Monopoly Extraction of an Exhaustible Resource with Two Markets (with an Application to Antibiotics)

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Abstract

Although much has been written about the implications of monopoly power for the rate of extraction of natural resources, the specific case in which the resource can be sold in two markets with different elasticities of demand has escaped notice. This analysis is relevant in the case of many resources — such as natural gas used for power generation and household heating, or petroleum used for making plastics and as fuel — and is particularly useful in current policy discussions regarding the simultaneous use of antibiotics (whose effectiveness is considered a resource) for growth promotion in cattle and poultry, and for disease treatment in humans.

1 Introduction

A number of authors have written on the implications of monopoly for the extraction of an exhaustible resource: ), ), ), ), ), ), ), and ), among others. Reviews of this literature are included in ); ); ); and ). However, based on these and our own review of the literature, there has been no previous analysis of a relatively simple but important case, namely, one in which the sole owner of a resource can sell to two markets at different prices. Although only a slight variation on the model in ), which features constant elasticity of demand with zero extraction costs, our basic model does not yield the result that the monopolist extracts at the same rate as the social planner. Nor does it confirm Hotelling’s suggestion that the monopolist is the

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conservationist’s best friend. Instead, a monopolist facing two markets with differing iso-elastic demand schedules extracts more rapidly than the social planner.\(^1\)

When the monopolist can discriminate between the two markets, it sets prices so that they rise at the rate of interest, as does the social planner. However, unlike the planner, the monopolist finds it beneficial to set a different price in each market, and these prices are such that the quantity sold in the market with low demand elasticity is less than the socially optimal quantity, while the quantity sold in the market with relatively high demand elasticity is greater than the socially optimal quantity. The total quantity sold is higher than under the social planner. When arbitrage forces the monopolist to sell at the same price in both markets, the monopolist acts like a social planner in that prices are equal, but these prices differ from those of the social planner, rising in such a way that they encourage faster consumption of the resource.

These results are not just of academic interest, since many resources have multiple uses. In a number of cases, resources are sold in segmented markets where arbitrage is difficult. For example, petroleum is sold for both energy generation and plastics, and gold is mined for uses ranging from jewelry, coins and dentistry to coating electronic contacts and stereo speaker wires and toning silver images in photography. In such cases, the resource may have a different set of substitutes in each of the market in which it sold, which in turn influences its demand in that market. For instance, there may be many alternatives to gold for use in electronics, but few others for use in engagement rings. With a different demand curve for gold in each market, the monopolist may, in addition to its ability set a higher price in each market, also be able to engage in price discrimination between markets. In this situation, we find that the monopolist extracts the resource at a rate that is greater than socially optimal in the market where demand is relatively elastic, and at a rate that is smaller than socially optimal in the market where demand is relatively inelastic. We find that these results are particularly useful in understanding the implications of various public policy interventions to address the problem of growing resistance to antibiotics, which are sold in both animal and human markets.

The basic model and results are presented in Section 2. Public policy implications of the results are discussed in Section 3. Section 4 concludes the paper.

## 2 Model

Consider a single exhaustible resource that is sold in two separate markets with two different elasticities of demand. Let us call these two markets \(A\) and \(B\). Total stock of the available resource is \(K_0\). We make the following assumptions:

1. There is no cost to extracting the resource other than the scarcity value.

\(^1\)A similar result in which the monopolist extracts too rapidly is provided by Lewis et al. (1979), who obtain this result both when there are fixed costs that do not vary with the extraction rate, as well as when demand elasticities vary with consumption, instead of time.
2. The elasticity of demand in each market is constant and greater than 1.

3. There is no possibility for arbitrage between markets. Moreover, the monopolist cannot engage in price discrimination within each market.

The first two assumptions are identical to those made by ?) and are both unrealistic and unduly restrictive. However, our choice of functional form is for essentially the same reason as the earlier paper, namely for analytical tractability and intuitive transparency. We find that the results of this paper are robust to other functional forms as well, although the analysis is far more tedious and far less intuitive. Since our purpose is, in part, to contrast the implications of monopoly for the rates of extraction and consumer welfare in the two markets, the choice of demand function is less critical than for comparing the overall outcome with that achieved by a social planner. The third assumption is added for our two-market problem in order to determine how a monopolist’s behavior compares with that of a social planner, both with respect to the quantity sold in each market and to total extraction. Our final caveat relates to the structure of the model, which is set up with a eventual exhaustion constraint where the sum of quantities extracted over the planning horizon is set equal to the initial stock. This assumption is also made for ease of exposition, and an alternate approach to solving the problem using optimal control methods could be followed.

