compliance equilibrium values. Production tended to be higher in the Weak Enforcement treatment. This is a consequence of significant noncompliance in this treatment, which we will turn to momentarily.

Figure 2a: Third stage production and permit bank, Full Compliance

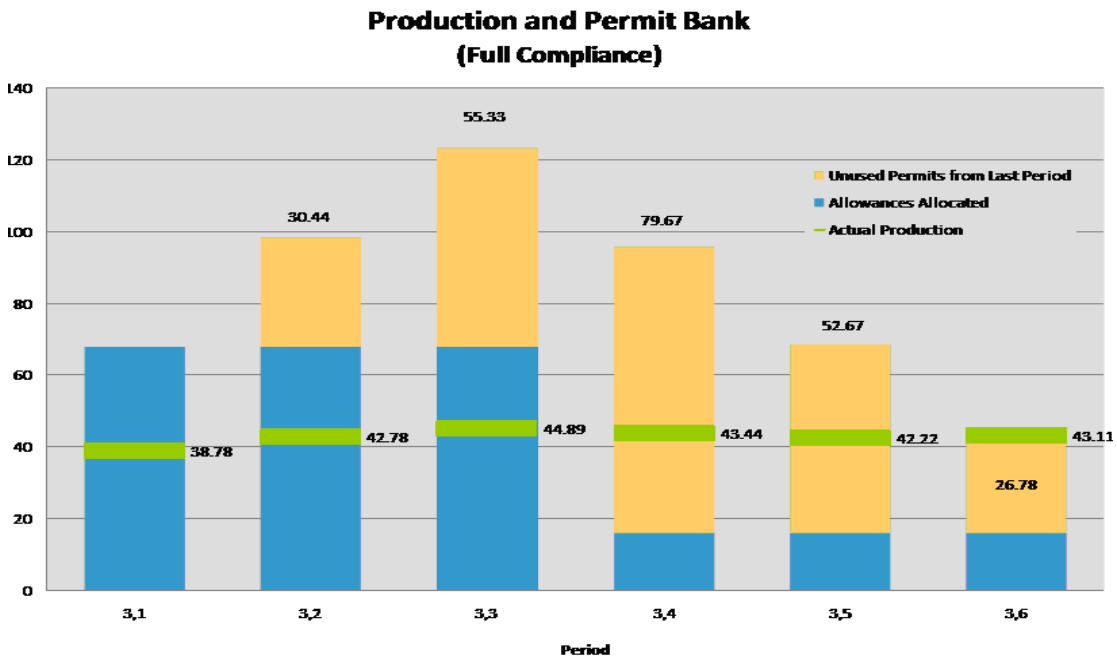


Figure 2b: Third stage production and permit bank, Forced Compliance

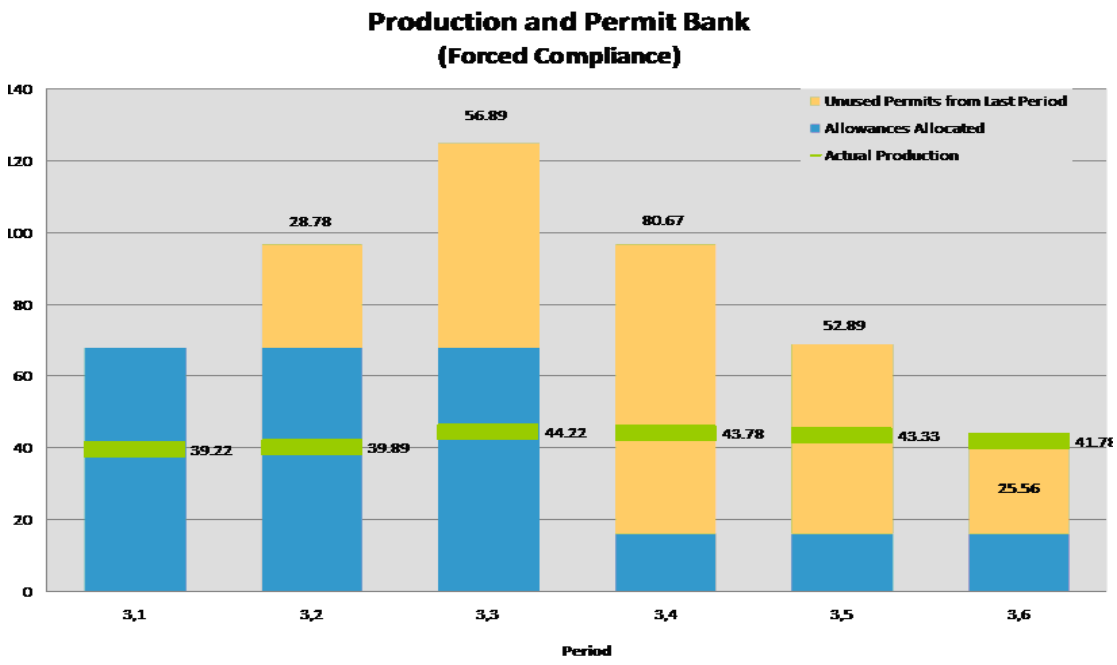
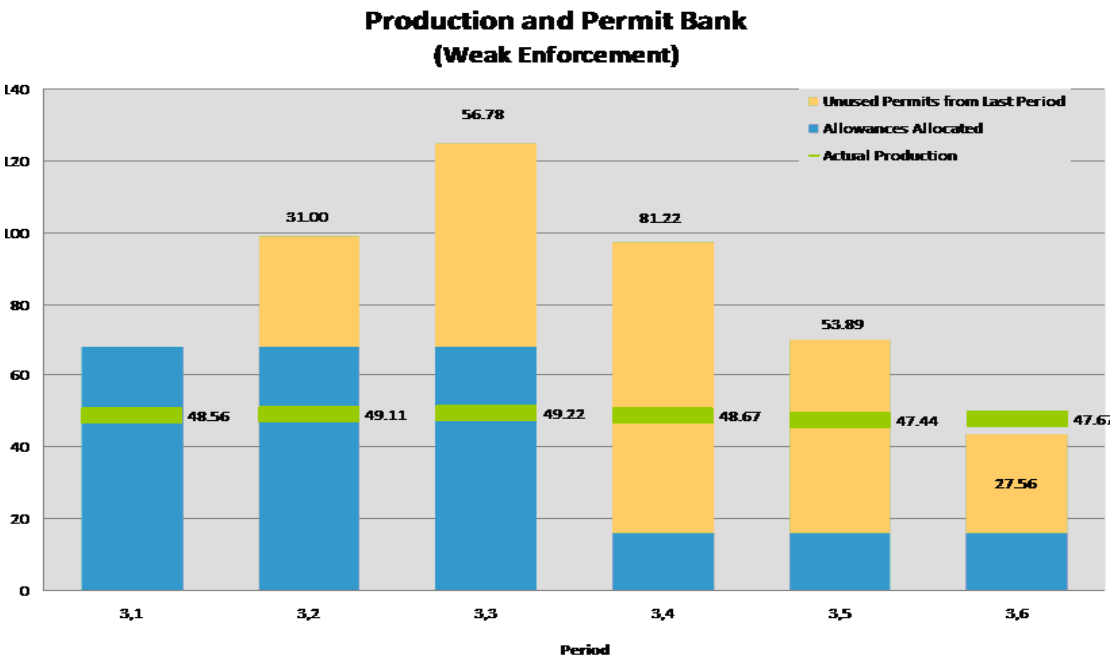


Figure 2c: Third stage production and permit bank, Weak Enforcement



Now let us turn to the main hypothesis of this study, that subjects are compliant under the Full Compliance treatment despite imperfect monitoring and a low permit violation penalty. Tables 2a and 2b are the frequency distributions of third stage permit violations and reporting violations for the Full Compliance treatment. Although the subjects were not perfectly compliant as theory predicts, the enforcement strategy of this treatment did achieve very high rates of compliance. Note that subjects complied with their permits 96.5% of the time and that two-thirds of the violations were one unit violations. Thus, most of the violations in the third stage of this treatment are more likely to be the result of subjects probing the extent to which they can violate their permits and get away with it, rather than systematic noncompliance choices. There are more reporting violations than permit violations, but again most of these are one unit violations.

It is likely that 3.5% permit violation rate and the 7.2% reporting violation rate are statistically significant. Thus, strictly speaking our hypothesis is rejected. However, it appears that an enforcement strategy for an emissions trading program with permit banking can achieve \high rates of compliance despite imperfect monitoring, low permit violation penalties, and modest reporting violation penalties.

Table 2a: Third stage permit violations, Full Compliance

Permit Violations	Frequency	Percent
0	417	96.53
1	10	2.31
2	4	0.93
9	1	0.23
Total	432	100.00

Table 2b: Third stage reporting violations, Full Compliance

Reporting Violations	Frequency	Percent
0	401	92.82
1	19	4.4
2	7	1.62
4	2	0.46
> 4	3	0.69
Total	432	100.00

As expected there was significant noncompliance in the Weak Enforcement treatment. Tables 3a and 3b are the frequency distributions of third stage permit violations and reporting violations for this treatment. Although the permit compliance rate is lower than in the Full Compliance treatment it is still close to 90%. Moreover, about half of the permit violations were one unit violations. It may seem surprising that there are not more permit violations in this treatment, but this is consistent with the significant amount of banking we observe in Figure 2c. One cannot simultaneously bank permits and violate them. Table 3b reveals that the main effect of weak enforcement is on production reporting. About 32.3% of reporting choices were violations, and half of these were 3 units or greater.

Table 3a: Third stage permit violations, Weak Enforcement

Permit Violations	Frequency	Percent
0	384	88.89
1	24	5.56
2	7	1.62
3	8	1.85
> 3	9	2.08
Total	432	100.00

Table 3b: Third stage reporting violations, Weak Enforcement

Reporting Violations	Frequency	Percent
0	293	67.82
1	35	8.1
2	34	7.87
3	27	6.25
4	17	3.94
5	5	1.16
>5	21	4.86
Total	432	100.00

Moreover, the main effect of reporting violations that are undetected is to allow total production to exceed the number of permits supplied. Table 4 contains total production and undetected reporting violations for the six periods in the third stage of the Full Compliance and Weak Enforcement treatments averaged across groups. Recall that 252 permits were supplied in each stage, 68 permits for the first three rounds and 16 for the last three. The percentages in Table 4 are with respect to the 252 permit cap. The data for the Full Compliance treatment reflect the high rate of compliance we've already observed. However, under the Weak Enforcement treatment total production tended to be about 38.67 units (15.34%) above the supply of permits. This matches the average number of undetected reporting violations. Undetected and unreported permit violations averaged about 14 units in this stage of the Weak Enforcement treatment. Thus, about 36% of undetected reporting violations were successful attempts to cover up permit violations while the remaining 64% were successful attempts to simply increase individual permit banks.

Table 4: Third stage total production and undetected reporting violations

Treatment	Total production	Undetected reporting violations
Full Compliance	255.22 (1.01%)	2.89 (1.15%)
Weak Enforcement	290.67 (15.34%)	38.22 (15.17%)

The higher total production in the Weak Enforcement treatment is reflected in average permit prices. In the third stage of this treatment the average permit price was $70.12. Recall that the predicted price is $79. Average prices in the third stage of the Full Compliance and Forced Compliance treatments were $75.30 and $77.68, respectively.

We also calculated the percentage of realized potential gain over the no-trade, no-banking, and no-violations outcome (autarchy) for each treatment. In the third stage of the Forced Compliance treatment subjects earned about 95% of the potential gain. This suggests that the subjects understood the basic incentives of trading within and across time periods very well; consequently the baseline markets functioned well. The efficiency gain in the third stage of the Full Compliance treatment was significantly lower at 77%. This drop in efficiency is likely due to the fact that the need to make decisions about permit and reporting compliance significantly increased the complexity of the environment. Despite this we think it is important to stress that the subjects were able to capture a large part of potential gains. The efficiency gain in the third stage of the Weak Enforcement treatment was 118%. The subjects in this treatment did very well largely by getting away with reporting violations, which allowed them to increase production beyond the permit cap.

5. Concluding remarks

In this paper we have described a study that uses economic experiments to test hypotheses about compliance behavior and enforcement in emission trading programs with bankable permits. Imperfect monitoring of emissions requires firms to self-report their emissions when permit banking is allowed. Consequently, recent theoretical work highlights the importance of motivating truthful emissions reporting in maintaining compliance in dynamic trading programs with less than perfect monitoring. In fact, very high penalties for permit violations have limited deterrence value in these programs.

Our experiments address two important issues. The first is a test of the theoretical result that an enforcement strategy with imperfect monitoring and a permit violation penalty that is set below predicted permit prices can induce subjects to report truthfully and to remain permit compliant. The second concern is about the effects of weak enforcement on the performance of emission markets with banking. Clearly, it is premature to draw any firm conclusions from our preliminary presentation of the results. However, it appears that we may have qualified support

for our main hypothesis. That is, it appears possible to achieve high rates of compliance with imperfect emissions monitoring, a low permit violation penalty, and a modest reporting violation penalty. A weaker enforcement strategy (low monitoring probability in our case) results in aggregate emissions well beyond the permit cap, but this is mainly through reporting violations rather than permit violations. Rigorous analysis of the experimental data will reveal whether these results hold up and will reveal further results about compliance behavior in emissions markets with bankable permits.

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Can Markets for Development Rights Improve Land Use and Environmental Outcomes?

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Prepared for
Workshop on Market Mechanisms and Incentives:
Applications to Environmental Policy

Environmental Protection Agency
NCEE and NCER

Resources for the Future
April 29, 2009

Can Markets for Development Rights Improve Land Use and Environmental Outcomes?

I. Introduction

Undeveloped open space can provide public benefits to communities by maintaining wildlife habitat, protecting sensitive ecological resources, preserving prime farmland or historically significant areas, protecting scenic views, and maintaining buffers for key aquatic resources. These social values are not likely to be fully captured by private land owners in the decisions they make, leading open space to be under-provided by private land markets. To provide these public goods, some communities are relying on publicly funded programs such as Purchase of Development Rights (PDRs) to preserve land. In PDR programs, the local government purchases and retires the development rights, placing a conservation easement or other restriction on the property. Other communities are instituting large lot or agricultural zoning restrictions. Still others have required clustering of development, essentially requiring open space be set aside.

Another approach that has received a good deal of attention lately is to use a more private market-based approach known as Transfer of Development Rights (TDRs). TDRs aim to preserve land from development in some areas by transferring that development to another location. Developers purchase rights from landowners, whose land is then placed under easement; the developers are permitted to use the rights to develop alternative properties more densely than would be allowed under baseline zoning regulations. Although a TDR market must be set up by government, the transactions in development rights are made by individual land owners, and do not require the kind of government funding that many other programs require, such as PDRs and other conservation easement purchase programs.

