

Censorship: the Key to Lock-In?

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ABSTRACT

Markets for information and entertainment are frequently characterized by increasing returns to scale in production and distribution. This implies that incumbent technologies enjoy an advantage over newcomer technologies; such markets can become locked into an inferior technology. Governments often heavily influence media markets through both direct ownership and censorship. I present a dynamic model with heterogeneity among consumers and firms in order to analyze the role of censorship in media markets. I assume there is a negative consumption externality across consumers and a negative cost spillover which an incumbent producer imposes on a newcomer. In a decentralized equilibrium, there is over-production of media from the incumbent technology. This reduces consumer utility and engenders lock-in of the inferior incumbent technology. I model censorship as a tax on information produced under the incumbent technology. A central planner who censors incumbent media can improve upon the decentralized equilibrium by reducing negative consumption externalities and unlocking the superior technology. I also show that censorship is only Pareto optimal when coupled with lump-sum transfers across consumers.

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1 Introduction

Information and entertainment markets are unique in at least two ways. First, information goods are inherently non-rival. One individual can consume a particular book, newspaper, or television program regardless of the number of other individuals that have consumed the same source of information. Second, the production and distribution of information is fundamentally characterized by high fixed costs and low (possibly zero) marginal costs. In such an environment consumers benefit greatly from the production of information. Perfect competition will push the price of information towards its low marginal cost. Consequently, potential suppliers of information may not be able to recoup high fixed costs and face inefficiently weak incentives to produce information in a competitive environment.

Government might resolve the shortcomings of competitively supplied information and entertainment. Djankov, McLiesh, Nenova and Shleifer (2003) estimate that for the average country in their sample of 97 economies, 29% of newspaper firms and 60% of television firms were directly owned by the state in 1999. They also find that state ownership may not improve the performance of media industries: direct governmental control of media is significantly associated with lower civil liberties, life expectancy, and greater imprisonment of journalists. Starr (2004) shows that over the past five centuries, guild licenses, copyrights, postal subsidies and censorship have also been regularly employed in Europe and the United States to indirectly influence private sector supply of information.

In markets for information and entertainment, censorship has exerted a particularly enduring influence. It is natural to view censorship as just one policy implemented by generally repressive governments. However, censorship is often pursued by governments which otherwise foster free expression. In the United States, government fines levied on radio and television broadcasters

increased by 164% over the years 2000-04.¹ There is pending legislation in the U. S. which seeks to increase the maximum fine on broadcast firms to \$250,000 - \$500,000 per incident of “indecentcy.”² If these fines are implemented, a broadcast media firm would face a maximum fine approximately 4-8 times greater than the maximum fine levied for mismanagement of a nuclear power plant in 2004.³

There is little evidence that, once intellectual property rights have been established and administered, the performance of media industries improves in response to government influence. Why is such influence pervasive? In this paper, I analyze media censorship from the perspective of a dynamic theoretical model. First, I assume that agents are heterogeneous in their preference for information. A particular piece of information can be consumed by agents of different types since information is non-rivalrous but I assume that some agents experience disutility from information consumed by others. Along with this negative consumption externality, I assume the production of information takes place under increasing returns to scale and that there are two technologies for producing information: an inferior incumbent and a superior newcomer. These assumptions imply that social welfare is not maximized in the competitive equilibrium. There is over-production of the externality-producing information and insufficient adoption of the superior technology.

The possibility that producers might lock-in to inferior technology was first proposed in Farrell and Saloner (1985, 1986) and evidence of the existence of lock-in has been discussed by David (1985) and Liebowitz and Margolis (1990, 2001). My model extends prior work by considering the role of competitively determined prices in generating lock-in: because of increasing returns, a newly introduced superior technology produces information with a high price. Under the assump-

¹The Federal Communications Commission reports that total indecentcy fines were \$48,000 in 2000 and \$7,928,080 in 2004, see <http://www.fcc.gov/eb/broadcast/ichart.pdf>.

²The lower house of Congress endorsed the \$500,000 fine on February 16, 2005 while the upper house passed the \$250,000 fine on June 21, 2005.

³The maximum Nuclear Regulatory Commission fine of \$60,000 in 2004 was obtained from <http://www.nrc.gov/reading-rm/doc-collections/news/2004/>, see also Swanson (2005).

tion that censorship acts as a tax on information produced by an incumbent technology, the price of information produced by the incumbent technology will rise relative to a decentralized competitive equilibrium. This increase in the incumbent price will engender greater consumption of a newcomer's output. Censorship can improve social welfare by simultaneously reducing the negative consumption externality and encouraging adoption, or "unlocking," of a newcomer technology. Provided there are transfers to compensate those who are harmed by the higher price of incumbent information, I show that censorship can lead to a Pareto improvement over the unregulated competitive equilibrium.

The remainder of the paper is as follows: in Section 2 I describe the model and solve for the decentralized competitive equilibrium. In Section 3 I describe the central planner's problem and derive the socially optimal level of censorship and transfers. I conclude with Section 4 which relates the model to some empirical issues and outlines some further extensions.

2 The Model and Decentralized Equilibrium

The theory in this paper contains a heterogeneous environment with two types of consumers for information produced by two types of firms. The model is dynamic in that the cost of producing information in the current period depends upon the equilibrium outcome in the prior period. I begin with a description of the payoffs and constraints for consumers and firms and then solve for the decentralized competitive equilibrium without censorship.

2.1 Consumers, Technology and Firms

Consumers

I assume there are two types of consumers indexed by $i = 1, 2$. There are a mass of consumers with N_i denoting the number of consumers of type i . The total number of consumers is N . I

assume each consumer type will maximize utility over one period so that individuals don't consider the impact of their current decisions on the future value of aggregate endogenous variables. Since there are a mass of consumers, this assumption captures the notion that each consumer is a small component of the market for information and does not consider the impact of her / his decision on the aggregate outcome in the future.⁴

Each individual can consume information produced by one of two firms: an incumbent and a newcomer. Variables corresponding to the newcomer firm will be marked by a tilde so that consumption of the incumbent information by an individual of type i in period t is $x_{i,t}$ while consumption of the newcomer good is $\tilde{x}_{i,t}$. I assume that the utility functions for each consumer type are Cobb-Douglas:

$$U_{1,t} = u_1 x_{1,t}^\alpha \tilde{x}_{1,t}^\beta (N_2 x_{2,t})^{-\eta} \quad (1)$$

$$U_{2,t} = u_2 x_{2,t}^\alpha \tilde{x}_{2,t}^\beta \quad (2)$$

where u_1 and u_2 are scaling parameters.⁵ Under these utility functions, the incumbent information consumed by all type two individuals exerts a negative spillover on the type one consumer. One type of information benefits the type two consumer while simultaneously reducing the utility of the type one consumer.

The newcomer's output is technologically superior in two ways. First, the consumption of

⁴By assuming a one-period horizon for consumers I also indirectly incorporate a coordination problem. In a multi-period setting, consumers might simultaneously adopt a new technology in order to increase future utility, in which case lock-in would not arise in the decentralized equilibrium.

