WAITING TO EXECUTE:

AN OPTIMAL STOPPING MODEL OF CAPITAL PUNISHMENT STAYS

Catherine M. Chambers
Central Missouri State University

and

Paul E. Chambers
Central Missouri State University

INTRODUCTION

In the summer of 1996, the U.S. Supreme Court upheld the section of the Antiterrorism and Effective Death Penalty Act of 1996 that strictly limited the federal appeals by state death row inmates [Greenhouse 1996]. More recently, the American Bar Association recommended a moratorium on capital punishment [*New York Times,* 1997]. In February 2000, Governor George Ryan of Illinois, a moderate Republican, imposed a moratorium on executions in that state, citing a record of convicting and sentencing innocent people to death [Johnson, 2000]. Liebman et. al. [2000] find that the overall error rate in capital cases in Illinois is not unusually high, and is in fact, slightly below the national average. The fact that this move met with little criticism from either major political party indicates some change in political will regarding capital punishment. Support for the death penalty remains high, but is at its lowest point in 19 years [Holmes, 2000; Liebman et. al., 2000]. According to a poll by the Charlotte (North Carolina) Observer, when life without the possibility of parole is offered as an alternative, support for the death penalty falls below 50 percent. Since Governor Ryan announced the moratorium on capital punishment in Illinois, support for change to the current system has grown even among political conservatives [Holmes, 2000].

The major emphasis of economic research regarding capital punishment has focused on execution as a deterrent to future crime [Ehrlich, 1975; 1977; Cover and Thistle, 1988; McAleer and Veall, 1989; Cloninger, 1991]. Contrasting with this focus, others ask, are there economic justifications for capital punishment delays? If so, what is the optimal length of capital punishment stays? At one extreme, McKee and Sesnowitz [1976] use principles from welfare economics to argue that capital punishment is not justifiable. In their analysis, the implementation of capital punishment fails to meet the Kaldor test for a Pareto improvement. Reynolds [1977] notes that

Paul E. Chambers: Department of Economics and Finance, Central Missouri State University, Warrensburg, MO 64093. E-mail: pchambers@cmsul.cmsu.edu

Eastern Economic Journal, Vol. 30, No. 2, Spring 2004

the McKee and Sesnowitz [1976] argument relies on an erroneous assumption that the gains (deterrence benefits) to beneficiaries of capital punishment are finite but the losses (loss of human life) to the losers are infinite. In general, economists agree that the value of a human life is not infinitely high. This proposition is supported by risk-taking behavior by individuals and limited willingness to pay for safety and preventative health care expenditures [Blomquist, 1979; Atkinson and Halvorsen, 1990; Viscusi, 1992]. The socially optimal policy regarding capital punishment is complicated not only by the fact that neither the benefits nor the costs of capital punishment are infinite, but also by two other factors: the benefits from implementing or delaying are both uncertain and any execution is irreversible.

Our focus is on a specific component of the capital punishment debate: delays in capital punishment. Although the legal justifications for delays in capital punishment cases, such as the right of the writ of habeas corpus, are well known, the analysis of the economic costs and benefits of delaying executions is limited. Fluctuations in the political consensus regarding capital punishment and resulting changes in the imposition of the death penalty in practice suggest that such costs and benefits are important to policymakers.

The employment of option value theory is useful when considering the implementation of the death penalty because it involves an action that has uncertain net benefits and that is irreversible. A significant body of literature exists concerning option values and irreversibility [Henry, 1974; Conrad, 1997; Pindyck, 1991; Dixit and Pindyck, 1994]. In broad terms, the focus of this literature is concerned with the benefits associated with "the value of flexibility, as opposed to irreversibility" [Lund 1991, 144]. In fields such as environmental economics, Arrow and Fisher [1974], Conrad [1980] and Hanemann [1989] have interpreted option value as the expected value of future learning of, as yet unknown, benefits from preserving an environmental good for which an irreversible decision would preclude learning of the benefits. In *Investment Under Uncertainty*, Dixit and Pindyck provide detailed coverage of theoretical models of irreversibility and the option value of waiting for improved, yet always incomplete, information. Although their focus is on investment, Dixit and Pindyck [1994, 23-25] note that models of irreversibility and option values are applicable to "fairly far-reaching problems" such as marriage, suicide, and legal reform. We follow Dixit and Pindyck's desire of future application of these techniques on broader social issues by modeling the effects of uncertainty and irreversibility of capital punishment delays.

When considering the socially optimal delay, it is important to note that there is not a consensus concerning the death penalty and that the population may be divided into two broad groups: those who favor and those who oppose the death penalty. If the policymakers have the goal of maximizing net benefits of the population, they face a tradeoff in setting the execution date.[1] By setting a relatively early execution date and executing a death row inmate, the welfare of the individuals who oppose capital punishment is reduced. In the opposing case, by delaying the execution of a death row inmate, the welfare of the individuals who favor capital punishment is reduced. It follows that the socially optimal execution date maximizes the expected present value of the flow of benefits of delaying the execution that accrue up to the execution date plus the benefits of execution. Since the benefits of an execution and the benefits of delaying an execution are uncertain, we assume that these variables are governed by specific stochastic differential equations. We proceed as follows. In the next section, we develop an optimal stopping model of capital punishment delays and discuss the comparative static results. In the final section, we present some conclusions.