Thus far, studies of TDR markets have relied on case studies of real-world programs, some theoretical economic models, and a very few econometric studies where data is available. But to fully assess land use outcomes and identify the features of the programs that determine those outcomes, a detailed simulation model of the land market is required. This model needs to capture both the spatial heterogeneity and the dynamics of the land and housing markets. Spatial heterogeneity is key as policies such as TDRs work to protect land of particular types in particular locations, while allowing development in other locations. It is essential for a land use model to capture that geographic detail. Incorporating market dynamics is also key. When a TDR or other program is introduced, the time path of future development is likely to be altered. To capture these changes, the model must represent the economic decisions of all of the parties involved: landowners, consumers, and developers.

In this paper, we develop a land use model that includes these features. We build an agent-based simulation model that, on one hand, is based on economic theory and, on the other hand, features the degree of heterogeneity that is adequate for our purposes. This framework captures agent optimizing behavior, the functioning of markets, spatial

heterogeneity, and a variety of other key features of real-world land and housing markets. We show how the model can be used to represent the dynamics of land use decisions over time. We describe the individual agents and their optimizing behavior, the market interactions among the agents, and the time path and spatial distribution of development and preservation outcomes that result both with and without a TDR program. We show how the model can be used to compare TDRs to a zoning policy and a PDR program. We also discuss alternative TDR program designs. At this is work in progress, the model has not been fully calibrated; only the farmer/landowner module is running and has been used for simulations. In this paper, we describe the framework of the full model but provide additional specific details only about the farmer/landowner component.

In the next section of the paper, we describe how TDRs work and review the literature on TDRs from both economics and planning. We discuss the design features and land market conditions that are key to determining whether TDR programs are successful in meeting their goals of land preservation. In section III, we describe some specific programs; we spend most of our time on two very active programs in Maryland but also briefly describe some other newer programs. This discussion provides the motivation for the simulation model. Section IV provides an overview of the agent-based modeling approach and briefly describes our model.

II. Transfer of Development Rights Markets

The most commonly used tool in the local planner's toolbox is zoning. Zoning laws set broad categories of uses for areas of land in a jurisdiction, as well as the intensity of use on that land. In the case of residential development, this means there are usually limits set on the density of development, most often expressed as the number of dwelling units permitted per acre. To protect open space, local government may set very restrictive density limits. But because it is impossible for the government to have all the information it needs to set the density limits optimally for every land parcel, it usually sets limits for broad categories covering large land areas. Moreover, these density limits are set at one point in time, and are not easy to change because landowners develop expectations about the value of land based on rules governing how it can be developed. For these reasons, broad zoning categories are a blunt instrument for internalizing the externalities associated with development and for protecting land-based environmental resources and open spaces.

TDR programs work in concert with zoning density limits to protect land in some areas while still allowing development in others. Land targeted for protection is the TDR "sending area." Property owners in this area are the suppliers of development rights to the TDR market. Demanders of development rights are usually developers who can use them in areas known as "receiving areas." The government allows more dense development in the receiving areas than is permitted by baseline zoning. TDR programs are voluntary thus individual parcels may be developed or preserved, depending on parcel characteristics and landowner preferences.

The advantages of TDRs for achieving improved land use allocations are numerous. Because they are voluntary, they give landowners more flexibility compared to strict mandates or broad zoning rules. Early studies argued that there can be substantial efficiency advantages to these types of tradable systems over a zoning-only approach (Carpenter and Hefley, 1982, Mills, 1980). By giving individual landowners the flexibility to go over or under the number of building rights allocated under zoning regulations, while maintaining a cap on the overall number of rights, land parcels can be allocated to their most efficient uses depending on their relative values in preservation and development (Mills, 1989, Thorsnes and Simon, 1999).

On the distributional side, TDRs have the potential to compensate landowners in areas targeted for preservation who may be subject to relatively restrictive zoning, thereby avoiding "takings" arguments by those landowners. Another political advantage is that TDR transfers occur through a private market, and therefore no tax dollars are needed for ensuring that land is preserved. This is in contrast to PDRs which can require many millions of dollars for preserving significant areas from development. And TDRs can achieve this preservation, while still accommodating growth in the region. Thus in comparison with PDRs and many other measures, which are growth controls, TDRs are more of a growth management tool.

Whether or not a TDR program in practice achieves the results found in theory depends heavily on the design of the program and the underlying fundamentals of the housing and land markets. TDR programs have been in existence since 1968 and proliferated in the 1970s and 1980s as concerns over suburban "sprawl" and loss of open space on the urban fringe began to mount (Johnston and Madison, 1997). Currently, about 140 TDR programs exist in the U.S. (Pruetz, 2003; Messer, 2007). However, only a handful of these programs have actual working TDR markets with significant numbers of transactions taking place each year. Many other programs lie dormant. Several authors offer suggestions for why programs fail and identify features that lead to success. Pruetz and Standbridge (2009) catalog these studies and highlight the factors that each study identifies as a key determinant of success. In our previous work, we have emphasized the importance of an adequate demand for density in TDR "receiving areas" (Walls and McConnell, 2007; Kopits, McConnell, and Walls, 2008). However, TDR program design is complex and multi-faceted, and a number of factors can be critical for success. The government is essentially creating a market, which is a difficult undertaking. In the next section, we walk through the key issues in program design.

II.1. What makes effective TDR markets so difficult to design and implement?

II.1.1. Designation of sending and receiving areas. Local government must decide which areas of the community are allowed to sell TDRs, i.e., the designated sending areas, and which are allowed to use TDRs to develop more densely, the receiving areas. Sending areas are usually clear: they are the areas with the resources that the community wants to protect. But designation of receiving areas is often more difficult. A narrow designation, in which receiving areas are limited to higher density areas and town

centers, may be intended to achieve some "smart growth" objectives but may severely limit the functioning of the TDR market if demand for additional density does not exist. Moreover, existing residents in those areas may object to higher density.

II.1.2. Baseline zoning density limits. One factor that determines whether demand for additional density exists is the baseline zoning in the receiving area. The more restrictive the zoning, the more likely there will be a residual demand for density and thus TDRs. Density limits in the sending area are also important. The more restrictive the limits in TDR sending areas, i.e., the fewer the houses permitted per acre of land, the less lucrative the development option vis-à-vis preservation and the more likely a landowner will be willingto sell her TDRs. TDRs will only work when there is a supply of and demand for development rights and the baseline density limits in both sending and receving areas are critical determinants of supply and demand..

II.1.3. The density bonus. The density bonus defines how many more dwelling units are allowed per acre in the receiving area relative to the baseline number of units allowed. For example, if the baseline zoning allows 1 dwelling unit per acre but 4 units per acre may be built with TDRs, the density bonus is 300%. In areas where building is constrained by the baseline density limits, a higher density bonus will increase demand for TDRs. However, as discussed above, if there is little underlying demand for additional density, it is possible that a higher density bonus will have no effect.

II.1.4. The TDR allocation rate. The TDR allocation rate is the number of TDRs a landowner in the sending area is permitted to sell and is usually based on acreage. .[1] Often, the allocation of TDRs is also based on the zoning density limits in the sending area. In cases where the sending area has been downzoned prior to, or in conjunction with, establishment of the TDR program, the TDR allocation rate is often related to the original density limits and therefore can provide some measure of compensation to landowners.[2]

II.1.5. Housing and land market conditions. A working TDR market is only established if the underlying housing and land market conditions support additional density in receiving areas and preservation of land as farmland or open space. For receiving areas, it is essential to know the additional value of housing densities beyond the baseline zoned densities. For sending areas, the agricultural value of land vis-à-vis the value in development is likely to be crucial. The issue of uncertainty looms large here, given the time dimensions involved and the irreversible nature of the development decision.

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[1] This is not always the case. For example, the complex program in the Lake Tahoe region of California and Nevada determines the number of TDRs a property owner may sell based on several property characteristics related to stormwater runoff. See Solimar Research Group (2003) for an analysis of this program. Other TDR programs, such as the one in Chesterfield, New Jersey, allocate the number of rights based on soil quality and slope to better reflect the actual number of housing units that could potentially be built on the land; Malibu, California's program works similarly.

[2] Planners often refer to the TDR "transfer ratio," the ratio of the number of TDRs allocated per acre to the allowable density (dwelling units per acre) in a sending area.

II.1.6. Other potential issues with created markets. Created markets, in general, come with several potential problems. One is market power. In the case of TDR markets, there may be market power on the part of either developers or landowners in the market for development rights. If developers have market power, for example, TDR prices may be inefficiently low and fewer TDR transactions take place than is optimal. Similarly, markets may be thin. Especially in the case of TDRs, this can be a problem, as these programs are established at the local level and some communities may have a limited number of buyers and sellers. Another problem centers around transaction costs. If it is costly to get information about prices or to actually transact with other parties, it may be difficult to make efficient trades (Stavins, 1995).

Given these difficulties, it is no wonder that many TDR programs have not been able to create working markets and protect land from development as expected. In the next section of the paper, we examine two TDR programs in detail and then briefly discuss problems in other programs and new approaches being tried.

III. TDR Programs in Practice

III.1. Calvert County, Maryland

The community with the most flexible and consistently active TDR market is Calvert County, Maryland. Calvert County's TDR program has been in existence since 1978 and since the first TDR sale in 1982, it has had an active private market with many buyers and sellers of development rights engaging in trades each year.

Calvert's program is focused on farmland preservation. The county targets for protection the land in its Farm and Forestry District, the prime agricultural land in the county. It allows TDRs to be transferred to town centers and residential zones and also to a zoning district called the Rural Community District (RCD), which covers about 40% of the land area of the county and which has relatively low baseline density limits. The RCD is also a designated sending area. Thus landowners in the RCD have a great deal of flexibility: they can sell TDRs and preserve their land from development or they can sell to a developer who could either build to the baseline density limits or purchase TDRs and build more densely. This treatment of the RCD zone in Calvert is unique among TDR programs. As we explained above, many communities have limited receiving areas to more dense residential areas and no other program that we know of has an overlap in sending and receiving areas.

In an analysis of the demand for TDRs in Calvert County, Kopits, McConnell, and Walls (2008) argue that designation of the RCD as a receiving zone led to the robust demand for TDRs there. They show that most TDRs used over the 1978-2002 period were in the RCD; nearly 50% of RCD subdivisions used TDRs compared with only 9% of subdivisions in the residential and town center zones.

In a separate study, the same authors analyze development in the county over the 1965-2001 period – a period that covers years with and without the TDR program – and conclude that the 1 house/3 acres and 1 house/5 acres density limits in the RCD constrained development in some subdivisions during the period prior to the TDR program (McConnell, Walls, and Kopits, 2007). They estimate that approximately 46% more houses would have been built in those constrained subdivisions, which would have led to 11% more houses overall in the county. The density limits established in the TDR program, 1 house/2.5 acres in the RCD, seemed to satisfy demand for density during the post-1978 period, according to the authors.[3]

Figure 1 shows the spatial patterns of development and preservation that existed in Calvert County as of 2002. The green areas are protected lands. APDs are Agricultural Preservation Districts, with light green being APDs that are not yet under permanent easement and the medium green being lands under easement;[4] the dark green areas are parks and other protected lands. Pink and red areas are subdivisions; pink are the subdivisions that have been built without TDRs and red are TDR subdivisions. The zoning categories are also shown on the map. Orange and yellow are the residential and town center zones; the cross-hatched blue is the Farm and Forestry District (previously known as the Farm Community and Resource Preservation Districts and thus denoted as FCD/RPD in the figure); and the white area is the RCD.

The map shows that most subdivisions are located in the northern part of the county, closer to the employment centers of Washington and Baltimore. It also shows that most of these subdivisions are in the RCD, the white areas that are rural and can be either sending or receiving areas, as we explained above. The protected lands, shown in green, are primarily in the prime agricultural areas, the blue hatched "FCD/RPD" zones. As of January 2008, the Calvert TDR program had permanently preserved 13,260 acres of land.[5]

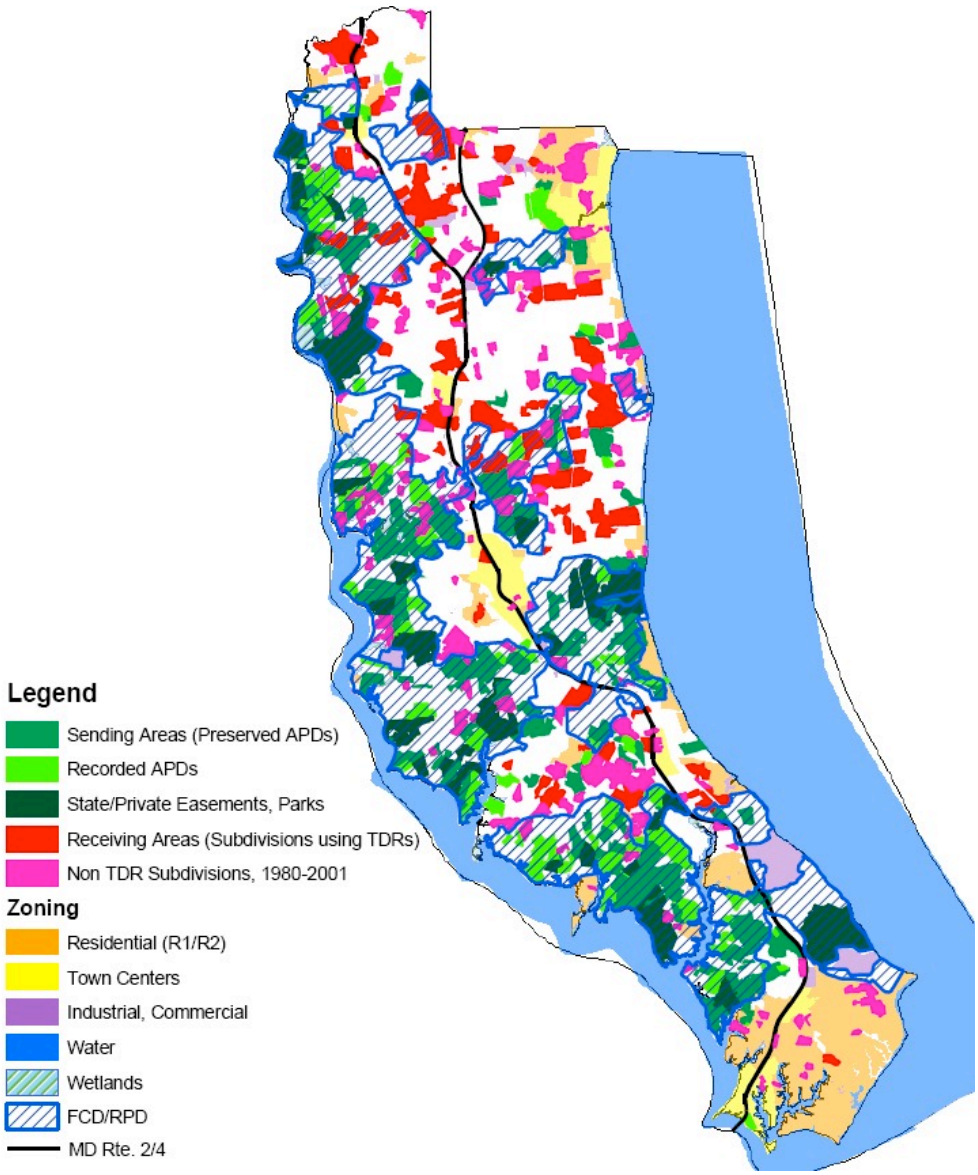
While we argued in our earlier work that the Calvert program has had success because of its flexibility and the resultant healthy demand for TDRs, some planners and farmland preservation advocates contend that this flexibility has led to more sprawl than would otherwise have occurred (Dehart and Etgen, 2007, pg. 108). Essentially, they are critical of the fact that there are developments (red areas) going into rural zones (white areas) as shown in Figure 1. In their view, all of the rural zones – both the FCD/RPD and the RCD, (the blue-hatched and white areas of the map) – should have been downzoned

[3] Two county-wide downzonings – one in 1999 and another in 2003 – reduced the RCD density limit to 1 house/10 acres and then 1 house/20 acres, where it currently stands today. However, with TDRs, developers were permitted to build up to 1 house/2.5 acres during the 1978-1998 period; today, they can go to 1 house/4 acres. This current density bonus is 500% -- i.e., developers are permitted to build up to 5 more houses per acre with TDRs than without. See Walls and McConnell (2007) for more details about these downzonings and other features of the program.