⁵More specifically,

$$u_1 \equiv \frac{(\alpha + \beta)^{\alpha + \beta - \eta}}{\alpha^{\alpha - \eta} \beta^\beta}$$

$$u_2 \equiv \frac{(\alpha + \beta)^{\alpha + \beta}}{\alpha^\alpha \beta^\beta}$$

newcomer information by the type two individual does not adversely impact the type one individual. This assumption is particularly appropriate when new techniques for producing information are inherently more private and less intrusive. Also, I assume that $\beta > \alpha$ so that, for all consumers, utility is more sensitive to consumption of the newcomer's output relative to the incumbent's output (the elasticity of utility with respect to \tilde{x} is greater than the elasticity with respect to x). For both of these reasons, the newcomer's output is a technological advancement. Finally, I assume the negative consumption externality is relatively strong and that it impacts a relatively large mass of consumers $\alpha < (N_1/N)\eta$ so that the existence of information produced by the incumbent is a net social burden. Note that this inequality is also sufficient to ensure that $\alpha < \eta$ so that an increase in consumption of incumbent information which is equal across consumer types will lead to a net decrease in the utility of the type one individual.

A consumer will pay a price of p (\tilde{p}) for each unit of information purchased from the incumbent (newcomer) and income is exogenous in each period.⁶ The budget constraint of a consumer of type i is therefore:

$$p_t x_{i,t} + \tilde{p}_t \tilde{x}_{i,t} = y_{i,t}^n \quad (3)$$

where $y_{i,t}^n$ is the net income of a consumer. Government (central planner) transfers across individuals can alter net income. Since optimal censorship / taxation will reduce the negative spillover on the type one individual at the expense of the type two individual, transfers will flow from type one agents to type two agents in order to compensate for the burden of censorship and create a Pareto improvement: $y_{1,t}^n = y_{1,t} - T_{1,t}$ and $y_{2,t}^n = y_{2,t} + T_{2,t}$.

Maximization of the utility functions (1)-(2) subject to the budget constraint yields standard

⁶Many information and entertainment markets are "two-sided": consumers receive the output of firms in media industries on one side of the market for free. Advertisers pay media firms on the other side of the market. For more on this point, see Anderson and Coate (2005). In two-sided markets, the output of media firms is directly free to consumers although the consumption of unwanted advertisements serves as an indirect price paid by consumers (Cunningham and Alexander (2004) carefully model advertising as an opportunity cost to consumers). For the sake of simplicity, I assume that consumers pay media firms directly and abstract from the role of advertisers.

Walrasian demand functions for information:

$$x_{i,t} = \frac{\alpha}{\alpha + \beta} \frac{y_{i,t}^n}{p_t} \quad \tilde{x}_{i,t} = \frac{\beta}{\alpha + \beta} \frac{y_{i,t}^n}{\tilde{p}_t}. \quad (4)$$

Aggregating demand across individuals yields expressions for total information demand:

$$x_t = \frac{\alpha}{\alpha + \beta} \frac{y_t}{p_t} \quad (5)$$

$$\tilde{x}_t = \frac{\beta}{\alpha + \beta} \frac{y_t}{\tilde{p}_t} \quad (6)$$

where total incumbent demand is $x_t = N_1 x_{1,t} + N_2 x_{2,t}$, total newcomer demand is $\tilde{x}_t = N_1 \tilde{x}_{1,t} + N_2 \tilde{x}_{2,t}$ and aggregate gross income is $y_t = N_1 y_{1,t} + N_2 y_{2,t}$.⁷

The indirect utility functions which emerge from consumer utility maximization are:

$$U_{1,t} = \frac{(y_{1,t}^n)^{\alpha+\beta} p_t^{\eta-\alpha}}{(N_2 y_{2,t}^n)^\eta \tilde{p}_t^\beta} \quad (7)$$

$$U_{2,t} = \frac{(y_{2,t}^n)^{\alpha+\beta}}{p_t^\alpha \tilde{p}_t^\beta}. \quad (8)$$

Notice that, because $\alpha < \eta$, a type one agent benefits from a *higher* incumbent price. This may seem counterintuitive but an increase in the price of the incumbent's output reduces the type two agent's consumption of the incumbent's information (see (4)). This reduces the negative consumption externality. Both consumers experience lower utility when the newcomer's price increases while the type two consumer experiences lower utility when the incumbent charges a higher price.

Technology

I denote the total incumbent good cost by c , and the total newcomer good cost by \tilde{c} . Each cost

⁷Total demand is obtained when a balanced budget condition is imposed on the transfers: $N_1 T_{1,t} = N_2 T_{2,t}$.

is determined by the following functions:

$$c_t = \frac{\chi}{\sigma_1 x_{t-1}^*} x_t^{1+\gamma} \quad \tilde{c}_t = \frac{\chi \sigma_2 x_{t-1}^*}{\sigma_1 \tilde{x}_{t-1}^*} \tilde{x}_t^{1+\gamma} \quad (9)$$

where x_{t-1}^* and \tilde{x}_{t-1}^* represent the market-clearing levels of the information good in the prior period and $\chi, \sigma_1, \sigma_2 > 0$. I also assume $0 < \gamma < 1$. The first condition on γ implies that the marginal cost of production is rising within a particular period while the second assumption implies that in a market-clearing steady-state, production of each good is characterized by increasing returns to scale. For example, the average cost of production of the incumbent good in the steady-state is decreasing in the level of steady-state production (x_{ss}^*): $(\chi/\sigma_1)(x_{ss}^*)^{-(1-\gamma)}$.

These functions also feature a negative cost spillover running from the incumbent to the newcomer. If production of the incumbent good drops the total cost of the newcomer is lower. Negative cost spillovers are assumed in order to capture additional advantages experienced by an incumbent technology. In particular, there are reasons to believe that network effects are important in information markets. A given technology is often useful because it adheres to a standard. This guarantees that individual users of the technology can easily exchange information with one another. An incumbent technology, with an existing base of users, is therefore more beneficial to each user. A new technology is typically more costly to use on a relative basis since it is frequently incompatible with the existing standard. The assumption of a negative cost spillover serves as an additional source of entrenchment for the incumbent technology.

Information Firms

I assume there is a representative producer for each of the two types of goods. I further assume that the incumbent goods producer alone faces censorship. Since information produced by the newcomer does not create a consumption externality, there is no reason to tax the newcomer.

There are also reasons to believe that a government may fail to censor new techniques for producing information due to either lags in adjustment of policy or additional complexities involved in monitoring the new technology.⁸ I formally model censorship as a production tax of τ for each unit of revenue received from sales of information by the incumbent to the type two consumer. Under these assumptions, the profits for the incumbent and newcomer are:

$$\pi_t = p_t N_1 x_{1,t} + p_t (1 - \tau_t) N_2 x_{2,t} - c_t \quad (10)$$

$$\tilde{\pi}_t = \tilde{p}_t N_1 \tilde{x}_{1,t} + \tilde{p}_t N_2 \tilde{x}_{2,t} - \tilde{c}_t. \quad (11)$$

I use a perfect competition equilibrium condition that profits for each firm are zero, this implicitly assumes that the threat of entry by media firms drives profits to zero.⁹ Under this equilibrium condition, the supply relationships for the two firms are:

$$p_t = \frac{\chi}{\sigma_1 x_{t-1}^*} \frac{x_t^{1+\gamma}}{x_t - \tau_t N_2 x_{2,t}} \quad (12)$$

$$\tilde{p}_t = \frac{\chi \sigma_2 x_{t-1}^*}{\sigma_1 \tilde{x}_{t-1}^*} \tilde{x}_t^\gamma. \quad (13)$$

Note that, because of dynamic increasing returns to scale, higher equilibrium production in the past leads each firm to supply its own information at a lower price in the present. Higher production by the incumbent in the past leads to higher current prices for the newcomer due to the cost spillover. Also, a higher level of censorship (taxation) increases the price of information for the incumbent. This final result is critical in determining the impact of censorship on the equilibrium behavior of consumers and firms.