THE MODEL

To model the optimal capital punishment delay, we assume that the population consists of two groups of individuals. Suppose individuals in the first group oppose capital punishment and receive utility from delaying execution of the death penalty. Individuals in the second group support capital punishment and, therefore, individuals in this group receive utility from implementation of the death penalty. Each group has distinct and well-defined preferences concerning capital punishment in that we assume that all individuals who oppose capital punishment have a positive marginal utility for any delay and the individuals who favor capital punishment have a negative marginal utility for any delay. A person who favors execution, therefore, receives the maximum benefit from immediate execution, with the expected benefits steadily decreasing as the length of the delay increases.[2] Similarly, those who oppose execution receive maximum benefits from an infinite delay (equivalent to a moratorium), with the expected benefits declining continuously as the delay decreases. The Moratorium Campaign considers the implementation of a moratorium as a step to abolishment of the death penalty. (See the Moratorium Campaign web site: www.moratorium2000.org.). It appears that the most effective tactic used by groups who oppose capital punishment is to call for a moratorium.

The reasons for favoring or opposing the death penalty are varied. Although the empirical evidence of the death penalty as a deterrent to crime is mixed, individuals may believe it is a deterrent and therefore favor capital punishment.[3] It is not only the actual deterrence that is relevant but also the perception of the deterrence. Ellsworth and Gross [1994] find that survey respondents admit that factual information concerning capital punishment has little influence on their attitudes. Ellsworth and Gross also note that capital punishment beliefs are largely motivated by emotional factors.[4] Due to the irrevocable nature of the death penalty and a belief in the sanctity of life, some individuals may feel strong opposition to the death penalty. Individuals may feel that human life is valuable and therefore delays are warranted. They may gain utility from knowing that individuals are not executed, and this value is similar to the intrinsic values associated with the existence of environmental goods [Krutilla, 1967]. As noted by West [1976] and Holden [1993], this opposition to the death penalty due to a belief that life is sacred may be influenced by religious beliefs. On a 1999 visit to the United States, Pope John Paul II urged Roman Catholics to oppose the death penalty [Johnson, 2000].[5] Concerns of fairness may also motivate support or opposition to the capital punishment, as reflected in the American Bar Association's recommendation of a moratorium on capital punishment, which referred to the use of capital punishment as "a haphazard maze of unfair practices" [*New York Times,* 1997]. Individuals fearing racial discrimination may oppose capital punishment since white support for capital punishment may be associated with racial bias [Aguirre and Baker, 1993; Barkan and Cohn, 1994]. Supporters of capital punishment, on the other hand, may also have concerns about fairness, since an individual's support of capital punishment may also be motivated by a feeling of retributive justice [Vidmar and Ellsworth, 1976; Gross, 1993; Ellsworth and Gross, 1994]. Another motive for opposition is the uncertainty of guilt. Individuals who oppose capital punishment may be concerned with the possibility of a miscarriage of justice. Bedau and Radelet [1987] identify twenty-three cases from 1900 to 1985 in which innocent individuals were erroneously convicted and executed.[6] According to the *New York Times* [Johnson, 2000], 85 people on death row have been found innocent and released since 1973. Liebman et. al. [2000] find that nationally, the error rate in capital cases, as indicated by reversals on direct appeal or post- conviction review at the state level or Federal Habeas Corpus, is 68 percent. The most common errors are "egregiously incompetent defense lawyering" and prosecutorial suppression of evidence that the defendant either is not guilty or does not deserve the death penalty.

Given the opposing views concerning capital punishment, we divide the population into two groups: those who oppose capital punishment and those who support it. These different views are reflected in different utility functions for the two groups. We begin with the utility function in which death penalty opponents gain satisfaction: the prevention of the execution of the death row inmate. The utility function is $u_A = u_A(n(t), z, I^A(t))$ where $u_A(\cdot)$ is the utility function, $n(t)$ is the number of death row inmates, which will change only if there is an execution, z is a composite commodity of all other goods and $I^A(t)$ is the information set that is known with certainty and is common to individuals opposing capital punishment.[7] For this group, an execution in the current period will reduce $n(t)$ and therefore reduce utility, while a delay in this period will maintain $n(t)$ and therefore utility.

Similarly, we model the utility function in which individuals gain satisfaction from the execution of the death row inmate. The utility function is $u_P = u_P(c(t), z, I^P(t))$, where $u_P(\cdot)$ is the utility function, $c(t)$ is the number of executions, z is a composite commodity of all other goods and $I^P(t)$ is the information set that is known with certainty and is common to individuals favoring capital punishment. For proponents of capital punishment, an execution increases utility in the current period. Any delay of execution in this period results in lower utility.