[4] A farmer's first step to selling development rights and preserving his land is to have the land designated as an APD. Once it is an APD, development rights can be lifted and sold.

[5] These numbers were provided by Bowen (2008); 5,366 acres have been preserved by the county's PDR program and 25,722 acres in total are under easement from all programs.

Figure 1. Land Use in Calvert County, Maryland



Source: Map created using subdivision, agricultural land, and TDR data from Calvert County Department of Planning and Zoning. See McConnell, Kopits, and Walls (2006).

and protected from development with TDR use permitted only in the town center and residential zones (the yellow and orange areas of the map). This view and the alternative view we have expressed in the publications cited above are clearly at odds. We have argued that an alternative program design in which receiving areas are more limited often dooms TDR programs to failure, because there is often no residual demand for density in those zones. If there is no TDR market created because of insufficient demand, then the goals of preserving farmland in the targeted preservation areas does not occur.

Sorting out these competing views of the Calvert outcome is difficult without knowing the counter-factual – i.e., what would have occurred had there been a different kind of TDR program or no program at all. This is an issue we return to below.

III.2. Montgomery County, Maryland

The alternative program design often held up by planners as a more appropriate model is embodied in the Montgomery County, Maryland, TDR program (Johnston and Madison, 1997). Montgomery County's program, which also targets farmland preservation, began in 1980 with downzoning of a 90,000-acre rural area of the county designated the Rural Density Transfer (RDT) zone. Original limits were 1 house/5 acres; the downzoning restricted development to 1 house/25 acres. To compensate landowners and to avoid a sharp reduction in growth in the county, landowners in the RDT zone were allocated TDRs equivalent to the original 1:5 density limit. These TDRs could be purchased and used by developers in a variety of other areas of the county ranging from very high density urban areas to suburban zones with baseline density limits of 1 house/2 acres.

The Montgomery program has preserved more land, by far, than any other TDR program. As of June 30, 2008, nearly 52,000 acres had been preserved.[6] Most of the TDR transactions took place in the 1980s, a period of high growth in the county. We have argued elsewhere that this growth, due in large part to the county's proximity to Washington, DC, created a strong TDR demand, and the RDT downzoning combined with the generous TDR allocation created a strong supply (McConnell and Walls, 2009). These two key ingredients led to an active TDR market.

Although the farmland preservation and "smart growth" advocates admire many features of the Montgomery program, it is important to first, highlight the lack of flexibility in the program compared with the Calvert program and second, dig deeper to look at the patterns of TDR demand and use in the county.

In contrast to Calvert, where there was no downzoning of the agricultural areas, Montgomery imposed a very restrictive downzoning, leaving landowners in the RDT with essentially only one option: to sell TDRs. Moreover, no other region of the 317,000-acre county was designated as a sending area, only RDT landowners can sell their development rights. And the RDT is a sending area only; not only can it not be a receiving area, the baseline density limits are very restrictive, making development a less attractive option. Essentially, this treatment of the 90,000-acre area is an example of "one-size-fits-all" zoning regulations that we described at the beginning of the paper. While it protects open space, it is likely to do so at high cost because of its lack of flexibility across landowners.

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[6] Acreage totals for the TDR program and other farmland preservation programs are available from the county's Department of Economic Development at http://www.montgomerycountymd.gov/content/ded/agservices/pdffiles/pie08.pdf.

By digging deeper into the workings of the program, we have found that despite the county's intent to have many receiving areas designated in high-density zones, most of the TDR use has been in the relatively low-density areas. Figure 2 shows, by zoning category, the maximum number of TDRs allowed by county rules, the maximum allowed by the individual Planning Areas of the county, which set their own, usually more restrictive rules, and the actual number of TDRs used. The figure makes clear that most TDRs have been used in the relatively low-density zone that allows 2 houses/acre, followed by the 1 house/2 acre zones. And even in these areas, the Planning Areas are not allowing as much density as the county would have permitted and developers are using far fewer TDRs than even the Planning Areas designate.

There are two likely factors leading to this outcome: (1) limited demand for density beyond baseline limits, and (2) high transaction costs due to the fact that TDRs do not confer a "by-right" density in receiving areas; in effect, each development must be negotiated individually, including the number of units and the density, through a lengthy review process.

Figure 2. Permitted and Actual TDR Use, by Zoning Category in Montgomery County, Maryland

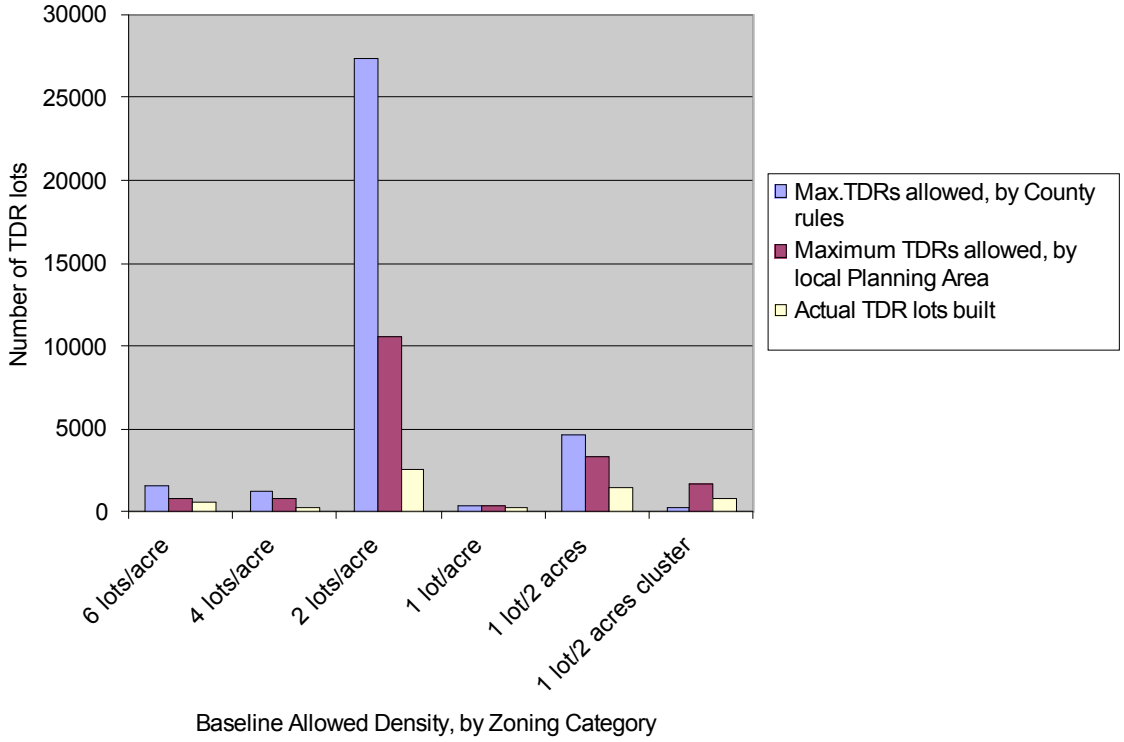
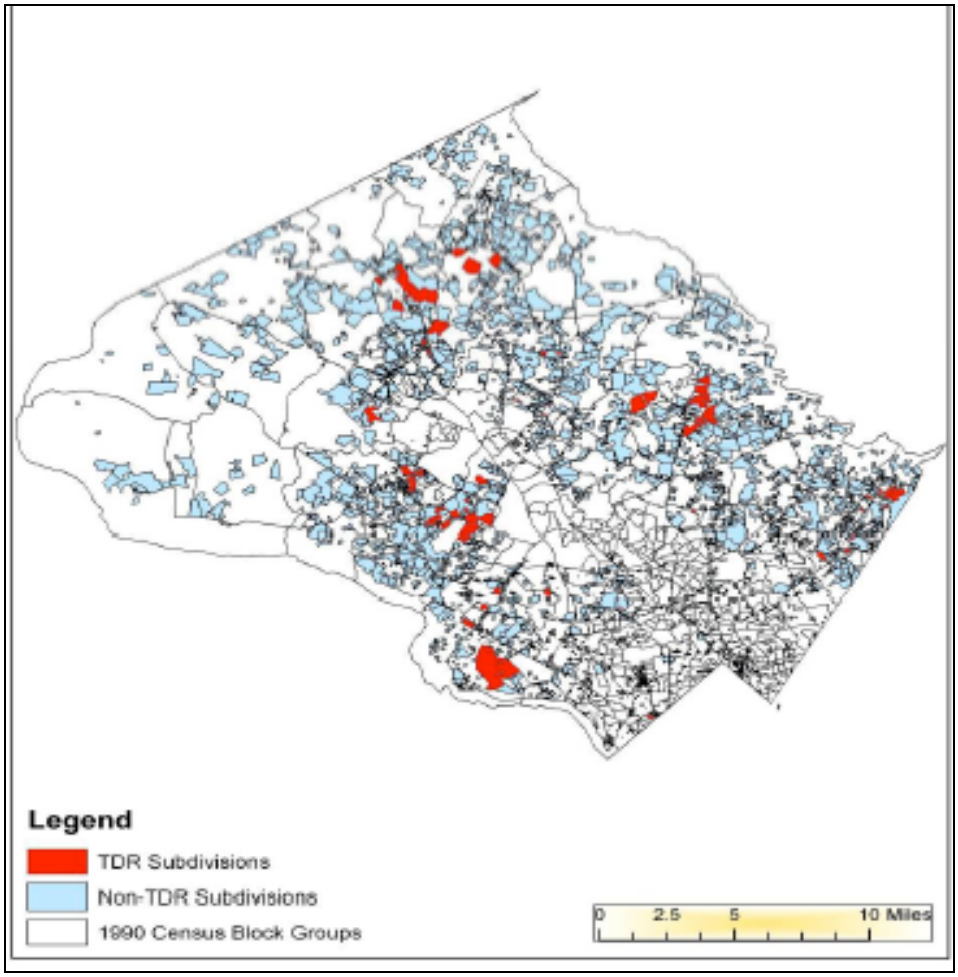


Figure 3 shows a map of the county with Census block groups outlined and all subdivisions built in the county between 1973 and 2004; TDR subdivisions are

highlighted in red and non-TDR subdivisions in blue. As we explained in the context of Figure 2 above, each of the Planning Areas can choose where to designate TDR receiving areas and what density to allow with TDRs. This is a partial explanation for the spatial patterns of TDR use that show up on the map; some areas of the county are limiting TDR use more than others. The other explanation is that developers are not using as many TDRs as they could, thus there are many more blue subdivisions than red ones on the map. And finally, it can be seen that TDR subdivisions are not located in the most densely developed area of the county, closer to Washington, DC, which is the lower portion of the map. The area designated for preservation, the RDT, is not highlighted on the map but lies in the north and west portion of the county where it is clear that there is little development.

Figure 3. Development Patterns in Montgomery County, Maryland



Source: Map constructed using subdivisions built (1973-2004) and TDR data (1980-2004) from Montgomery County Parks and Planning Department. See Walls and McConnell (2007) and references therein.

III.3. Other TDR Programs

While Montgomery and Calvert County are among the best-known programs and are by far the most successful in terms of protecting land from development, there are many other programs in existence. By Pruetz's (2003) count, there are approximately 140 communities in the U.S. with some kind of TDR program on the books. However, several programs that we have studied exhibit the problems we discussed above: inactive markets that appear to be a result of very limited demand for TDRs. In some programs, changes in receiving areas, baseline density limits, or other factors that impact the demand side of the market have been implemented and have either dried up demand or increased it, depending on the change. Examples include Queen Anne's and St. Mary's Counties in Maryland and Malibu, California. Newer programs are trying innovative approaches on the demand side. Several communities have discarded the idea of trying to force additional density into established, high-density zones and rather, designated receiving areas in new "greenfield" locations. Chesterfield Township in New Jersey, Collier and Sarasota Counties on the Florida gulf coast, and Larimer County in Colorado are three examples.

Whether these newer programs will have active markets, and what the patterns of development and preservation will look like if they do, is unclear. Moreover, while we have speculated about how land uses have changed in the programs described above, it is difficult to know what the development and preservation outcome would have been had the program not been implemented -- the counter-factual. What would land use look like with either no TDR program or a program with different design features? We would like to be able to analyze the effects of different program parameters and designs to determine which are most important for creating effective markets for land preservation. It is also important to be able to assess trade-offs in program design – such as flexibility in the receiving areas – and land use outcomes.

These questions cannot be addressed without the aid of a spatially explicit model of land use. The model needs to incorporate decision-making on the part of landowners, consumers, and developers. It needs to capture market dynamics, as well as spatial heterogeneity. In the next section, we describe more carefully the features that need to be included and describe the model we are developing. We then describe the simulations we will undertake.

IV. A Land Use Simulation Model

To accomplish our goals – analysis of the spatial and time patterns of land use under alternative policies – we develop a simulation model of land use in a hypothetical community. As with all simulation models, we are facing many trade-offs. The major trade-off, as usual, is between the model's simplicity (that includes analytical simplicity and fast run times) and its ability to adequately represent all (or at least most) features that, based on current knowledge, are important for understanding outcomes of TDR

programs. Below we list and briefly explain the features that we believe are critically important for modeling TDR programs in a simulation context.

IV.1. Model Features.

Heterogeneity of agents. The presence of heterogeneous consumers is important for accurate representation of housing demand – in particular the relative demand for housing of different types. Some of the desired dimensions of consumer heterogeneity are income level and preference for lot size and open space. At the same time, farmer/landowners should be modeled as heterogeneous agents with respect to their commitment to farming and initial land endowment.

Heterogeneity of land parcels. Three significant features of land parcels that should be reflected in the model are (i) heterogeneous agricultural productivity, (ii) differing sizes of existing farms, and (iii) spatial location of parcels and therefore, their attractiveness for development.