⁸The internet is a clear example of an innovation in information technology which is inherently more difficult to tax.

⁹This assumption could be loosened in order to analyze the equilibrium under imperfect competition and markups. Such an analysis is left for future research.

2.2 Market Clearing Price Dynamics

The remainder of the paper analyzes the behavior of consumers and firms under market clearing prices which equate the demand for information to supply (market clearing equilibrium values will be marked with a star). Using equations (5)-(6) and (12)-(13), I obtain the following expression for market-clearing prices:

$$p_t^*(\tau_t, \tau_{t-1}) = \left(\frac{\alpha}{\alpha + \beta} \right)^{\frac{\gamma}{1+\gamma}} \left(\frac{\chi}{\sigma_1} \frac{1}{x_{t-1}^*} \right)^{\frac{1}{1+\gamma}} \frac{y_t^{\frac{\gamma}{1+\gamma}}}{(1 - \tau_t N_2 y_{2,t}^n / y_t)^{\frac{1}{1+\gamma}}} \quad (14)$$

$$\tilde{p}_t^*(\tau_{t-1}) = \left(\frac{\beta}{\alpha + \beta} \right)^{\frac{\gamma}{1+\gamma}} \left(\frac{\chi \sigma_2}{\sigma_1} \frac{x_{t-1}^*}{\tilde{x}_{t-1}^*} \right)^{\frac{1}{1+\gamma}} y_t^{\frac{\gamma}{1+\gamma}}. \quad (15)$$

The incumbent market-clearing price depends upon the level of censorship (taxation). Market-clearing prices for each good depend upon the lagged equilibrium output of each producer due to dynamic increasing returns to scale. Because prior levels of taxes will influence the level of market clearing production in the past, both prices also depend upon the previous level of taxation.

The expressions for the market-clearing level of demand (equations (5) and (6)) can be combined with market-clearing prices to obtain a system of first-order nonlinear difference equations for market-clearing level of prices:

$$p_t^*(\tau_t, \tau_{t-1}) = k_t(\tau_t) p_{t-1}^*(\tau_{t-1}, \tau_{t-2})^{\frac{1}{1+\gamma}} \quad (16)$$

$$\tilde{p}_t^*(\tau_{t-1}) = \tilde{k}_t \left[\frac{\tilde{p}_{t-1}^*(\tau_{t-2})}{p_{t-1}^*(\tau_{t-1}, \tau_{t-2})} \right]^{\frac{1}{1+\gamma}} \quad (17)$$

where

$$k_t(\tau_t) = \left(\frac{\chi}{\sigma_1} \right)^{\frac{1}{1+\gamma}} \left(\frac{\alpha + \beta}{\alpha} y_t^{-1} \right)^{\frac{1-\gamma}{1+\gamma}} (1 - \tau_t N_2 y_{2,t}^n / y_t)^{\frac{-1}{1+\gamma}} \quad (18)$$

$$\tilde{k}_t = \left(\frac{\chi \sigma_2}{\sigma_1} \right)^{\frac{1}{1+\gamma}} \left(\frac{\beta}{\alpha + \beta} \right)^{\frac{\gamma}{1+\gamma}} \left(\frac{\alpha}{\beta} \right)^{\frac{1}{1+\gamma}} y_t^{\frac{\gamma}{1+\gamma}}. \quad (19)$$

Note that the central planner can always choose the value of k_t since it is monotonically increasing in current taxation and transfers to the type two consumer. This also implies that the central planner can use current policy to select the incumbent's price. Higher taxes reduce supply while greater transfers to the type two consumer increase demand. Either policy increases k_t and the market-clearing price for information produced by the incumbent.

2.3 Decentralized Competitive Steady State

If a central planner does not attempt to influence the competitive outcome in the steady-state, taxes and transfers are zero ($\tau_{ss} = T_{1,ss} = T_{2,ss} = 0$ and $y_{i,ss}^n = y_i$). Also, market-clearing prices are stable over time as part of a steady-state: $p_t^*(0) = p_{t-1}^*(0) = p_{ss}^*(0)$ and $\tilde{p}_t^*(0) = \tilde{p}_{t-1}^*(0) = \tilde{p}_{ss}^*(0)$. The laws of motion (16)-(17) yield the solution for decentralized market clearing prices in a steady-state equilibrium:

$$p_{ss}^*(0) = [k_{ss}(0)]^{\frac{1+\gamma}{\gamma}} \quad (20)$$

$$\tilde{p}_{ss}^*(0) = \tilde{k}_{ss}^{\frac{1+\gamma}{\gamma}} [k_{ss}(0)]^{\frac{-(1+\gamma)}{\gamma^2}}. \quad (21)$$

I find that as k increases the price of the incumbent's information rises and the newcomer's falls.

Combining this result with the indirect utility functions (7)-(8) I obtain consumer welfare under the decentralized steady-state:

$$U_{1,ss}^*(0) = \frac{y_{1,ss}^{\alpha+\beta}}{(N_2 y_{2,ss})^\eta} \tilde{k}_{ss}^{\frac{-\beta(1+\gamma)}{\gamma}} [k_{ss}(0)]^{\frac{1+\gamma}{\gamma} (\eta + \frac{\beta}{\gamma} - \alpha)} \quad (22)$$

$$U_{2,ss}^*(0) = y_{2,ss}^{\alpha+\beta} \tilde{k}_{ss}^{\frac{-(1+\gamma)}{\gamma}} [k_{ss}(0)]^{\frac{1+\gamma}{\gamma} (\frac{\beta}{\gamma} - \alpha)}. \quad (23)$$

Because $\beta > \alpha$ and $\gamma < 1$ the utility of each consumer is increasing in k .

With a higher value of k , demand for the incumbent's information increases and / or supply

contracts. As the price of the incumbent’s information rises, both consumers shift their demand toward the newcomer. The newcomer benefits from increasing returns to scale as its technology is “unlocked” and the newcomer’s price falls. Both consumers are directly harmed by the higher price of the incumbent’s information but benefit from the unlocking of the superior technology. Because this newcomer is superior, this “unlocking” results in a net increase in utility. The utility of a type one agent increases at a faster rate because the negative consumption externality falls as consequence of lower incumbent consumption by the type two agent. The competitive equilibrium features lock-in since consumer welfare can be improved by pushing k above its decentralized value of $k_{ss}(0)$. In the next section, I analyze the socially optimal level of censorship.