Of course, utility is never observable, but may be implicitly estimated using observable data and consumer behavior. In implicit market analysis, willingness to pay (WTP) is one of two standard methods for estimating economic values [Carson, 2000; Freeman,1994]. The benefits of delaying the execution are derived from the fact that it provides a group of individuals utility. This group, therefore, is willing to pay to prevent the execution. Assuming perfect information, total willingness to pay may be defined as the maximum amount this group would be willing to give up to delay the execution. The total willingness to pay of each individual belonging to this group, $w_{Ai}(t)$, is the difference between the ith individual's expenditure function after the execution and that individual's expenditure function prior to the execution, $w_{Ai}(t)= e_{Ai}[n(t) - c(t), z, U^A, I^A(t)] - e_{Ai}[n(t), z, U^A, I^A(t)]$ where $e_{Ai}[\cdot]$ is the expenditure function of the ith individual (i = 1, 2,..., j), U^A is the reference level of utility of the ith individual opposing capital punishment. Since, after the execution, $n(t)$ is smaller, the welfare of this group has been reduced. The individuals respond by spending more on all other goods in order to maintain their reference utility level, U^A. The total benefits of delaying the execution are equal to the sum of the identical individuals' willingness to pay,

$$(\sum_{i=1}^{J} w_{Ai}(t) = \acute{A}(t)). \tag{1}$$

The total willingness to pay of the ith individual belonging to the group of proponents of capital punishment, $w_{Pi}(t)$, is the difference between the ith individual's expenditure function before the execution and that individual's expenditure function after the execution, $w_{Pi}(t)= e_{Pi}[n(t), z, U^P, I^P(t)] - e_{Pi}[n(t)-c(t), z, U^P, I^P(t)]$ where $e_{Pi}[\cdot]$ is the expenditure function of the ith individual (i = 1, 2,..., k), U^P is the reference level of utility. Since execution delays reduce the welfare of this group, the individuals respond by spending more money on all other goods in order to maintain his or her reference utility level, U^P. The total benefits of implementing the execution are equal to the sum of the identical individuals' willingness to pay,

$$(\sum_{i=1}^{K} w_{Pi}(t) = P(t)). \tag{2}$$

We focus on the specific case where a state has death row inmates without executions.[8] At time, t, let $\acute{A}(t)$ denote the benefits of delaying the execution to individuals who are anti-capital punishment. Note that $\acute{A}(t)$ is a flow variable that accumulates over the period of the capital punishment delay. Allow $E[A^f(0)]$ to denote the expected sum of the future flow of benefits of delaying the execution that accrue over the infinite horizon, as measured from time t = 0.[9] The expected sum of the future discounted flow of benefits of delaying the execution is given by

$$E[A^f(0)] = \int_0^{\infty} e^{-rt} \ \acute{A}(t)). \tag{3}$$

where r is the social discount rate which is common to both groups. At time, t, let $P(t)$ denote the benefits of the execution to individuals who are pro-capital punishment, (t). Note that $P(t)$ is not a flow variable since this benefit occurs only at the time of the execution.

Whether they are motivated by the welfare of constituents or not, the policymakers affect the occurrence or number of executions, and through policy decisions, therefore, affect welfare. A tradeoff exists since an early execution causes a portion of the population to forgo future benefits of delaying the execution. A later execution, however, causes the other portion of the population delays in receiving the benefits that they receive from that execution and, therefore, reduces the present value of the benefits of the execution. To maximize net benefits, policymakers choose an execution date, T, to maximize the expected present value of the flow of benefits of delaying the execution that accrue up to the execution date plus the discounted benefits of the execution.

In reality, the values of the cumulative benefits of the delays and the benefits of execution are uncertain. That is, both the benefits of delaying the execution to the group that opposes capital punishment $\dot{A}(t)$,and the benefits of execution to the group that favors capital punishment, $P(t)$, are assumed to be stochastic, since these values may be affected by nondeterministic factors. To explicitly model the optimal stopping rule, we assume that $\dot{A}(t)$and $P(t)$ follow specific stochastic processes (geometric Brownian motion).[10] We assume that percentage changes in the two variables are governed by the following stochastic differential equations:

(4) $$d\dot{A} = \dot{A}[adt + \sigma_a dz_a]$$

(5) $$dP = P[pdt + \sigma_p dz_p]$$

where a and p are constants (the expected growth rates in benefits for each group), σ_a and σ_p are the instantaneous standard deviations of the percentage changes in the benefits of delaying and the benefits of execution, z_a and z_p are Wiener processes. Note that equations (4) and (5) reflect the benefits and not the number of people favoring or opposing capital punishment. Equations (4) and (5) are geometric Brownian motion processes, which implies that changes in the benefits over time, for each group, are explained by a deterministic component represented by expected trend terms (adt and pdt) and a stochastic term ($\sigma_a dz_a$ and $\sigma d_p z_p$). The random variable z_a associated with the benefits of delaying the execution to the group that opposes capital punishment may be thought of as new information. New information, in the form of an unexpected removal of a death row inmate due to a reversal based on a direct or collateral review or a death due to natural causes or suicide/homicide, may cause willingness to pay to deviate from its trend value. This group receives new information, which by definition is independent over time, and reevaluates its willingness to pay. Similarly, we assume that changes in the benefits of implementing an execution have a deterministic component represented by a trend term, pdt and a stochastic component, $\sigma_p dz_p$.[11] Again the random portion associated with the benefits of implementing may be thought of as new information. When new information arises, the group favoring execution reevaluates its benefits.