Heterogeneity of dwelling units. Heterogeneity of dwelling units is critically important for a representation of demand for housing. In particular, in order to effectively represent the interaction between zoning rules, construction of new housing, and the overall housing supply, there should be a quite rich representation in the variety of housing. In particular, individual houses should differ by the house size (in square feet of floor space), lot size, location and possibly other characteristics, such as the presence of nearby open space.

Endogenous prices. In order to evaluate and compare the modeling outcomes, the prices of land, housing units, and TDRs should be determined through market forces. Also, modeling of counterfactuals and alternative policies is meaningful only if the changes can be propagated through the entire system of prices represented in the simulation model.

Spatially explicit modeling. Evaluating spatial outcomes is at the heart of measuring TDR program effectiveness. Thus, it is essential for the modeling framework to distinguish more rural areas from urbanized regions and environmentally sensitive areas, or other target preservation areas, from non-sensitive areas. In addition, spatially explicit modeling is important for correct determination of the location-related price differentials in the housing and land markets.

Dynamic modeling. The process of land development is an intrinsically dynamic process, as is the land preservation decision. Farmer/landowners evaluate their choices each period in the context of expectations for the future and the recognition that both development and preservation are irreversible decisions. In addition, we are interested in the outcomes of land preservation over a reasonably long period of time, on the order of several decades, rather than in a single period.

Explicit representation of housing density, zoning, and other land use regulations. In order to be able to test the effectiveness of land use policies and regulations, they have to be explicitly represented in the model. Moreover, policies such as TDRs work together with zoning regulations, therefore it is critical to represent this real-world setting.

Optimizing behavior of individual agents. The assumption that all individual agents try to achieve the best outcomes for themselves and not just follow some rules of thumb is a standard feature of economic models. Sometimes, due to imperfect information or uncertainty about the future, the individual agents might achieve outcomes that are inferior to the true optima. Nevertheless, it is important to assume that each agent intends to achieve the best possible outcome, conditionally on the limited access to market information.

Ability to evaluate outcomes (welfare analysis). The goal of the TDR programs, first of all, is land preservation. Therefore, it is natural to assume that the amount and the location of preserved land is the desired measure of the program effectiveness. However, in addition to preserving land, a TDR program would alter the construction pattern that would otherwise occur, affect land and housing prices, and ultimately would impact the well-being of all economic agents in the model. For example, one particular design of a TDR program may result in land preservation but a welfare loss, while another program design might preserve as much land with no welfare loss. The welfare calculation adds an important dimension to the program evaluation. Given the complexity of the effects, it is highly desirable to be able to evaluate the outcomes of the program from a broader standpoint. Moreover, it is likely that the presence of a TDR market would have a different impact on different groups of agents (e.g. low income consumers vs. high income consumers). The ability of the modeling framework to produce a welfare analysis is a strong feature that is very helpful in producing quantitative comparisons for policy analysis.

Faced with this long list of the model's features and capabilities that the model should have, we have very limited options. Given the importance of agent heterogeneity and an explicit treatment of space, we cannot employ simple and elegant urban economics models with closed-form solutions. Essentially the only two sensible alternatives are large-scale spatially disaggregated equilibrium models (e.g. Safirova et al. 2006) and agent-based models (ABM). Following the preliminary modeling and analysis, we came to the conclusion that an accurate representation of salient features of TDR markets requires levels of heterogeneity (especially among agents and dwelling types) that cannot be adequately handled in a spatial equilibrium model. In the next sections we describe advantages and drawbacks of the agent-based models and contrast them with those of alternative modeling approaches.

IV.2. Why use ABMs for Land Markets?

Economic models of urban land use and land markets vary in their representations of space, spatial heterogeneity, price expectations, and levels of uncertainty, but they

typically fall into the category of either econometric or spatial equilibrium approaches (Irwin, 2009). Econometric models of land use change typically rely on micro-data to estimate models of land conversion and other phenomena and then use the estimated model to simulate outcomes. Examples include Irwin and Bockstael (2002), Irwin et al. (2003), and Towe et al. (2008). These models are based on theoretical economic models in which individuals are assumed to maximize their net expected returns by choosing the most profitable land use (Arnott, 1980; Arnott and Lewis, 1979; Capozza and Helsley, 1990). Intertemporal land use decisions are driven by land owners' forward-looking rent expectations. As outlined by (Irwin, 2009) this method allows for the inclusion of substantial spatial heterogeneity, but data requirements are often restrictive and methodological issues such as spatial dependence, endogenous regressors, spatial instability of parameters, and selection biases can arise. Furthermore, econometric modeling is limited in its ability to represent land use dynamics (Parker et. al., 2003). Econometric parameters ineffectively capture feedbacks that occur over multiple spatial and temporal scales that often drive land use change dynamics (Irwin, 2009).

Spatial equilibrium models are foundational to urban economics (Glaeser, 2008). They are based on the assumption that given a sufficiently long period of time, mobile consumers will locate across a spatially heterogeneous landscape so that utility is equal for all consumers and location disamenities are perfectly offset by prices. The spatial structure of these models is often based in the monocentric city model with travel costs to the central business district accounting for spatial variations (see Bento et al. (2006), for example). Newer versions of these models abandon the monocentricity assumption (Epple and Sieg, 1999; Walsh, 2007). The spatial equilibrium assumption provides analytical tractability for modeling urban land use patterns and captures the capitalization process (Irwin, 2009). However, these models quickly become complex when adding the spatial detail often necessary to analyze land use policies such as TDRs. And the equilibrium requirement does not allow for an explicit representation of land use change dynamics in the model, which makes the integration of economic and ecological models extremely difficult (Irwin et. al., 2007). Furthermore, in reality, cities tend not to be in spatial equilibrium. The importance of out-of-equilibrium market dynamics has gained growing recognition among economists (Arthur, 2006).

Driven by these limitations, the use of ABMs for land markets has grown rapidly (e.g. Arthur, Durlauf, and Lane, 1997; Epstein and Axtell, 1996; Kirman and Vriend, 2001; LeBaron, 2006; Lux, 1998; Tesfatsion, 2006). ABMs offer several advantages over traditional economic models because they can explicitly represent causal drivers of land market dynamics. These advantages are outlined in Parker and Filatova (2008) and we summarize them here:

1) *Heterogeneous goods can be traded by heterogeneous agents.* Unique attributes of land (productivity, neighborhood characteristics, etc.) can be represented explicitly and are selected and traded by heterogeneous agents. For example, farmers selling their land have heterogeneous agricultural returns derived from their land's productivity and operating costs, and they may have different heuristics for decision-making (prediction models and preferences for farming

versus selling). Developers differ in their costs and the housing demands they face based on the zones in which they operate. Consumers differ in preferences and income. Heterogeneity in all of these agents drives their interactions and ABMs allow for that. Transaction prices then emerge dynamically.

2) *Spatial and agent-agent interactions are explicitly represented*. Location-specific land uses and option values affect the use and value of surrounding land through spatial externalities. The dynamics of these uses and values are driven by competition between agents' bid and asking prices and future price expectations. Heterogeneous consumers value living in specific locations differently. ABMs capture these differences by modeling competing consumer bids for a specific location, therefore explicitly modeling the emergence of neighborhood effects. Furthermore, transitional dynamics of that location will be dependent on which consumers value that location more in the future. Thus, feedbacks emerging from consumer competition for spatially unique land uses are preserved locally and dynamically adjusted.

3) *By modeling agent-agent and agent-environment interactions, market non-equilibrium outcomes can be represented.* Land markets are rarely in equilibrium and typically display such complex behaviors as cyclical growth and decline and bubbles (Arthur, 2006). Land markets and associated urban growth patterns tend to be path-dependent and driven in large part by out-of-equilibrium dynamics (Arthur, 2006; Tesfatsion, 2006). ABMs allow these dynamics to emerge rather than exclude them through abstract market adjustments.

ABMs have some drawbacks. Many of the models developed and used to analyze land use dynamics and spatial outcomes, for example, are highly complex and detailed – the UrbanSim model, for example (Waddell, 2002) – making it difficult to understand model results and attribute those results to particular factors. In addition, the models can generate multiple plausible outcomes and developing rules for choosing among them can be difficult and sometimes seem arbitrary. However, land use change and urban growth are spatially complex and path-dependent phenomena; ABM modeling provides the necessary flexibility and richness to address such challenges without the traditional spatial equilibrium and representative agent simplifications needed for analytical tractability.

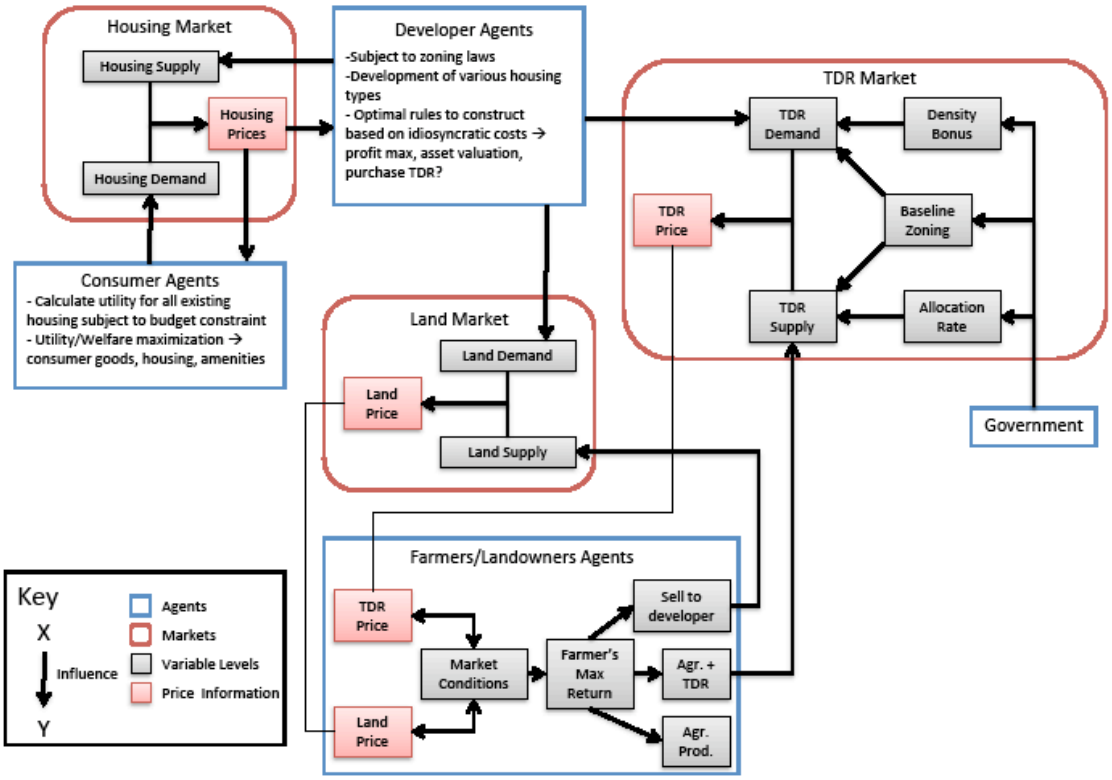
In the next section, we describe our modeling framework and give examples how it can be used to simulate scenarios and policies.

IV.3. Preliminary Description of the Simulation Model

The agent-based simulation model we are currently building will represent three interconnected markets – the land market, the housing market, and the TDR market. While the land market and the housing market are both spatially explicit, the TDR market will encompass the entire modeling area. At present, we have built a first version of the land market and continue to work on the details of modeling the other two markets.

Figure 4 provides a visual description of the model, including the interactions among the markets. In what follows, we briefly describe the agents in the model and their decisions, the role of individual markets, and the interaction between different markets. Then, for illustration purposes, we provide several examples of how scenarios of interest can be modeled in this framework.

Figure 4. Interdependence of Agents and Markets in the Land Use Simulation Model



IV.3.1. Behavior of Agents in the Model

Consumers. Consumer agents in the model are the force that determines the demand for housing. Consumers are endowed with exogenous income and intend to optimize their utility functions that depend on housing characteristics and a non-housing consumption good. The housing characteristics we explicitly incorporate in the model include square footage of the house, lot size, house location, and a general, spatially-differentiated environmental amenity. The housing supply in each period consists of houses, each of which is a bundle of housing characteristics. As a result of bidding for houses, housing is allocated among consumers, and prices of individual transactions are determined endogenously in the model.

Developers. Developers in this model play two roles. On the one hand, they serve as landlords for existing housing and accept or reject consumers' bids. On the other hand,

they produce new housing by first purchasing land from farmers and then constructing the new housing. Developers intend to optimize their profits from constructing new housing and select the most profitable types (bundles of characteristics) of housing to satisfy their goal. Their costs of construction are exogenously determined. In making their decisions, developers are faced with zoning density limits that vary spatially. These limits constrain the lot sizes of the houses that the developer can build. If the most profitable lot size is smaller than allowed by the zoning regulations – i.e., density is greater –purchase of TDRs may occur if that is the most profitable option. Thus, the developers engage in transactions with farmers both by purchasing land and TDRs.

Farmer/Landowners. Farmers in the model provide a supply of land for future residential development. In each model period, a farmer can decide to sell his land to the developer, sell TDRs to the developer and continue farming in perpetuity, or not sell land or TDRs but just continue farming until the next period. Farmers are endowed with heterogeneous plots of land that differ from each other by their size, agricultural productivity, and operating costs. Farmers' decisions are described in more detail in the last section of the paper.[7]

The actions of agents who participate in more than one market (developers and farmers) establish the connections between the markets in the model. And consumers, although they ultimately purchase housing in one particular location, bid on houses over the entire region. Those features lead to a tightly integrated market system where each impact in one part of the system is propagated through several channels and affect the rest of the region.

IV.3.2. Characterization of Markets in the Model

Housing Market. The housing market determines the overall level of housing prices in the entire region. If housing supply lags demand, housing prices increase and provide a signal for developers to construct more housing. A similar mechanism is engaged for specific housing characteristics. For example, when there is a relative shortage of houses on small lots, their relative profitability will increase and the developers will be encouraged to build more of such houses.

Land Market. The land market determines the dynamics of land development over time. If a developer escalates his willingness to pay for land due to greater housing demand, the farmers are more likely to sell their land. On the other hand, new housing construction temporarily reduces the pressure on housing prices and reduces the developers' willingness to pay for land. Such mechanisms work in different segments of the land marker and can lead to interactions between the segments. For example, a massive housing construction in one segment will indirectly reduce housing prices and therefore the developers' willingness to pay for land in other markets.

[7] At this point, the farmer module has been fully programmed and run under various scenarios, thus more details of this module are available than the others.

TDR Market. The TDR market is closely connected with other markets, and especially the land market. The sharp difference between the TDR market and other markets is that this is the single market for the whole region, since the TDRs as a commodity is not a local good. As such, the presence of the TDR market reinforces the interconnectedness between local land markets, since developers and farmers can buy/sell TDRs anywhere in the region. Note also from Figure 4 the role that government plays. Several zoning and TDR design parameters affect the TDR market.