3 Social Welfare Under Censorship

I assume the central planner maximizes a particular social welfare function (SW_t) which is log-linear and adjusted for distortions caused by the deviation of the incumbent’s price from the decentralized equilibrium:

$$SW_t = N_1 \ln \frac{U_{1,t}^*(\tau_t, \tau_{t-1})}{U_{1,t}^*(0)} + N_2 \ln \frac{U_{2,t}^*(\tau_t, \tau_{t-1})}{U_{2,t}^*(0)} - .5\lambda \left[\frac{p_t^*(\tau_t, \tau_{t-1})}{p_t^*(0)} - 1 \right]^2. \quad (24)$$

Under this function, social welfare is higher whenever a consumer’s utility in the centralized market-clearing equilibrium ($U_{i,t}^*(\tau_t, \tau_{t-1})$) increases relative to the decentralized market-clearing equilibrium ($U_{i,t}^*(0)$).¹⁰ The utility of each consumer type is weighted by the number of consumers of that type. Other things equal, social welfare decreases at an increasing rate as the central planner pushes the incumbent’s price away from the decentralized market-clearing price; $\lambda > 0$ captures the magnitude of this effect. At higher levels of censorship it is more likely that firms will attempt to

¹⁰Note that producer surplus doesn’t enter the social welfare function since I focus on a zero profit competitive equilibrium in all cases.

circumvent the central planner's taxation in order to increase revenues. Although such distortions are not directly modelled, the third term in the social welfare function addressed the possibility that greater resources are used to enforce censorship as the information market is pushed far away from the decentralized competitive equilibrium.¹¹

I investigate the government's problem under three objectives. First, it is possible that a government may entirely lack knowledge regarding the superiority of a new technology and solely design censorship to reduce current negative consumption externalities. I refer to this as a short-sighted policy. Second, a central planner might pursue a far-sighted objective under which it uses censorship to both reduce consumption externalities and increase the adoption of superior technologies in the long run. Finally, social welfare can be maximized in a dynamic context under which censorship is designed to improve upon the decentralized equilibrium in both the short and long run. Under each of these objectives I solve for transfers which guarantee Pareto optimal censorship.

3.1 Short-Sighted Policy

I begin by assuming that the central planner ignores the long-run dynamic implications of censorship. In essence, the government ignores the laws of motion for market-clearing prices (equations (16) and (17)). This approach is appropriate in a situation where the quality of the newcomer technology and the dynamic increasing returns to scale are unknown to the central planner. The government is simply aware of the negative consumption externality and attempts to reduce that externality in the present. I also assume that the government holds past and future policy exogenous when setting the level of current media taxation. I obtain the government's objective function

¹¹It is straightforward to solve the social planner's problem when $\lambda = 0$. This creates corner solutions for the optimal policy which are qualitatively similar to the interior solutions which emerge when $\lambda > 0$.

by combining the indirect utility functions (7)-(8) with the social welfare function above:

$$SW_{1,t} = s_{1,t} + N_1(\eta - \alpha) \ln \frac{p_t^*(\tau_t)}{p_t^*(0)} - N_2\alpha \ln \frac{p_t^*(\tau_t)}{p_t^*(0)} - .5\lambda \left[\frac{p_t^*(\tau_t)}{p_t^*(0)} - 1 \right]^2 \quad (25)$$

$$s_{1,t} \equiv (\alpha + \beta) \ln \left(\frac{y_{1,t}^n}{y_{1,t}} \right) + (\alpha + \beta - \eta) \ln \left(\frac{y_{2,t}^n}{y_{2,t}} \right). \quad (26)$$

I solve the central planner's problem by using a two step procedure. First, I find the ratio of market-clearing prices with and without censorship ($p_t^*(\tau_t)/p_t^*(0)$) which maximizes $SW_{1,t}$. I then find the level of censorship and transfers which are consistent with the welfare-maximizing price ratio.

The first and second order conditions for an interior welfare-maximizing price ratio are:

$$\frac{\partial SW_{1,t}}{\partial [p_t^*(\tau_t)/p_t^*(0)]} = \frac{N_1(\eta - \alpha)}{p_t^*(\tau_t)/p_t^*(0)} - \frac{N_2\alpha}{p_t^*(\tau_t)/p_t^*(0)} - \lambda \left[\frac{p_t^*(\tau_t)}{p_t^*(0)} - 1 \right] = 0 \quad (27)$$

$$\frac{\partial^2 SW_{1,t}}{\partial [p_t^*(\tau_t)/p_t^*(0)]^2} = \frac{-N_1(\eta - \alpha)}{[p_t^*(\tau_t)/p_t^*(0)]^2} + \frac{N_2\alpha}{[p_t^*(\tau_t)/p_t^*(0)]^2} - \lambda < 0. \quad (28)$$

The second-order condition will hold since I've assumed strong negative consumption externalities and that the mass of type one consumers is sufficiently great ($\alpha < (N_1/N)\eta$). A solution to the first-order condition will represent an interior optimum for the central planner.

The first-order condition can be manipulated to obtain a quadratic in the ratio of censored to uncensored market-clearing prices. The solution to this quadratic is:

$$\frac{p_t^*(\tau_t)}{p_t^*(0)} = .5 + \sqrt{.25 + \frac{N_1\eta - N\alpha}{\lambda}} \equiv \kappa_1^* > 1. \quad (29)$$

Under a short-sighted objective the central planner will choose an incumbent price above the decentralized market-clearing price.¹² This policy reduces the negative consumption externality

¹²I ignore the second solution to the quadratic since it implies negative prices.

and results in higher social welfare, relative to the competitive equilibrium. According to this solution for the central planner's problem, the incumbent price under censorship is greater as the number of type one consumers (N_1) increases, the negative consumption externality is worse (larger η) and the distortion from censorship (λ) is lower.

In order for government censorship to represent a Pareto improvement over the decentralized equilibrium, the utility of each consumer type in the centralized equilibrium must be no less than utility in the decentralized equilibrium: $U_1^*(\tau_1) \geq U_1^*(0)$ and $U_2^*(\tau_1) \geq U_2^*(0)$. I represent the Pareto optimal tax which achieves the price ratio (29) by τ_1^p . Combining an assumption that the type two consumer is indifferent between censorship and the decentralized equilibrium ($U_2^*(\tau_1) = U_2^*(0)$) along with the government's balanced budget condition yields the following values for transfers:

$$T_{1,t} = \left(\kappa_1^{\frac{\alpha}{\alpha+\beta}} - 1 \right) (N_2/N_1)y_{2,t} \quad (30)$$

$$T_{2,t} = \left(\kappa_1^{\frac{\alpha}{\alpha+\beta}} - 1 \right) y_{2,t} \quad (31)$$

Notice that the optimal transfers to the type two agent are increasing in type two's gross income and the level of prices under censorship.

Provided the following conditions hold:

$$\eta \min \left\{ \frac{N_1}{N}, \frac{\beta}{\alpha + \beta} \right\} > \alpha \quad (32)$$

$$\frac{N_1 y_{1,t}}{N_2 y_{2,t}} > \frac{\kappa_1^{\left(\frac{\beta\eta}{\alpha+\beta} - \alpha \right) \frac{1}{\alpha+\beta}} \left(\kappa_1^{\frac{\alpha}{\alpha+\beta}} - 1 \right)}{\kappa_1^{\left(\frac{\beta\eta}{\alpha+\beta} - \alpha \right) \frac{1}{\alpha+\beta}} - 1} \quad (33)$$

the type one consumer will strictly prefer censorship under a short-sighted objective. Consider (33): as the income of a type one agent increases, it becomes easier for to pay transfers to the type two agent and still benefit from taxation of the incumbent technology. As the income of the

type two consumer decreases, transfers to the type two agent decrease and it is more likely that the type one agent experiences a net benefit from higher incumbent prices (post transfer). The relative number of agents plays a complicated role in this model. For example, as N_1 increases the burden of compensating transfers is spread across a wider number of consumers but transfers must be higher since the central planner chooses a higher incumbent price.