The anecdotal evidence suggests that shifts in preferences for the death penalty appear to be greatly affected by two opposing factors: fairness and retribution. According to Healy [2001], in the early to mid-1990s a decline in support for capital punishment was not expected with the high level of violent crime. Capital punishment support, however, did decline 10 to 20 percentage points although it remained between 60 percent and 75 percent with the overriding factor in the decline being attributed to concerns of fairness. Again it can be noted that preferences are not stable and may shift in the opposite direction due to factors such as retribution. Recent events in the state of Maryland also revealed a sudden shift in the preferences for the death penalty. On 9 May 2002, Maryland Governor Parris N. Glenening

ordered a moratorium on executions due to concerns about the fairness of the Maryland's death penalty [Clines, 2002]. The suburban sniper case, however, generated a rivalry between prosecutors in an attempt to be the first to try the case with Governor Glenening maintaining that the moratorium would not be a factor in the sniper case [Clines and Drew, 2002]. Given the public outrage after the Oklahoma City bombing, retribution appears to have played a role in the support of the death penalty of Timothy McVeigh. The stochastic terms in equations (4) and (5) may reflect changes in sentiment following such high-profile cases.

Consider the characteristics of an execution at date, T. If execution is planned for time T, a portion of the population forgoes the expected discounted value of the future flows of benefits of delaying the execution

(6) $$E[A^f(T) = \int_T^{\infty} e^{-rt}\, \dot{A}(t)\, dt.$$

Recall that the expected sum of the future discounted flow of benefits of delaying the execution is given by

(7) $$E[A^f(0)] = \int_0^{\infty} e^{-rt}\, \dot{A}(t)\, dt.$$

However, this portion of the population does receive the expected discounted value of the flow of benefits of delaying the execution up to time T of

(8) $$E[A^f(0)] - E[A^f(T)] = \int_0^{T} e^{-rt}\, \dot{A}(t)\, dt.$$

For execution planned at T, the expected discounted value of the execution is $e^{-rT} P(T)$. The socially optimal timing of an execution maximizes $e^{-rT} P(T) + E[A^f(0)] - E[A^f(T)]$. From the solution of this optimal stopping problem, the optimal execution date may be expressed in terms of the ratio of the current execution value to the expected flow of forgone benefits of delaying the execution, $P(T)/E[A^f(t)]$. The optimal delay ends at time T if and only if $P(T)/E[A^f(t)] \geq [1 + (1/\beta]$ where β is a positive parameter.[12] Allow R^* to denote the threshold or critical ratio of the benefits of the execution to the benefits from delaying where $R^* = [1 + (1+\beta)]$. For example if $R^* = 2$, the execution is socially optimal only if the benefits of the execution are two times as great as the expected benefits from delaying. Note that this result contrasts with traditional cost-benefit analysis in an environment with uncertainty and reversible actions.[13] In an environment with uncertainty and *reversible* actions, the expected benefits must be as least as great as the expected costs implying $P(t)/E[A^f(t)] \geq 1$. $P(t)$ is without the expectations operator since $P(t)$ is observable at time t and $A^f(t)$ is a flow of future benefits, which are only known in expectations at t. Why does an optimal execution only occur when the net benefits obtain a threshold level where the expected benefits of the execution are *higher* than the expected benefits of delaying the execution? The answer lies in the irreversible nature of capital punishment. The irreversibility affects the cost-benefit analysis given that an execution results in the loss of an option to wait and see if the trends in the relative benefits reverse themselves. The cost/benefit analysis of taking the irreversible action must take into account the option that is lost due to the action.

Crucial to the capital punishment debate is existence of uncertainty. Intuitively, the overall level of uncertainty is an important factor that affects the critical ratio. Waiting and observing realizations of the changes in the net benefits of capital punishment provides information to the policymaker, who can update his or her information set. If the changes in the net benefits, however, are primarily due to the uncertainty, the policymaker's decision is less clear and caution is warranted.[14] This caution takes the form of higher threshold level or critical ratio, R^*,and therefore, a reduced likelihood of execution.

R^* also increases with increases in the expected growth rate of the benefits of execution, ρ. Recall that parameter, ρ, reflects the trend or the expected growth rate in the benefits of an execution. This could be due to an increase in the number of people supporting capital punishment or a strengthening of preferences among members of this group. If the benefits of execution are expected to increase in the future, it is optimal to allow longer delays, other things equal, to receive higher benefits in the future. By waiting, the execution is delayed, but during that delay, the expected benefits for the group that favors executions grow so that they actually receive greater benefits when the execution is finally carried out.

Increases in the expected growth rate of the benefits of delaying the execution reduce the critical ratio. This result appears at first counterintuitive. Execution is less attractive, however, because the increase in this growth rate increases the forgone benefits of delaying the execution by a greater degree than it decreases the critical ratio. Although R^* decreases, because the denominator of the ratio, $E[A^f(t)]$ is increasing, it is actually less likely that this critical ratio will be reached. As the parameter, α, increases, R^* decreases; however, the execution does not become more attractive since $E[A^f(t)]$ increases by a greater degree. To see this, note that the optimality condition may be written as $P(t) \geq R^* E[A^f(t)]$.