IV.3.3. Examples of How the Model Can be Used

Although some specific modeling details have yet to crystallize, the connections between the markets in the model allow us to hypothesize how some of the scenarios of interest will be represented in this framework once the full model is complete. Each of the following could be implemented and compared to a baseline run of the model which would include a baseline TDR program of a design we specify. That baseline program will include a large rural sending area targeted to certain areas that have the highest value in preservation, and a receiving area that is also broadly defined to include a fairly large area with the ability to add density to a range of baseline lot sizes. This baseline model would yield a time path for the sale and use of TDRs over time, in addition to the results in the markets for land and housing development over time. Here we describe farmland protection, but TDR programs can apply to protection of other land-based resources.

Elimination of the TDR program. Here we assume that the TDR program was never implemented and no land has been preserved. This is the counter-factual to which the results of any TDR program must be compared. What would have happened if we did not have this program? Elimination of the TDR program will take away the opportunity to preserve land from development, particularly those areas that were designated for preservation under the TDR program. Farmers with the highest agricultural land productivity in these areas would be more likely to enter their land into the pool of potentially developable lands. However, based on their high value in agriculture, those lands are unlikely to be developed early. Instead, the housing construction in urbanized areas will be limited to lower density units since TDRs are unavailable. The overall outcome will depend on housing market conditions and the parameters of the developers' profitability conditions in different regions, but it likely to result in lower density development and less land preserved.

Assessment of the Effects of Changing the Receiving Areas. There is controversy about whether receiving areas should be designated only in high density urbanized areas, and not at all in low-density areas. We discussed this issue above in Section III . If the TDR program were changed to allow TDRs only in areas that already have high baseline densities, markets throughout the urban area could change. The demand for TDRs might fall, because of the reduced options to developers for building with extra density. The model can be used to explore the parameters of housing demand that affect this outcome. In other words, under what conditions would the TDR market continue to function, additional housing be built in these limited areas, and land preserved?

A Decrease in Baseline Zoning Density Limits in Urbanized Areas. A decrease in the density limits in urbanized areas (downzoning) will lead developers to either build housing units on large lots, or to purchase more TDRs to be able to construct higher density housing. Initially, this policy is likely to increase the demand for TDRs and increase land conservation in the sending areas. However, if TDRs cannot be used to reach the original density levels or if TDR costs are too high, there is likely to be pressure to develop in other parts of the region, including more rural areas. In fact, "leapfrog" development is often a criticism of downzoning, urban growth boundaries, and other growth controls (Pendall, 1999). Ultimately, the overall impact of the down-zoning policy in our model will depend on model parameters and we will explore these results. Without computer simulation of a well-parameterized, spatially-explicit, dynamic model, it is impossible to determine the overall regional effects of this change.

As we stated in the discussion of agent-based models, their development requires a construction of a set of rules that govern the model's propagation from one period to the next. While such sets of rules are not unique and at times may seem arbitrary, the development of a consistent set of rules that produces a realistic development pattern is a complicated task. At present, we have constructed a set of rules that depict the interactions between farmers and developers in the land market. In the next section we describe the workings of the land market in detail.

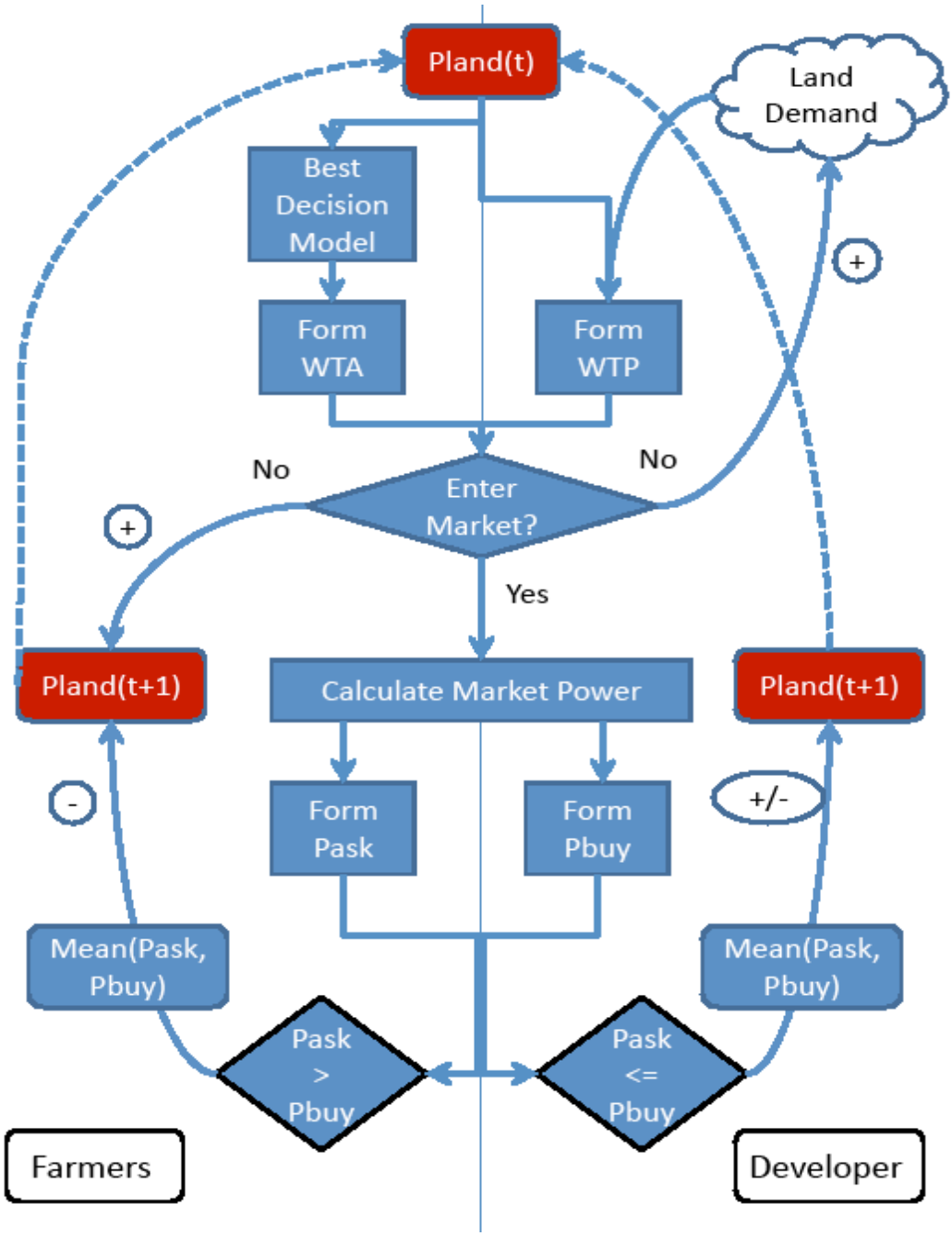
IV.3.4. Detailed Description of Land Market Interactions

Land market interactions between farmers and developers that endogenously generate land prices are depicted in Figure 5 and are described below. Farmers are each endowed with a randomly generated set of characteristics including acreage, land productivity, operating costs, and farming versus selling preference. Acreage is allocated randomly (within a spatially-delineated zone) then assigned an agricultural productivity that is uncorrelated with acreage. Agricultural return is calculated as the revenues from agricultural output, considering the land's productivity, minus each farmer's idiosyncratic operating cost. A farmer's baseline willingness to accept (WTA) payment to sell his land is determined by calculating the value of his agricultural return per acre in perpetuity. This WTA is adjusted dynamically through price prediction models. Farmers attempt to predict the price of land in a given period using information about past prices. Prediction models allow farmers to follow trends in land prices and secure speculative profits if they exist.

To represent the heterogeneity of farmers, each farmer is randomly assigned twenty prediction models of six different prediction methods. Predictions models are adapted from those described by Arthur (1994) in the "El Farol Café" problem to describe consumers' decisions over spatial goods. Prediction models apply prediction method-specific rules to past price information over a specified time period before the present (i.e. anywhere from 1 to 10 years before the present). Each price prediction model utilizes one of the six different methods for predicting the price of land in each farmer's zone in the next period. Twenty are assigned to ensure diversity in the parameters of

prediction models of the same type (i.e. a farmer may have multiple versions of the same type of prediction model, but each version may specify a different time span of past price information over which current predictions are based).

Figure 5. Land Market Interactions between Developers and Farmers



For example, one prediction method looks back into past price information 'x' years ago up to the present and extrapolates a trend that is used to predict next period's price. Another prediction method calculates a mean price over 'x' years ago up to the present and uses that mean as a prediction for next period's price. Others are purely numerical prediction methods, which also look over varied time spans into the past, use cycle predictors, price change analysis, and trend mirroring. In addition, behavioral prediction methods, which use the behavior of other farmers to predict next periods' price, are included. A farmer in Zone 'z' uses the rate of farmers selling their land 1) in their zone and 2) over the entire region to inform their own decision.

All models in the farmer's 'projection model bank' are used to make a prediction for the next time period's price (t+1). In the next time period, after that period's price is known, error squared is calculated for each model by squaring the difference between the predicted price and the actual price, and the projection model with least error is used as the prediction of the current period's price. This same process of prediction and evaluation is used every period so that the most successful prediction model is used every time.

IV.3.5. Determination of Land Prices and Farmers' Decisions

Based on current and expected conditions of the land market, farmers are making the decision whether to continue farming, sell their land to developers, or continue farming and sell their development right on the TDR market (Figure 5). Farmers are making these decisions based on limited information. For instance, they know their current agricultural return, current and past land prices within their zone, and the number of farmers in their zone, but they do not know the explicit rate of population growth, future land prices, nor the decisions or sale prices of other farmers in their zone. Therefore, farmers use their prediction models to fill-in these knowledge gaps through time and choose the option that maximizes their expected profit.

Given the price of land in period *t* (which was generated by farmer-developer interactions in period *t-1*), farmers use their most successful prediction to set their WTA in the current period. This represents a price floor below which the farmer will not sell his land, and ensures that he receives at least the agricultural value of his land in perpetuity. Since a farmer's WTA is dynamically adjusted based on the farmer's most successful prediction of the current period's price, it will follow market trends as predictions are utilized and discarded based on their success at predicting changing prices. Simultaneously, a developer will generate his own willingness to pay (WTP) based on the profitability of conversion of purchased land to a particular housing type. The developer's WTP is calculated for each possible housing type and is based on the maximum positive difference between rent at *t* for each housing type and its corresponding construction costs.

At the beginning of each time step, the model checks if any farmers' WTAs are below a developer's WTP. If so, mutually beneficial transactions may exist and the corresponding farmers enter the land market. At this point, land supply and demand are

known to all parties in the current period and each perceives the market power of buyers and sellers according to the procedure proposed by Parker and Filatova (2008):

$$P_{ask} = \text{WTA} \cdot (1 + \varepsilon); \quad P_{bid} = \text{WTP} \cdot (1+\varepsilon)$$

where ε= (Land Demand -Land Supply)/(Land Demand +Land Supply) and thus provides a measure of the relative size of excess demand for land. If farmers supply more land than is demanded by developers, market power lies with the developers and they formulate a bid price (P_{bid}) below their initial WTP. Conversely, if developers demand more land than farmers supply, market power belongs to the farmers and they increase their asking price (P_{ask}) above their initial WTA. If P_{bid} falls below P_{ask}, then the farmer withdraws and is returned to the farmers' pool to await the same decision process next time step. However, if P_{bid} remains above P_{ask}, then a mutually beneficial transaction is made. Through individual transactions, the developer buys all of an individual farmer's land beginning with the lowest asking price. Market land prices are the aggregate result of individual exchanges between farmers who sell their land and the developers who buy it. We consider the equilibrium mean price for each zone in $t+1$ to be the mean of all sale prices in period t, weighted by farm size.

This method for endogenously generating land prices has several important consequences. First, the land market is responding to the behavior of farmers making decisions under incomplete information. Predictions are made based on past and present trends in land prices and substantial uncertainty about future trends. In general, farmers with the highest productivity will have the lowest probability of selling and the highest asking prices all else equal. As a consequence, land prices will start low because farmers with low productivity/low asking prices will sell first and the mean selling price will be low. But as farmers and their land leave the land market, the market price for land will increase -- the result of land supply decreasing and the average asking price of remaining farmers increasing. More farmers will sell as the price increases. Fluctuations in land prices are caused by interactions between farmers and developers within the current market conditions as relationships of market power change through time. Farmers will try to do the best for themselves, but they may end up choosing to sell at a time that is not necessarily optimal.

The developer and consumer decision frameworks are well along, but not all aspects of those two components of the overall model are well enough developed to include detailed explanations here.

V. Concluding Remarks

In this paper, we described a market-based policy for preserving land as open space, Transfer of Development Rights. TDRs have many virtues, not the least of which is the potential to achieve open space protection at least cost. Because of the flexibility given to landowners and developers, TDRs can be more efficient than more command-and-control based policies such as restrictive zoning, urban growth boundaries, clustering requirements, and so forth. However, TDR program success depends on the functioning

of created markets and oftentimes these markets fail to work. Many communities have programs on the books that achieve very little. Moreover, even the programs that have worked best have achieved controversial outcomes and have been much debated. We described the Calvert and Montgomery County, Maryland, programs and the issues that have been put forth about those programs. In order to fully address these issues it is best to construct a simulation model of local land markets that captures all of the features of the land, housing, and TDR markets along with agent behavior in those markets and use that model to evaluate alternative policies. That is our objective in this research project.

We described the framework of our model and our plans for assessing alternative TDR programs. Our development of an agent-based model of the land market that fully incorporates economic behavior of agents, market-clearing conditions, and allows for welfare analysis will be unique in the economics literature on land markets. Although the model is not yet fully developed, we provided detail about the farmer/landowner module and how the agent-based approach plays out. In future work, we will show the consumer and developer components, baseline model runs, and analysis of alternative land use policies.

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Can Markets for Development Rights Improve Land Use and Environmental Outcomes?

By Virginia McConnell, Elena Safirova, Margaret Walls, and Nicholas Magliocca
Resources for the Future

Discussant comments – Heather Klemick

The project "Can Markets for Development Rights…" seeks to assess the efficiency and environmental outcomes of tradable development rights (TDR) and other programs to preserve open space using a new simulation model of land use dynamics. The report reviews the TDR approach to land use preservation and describes the key design issues that affect the performance of TDR programs. It also presents two examples of real-world TDR programs based in Maryland's Calvert and Montgomery Counties and discusses features that have led to their high levels of activity. The authors propose to build an agent-based model, which can represent heterogeneous consumer, farmer, and developer behavior and allow for out-of-equilibrium land market dynamics. Once the model is complete, they propose to examine outcomes under a variety of hypothetical policy scenarios, including a no-TDR baseline, TDR, tighter zoning restrictions, and other relevant options.

The project looks to be an exciting contribution to the literature on land use policies. I appreciated the careful justification of the selection of the agent-based model and the discussion of its pros and cons relative to other modeling approaches. The representation of heterogeneous farmer preferences strikes me as a particularly interesting way of adding complexity to behavior while adhering to the assumption that agents are rational profit-maximizers. The relevance of the work could even extend beyond local amenities to inform the development of policies to mitigate land-based greenhouse gas emissions, considering that more and more cities and counties are participating in voluntary carbon markets like the Chicago Climate Exchange.