The Pareto optimal tax which is consistent with the optimal price ratio ($\tau_{1,t}^p$) can be obtained by assuming the central planner's policy is in place for at least one period.¹³ According to the expression for incumbent information demand (equation (5)) the ratio of centralized to decentralized market-clearing incumbent output is: $x_{t-1}^*(0)/x_{t-1}^*(\tau_1) = p_{t-1}^*(\tau_1)/p_{t-1}^*(0) = \kappa_1^*$. Combining this result with (14) while substituting the expression for the Pareto type two transfer results in an expression for the Pareto optimal level of censorship:

$$\tau_{1,t}^p = \frac{(1 - \kappa_1^{*- \gamma})y_t}{N_2 \kappa_1^{*\frac{\alpha}{\alpha+\beta}} y_{2,t}}. \quad (34)$$

I find that a higher value of κ_1^* doesn't necessarily translate into higher censorship / taxation under a Pareto optimal policy since transfers will, at least in part, directly result in a higher incumbent price. If the government tries to achieve a higher incumbent price it will need to increase transfer to the type two consumer in order to meet the Pareto condition. Although total demand does not depend on the level of transfers (see (5)), higher transfers imply that a larger portion of demand originates from the type two consumer. The incumbent producer only receives a fraction of this expenditures from the type two consumer, due to censorship, so it increases p in order to compensate for lower net revenues.

This point is further illustrated by a non-Pareto policy in which transfers to the type two

¹³For analytical simplicity, I ignore the issue of adjusting censorship during implementation.

consumer are zero but overall social welfare increases under censorship. The tax supporting the optimal incumbent price ratio without Pareto transfers is:

$$\tau_{1,t}^{np} = \frac{(1 - \kappa_1^{*- \gamma})y_t}{N_2 y_{2,t}} > \tau_{1,t}^p. \quad (35)$$

Censorship is higher under the non-Pareto policy. There are no transfers, so the central planner achieves a greater incumbent price through taxation alone. Censorship also increases monotonically with the incumbent price ratio under a non-Pareto policy.

The implications of censorship are illustrated in Figure 1 where equilibrium prices and consumer utility are calculated under the parameter values listed in the Appendix.¹⁴ I assume that in period zero the newcomer's output is produced and consumer under market-clearing conditions.¹⁵ In the decentralized equilibrium without censorship \tilde{p} falls as the newcomer experiences economies of scale. In contrast, p increases as the incumbent encounters lower demand for its output and diseconomies of scale. Both consumer types experience higher utility as the newcomer's technology is adopted but after ten periods there is lock-in since the price of the newcomer's information remains almost three times greater than the incumbent's price. In contrast, censorship causes the price of the incumbent's information to rise above the price of the newcomer's information after two periods have passed.¹⁶ Without transfers this unlocking of the superior technology during the first two periods of censorship causes the type two consumer to experience lower utility (relative to the decentralized equilibrium). The Pareto optimal policy involves over-compensating the type two consumer with transfers since the government ignores the unlocking benefit created by taxation of

¹⁴For the purpose of these figures, $x(0)$ is the value of x in the decentralized equilibrium, $x(\kappa_i^*)$ is the equilibrium value of x under censorship without transfers, and $x(\kappa_i^{*P})$ is the value of x under Pareto optimal censorship including transfers.

¹⁵In period -1 I assume that the price of the newcomer's information is 100,000 time the price of the incumbent so that the newcomer produces a very small amount of information initially.

¹⁶The optimal tax on the incumbent is approximately 240% in this example.

the incumbent. Censorship with properly designed transfers is Pareto optimal under a short-sighted objective.

3.2 Far-Sighted Policy

I now consider a government which maximizes the social welfare function in the long run. In this circumstance, the central planner considers both the negative consumption externality and the long-run impact of censorship on technological adoption but ignores the impact of implementing censorship in the short run. I represent the steady-state level of censorship by τ_2 .¹⁷ According to the law of motion for the newcomer price (16), the steady state newcomer price is:

$$\tilde{p}_{ss}(\tau_2) = \tilde{k}^{\frac{1+\gamma}{\gamma}} p_{ss}^*(\tau_2)^{-\frac{1}{\gamma}} \quad (36)$$

In the long run, the newcomer experiences greater returns to scale, and lower prices, as the incumbent increases its price. Substitution of this result into the social welfare function (24) yields the far-sighted objective function:

$$SW_2 = s_2 + N_1 \left(\eta + \frac{\beta}{\gamma} - \alpha \right) \ln \frac{p_{ss}^*(\tau_2)}{p_{ss}^*(0)} + N_2 \left(\frac{\beta}{\gamma} - \alpha \right) \ln \frac{p_{ss}^*(\tau_2)}{p_{ss}^*(0)} - .5\lambda \left[\frac{p_{ss}^*(\tau_2)}{p_{ss}^*(0)} - 1 \right]^2 \quad (37)$$

$$s_2 \equiv (\alpha + \beta) \ln \left(\frac{y_1^n}{y_1} \right) + (\alpha + \beta - \eta) \ln \left(\frac{y_2^n}{y_2} \right). \quad (38)$$

Now the utility of both consumer types is increasing in the ratio of centralized to decentralized prices (see the second and third terms of SW_2). Even though the incumbent price is higher under censorship, the net impact of taxation is an increase in consumer welfare since the newcomer is both superior and produced under increasing returns to scale ($\beta/\gamma > \beta > \alpha$). This implies that Pareto optimal censorship will not require transfers to the type two agent since s/he benefits from

¹⁷In this section, I remove the time subscript to denote that a variable is in its steady state.

ensorship in the long run.

The first and second order conditions are:

$$\frac{\partial SW_2}{\partial [p_{ss}^*(\tau_2)/p_{ss}^*(0)]} = \frac{N_1 \left(\eta + \frac{\beta}{\gamma} - \alpha \right)}{p_{ss}^*(\tau_2)/p_{ss}^*(0)} + \frac{N_2 \left(\frac{\beta}{\gamma} - \alpha \right)}{p_{ss}^*(\tau_2)/p_{ss}^*(0)} - \lambda \left[\frac{p_{ss}^*(\tau_2)}{p_{ss}^*(0)} - 1 \right] = 0 \quad (39)$$

$$\frac{\partial^2 SW_2}{\partial [p_{ss}^*(\tau_2)/p_{ss}^*(0)]^2} = \frac{-N_1 \left(\eta + \frac{\beta}{\gamma} - \alpha \right)}{[p_{ss}^*(\tau_2)/p_{ss}^*(0)]^2} - \frac{N_2 \left(\frac{\beta}{\gamma} - \alpha \right)}{[p_{ss}^*(\tau_2)/p_{ss}^*(0)]^2} - \lambda < 0. \quad (40)$$

Since the newcomer is technologically superior, the second order condition is guaranteed to hold.

The price ratio which solves the first-order condition is:

$$\frac{p_{ss}^*(\tau_2)}{p_{ss}^*(0)} = .5 + \sqrt{.25 + \frac{N_1 \eta + N(\beta/\gamma) - N\alpha}{\lambda}} = \kappa_2^* > \kappa_1^* > 1. \quad (41)$$

Relative to the short-sighted objective, the central planner will choose a higher incumbent price. Both the short and far-sighted governments attempt to reduce the consumption externality by setting a higher incumbent price. The far-sighted government pushes this price even higher in order to achieve a second goal: greater adoption of the superior technology. All of the prior comparative statics for the incumbent price continue to hold. Also, the incumbent price is increasing in the elasticity of utility with respect to newcomer information (β). Unlocking occurs at a lower rate as γ increases (the steady-state elasticity of average costs with respect to output is $1 - \gamma$ in absolute value). For this reason, the optimal incumbent price decreases in γ .