The degree of time preferences, reflected by the social discount rate, r, affects the critical ratio. Similar to a dynamic optimization model with deterministic costs and benefits, the social discount rate affects the present value of the stream of benefits. The greater level of patience reflected by a lower discount rate implies that both groups are more willing to wait to receive future benefits. The individuals who favor execution are more tolerant of delays, holding all else constant. Individuals who oppose executions always benefit from delays, but a lower discount rate implies that the present value of benefits from delaying is even greater, which is also consistent with delayed executions.

Increases in the discount rate reduce the present value of future benefits of delaying the execution and of future execution, encouraging an earlier execution. At the extreme of an infinitely high social discount, which is consistent with a patience level of zero, the decision is reduced to a static problem where neither party involved is willing to wait. For individuals who favor execution, only immediate executions are favored. The individuals who oppose capital punishment are too myopic to benefit from delays in the implementation of capital punishment.

Interestingly, at sufficiently low social discount rates, execution may never be socially optimal. If either of the expected growth rates of benefits (α or ρ) exceeds the social discount rate, the execution cannot be socially optimal. This may seem paradoxical, but consider the case where the expected growth rate of the benefits received from an execution exceeds the discount rate ($\rho > r$). This result becomes apparent when you note that there is always a greater expected discounted gain from waiting. At any point in time, it pays, in expectation, to wait because more is gained by waiting through the expected growth in benefits from the execution than is lost through discounting. In this case, the group that receives the benefits from the execution is always better off from waiting since the reward from waiting exceeds the cost of waiting.[15]

CONCLUSIONS

Our approach to analyzing capital punishment differs from much of the previous research in that we focus on a specific component of the debate: the length of capital punishment delays. This focus on the capital punishment delays arises from the concerns over uncertainty and irreversibility. Although most members of society do not consider the implementation of a capital punishment execution to be an easy decision, in a world of complete information, the decision to implement capital punishment is greatly simplified. We do not, however, live in a world with complete information. To capture the important aspects of uncertainty and the irreversible nature of a capital punishment decision, we use an optimal stopping model that allows us to consider these factors and others that influence optimal capital punishment delays. For modeling simplicity, the members of society are divided into two broad groups: those individuals who favor and those who oppose the death penalty. As a proxy for opponents to capital punishment, we use the individuals who favor lengthy capital punishment delays and for a proxy of proponents of capital punishment, we use individuals who favor limited capital punishment delays. Modeling delays does not perfectly address the economics of capital punishment but it does capture significant components that are not currently modeled in economics. By considering the length of delays, we can measure the tradeoff that occurs between welfare of the proponents and opponents of capital punishment.

The loss of a human life due to an execution significantly affects the cost/benefit analysis because the execution is irreversible. While the naive form of cost/benefit analysis requires the ratio of expected benefits to be at least as great as the expected costs, the decision with uncertainty and irreversibility requires that the ratio of expected benefits be greater than the expected cost. This requirement arises from the loss of a quasi-option value associated with delays. The quasi-option exists due to the value from waiting to see if trends will change.

Our results show that the higher levels of uncertainty regarding the benefits for either group imply greater caution and, therefore, longer delays are warranted. This degree of caution is greatly influenced by the irreversible nature of an execution. Also, we find that higher expected growth in the benefits to either group reduces the benefits of implementing an execution immediately, since delays in execution allow greater benefits for this group. Moreover, we find general conditions in which executions are never socially optimal. An execution is not socially optimal if the expected growth rate of either the execution or the benefits from delaying exceeds the social discount rate. In such cases, welfare is always improved by delaying.

Finally we must note a caveat regarding political pressure: it is unlikely that the socially optimal policy would be enacted. As is well known from the public choice literature, there are numerous reasons why policymakers or bureaucrats do not have an incentive to carry out the socially optimal policy. They may, however, experience political pressure from both proponents and opponents of capital punishment. Since a formal market for preventing executions does not exist, the willingness to pay is reflected partly by the lobbying efforts to prevent and/or delay executions and protest activities by capital punishment opponents or lobbying to minimize delays in implementing the death penalty by proponents, all of which are costly. Since political markets are imperfect, however, the policymaker may engage in legislative shirking and seek his or her own ideological preferences at the cost of the constituent's interest. Even with the naive assumption that the policymaker is a vote-maximizer and acts in a manner that is consistent with the preferences of the majority of the constituents, it is very unlikely that the socially optimal policy is pursued. Although capital punishment decisions may be based on political or ideological motives, we provide important insights in understanding the capital punishment delays.

APPENDIX

Optimal Stopping Rule

The optimal execution occurs at time T if and only if $P(t)/E[A^f(t)] \geq [1+(1/\beta)]$. The Hamilton-Jacobi-Bellman equation associated with the optimal stopping requires that parameter β, must satisfy the characteristic equation, $\frac{1}{2}\sigma^2\beta^2 + (p-a+\frac{1}{2}\sigma^2)\beta + (p-r) = 0$ where the joint uncertainty is given by $\sigma = \sigma_a^2 - \rho\sigma_a\sigma_p + \sigma_p^2$.