I have four major comments on the report. Even if the authors cannot feasible address all of these points in the modeling framework as part of the current project, it would at least be helpful to see more discussion of these issues in the final paper or future extensions to address them.

- *Heterogeneity of amenities/externalities*. Although after further discussion with the authors, I understand that this issue will be addressed in future model extensions, I would still have liked to see a more detailed discussion of the heterogeneity and spatial distribution of open space externalities provided by land parcels targeted for preservation in the current paper. The report did not make clear whether amenities provided by open space parcels are assumed to be homogeneous (with distance from homes to the parcels the only source of variation), or whether the model allows open space parcels to provide different levels or types of amenities (whether recreational opportunities, scenic views, storm water runoff management, etc.). These local externalities could be uncorrelated or even negatively correlated with farmland productivity, and could

even depend on proximity to other open space parcels. To what extent will these complexities be addressed by the model in the future?

The report also led me to wonder whether there any TDR policies in place that establish trading ratios based on the value of environmental amenities. If TDR programs neglect to do so but these differences are important, what are the implications for the efficiency of outcomes?

- *Aggregate cap on development*. Can the model be used to solve for an "optimal" cap on development in the community? My understanding is that the environmental improvements are being driven by the aggregate cap (implemented through zoning), and the trading regime is a mechanism to achieve the environmental benefits at least cost. Even if it is not possible to use the model to solve for the cap, it would be helpful to see more discussion about how caps could be chosen to maximize welfare.
- *Distributional impacts*. The authors discussed the importance of welfare analysis for evaluating outcomes, and it seems that they will have the capability to evaluate welfare impacts for different sub-groups, not just the community as a whole. I encourage the authors to report on these impacts in the final report, since it could be quite interesting to see which groups (homeowners vs. renters; farmers with different agricultural productivity and open space externalities) benefit or lose out from the different policy options considered.
- *Relevance of the policy scenarios*. The no-TDR baseline and change in sending/receiving areas seem like interesting scenarios to consider, but I wondered whether downzoning in an urban area is the most relevant scenario. Presumably a community interesting in preserving open space would instead target downzoning to rural areas. (Though, based on my discussion with the authors, it seems that this is indeed a common scenario actively considered by several TDR programs.)

Understanding that the report represents a work in progress, I do also have two minor comments:

- Figure 3 is confusing. Even though the sending areas and urban areas are discussed in the text, it would be helpful to see these labeled, and to ultimately include a map more akin to Figure 1.
- I'd recommend tempering any statements claiming that Calvert and Montgomery Counties' TDR programs are the most "successful," recognizing (as the authors do later in the report) that there hasn't been sufficient analysis to assess whether current programs have been welfare-improving relative to counterfactual scenarios with alternative or even no preservation policies.

Preliminary Findings on
Ohio's Great Miami River Water Quality Credit Trading Program*

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Abstract: Water quality trading (WQT) has been advocated and attempted since Dales first introduced the idea in 1968. Yet this policy approach has achieved relatively little success in creating and sustaining WQT program. The Great Miami River Water Quality Credit Trading Program, run by the Miami Conservancy District (MCD), has shown to be an exception. Through innovative design and effective leadership, the program has come to resemble an actual market in which buyers are paying for pollution reductions and sellers are offering to provide those reductions in response to a price signal. A critical program design element has been to rely on county-level extension agents at Soil and Water Conservation District (SWCD) offices, which acts as intermediaries between farmers and the MCD program managers. Because of their longstanding relationship with farmers, these agents are able to recruit and advise effectively the potential applicants into the program. In this paper we summarize what can be learned from this experience to date and provide preliminary findings about the implications for WQT programs nationally. We draw primarily upon the bids from farmers to the program and interviews with county-level SWCD agents. Two main conclusions can be drawn at this stage in our research. First, bids have varied systematically across counties, influenced more by the agents who are assisting the farmers than variation of the properties of the farms and practices. Second, we find evidence that bids are influenced by strategic behavior at the county level and are also influenced by the opportunity available to farmers to receive conservation payments from the Farm Bill programs. Hence, despite its use of a reverse-auction structure, the MCD program has not pushed farmers to reveal their direct cost of implementing a conservation practice. Overall, the MCD experience demonstrates how effective design can improve the prospects for WQT, but it also demonstrates some of the limitations this approach has in achieving a cost-minimizing allocation of pollution reduction efforts.

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* This article was developed under a STAR Research Assistance Agreement No. RD-83367401-0 awarded by the U.S. Environmental Protection Agency. It has not been formally reviewed by the EPA. The views expressed in this document are solely those of the authors and the EPA does not endorse any products or commercial services mentioned in this publication. The authors also receive funding through Texas AgriLife Research with support from the Cooperative State Research, Education & Extension Service,, Hatch Project TEX8604.

Preliminary Findings on

Ohio's Great Miami River Water Quality Credit Trading Program

I. Water Quality Trading in the U.S.

In his seminal article, Dales (1968) used the case of water quality to outline how markets could be more efficient to meet pollution reduction goals. Although his depiction of a cap-and-trade program looks prescient today, his speculation that this approach would be used to address water pollution has been far from realized. While markets for air pollutants trade daily with volumes valued in the millions of dollars, the water quality trading (WQT) markets that exist are small and local and most have few if any actual trades.

The failure of WQT to lead to substantial trading activity is not for lack of potential or institutional effort. If cost heterogeneity were all that is required for a market to prosper, water quality trading would be an instant success. The prototypical trade is between a highly regulated point-source polluter such as a waste water treatment plant and agricultural nonpoint sources. There is usually a wide gap between the marginal abatement costs, as reported by the USEPA (1994), which predicted that trading could save between $700 million and $7.5 billion.

In terms of institutional support, overall EPA has been a strong supporter of WQT. The agency has provided substantial financial and institutional support as have many state-level environmental agencies. There are still important institutional barriers, including the lack of specific authorizing language in the Clean Water Act and some resistance within the agency (USEPA, 2008). Nonetheless, on balance, the EPA has not been a systematic barrier to trading.

Yet despite these economic and institutional forces that seem to favor WQT, in practice the policy instrument have had very limited effect to date. While transferable permit programs for air pollutants and lead in gasoline expanded rapidly in the 1980's and 90's,[1] applications to water pollution problems were rare and typically resulted in no water quality changes or trades of significance. Early efforts such as Wisconsin's Fox River program were largely unsuccessful

(David et al., 1980) and other programs such as Colorado's Lake Dillon program sat unused for over a decade (Woodward, 2003). By the time of their 2004 review of WQT programs, Breetz et al. identified 34 programs nationally that include some authorization for trading between point and nonpoint sources, yet few of these have led to more than a handful of real trades.

There are several programs that might be deemed successful, in which "trading" has facilitated economically productive enterprises or reduced costs (USEPA 2007). The Rahr Malting Company and the Southern Minnesota Beet Sugar Cooperative have both paid farmers to implement nutrient-reducing practices as part of an agreement to allow them to emit nutrients into the Minnesota River. In the Connecticut portion of the Long Island Sound watershed, the "trading" that exists is more like a tax-subsidy scheme, occurring each year after emissions have been reported. Those emitting in excess of their permit must pay, while those emitting less than their permit are paid, both at the same rate. Other programs involve trading among point sources (Tar Pamlico and Neuse River in North Carolina and the Grassland Area Farmers in California) operating under a group permit. However, none of these "success stories" seems to be delivering on the potential that Dales (1968) envisioned. In the Minnesota programs, the demand for pollution offsets comes from a single source, and there is limited diversity in the practices that can reduce pollution. The remaining programs do not include nonpoint sources, and therefore forego the cost savings that WQT has the potential to provide.

What is it about water pollution that makes the development of markets for its control so much more difficult than for air pollution? Numerous reviews and critiques of WQT have been published including Hoag and Hughes-Popp (1997), Jarvie and Solomon (1998), Shabman et al. (2002), and Horan et al. (2004). Together, they identify some important challenges faced by WQT. First, the geographic scope of such a market is defined by a watershed, which tends to be smaller than airsheds that define air pollution market. Second, monitoring and enforcement of trades is more difficult in WQT, particularly when a substantial part of loading problem is attributable to nonpoint sources such as agricultural practices. These factors combine to create

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[1] Stavins (2008) includes a concise summary of these early efforts.

thin markets with high transaction costs per trade, substantially limiting the trading that might occur in such programs.

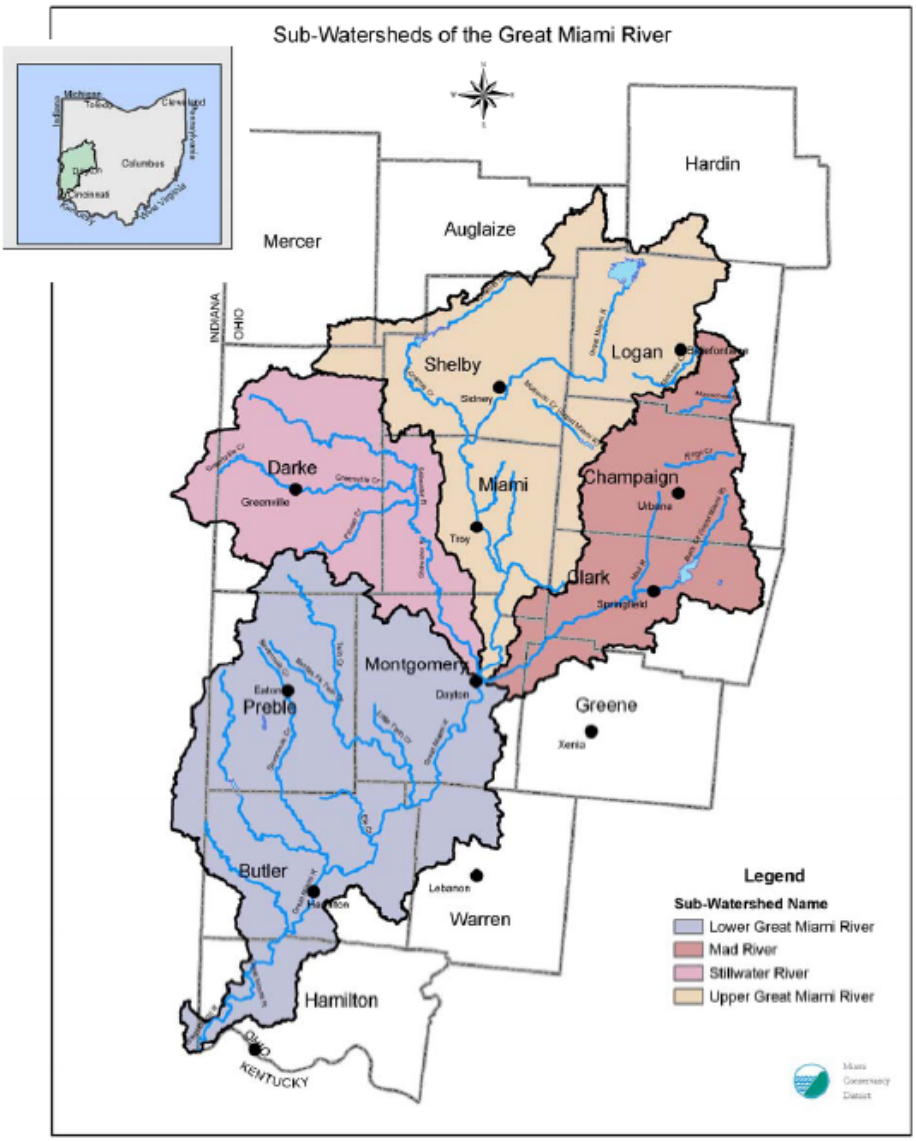
WQT programs in the U.S. have been very limited in scope and have not looked much like a true market in which a variety of buyers and sellers are trading nutrient credits. The program that is the focus of our research project is an exception. In Ohio's Great Miami River Water Quality Credit Trading Program, run by the Miami Conservancy District (MCD), point sources have paid over $1 million to purchase offsets of their emissions. Agricultural landowners have participated in five rounds of bidding program in which 51 projects have been funded from 171 bids submitted. While the program lacks a central exchange like the SO_2 program, it definitely resembles something akin to what economists would call a market.

In this paper we summarize what we have learned so far about the MCD program, highlighting the program's features that we believe are responsible for its success and some of the implications for WQT in general. A main observation is that the program's choice to use county-level agents as intermediaries to provide the conduit through which bids are submitted was an institutional innovation that has led to much higher level of bidding by farmers. However, this feature has also distorted bidding in a way that appears to have created a wedge between the farmers' reservation price and the bids that are actually submitted. That is, some agents have learned the screening criteria set by the MCD program managers, and they have the incentive to help their farmers obtain the highest bid possible. We also discuss how the program's design and policy setting raise interesting issues about the feasibility of obtaining bids that will lead to a cost-minimization in a WQT program.

II. Background and history of the MCD Program

The Great Miami River Watershed is located in southwestern Ohio and covers an area of nearly 4,000 square miles. Though dominated by agricultural lands (83% of all land), the watershed also includes major metropolitan areas including Dayton and part of Cincinnati. The watershed includes over 1,000 stream miles, of which 19.8% are rated as partially attaining aquatic life standards and 21.4% do not meet the standards (MCD, 2005).

Figure 1: Map of the Great Miami River Watershed



Source: Miami Conservancy District. 2005

For WQT programs, a Total Maximum Daily Load (TMDL) report serves as roughly analogous to the cap in standard cap and trade program. A complete TMDL report defines the maximum allowable levels of specific pollutants and allocates pollution reduction responsibilities to different groups of polluters. The Great Miami watershed is composed of four subwatersheds and TMDLs will eventually be developed for each of these. A TMDL was completed in 2004 for the Stillwater, and the Mad River TMDL is currently being prepared. The upper Great Miami watershed was assessed in 2008 and the process of developing a TMDL is ongoing and the

TMDL for the lower Great Miami watershed is scheduled to start in 2010 (Personal communication, Beth Risley). When implemented, TMDLs usually place a substantial and binding burden on the point sources in the watershed. Kieser and Associates (2004) reports 334 point source polluters in the watershed with most of the load coming from large waste water treatment facilities. The prospect that the TMDLs would impose restrictions on these sources, combined with an estimate that the cost of nutrient reductions by point sources might be more than thirty times more expensive than from nonpoint sources (Kieser & Associates, 2004), served as the impetus for demand for the trading program.

In the Great Miami watershed, the management of water quality issues is primarily the responsibility of the Miami Conservancy District (MCD). The MCD was established under the Conservancy Act of Ohio in 1915 with the core responsibility to provide flood protection for communities within the watershed. As political subdivisions of the state of Ohio, conservancy districts can form at the initiative of local land managers or communities to solve water management problems, usually flooding. In addition to flood protection, other approved purposes of conservancy districts include conserving and developing water supplies, treating wastewater and providing recreational opportunities. The MCD has accepted a lead role in developing a strategy for the reducing nutrient limitations in order to comply with the TMDLs.