As discussed above, censorship by itself is Pareto optimal. A far-sighted government does not employ transfers. The tax corresponding to the optimal price ratio (41) is:

$$\tau_2 = \frac{(1 - \kappa_2^{*\gamma})y}{N_2 y_2} > \tau_{1,t}^{np} > \tau_{1,t}^p. \quad (42)$$

As a government places greater weight on the future it pursues higher levels of censorship. Since

transfers are unnecessary, censorship must be even greater in order to achieve the relatively high optimal price ratio dictated by the far-sighted objective. Direct transfers to those harmed by censorship are rarely observed in information markets. This could be a consequence of far-sighted policy in the presence of lock-in.

Figure 2 illustrates the dynamics of the model.¹⁸ With far-sighted censorship, the newcomer's price falls below the incumbent's price more quickly and by a larger amount. The type one consumer experiences a larger benefit from censorship since s/he doesn't provide transfers. The type two agent experiences a short-run loss as a consequence of a higher incumbent price. However, unlocking of the superior technology in the long run compensates for the burden of censorship and leaves the type two agent better off after four periods.

3.3 Dynamic Policy

The last central planner problem I consider is maximization of social welfare (equation (24)) over both the short and long run. Such a policy simultaneously and optimally addresses the negative consumption externality and lock-in. In order to find the optimal dynamic policy, the central planner will treat the decentralized to centralized price ratios for the incumbent and the newcomer as two state variables. The government chooses k_t from (16) in order to maximize social welfare in the present and in the future. I assume the central planner applies a discount factor of δ to social welfare one period in the future. The value function for this problem is:

$$V_t \left[\frac{p_t^*(\tau_t, \tau_{t-1})}{p_t^*(0)}, \frac{\tilde{p}_t^*(\tau_t)}{\tilde{p}_t^*(0)} \right] = \max_{k_t} \left\{ SW_t + \delta V_{t+1} \left[\frac{p_t^*(\tau_{t+1}, \tau_t)}{p_t^*(0)}, \frac{\tilde{p}_t^*(\tau_{t+1})}{\tilde{p}_t^*(0)} \right] \right\} \quad (43)$$

¹⁸This figure employs the same parameter values as Figure 1. The optimal tax on the incumbent is approximately 500% under a far-sighted objective.

subject to

$$\frac{p_t^*(\tau_t, \tau_{t-1})}{p_t^*(0)} = \left[\frac{k_t(\tau_t) p_{t-1}^*(\tau_{t-1}, \tau_{t-2})}{k_t(0) p_{t-1}^*(0)} \right]^{\frac{1}{1+\gamma}} \quad (44)$$

$$\frac{\tilde{p}_t^*(\tau_t)}{\tilde{p}_t^*(0)} = \left[\frac{\tilde{p}_{t-1}^*(\tau_{t-1})}{\tilde{p}_{t-1}^*(0)} \right]^{\frac{1}{1+\gamma}} \left[\frac{p_{t-1}^*(\tau_{t-1}, \tau_{t-2})}{p_{t-1}^*(0)} \right]^{\frac{-1}{1+\gamma}} \quad (45)$$

where SW_t is given by (24) and the laws of motion for the state variables are obtained from (16)-(17). The first-order condition for the dynamic policy objective is:¹⁹

$$N_1(\eta - \alpha) - N_2\alpha - \lambda \left[\frac{p_t^*(\tau_t, \tau_{t-1})}{p_t^*(0)} - 1 \right] \frac{p_t^*(\tau_t, \tau_{t-1})}{p_t^*(0)} + \quad (46)$$

$$+ \frac{\delta}{1 + \gamma} \left[V_{1,t+1} \frac{p_{t+1}^*(\tau_{t+1}, \tau_t)}{p_{t+1}^*(0)} - V_{2,t+1} \frac{\tilde{p}_{t+1}^*(\tau_t)}{\tilde{p}_{t+1}^*(0)} \right] = 0$$

while the envelope conditions are:

$$V_{1,t} = \frac{N_1(\eta - \alpha)}{p_t^*(\tau_t, \tau_{t-1})/p_t^*(0)} - \lambda \left[\frac{p_t^*(\tau_t, \tau_{t-1})}{p_t^*(0)} - 1 \right] \quad (47)$$

$$V_{2,t} = \frac{-N\beta}{\tilde{p}_{t+1}^*(\tau_t)/\tilde{p}_{t+1}^*(0)}. \quad (48)$$

The government encounters three benefits from censorship. The first two are a lower negative consumption externality in the present (the first term in (46)) and one period in the future (the first term in (47)) since taxation raises the incumbent's price over two periods. In addition, censorship reduces the future price of the newcomer's information (per (48)). The costs of censorship are determined by: 1) price distortions in the present and the future (see the third term in (46) and the second term in (47)) and 2) a higher price for the incumbent good in the present (the second term in (46)). An optimal tax policy equates these marginal costs and the marginal benefits.

¹⁹Note that V_1 is the partial derivative of the value function with respect to the first argument while V_2 is the partial with respect to the second.

Combining the first-order condition with the envelope conditions yields a policy rule which is a non-linear first-order difference equation:

$$\frac{\lambda\delta}{1+\gamma} \left[\frac{p_{t+1}^*(\tau_{t+1}, \tau_t)}{p_{t+1}^*(0)} - 1 \right] \frac{p_{t+1}^*(\tau_{t+1}, \tau_t)}{p_{t+1}^*(0)} - \frac{N\beta\delta}{1+\gamma} = \frac{[N_1(\eta - \alpha) - N_2\alpha](1 + \gamma + \delta)}{1 + \gamma} - \lambda \left[\frac{p_t^*(\tau_t, \tau_{t-1})}{p_t^*(0)} - 1 \right] \frac{p_t^*(\tau_t, \tau_{t-1})}{p_t^*(0)} \quad (49)$$

The steady-state solution to this policy rule is:

$$\frac{p_t^*(\tau_3)}{p_t^*(0)} = .5 + \sqrt{.25 + \frac{N_1\eta - N\alpha}{\lambda} + \frac{\delta}{1 + \gamma + \delta} \frac{N\beta}{\lambda}} = \kappa_3^* > 1. \quad (50)$$

Note that $\kappa_1^* < \kappa_3^* < \kappa_2^*$ so the optimal price ratio which emerges in the steady state under a dynamic policy objective is between the ratio from the short and far-sighted objectives. The government tries to unlock the superior technology (so the optimal price ratio under the short-sighted objective is lower), but does this at a slower rate than when s/he has a far-sighted objective since the benefits of unlocking are deferred.

If I apply a transformation of variables to the policy rule (49) so that

$$x_t \equiv \left[\frac{p_t^*(\tau_t, \tau_{t-1})}{p_t^*(0)} - 1 \right] \frac{p_t^*(\tau_t, \tau_{t-1})}{p_t^*(0)} \quad (51)$$

I obtain the following general solution for x :

$$x_t = \left[x_0 - \frac{N_1\eta - N\alpha}{\lambda} - \frac{\delta}{1 + \gamma + \delta} \frac{N\beta}{\lambda} \right] \left[\frac{-(1 + \gamma)}{\delta} \right]^t + \frac{N_1\eta - N\alpha}{\lambda} + \frac{\delta}{1 + \gamma + \delta} \frac{N\beta}{\lambda} \quad (52)$$

The value of x will either explode or converge to zero if x_0 deviates from the complementary solution (the last two terms in (51)). However, it is not optimal for the price ratio to explode or

converge towards zero. As the price ratio approaches infinity the marginal social welfare loss from distortions rises at an increasing rate (due to the quadratic) while the marginal benefit is constant (the constant terms in (49)). This can not maximize social welfare. The same argument holds true as the price ratio converges towards zero. So, the optimal policy entails setting the price ratio at the steady state value.