Derivation of the Comparative Statics for the Optimal Stopping Date

Note that convergence requires $r > a$ and $r > p$. It follows that by adding $(r-p)$ and $\frac{1}{2}\sigma^2\beta^2$ to both sides of the characteristic equation and then dividing through by β yields the expression, $D = \sigma^2\beta + p - a + \frac{1}{2}\sigma^2 = \beta^{-1}(p - r + \frac{1}{2}\sigma^2\beta^2)$ which must be positive. To derive the comparative statics for the critical ratio, implicitly differentiate the characteristic equation of the optimal stopping problem and use the sign of D. The critical ratio is a function of β which is a function of parameters: a, p, σ^2 and r. The comparative statics of β for p, σ^2 and r are straightforward and are:

(A1) $$\partial\beta/\partial p = -(1+\beta)/D < 0,$$

(A2) $$\partial\beta/\partial\sigma^2 = -\beta(1+\beta)/D < 0,$$

(A3) $$\partial\beta/\partial r = 1/D > 0, \text{ and}$$

(A1) $$\partial\beta/\partial a = \beta/D > 0.$$

The final comparative static for the growth rate in the benefits from the execution, a, is less intuitive. Both the critical ratio, R^*, and the expected future flow of benefits of delaying the execution $E[A^f(t)]$ on the right-hand side of the optimality condition, $P(t) \geq R^* E[A^f(t)]$ are affected by changes in the parameter a. As the parameter, a, increases, R^* decreases; however, the execution does not become more attractive since $E[A^f(t)]$ increases by a greater degree. To see this, note that the optimality condition may be written as $E[A^f(t)] = (A(t))/(r-a)$ if the convergence condition is met, $r > a$. To show that increases in parameter a discourage execution, partially differentiate the optimality condition with respect to a. Increases in parameter a discourage execution if $\frac{1}{2}\sigma^2 + \sigma^2\beta^2 + \frac{1}{2}\sigma^2\beta^2 > 0$ which holds since β is the positive root of the characteristic equation and $\sigma^2 > 0$.

NOTES

The authors would like to thank O. David Gully, Peter Groothuis, William Hoyt, John Whitehead and particularly the editor of this *Journal* for helpful comments on earlier versions of this paper. All remaining errors are, of course, the responsibility of the authors alone.

1. As is well known, the public choice literature suggests that the maximization of social welfare is an unlikely outcome from the behavior of policymakers and bureaucrats [for example, see Niskanen,1971]. However, differences between states in death penalty statutes (12 states do not have the death penalty) and in both imposition of the death penalty and actual execution rates may indicate that policymakers are influenced by public opinion in their states. Imposition of the death penalty in states with such laws varies from 5.72 to 54.48 per 1000 homicides over the period 1973-1995. Actual executions per 1000 homicides ranged from 0 to 2.71.6 states with death penalty laws had no executions in this period [Liebman et.al., 2000]. On 18 July 2002 the Senate Judiciary Committee approved the Innocence Protection Act, sponsored by Senator Patrick Leahy (D-VT) and others, a package of death penalty reforms, including post-conviction access to DNA tests and competent counsel reforms.This may be further evidence of policymakers being influenced by public opinion. Committee chairman Patrick Leahy (D-VT) cited Liebman's work in his support for the changes (see Senator Leahy's web site at www.leahy.senate.gov). For an example of public choice analysis of a related area of crime enforcement, see Benson, Kim and Rasmussen [1994].They specifically address the public choice aspects of the behavior of police bureaucrats.
2. It is plausible that even proponents of capital punishment favor some waiting period after the trial.The addition of a small t after the trial allows this possibility and the inferences from the extended model are qualitatively unchanged.
3. For a survey of the evidence of the death penalty as a deterrent see Zimring and Hawkins [1986]. Dezhbakhsh et al. [2001] reexamine the issue using more recent data.
4. In the measurement of nonmarket goods, the framing or description of the good influences the perception and therefore the valuation of the good [Arrow et al., 1993]. Lord, Ross and Lepper [1979] show that when confronted with identical new information concerning the deterrent effect of capital punishment, both proponents and opponents of the death penalty viewed the information as evidence to support their prior beliefs. For a summary, see Rabin (1998).
5. Religious beliefs may also be positively correlated with the support of capital punishment [Finlay 1985].
6. Markman and Cassell [1988] argue that the Bedau-Radelet study suffers from a number of flaws. However, if individuals who oppose capital punishment incorrectly perceive a high degree of fallibility associated with capital punishment, they are more likely to be worse off due to a higher number of executions.