Faced with TMDLs to be completed throughout its watershed, the MCD began exploring the possible use of WQT as a means to cost effectively address the water quality concerns of the district. The MCD's interest in WQT coincided with the development of guidance from US EPA on the issue (2003) and the initiation of a process to develop rules of trading with Ohio EPA. Kieser & Associates (2004) carried out a preliminary economic analysis of the opportunities for trading and that report found evidence that WQT could lead to a substantial reduction in the cost of meeting nutrient load restrictions.

The MCD plays a central role in the WQT market. Its responsibilities include acting as a broker for trades, supervising the collection of WQ data, issuing requests for nonpoint WQ improving projects, maintaining data on credits, and managing an insurance pool of credits (MCD 2005). The program became fully operable in 2006. Under the rules authorizing the program, point sources can purchase credits from MCD in order to offset nutrient load reductions that will be

required in their National Pollutant Discharge Elimination System (NPDES) permits. MCD in turn purchases credits from nonpoint sources.

Though often described as acting as a broker (USEPA 2008), MCD's role is more like a clearinghouse as described by Woodward et al. (2002). MCD plays a central role, purchasing all credits from nonpoint sources and being the sole seller of the credits to the nonpoint sources. There are no direct contractual agreements between the point sources and the nonpoint sources. The MCD program was initiated using a $1 million USDA NRCS grant, but wastewater treatment plants have since made payments of $1.2 million to the program to obtain credits for reductions.

As mentioned above, the TMDLs in the watershed serve as the drivers for participation by point sources. However, the salience of these limits has been diminished by the slow pace of TMDL development. In addition, Ohio EPA admitted in April 2008 that it likely overstated the phosphorus loads in the 2004 TMDL for the Stillwater, the only one that has been completed (Sutherly, 2008). Without a firm requirement that point sources be required to reduce their loads, it is unlikely that demand for credits will persist. As of the end of 2008, the MCD had essentially exhausted the funds it had available for credits (personal communication, Dusty Hall, MCD), and new funds are unlikely to arise until point sources face a credible and impending threat of regulations on their loads.

III. Innovative design features of the Great Miami Program

As we have indicated above, the MCD program stands apart from the vast majority of the WQT programs that have been attempted to date. Seven wastewater treatment plants have made payments into the program and have received credits in return. More impressive is that 171 bids have been submitted by nonpoint sources offering to implement nutrient-reducing practices on their land and these practices have come from a wide range of sources, with bids coming from 10 of the 15 counties within the watershed. If WQT is to become a central part of the nation's approach to address water quality problems, such widespread participation will be necessary.

There are several features of the MCD program that have, in our opinion, been critical to its success. First, one cannot understate the importance of an influential and inspired leadership.

The manager of the MCD program has been an effective leader for the program and organized over 100 meetings with various stakeholders during the process of formulating the program. This effort led to widespread support for the trading program from the stakeholder, representing farmer groups, municipalities, regulatory agencies, and others. While it may not be possible to replicate this inspired leadership, the lesson of taking the time to develop widespread support for the program should not be ignored.

The second feature of the program that we want to highlight is MCD's intermediary role as a clearinghouse in the program. This role means that point sources do not need to negotiate independently with farmers, nor do they sign contracts directly with the farmers. Instead, the point sources in the program deal only with the MCD office, which then accepts the responsibility of obtaining the necessary offsets from farmers. Buyers in this market face none of the transaction costs associated with negotiation, aggregation of sellers, or monitoring and enforcement. This effect is very important to the program's success given that transaction costs have often noted as a problem in WQT programs (Jarvie and Solomon. 1998).

Related to the previous point, but even more innovative in the MCD program was the coordination of the bids with the county-level SWCD offices throughout the watershed. Farmers wishing to be paid to reduce their load by implementing best management practices (BMPs) submit bids to the reverse auctions run periodically by the MCD. In this first-price reverse auction, the winners are those who submit the lowest bids in dollars per pound.[2] Farmers do not, however, interact directly with the MCD program managers. Instead, SWCD agents are the sole contact of the farmers with the program. These agents actively promote the program within their county to help recruit farmers, provide advice on bidding and other information on submitting project applications, disburse funds if a bid is accepted, and monitor the projects for compliance. As discussed by Breetz et al. (2005), SWCD agents have been used by other WQT programs and the longstanding relationships that these agents offer have played an important role in obtaining farmer participation. In other words, these agents have the trust and frequent contact with farmers, which would be costly to establish for any newly established WQT program. The MCD

program has taken advantage of these ties to a greater extent than any other program, and we believe this is a central reason that for the large number and variety of farmers who have submitted bids to the program.

An additional important innovation in the MCD program has been the use of a standardized Spreadsheet Tool for Estimating Pollutant Load (STEPL, USEPA Region 5, 2005). As in all WQT programs involving nonpoint sources, the nutrient reductions achieved by a change in agricultural practices is difficult to measure for each farm individually. Hence, the expected nutrient reductions for a given practice are estimated using standardized formulas. The STEPL spreadsheet, which is completed by the SWCD agent, gives estimates of the nutrient reductions that can be achieved through the implementation of a particular management practice. Separate spreadsheets are available for tillage practices, gully stabilization, bank stabilization, and manure management. The spreadsheet uses geographically specific soil characteristics, slopes, and other physical characteristics, in order to estimate the pounds of nutrients that will enter waterways before and after a practice is implemented. This creates reasonable estimates of the load reductions that can be achieved through the program, and a consistent model that is used by SWCD agents throughout the watershed. Inevitably, the spreadsheet is not a perfect predictor of mean runoff and there is some degree of subjectivity in its completion. Further, it represents overall annual estimates, and therefore, it ignores the inherent temporal and spatial variability in nutrient loads that economists have noted repeatedly is an important factor in designing an optimal trading program (Shortle, 1987; Hennessy and Feng. 2008). Finally, there does not appear to be any attempt to calculate site-specific transfer rates to equate the environmental impact of loads throughout the watershed. Despite these limitations, the spreadsheet does represent a practical means of calculating the nutrient reductions that a farmer can provide.

There are two other features of the MCD project applications that had potential to yield valuable information, but do not appear to have worked in practice. First, the applications filed with each bid include space for detailed information on the costs that a farmer would face in implementing his or her practice. If completed and accurate, this would have provided program managers and

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[2] Total pounds are calculated by simply summing up the pounds of nitrogen and phosphorus and

analysts valuable information about the underlying cost of reducing nutrient loadings. The applications also ask about ancillary benefits that might be provided by a practice change. In both case, however, these variables were not used in making funding decisions and at least some SWCD agents were aware of this fact. As a result, these data are unreliable and of little value in assessing the program.

IV. Preliminary findings on the MCD program

In this section we summarize our preliminary findings in our evaluation of the MCD program. Our observations are based on two sources: the complete set of project applications that have been submitted to the program and semi-structured interviews with program managers, SWCD agents, and farmers. In the fall of 2009 we will be conducting a survey of SWCD offices and farmers in Ohio to provide a stronger statistical foundation for our analysis and explore additional issues.

The traditional model of a farmer's willingness to implement a conservation practice assumes that the reservation price is primarily equal to the change in a farmer's profits that is expected to result from the practice plus a risk premium if the practice changes the distribution of returns over time (Kurkalova et al. 2006). If this holds and a large number of bids are obtained, then theory predicts that bids will tend to be an increasing function of the cost of implementing the conservation practice (Latacz-Lohmann and Van der Hamsvoort, 1997). The reverse auction process, therefore, can be an important step in the achievement of a cost-minimizing outcome.

In practice, we have found that bidding in the MCD program is only loosely tied to the actual cost to the farmers of the associated programs. Our observations to date focus on three main issues that we have found to be particularly interesting about the MCD program: the interaction between the program and existing Farm Bill programs, the importance of county-level institutions, and the extent to which learning has occurred over time.

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multiplying by the duration of the proposed BMP.

A. Water quality trading in the context of Farm Bill programs

The first reason why bids to the MCD program do not appear to simply reflect the underlying costs of implementation is because of the interaction with the USDA Farm Bill programs. In the MCD program, no practice receiving funding from other sources can also generate credits saleable to the MCD program.[3] This is an important restriction since it helps ensure that credits generated reflect additional nutrient reductions that would not be achieved without the payment. As we have learned through our interviews of SWCD agents, however, because of this, the MCD program is not viewed in isolation but as an option to be added to the regular programs with federal funding, especially the Environmental Quality Incentive Program (EQIP) and the Conservation Reserve Program (CRP). The interviews gave us the strong impression that the SWCD agents view their job as primarily one of achieving conservation objectives while at the same time serving the farmers in their counties. While it certainly holds that a farmer's willingness to adopt a conservation practice will depend upon the cost of that practice, they are also guided by the SWCD agents about which program will be their best option. Farmers likely to qualify for higher payments from the MCD program, therefore, are the most likely to apply.

For example, the continuous CRP program[4] funds small scale conservation activities such as grass waterways to reduce erosion and nutrient run-off within a farm. When farmers can qualify for this program, the CRP program pays 90% cost share and rental payment to the farmers. As one SWCD agent said, "CRP is gold." Similarly, in the Miami watershed, EQIP pays farmers to implement manure management. Since these programs offer an alternative funding source, farmers are unlikely to place MCD bids that differ much from the costs-share rates available through those programs, even if the farmers' actual costs are far below those rates. Further, even

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[3] In the first year of the program this restriction was not established at the time bids were solicited. However, when bids were evaluated, it was decided that already funded projects could not qualify for funding and this restriction was clarified in later rounds of bidding.

[4] The continuous CRP, which funds small-scale conservation and has a continuous source of funding, is commonly used in the watershed. In the watershed in recent years there have been no opportunities for farmers in the Great Miami watershed to participate in the general signup CRP program, which has a competitive bidding process and makes payments for the retirement of cropland production.

for farms who do not qualify for any of the USDA programs, the government programs provide an initial price signal that may influence the bids.

There are several reasons that were mentioned during our interviews for why the MCD program can be a preferred source of funding to the Farm Bill conservation programs. First, the MCD program often provides greater flexibility. For example, consider the case of a farmer who enters a five-year contract for adopting conservation tillage and then wants to till one year. The Farm Bill programs consider this a violation, whereas the MCD program would just pay for four of the five years of conservation tillage.

Second, another advantage of the MCD program is that the Farm Bill programs may have insufficient funds. In particular, the EQIP program has a backlog due to the low acceptance rate, and therefore, the MCD program is a viable alternative. Third, there are some criteria that make landowners ineligible to compete for the Farm Bill program. For example, land is not eligible for participation in the continuous CRP program, according to program rules, if it was not in the crop rotation during the period 1996-2001. Additionally, some conservation practices are only permitted in the MCD program, such as retiring cropland to establish hayfield with some livestock grazing. We have been told these reasons directly during interviews. Our upcoming survey of a much larger group of farmers will help to document the relative importance of these and other reasons.

B. County-level support and guidance

As discussed above, the MCD program relies heavily on county-level SWCD agents. In this section we will discuss how these agents have played central roles in the bidding process. With the exception of Breetz and her colleagues (2005, 2007), the economics literature on water quality trading has seen intermediaries as playing a relatively minor role in WQT programs. In policy discussions of water quality trading programs there is often mention of the role that might be played by “aggregators” or brokers to reduce the transaction costs of identifying the farmers who might be interested in participating. Woodward et al. (2002) emphasize that an institution might play an intermediary role as a “clearing house” for trading in which a single price is established for credits.

In terms of its ability to reduce transaction costs, we believe that the MCD program has been quite successful. The county-level SWCD agents have long-term relationships with farmers and know well the conservation practices that have the best potential to reduce nutrient runoff. Hence, by relying on SWCD agents to act as intermediaries, the MCD program has been able to generate a large number of bids from farmers and had a credible monitoring and enforcement.

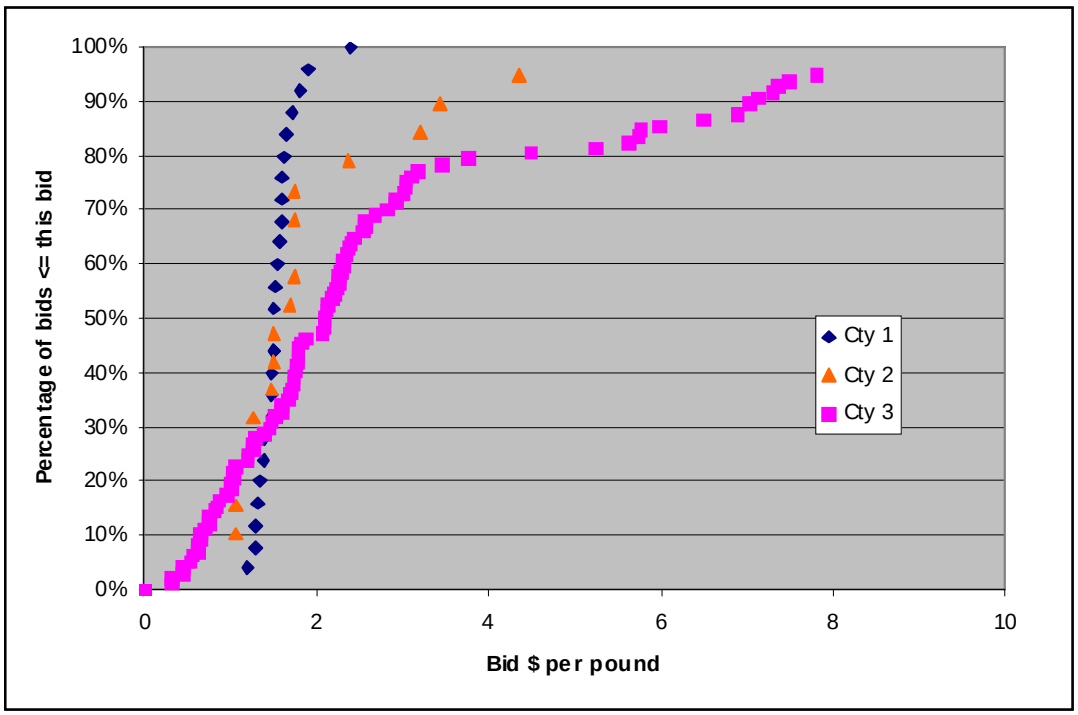
In our conversations with SWCD agents, however, we have found that the agents have done more than just reduce transaction costs. In contrast with the well established and larger Farm Bill programs, most farmers are not even aware of the MCD program. Therefore, the SWCD agents are critical for disseminating information about the purpose and rules of the new MCD program. Through newsletters to farmers and direct conversions either in the SWCD office or during field visits, they have also played a critical role in recruiting potential participants. They have an active role in the project application, often providing advice on bidding strategies and assessing the likelihood of acceptance in Farm Bill versus MCD program. As a result, the bids do not reflect just the preferences and costs of the farmers; they are filtered by the information and help that the SWCD agents provide. These agents, seeing themselves as primarily serving the interests of the landowners in their district, will guide the farmers toward the program with greater success and bids that maximize the payments that they can obtain from the program.