The Pareto optimal policy will involve time-varying transfers to the type two consumer as the superior technology becomes unlocked. The type two consumer loses utility as a result of a higher incumbent price every period following implementation of the optimal dynamic level of censorship (κ_3^*). The law of motion for the newcomer price, (17) can be used to show that j periods after the dynamic policy is implemented in period t , the newcomer price will be below the decentralized price according to:

$$\frac{\tilde{p}_{t+j}^*(\tau_3^*)}{\tilde{p}_{t+j}^*(0)} = \kappa_3^{*\frac{-1}{\gamma}} \left[1 - \frac{1}{(1+\gamma)^{j+1}} \right] \quad (53)$$

for $j \geq 1$. As time passes (j increases) the newcomer price falls relative to its decentralized level, thereby providing higher utility for the type two consumer. One can show that this fall in the price of the newcomer output just compensates for the higher price of the incumbent output after:

$$j^* = \frac{\ln[\beta/(\beta - \alpha\gamma)]}{\ln(1 + \gamma)} - 1 \quad (54)$$

periods have elapsed. For all periods $j \geq j^*$ after implementation, transfers to the type two agent are zero and censorship is Pareto optimal. For $j < j^*$ the government must transfer:

$$T_{2,t+j} = \left\{ \kappa_3^{*\frac{1}{\alpha+\beta}} \left[\alpha - \frac{\beta}{\alpha} \left(1 - \frac{1}{(1+\gamma)^{t+j}} \right) \right] - 1 \right\} y_{2,t+j} \quad (55)$$

to the type two consumer in order to compensate for the higher incumbent price. As time passes

the benefits of unlocking accrue so the transfers to the type two agent decline. Comparing Pareto transfers under the short-sighted objective (31) to (55) it becomes clear that, for a given ratio of censored to uncensored incumbent prices, a central planner following a dynamic objective sends lower transfers to the type two consumer since a dynamic government understands and reacts to unlocking of the newcomer technology. It is therefore sufficient to use (33) with κ_3^* substituted for κ_1^* in order to ensure that the type one agent strictly prefers Pareto optimal censorship.

Figure 3 illustrates the behavior of the model under dynamically optimal censorship. These results are a hybrid of the short-sighted and far-sighted outcomes. Relative to a far-sighted policy, the price of the newcomer takes one additional period to fall below the incumbent's price. The newcomer's price does fall fairly significantly in the long run as a consequence of unlocking. Under the Pareto optimal policy, the type one consumer loses some utility as transfers flow to the type two consumer but the transfers are zero from the fourth period onward. The type one consumer strictly prefers censorship during all periods. The type two consumer is indifferent between censorship and the unregulated outcome until the fourth period following which s/he benefits from unlocking of the superior technology. Censorship is not Pareto optimal in the absence of transfers since, in the short run, censorship harms the type two consumer.

4 Conclusion

I have presented a model of media markets in which information generates a negative externality across a heterogeneous group of consumers. The externality introduces an inefficiency in the model's competitive equilibrium which is compounded by insufficient adoption of a superior technology for producing information. Censorship can improve upon the competitive equilibrium in two ways. Through taxation of the incumbent, censorship increases the price of the externality-producing information and can improve the welfare of the majority of agents. Second, censorship causes a

shift in the demand for information toward the newcomer firm since it produces uncensored, and superior, information. The newcomer consequently experiences increasing returns to scale and the superior technology is unlocked in the long run. Along with this positive theory, the model indicates that censorship alone is not Pareto optimal. Media taxation can harm certain agents in the short run. Provided the benefits from media taxation are sufficiently large, a central planner can implement Pareto optimal censorship through appropriate use of lump sum transfers.

There are a number of examples in which censorship seems to have encouraged the adoption of a superior technology. The information conveyed by broadcast radio and television in the United States is subjected to a certain level of governmental oversight. Unlike print media, broadcast industries do not hold an absolute right to free expression since they employ a finite public resource: the broadcast spectrum. Since this resource is scarce, government must select the firms which can broadcast and (implicitly and explicitly) the type of information which is conveyed to consumers. Whiteside (1985) shows that, although cable television was initially developed in the late 1940s, it was not widely employed for the next 35 years. Mullen (2003) notes that the rapid adoption of cable television in the 1980s followed a landmark court case which prohibited government regulation of information conveyed over cable systems.²⁰ This is one of the earliest instances in which a censored incumbent technology was surpassed by an uncensored superior newcomer.

Sakr (1999) indicates that the rapid growth of satellite television in the Middle East was partly attributable to censorship of domestic television. Internet communication and U. S. satellite radio are two more technologies which have, to some extent, been unlocked by censorship of incumbent forms of media. My theory can also shed light on inefficiencies in other industries. According to Cowan and Gunby (1996) the agricultural industry faces two technologies for controlling pests: chemical pesticides and integrated pest management (IPM). Research suggests that IPM is a su-

²⁰The case was *Home Box Office v. F. C. C.* issued by the U. S. Court of Appeals for the District of Columbia on March 25, 1977.

perior technology but the majority of farms are locked into the use of chemical pesticides. Rare instances widespread IPM adoption have been orchestrated by government decree. My model suggests that taxation of chemical pesticides would simultaneously reduce pollution externalities, encourage the adoption of IPM, and increase government revenues. In contrast, implementation of IPM by government fiat fails to generate revenues.

The existing model could be extended in a number of ways. First, it would be useful to analyze whether the model's predictions are robust to uncertainty over externalities and the nature of technology. In addition, the competitive equilibrium of a model with externalities and lock-in may be quite different when consumers and firms are more forward-looking. The model also suggests that taxation may be politically preferred to subsidies as a means for solving inefficiencies in media markets since a subsidy of superior technologies would fail to reduce negative consumption externalities in the present. A more general approach could investigate this possibility. Finally, the model's prediction that superior novel technologies are adapted more rapidly when incumbent technologies are taxed could be tested empirically.

5 Appendix

5.1 Parameter Values

The following parameter values were employed to obtain Figures 1 - 3. I restrict the theoretical analysis to the case in which $\gamma < 1$ while the figures are obtained from an assumption that $\gamma > 1$.

Qualitatively identical, but less legible, figures can be obtained when $\gamma < 1$.