7. Although the life of an individual capital punishment inmate is finite, we assume the overall population has infinite life in that there are a sufficient number of new entrants to death row to replace death row inmates who have died due to natural causes.
8. Note that for lengthy periods after Gregg v. Georgia, California, Illinois, Pennsylvania and Ohio had significant death row populations with no executions [Zimring and Hawkins, 1986].
9. This horizon is consistent with the problem faced by an infinitely lived social planner. Although the life of an individual capital punishment inmate is finite, we assume the overall population has infinite life in that there are new entrants to death row.
10. Note the geometric Brownian motion process is the most commonly used stochastic process in financial economics theory. As noted by Dixit and Pindyck [1994], the "(g)eometric Brownian motion is frequently used to model securities prices, as well as interest rates, wage rates, output prices, and other economic and financial variables." For examples of applications to the modeling of nonmarket benefits, see Conrad [1997] and Chambers et al. [1994]. Cox and Ross [1976] considered geometric Brownian motion to be the workhorse of the option valuation literature. This popularity is due to the relative ease of deriving closed form solutions and its appealing properties. For example, if x_t follows a geometric Brownian motion process $dx_t = x_t\, [\mu dt + \sigma dz]$, then x at time 2 is lognormal where $s_2 = s_1 \exp(\mu - \frac{1}{2}\sigma^2 + sz)$ [Lund, 1991, 146].
11. Danigelis and Cutler [1991] provide empirical evidence of a positive trend for the support of the death penalty. Ellsworth and Gross [1994] also provide similar evidence.
12. The critical ratio is based on the Reed's [1993] optimal stopping model for the harvest of old-growth forests. See also McDonald and Siegel [1986] for an optimal stopping analysis of investment decisions, and Pindyck [1991] for a comprehensive and accessible survey of dynamic optimization and uncertainty.
13. Coggins and Ramezani [1998] strongly make this point by stating that "((d)ecision problems with stochastic, dynamic, and irreversible elements should not be treated using expected net present value (ENPV) analysis."
14. The level of uncertainty in the model is captured by the parameters σ_p, σ_a and the interaction or joint uncertainty, $\sigma = \sigma_a^2 - \rho\sigma_a\sigma_p + \sigma_p^2$
15. This parallels the result in the forestry models in which harvesting is never optimal if the expected growth rate exceeds the social discount rate as shown by Reed [1994]. Similar results arise in simple deterministic wine storage and forestry problems [Chiang, 1984].

REFERENCES

Aguirre, A. and Baker, D. Racial Prejudice and the Death Penalty: Research Note. *Social Justice*, Spring 1993, 150-55.

Arrow, K. and Fisher, A. Environmental Preservation, Uncertainty, and Irreversibility. *Quarterly Journal of Economics*, May 1974, 313-19.

Arrow, K., Solow, R., Portney, P., Leaner, E., Radner, R., Schuman, H. Report of the NOAA Panel on Contingent Valuation. *Federal Register*, January 1993, 4602-4614.

Atkinson, S. and Halvorsen, R. The Valuation Risks to Life: Evidence from the Market for Automobiles. *Review of Economics and Statistics*, February 1990, 133-6.

Barkan, S. and Cohn, S. Racial Prejudice and Support for the Death Penalty by Whites. *Journal of Research in Crime and Delinquency*, May 1994, 202-209.

Bedau, H. and Radelet, M. Miscarriages of Justice in Potentially Capital Case. *Stanford Law Review*, November 1987, 21-179.

Benson, B., Kim, I., and Rasmussen, D. Estimating Deterrence Effects: A Public Choice Perspective on the Economics of Crime Literature. *Southern Economic Journal*, July 1994, 1618.

Blomquist, G. Value of Saving Life: Implications of Consumption Activity. *Journal of Political Economy*, June 1979, 540-58.

Carson, R. Contingent Valuation: A User's Guide. *Environmental Science and Technology*, March 2000, 1413 -18.

Chambers, C., Chambers, P., and Whitehead, J. Conservation Organizations and the Option Value to Preserve: An Application to Debt-for-Nature Swaps. *Ecological Economics*, February 1994, 135-43.

Charlotte Observer. Uncertain Justice, five part series. September 2000.

Chiang, A. *Fundamental Methods of Mathematical Economics*. New York: McGraw-Hill, 1984.

Clines, F. Death Penalty Is Suspended In Maryland. *New York Times*, 10 May 2002.

Clines, F., and Drew, C. Maryland County is First to Move on Sniper Charges. *New York Times*, 26 October 2002.

Cloninger, D. Lethal Police Response as Crime Deterrent: A 57-City Study Suggests a Decrease in Certain Crimes Approach. *American Journal of Economics and Sociology*, January 1991, 59-69.

Coggins, J. and Ramezani, C. An Arbitrage-Free Approach to Quasi-Option Value. *Journal of Environmental Economics and Management*, March 1998, 103-125.

Conrad, J. Quasi Option Value and the Expected Value of Information. *Quarterly Journal of Economics*, June 1980, 813-20.

Cover, J. and Thistle, P. Time Series, Homicide, and the Deterrent Effect of Capital Punishment. *Southern Journal of Economics*, January 1988, 615-22.

__________. On the Option Value of Old-Growth Forest. *Ecological Economics*, August 1997, 97-102.

Cox, J. and Ross, S. The Valuation of Options for Alternative Stochastic Processes. *Journal of Financial Economics*, January/March 1976, 145-66.

Danigelis, N. and Cutler, S. Cohort Trends in Attitudes About Law and Order: Who's Leading the Conservative Wave? *Public Opinion Quarterly*, Spring 1991, 24-49.