Further, some of the counties have been more aggressive in promoting the MCD program than others. The majority of the applications (83%) have come from only three counties. On the other hand, three of the ten participating counties have submitted three or fewer applications each. Five counties in the watershed did not submit any applications in the first four rounds (Auglaize, Champaign, Hamilton, Hardin, and Logan), though for most of the nonparticipating counties only a small percentage of the county's area lies within the Miami watershed (See Figure **1**).

The SWCD agents' influence on bidding can be seen in Figure 2 where we display the distributions of the bids from the three counties that have submitted the most bids to the program. The bids from county 1 are remarkably concentrated around the mean value of $1.55 with a standard deviation of only $0.23, all falling within a very narrow band between $1.20 and $2.40 per pound. In contrast, County 3's bids averaged $4.92, had a standard deviation of $7.13 and ranged from $0.31 per pound to as high as $65 per pound with about 5% of the 97 bids from

that county exceeding $10 per pound. Although there is spatial variation across the watershed in soils, farm types and conservation practices being proposed, it is highly unlikely that this is the source of the striking variation across the counties as seen in the figure.

Figure 2: Distribution of bids from three counties[5]



source: MCD Application data set.

We also found evidence for the SWCD influence on bidding in our interviews with the agents and farmers. In county 1, for example, the agent who helped most of the bidders had the farmers choose their bids from a range of *prices per pound* of nutrients reduced, with clear knowledge of the price that has been paid in prior rounds of the MCD program. In contrast, the agents in county 3 had farmers choose practices and specified set *prices per acre*, regardless of soil characteristics that influence the emission reductions that can actually be achieved. The role played by SWCD agents indicated that they view their role in the MCD program differently than in the Farm Bill conservation programs. In the MCD program an agent is actively helping his or

[5] County names are not identified here to diminish the extent to which this report exposes details of the program that will influence future bidding.

her farmers compete with the farmers of the other counties. In contrast, when working with the Farm Bill programs the agents either are simply technical assistants of applications (e.g., continuous CRP has eligibility criteria but no competitive bidding) or help generate a pool of applicants that compete at the county level for a fixed amount of money (e.g., EQIP provides a fixed budget for each county office).

C. Learning over time

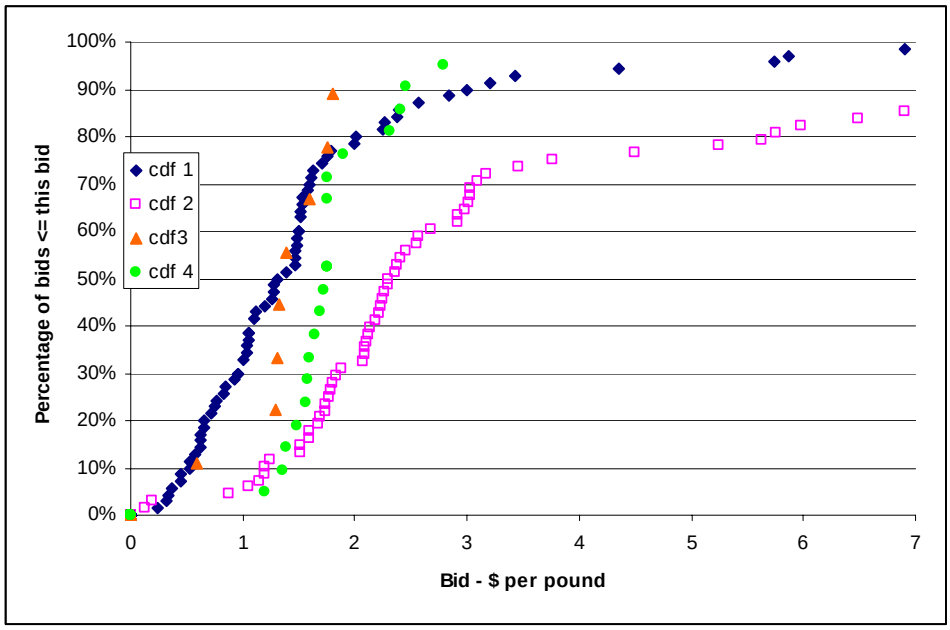
Five rounds of bids have taken place in the MCD program, providing an opportunity to determine whether bidders and the SWCD agents who assist in the bidding have learned over time. There is some evidence of learning as seen in Figure 3.[6] The most evident pattern is the sharp contrast between the first and second rounds. These two rounds make up 82% of all the bids made. There is a sharp shift in the distribution of bids from round 1 to round 2. The average bid in round 1 was $1.65 per pound-year, but this increased to $4.57 in round 2. The difference between these two periods can largely be attributed to a change in the MCD's eligibility criteria. Prior to round 1, MCD had indicated that bids that also received conservation funding from government cost-share programs could participate. However, such applications were not accepted in round 1 and the MCD clarified that policy change to the SWCD offices prior to round 2. It appears that the SWCD offices then expected the MCD to pay higher prices in round 2. In fact, the highest price per credit that the MCD paid in round 2 was 3¢ lower than the highest price paid in round 1.

The experience in rounds 1 and 2 seem to have had two main effects. First, we see that far fewer bids were offered in rounds 3 and 4. Some of the counties that were the most active participants in the first two rounds actually dropped out completely in the later two rounds. The differences across counties seen in Figure 2 is to some extent a result of the fact that different counties are participating in later rounds, after some learning has occurred, than were active in rounds 1 and 2. Secondly, we see in round 3 and 4 more concentrated bids. In round 1 there was a $5.38 gap between the bids at the 5th and 95th percentiles, and this gap increased to $12.46 in round 2. By

[6] For a variety of reasons, only two bids were submitted in round five. Hence, we exclude it from this figure.

rounds 3 and 4, the bids had become much more concentrated with the centrally 90% spread falling to $1.20 and $1.60 respectively. Clearly, by round 3 bidders were getting much better information about how much to bid. This was accompanied by a sharp decline in the number of bidders and the county that submitted the most bids in rounds 1 and 2 did not solicit any bids after that point. To our surprise, we found that there are very few (perhaps one or two) farmers who have offered repeat bids in the data. Hence, we believe that the changes seen in Figure 3 reflect learning by the SWCD agents, not individual farmers.

Figure 3: Distributions of bids in rounds 1 - 4



source: MCD Application data set.

Based on these data and our interviews with SWCD agents, there appear to be two main types of agents. The first type attempted to participate during the first two rounds in the MCD program. In the early rounds there was some uncertainty and confusion among the agents due to novelty of the program, the evolving rules and bidding, and the fact that the MCD's ranking based on dollars per pound as opposed to Farm Bill programs that are tied to practices and land area. Some of the agents that failed in those rounds, despite substantial effort, became discouraged and declined to participate in later rounds. The second type of agent was able to learn quickly about the MCD program criteria or began participating after the bugs had been worked out. They experienced higher acceptance rates for their farmers and have continued to promote the MCD

program and recruit farmers. This is seen in Table 1, where we see that the number of counties participating in the MCD program fell sharply after the second round, while the acceptance rate went up sharply.

Table 1: Counties Participating and Acceptance Rates

Round	**1**	**2**	**3**	**4**
Number of counties with an application	9	6	3	4
Acceptance Rate	18%	22%	89%	67%

While there certainly is variation across the watershed, it seems unlikely to us that there are no cost-effective opportunities to reduce nutrient loading in 3/4 of the counties in the watershed. If this is true, then for reasons that are entirely unrelated to the cost of achieving water quality improvements, participation in the program is concentrated in some counties and not in others. Hence, this process of learning has important implications for program efficiency. Where SWCD have stopped participating, a substantial portion of the watershed, landowners are not even aware of this WQT program and certainly not submitting bids.

D. Practices across counties

One of the features of the MCD program that distinguishes it from most other WQT programs to date is that it has involved a wide range of pollution reducing practices. Two other programs that have paid a large number of farmers to implement practices were established for point sources in Minnesota: the Rahr Malting Company and the Southern Minnesota Beet Sugar Cooperative. In both cases, the range of management practices that could apply for funding was relatively narrow. In contrast, a wide range of practices could apply for funding in the MCD program. As indicated above, the nutrient load reductions are calculated using four separate spreadsheets, however, each of these offers many combinations and variations of practices that might be proposed. Aggregating into five main practice types, we see that 40% of the applications have proposed some sort of tillage or field management change, and this makes up almost exactly

40% of all of the accepted projects. In contrast, projects that have proposed funding of a technological way to reduce runoff, mostly in the form of variable rate fertilizer applications, were rejected in all cases. The most successful category is hayfield and sod establishment, where 9 of the 11 proposals have been accepted. These projects were relatively small, averaging only 2,400 pounds per project, when compared to other practices such as livestock management projects, which averaged 50,790 pounds per project. In fact, livestock project represent XX% of the total nutrient reductions accepted by the MCD program.

Table 2: Applications by practice type

Practice Type	Applications	% Accepted	Average Lbs/Project	Average bid/lb
Grass waterways	49	10%	1,449	1.54
Livestock	18	56%	50,970	1.40
Tillage	67	31%	8,253	1.22
Hayfield & Pasture	12	75%	2,436	1.51
Bank Stabilization	7	71%	7,005	2.10
Fertilizer Management	16	0%	7,727	1.12
All Applications	169*	30%	10,316	1.35

* Includes only projects in rounds 1-4, excluding the two proposals submitted in round 5
Source: MCD Application data set.

Across the watershed there is substantial variation in the types of agricultural operations. According to the 2002 Agricultural Census, 88% of the agricultural revenue was derived from crops in counties 7 and 10, whereas, county 1 is livestock dominated with only 17% of the agricultural revenue was from crops (Table 3). Hence, it is not suprising that there is also variation of in the practices that are proposed across the watershed. We find that counties tend to specialize in one or two practice types. For example, 13 of the 25 applications from county 1 specifically related to livestock, consistent with the strong presence of the livestock sector in that county. However, not all of the variation can be explained as a reflection of the agricultural sector in the counties. The applications from counties 2 and 3, for example, seem out of proportion with the distribution of revenue for these counties. Some of this can be explained by changes in program rules over time, in particular the fact that livestock practice were not allowed until the third round of bidding, due to delays in formulating the nutrient worksheet to evaluate

livestock projects. But, consistent with our meetings with SWCD agents, there also appears to be specialization by county offices that does not reflect only the agricultural sector in the county.

Table 3: Practice types in applications by county
(Predominant practice for each county in bold face)

		Management Practices in Project Proposals						
County*	% of Agriculture Revenue From Crops**	Bank Stabilization	Tillage	Fertilizer Management	Grass Waterways	Hayfield & Pasture	Livestock	Total MCD Applications
County 1	17		5		1	6	**13**	25
County 2	42	**7**	1	5	5		1	19
County 3	56		**46**	11	40			97
County 4	78		**5**		1			6
County 5	78					**5**		5
County 6	57		**3**			1	1	5
County 7	88		**4**					4
County 8	68		1		**2**			3
County 9	13						3	3
County 10	88		**2**					2
County 11	43							0
County 12	74							0
County 13	83							0
County 14	82							0
County 15	36							0
All Counties	40	7	**67**	16	49	12	18	169

* County numbers are the same as in Figure 2.
** Agricultural Revenue data is from the 2002 Census of Agriculture. The remaining portion of the revenue is from livestock.
Source: MCD Application data set.

V. Conclusions on the efficiency of bidding in the MCD program

We have argued that the MCD program is probably the most interesting point-nonpoint source WQT program to be developed to date. In sheer volume of trades it is among the largest WQT programs and in terms of variety of traders and prices paid, it is unsurpassed. The MCD *looks* like a real market with the MCD playing the central role of a clearinghouse. Since many of the payments made by point sources were made in anticipation of TMDL restrictions that have not yet materialized, ex post, it is not possible to document whether there have been any cost savings. However, as TMDLs are finalized in the coming years, the watershed has the advantage of an institutional capacity that will make it possible to use trading as an alternative to wastewater plant upgrades.

However, there are three aspects of the MCD program that require attention and have may have inhibited the program's efficiency to date. First, we find evidence that the prominent role of the SWCD agents has introduced some distortionary impacts on the bidding. Second, although the program has not witnessed a great deal of repeat bidding by landowners seeking to "game the system," there is evidence that county-level representatives have learned over time and this is leading to bids that are near to the price being paid by MCD. To some extent it appears that much of the learning was done at the expense of counties that submitted a large number of bids in the early rounds. Counties that began bidding in later rounds were able to set their bids more precisely to increase the chance of having a bid accepted. Finally, our interviews have indicated that bids in the program have also been influenced by the options that farmers have to take advantage of conservation funding in the USDA Farm Bill programs. It is too early to tell if these effects will diminish over time. But if future programs use the MCD program as a model, we believe it would be useful to structure the program in a way that provides a common body of information and guidance.

Together, the distortionary role of SWCD agents in setting bids and the alternative available to farmers to obtain funding from other sources mean that bids in the MCD program do not reflect simply the cost of implementing a project. We do not know the magnitude of this difference and future work will attempt to measure it to the extent possible. But if there is a gap, then farmers

in the MCD program will not tend to reveal in their bids their true reservation price for implementing a BMP, which is the principal motivation for using a reverse auction type structure (Latacz-Lohmann and Van der Hamsvoort, 1997).

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Background

- US EPA (2004) *Water Quality Trading Assessment Handbook*, EPA 841-B-04-001.
- King, Dennis (2005) "Crunch Time for Water Quality Trading," Choices, 20(1), pp. 71-75.
  - Why are there so few WQ trading success stories
  - Why aren't the point and nonpoint sources who are supposed to benefit from WQ trading more supportive
  - What can be done to improve the situation

Woodward and Newburn

- Success factors of the Great Miami Program
  - Inspired leadership
  - MCD's intermediary role as a clearinghouse
  - Role of SWCD offices and agents
    - Standardized Spreadsheet tool for Estimating Pollutant Load (STEPL)

To Increase Usefulness to EPA: Quantification

- Are the SWCD Agents worth the cost
  - Working for the NPs
  - Working harder in some counties than others
  - Is there gaming or not, and will it be measurable
- CRP and EQIP interfere (slippage)
  - Interference measurable
- If NPs are not revealing their reservation price
  - How far off are they
- If TMDLs are drivers and TMDLs don't exist
  - To what extent is this lack of a regulatory stick reducing the efficiency of the program

To Increase Usefulness to EPA: Action

- "If this is true [interference by SWCD and other programs] and general, then farmers in the MCD program will not tend to reveal their reservation price in their bids, which is the principal motivation for using a reverse auction type structure."
  - Principal yes, but there are coordination features the auction adds
  - What is the alternative [if this is a successful WQT program, what does this augur] or
  - How can this be fixed
    - Can the role of the SWCD agents be modified
    - Can some information be withheld (as it is in the CRP's EBI) to increase competition

In General

- “Hence, despite its use of a reverse-auction structure, the MCD program has not pushed farmers to reveal their direct cost of implementing a conservation practice. Overall, the MCD experience demonstrates how effective design can improve the prospects for WQT, but it also demonstrates some of the limitations this approach has in achieving a **cost-minimizing allocation** of pollution reduction efforts.”
  - This doesn’t bother me if it can be quantified