α	0.5
β	0.75
η	0.75
χ	1
σ_1	1
σ_2	0.1
γ	1.46
y_1	10
y_2	1
N_1	50
N_2	10
λ	0.6
δ	0.95

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Figure 1 : Short-Sighted Policy

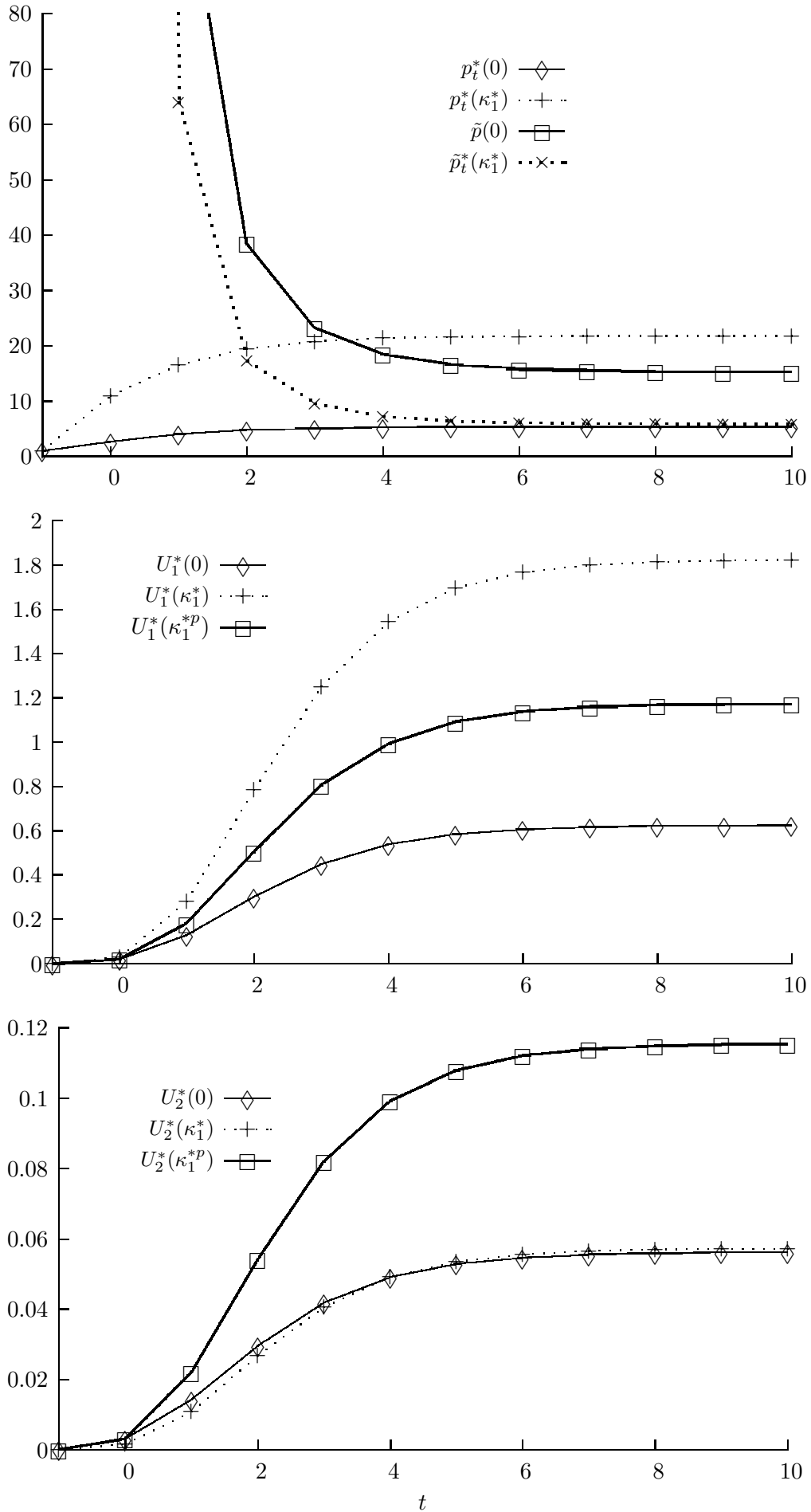


Figure 2 : Far-Sighted Policy

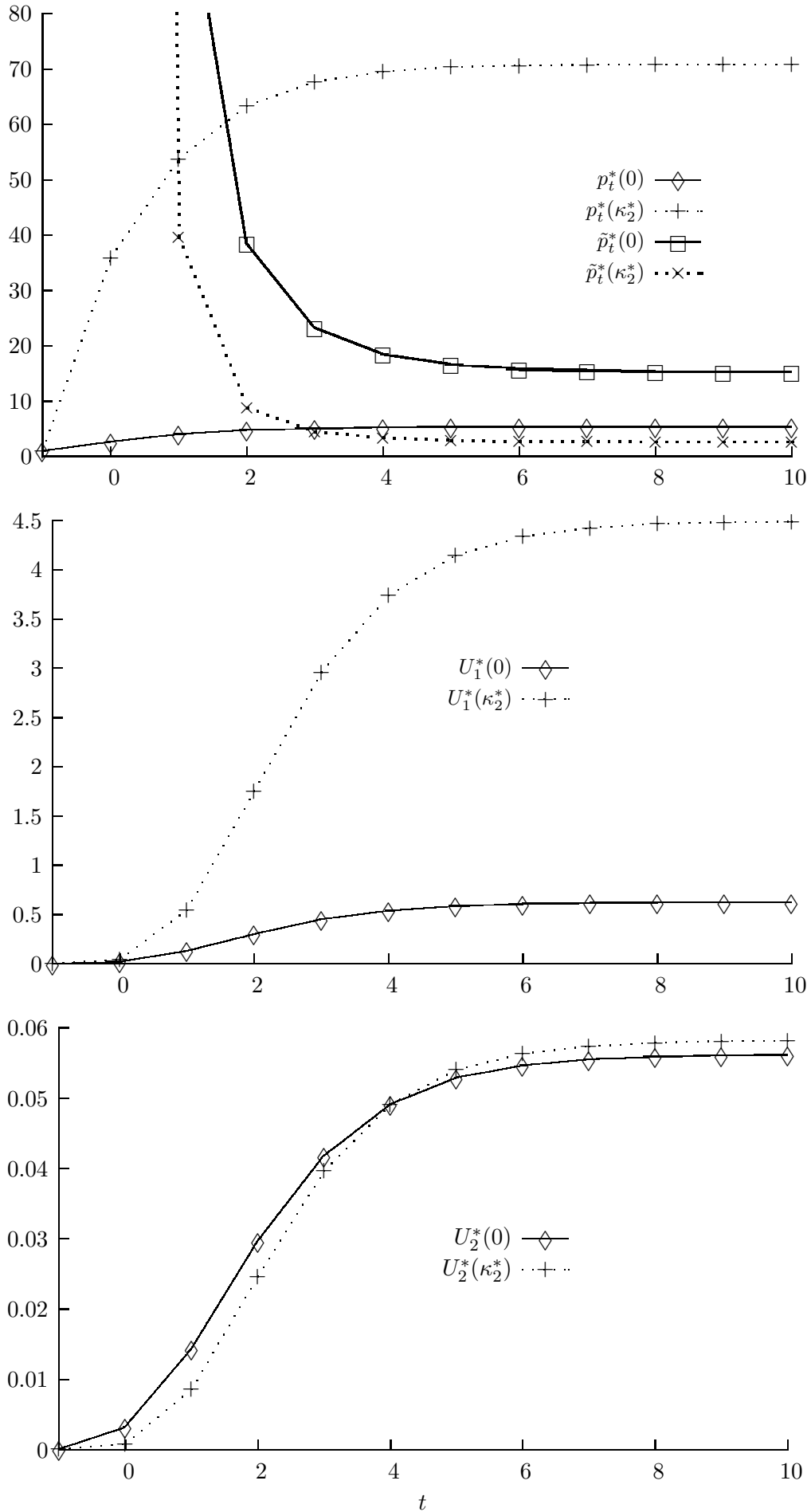


Figure 3 : Dynamic Policy