Dezhbakhsh, H, Rubin, P. and Shepherd, J. Does Capital Punishment Have a Deterrent Effect? New Evidence from Post-moratorium Panel Data, Department of Economics, Emory University, Working paper #01-01, January 2001.

Dixit, A. and Pindyck, R. *Investment Under Certainty*. Princeton: Princeton University Press, 1994.

Ehrlich, I. The Deterrent Effect of Capital Punishment: A Question of Life and Death. *American Economic Review*, June 1975, 397-417.

__________. Capital Punishment and Deterrence: Some Further Thoughts and Evidence. *Journal of Political Economy*, August 1977, 741-88.

Ellsworth, P. and Gross, S. Hardening of the Attitudes: Americans' Views on the Death Penalty. *Journal of Social Issues*, Summer 1994, 19-52.

Finlay, B. Right To Life and the Right To Die: Some Correlates of Euthanasia Attitudes. *Sociology and Social Research*, July 1985, 548-60.

Freeman, M. *The Measurement of Environmental and Resource Values: Theory and Methods*. Washington, DC: Resources for the Future, 1994.

Greenhouse, L. Justices Uphold Newly Set Limit on Federal Appeals by Inmates. *New York Times*, 28 June 1996.

Gross, S., The Romance of Revenge: Capital Punishment in America. *Studies in Law, Politics and Society*, 1993, 71-104.

Hanemann, W. Information and the Concept of Option Value. *Journal of Environmental Economics and Management*, January 1989, 23-37.

Healy, T. Death Penalty Support Drops as Debate Shifts: Foes Turning Focus from Moral Issues to Flaws in the System. *Baltimore Sun*, 25 July 2001.

Henry, C., Investments Decisions under Uncertainty: The Irreversibility Effect. *American Economic Review*, December 1974, 1006-1012.

Holden, J. Demographics, Attitudes, and Afterlife Beliefs of Right-To-Life and Right-To-Die Organization Members. *Journal of Social Psychology*, August 1993, 521-7.

Holmes, S. The Nation; Look Who' s Questioning the Death Penalty. *New York Times*, 16 April 2000.

Johnson, D. Illinois, Citing Faulty Verdicts, Bars Executions. *New York Times*, 1 February 2000.

Krutilla, J. Conservation Reconsidered. *American Economic Review*, September 1967, 777-86.

Leahy, P. <http://leahy.senate.gov/issues>

Liebman, J., Rifkind, S., and Fagan, J., A Broken System: Error Rates in Capital Cases, 1973-1995. Report for The Justice Project, <http://justice.policy.net/jpreport>, 2000.

Lord, C., Ross, L. and Lepper, M. Biased Assimilation and Attitude Polarization: The Effects of Prior Theories on Subsequently Considered Evidence. *Journal of Personality and Social Psychology*, November 1979, 2098-2109.

Lund, D. Financial and Non-financial Option Valuation, in *Stochastic Models and Option Values*, edited by D. Lund and B. Øksendal. Amsterdam: North-Holland, 1991, 143-63.

Markman, S. and Cassell, P. Protecting the Innocent: A Response to the Bedau-Radelet Study. *Stanford Law Review*, November 1988, 121-60.

McAleer, M. and Veall, M. How Fragile Are Fragile Inferences? A Re-Evaluation Deterrent Effect of Capital Punishment. *Review of Economics and Statistics*, February 1989, 99-106.

McDonald, R. and Siegel, D. The Value of Waiting to Invest. *Quarterly Journal of Economics*, November 1986, 707-727.

McKee, D. and Sesnowitz, M. Welfare Economic Aspect of Capital Punishment. *American Journal of Economics and Sociology*, January 1976, 41-7.

Moratorium Campaign. <http://www.moratorium2000.org>.

New York Times. *Bar Association Leaders Urge Moratorium on Death Penalty*, 4 February 1997.

Niskanen, W. *Bureaucracy and Representative Government*. Chicago: Aldine, 1971.

Pindyck, R. Irreversibility, Uncertainty, and Investment. *Journal of Economic Literature*, September 1991, 1110-48.

Rabin, M. Psychology and Economics. *Journal of Economic Literature*, March 1998, 11-46.

Reed, W. The Decision to Conserve or Harvest Old-Growth Forest. *Ecological Economics*, August 1993, 45-69.

Reynolds, M. Comment on Welfare Economic Aspect of Capital Punishment. *American Journal of Economics and Sociology*, 1977, 105-109.

Vidmar, N. and Ellsworth, P. Public Opinion and the Death Penalty, in *Capital Punishment in the United States*, edited by H. Bedau, A. Bedau, and C. Pierce. New York: MS Press, 1976.

Viscusi, K. *Fatal Tradeoffs: Public and Private Responsibilities for Risk.* Oxford: Oxford University Press, 1992.

West, L. Psychiatric Reflections on the Death Penalty, in *Capital Punishment in the United States*, ed. by H. Bedau, and C. Pierce. New York: AMS Press, 1976.

Zimring, F. and Hawkins, G. *Capital Punishment and the American Agenda*. Cambridge: Cambridge University Press, 1986.