2.1 Social Planner’s Problem

We frame the optimal resource allocation problem in terms of a social planner maximizing welfare (defined as total consumer surplus, since costs are absent) with respect to quantities sold in markets A and B, denoted by \( q^A_t \) and \( q^B_t \), subject to the constraint that total extraction not exceed the available resource stock. The resulting equilibrium corresponds to the market allocation under perfect competition. The optimization problem is represented in the following Lagrangean:

\[
U^S = \int_{t=0}^{\infty} e^{-rt} \left( \int_{s=0}^{q^A_t} P_A(s) \, ds + \int_{s=0}^{q^B_t} P_B(s) \, ds \right) \, dt - \lambda \left( \int_{t=0}^{\infty} (q^A_t + q^B_t) \, dt - K_0 \right), \tag{1}
\]

where \( r \) denotes the discount rate, \( P_A \) and \( P_B \) denote the price of the resource in the two markets, and \( \lambda \) is the shadow price of the resource. The optimum is characterized by the first-order conditions with respect to resource sales in each market

\[
q^A_t > 0, \quad P_A(q^A_t) = e^{rt} \lambda; \tag{2}
\]

\[
q^B_t > 0, \quad P_B(q^B_t) = e^{rt} \lambda; \tag{3}
\]

and the stock constraint

\[
\lambda > 0; \quad \int_{t=0}^{\infty} (q^A_t + q^B_t) \, dt \leq K_0; \tag{4}
\]
where a binding total extraction constraint leads to a positive shadow value of the resource \((\lambda)\).\(^2\)

The combination of (2) and (3) in any period \(t\) reveals that

\[
\begin{align*}
P_i(q_t^i, S_t) &= e^{rt} P_i(q_0^i, S_0); \quad i = A, B; \quad \text{\,(5)} \\
P_A(q_t^A, S_t) &= P_B(q_t^B, S_t); \quad t = [0, \infty]. \quad \text{\,(6)}
\end{align*}
\]

First, prices in each market rise over time at the rate of interest. Second, in an equilibrium where the planner is selling in both markets, those prices must be equal, reflecting equivalent scarcity costs. Consider price functions with constant elasticity of demand, such as

\[
P_i(q_t^i) = \left( \frac{q_t^i}{\mu_i} \right)^{-\frac{1}{\eta_i}},
\]

where \(\eta\) is the elasticity (in absolute value terms), while \(\mu\) represents a shifting parameter, indicating the relative size of the market. In our examples, we will designate market \(B\) as the one with the greater elasticity \((\eta_B > \eta_A)\). Since for these inverse demand functions, price goes to infinity as quantity goes to zero, we know that to satisfy the first-order conditions, some amount will be produced and sold in each market in every period, although those amounts will eventually become infinitessimally small. Solving for the extraction paths, we get

\[
q_t^A, S_t = e^{-\eta_A rt} q_0^A, S_0; \quad q_t^B, S_t = e^{-\eta_B rt} q_0^B, S_0. \quad \text{\,(7)}
\]

Since prices must be equal across the markets at all times including the start, we can solve for the initial quantity in market \(B\) in terms of that in \(A\):

\[
q_0^B, S = \mu_B \left( \frac{q_0^A, S}{\mu_A} \right)^{\frac{\eta_B}{\eta_A}}. \quad \text{\,(8)}
\]

Although prices are the same, the quantities will differ according to the elasticities and the demand-shifting parameter. Integrating (7) over time, we can express cumulative extraction for each market as a function of initial resource sales, the interest rate, and its own market elasticity:

\[
\int_{t=0}^{\infty} e^{-\eta_i rt} q_0^i, S dt = \frac{q_0^i, S}{r \eta_i}. \quad \text{\,(9)}
\]

\(^2\)The full complementary slackness conditions are

\[
\lambda \geq 0; \quad \int_{t=0}^{\infty} (q_t^A + q_t^B) dt \leq K_0; \quad \lambda \left( \int_{t=0}^{\infty} (q_t^A + q_t^B) dt - K_0 \right) = 0
\]

If some of the stock were left unexploited, then \(\lambda = 0\), but this would imply from 2 and 3 that prices were zero and extraction positive in all periods, which would violate the constraint of a finite stock. Thus, \(\lambda > 0\).
From (8), (9), and the stock constraint, we can solve for \(q^{A,S}_0\):

\[
q^{A,S}_0 = \frac{\eta_A}{\eta_A r} + \frac{\mu_B}{\eta_B r} \left( \frac{q^{B}_0}{\eta_A} \right) = K_0.
\]

With that solution, the entire optimal paths are determined.

### 2.2 Monopolist’s Problem

The monopolist’s problem is to maximize profits (revenues) subject to the total resource stock constraint:

\[
U^M = \int_{t=0}^{\infty} e^{-rt} \left( P_{A}(q^A_t)q^A_t + P_{B}(q^B_t)q^B_t \right) dt - \lambda \left( \int_{t=0}^{\infty} (q^A_t + q^B_t) dt - K_0 \right).
\]

Along the profit-maximizing path of resource sales in each market, the following first-order conditions must hold:

\[
q^A_t > 0, \quad MR_A(q^A_t) = e^{rt}\lambda; \quad (12)
\]

\[
q^B_t > 0, \quad MR_B(q^B_t) = e^{rt}\lambda; \quad (13)
\]

where \(MR_i\) denotes marginal revenue in market \(i\). The final condition is the same stock constraint as (4), although the actual shadow value may differ. Thus, for the monopolist to sell in both markets, their marginal revenues must be equal in each period, reflecting equivalent scarcity costs. Marginal revenues in each market must rise at the rate of interest. With constant elasticity demand, since marginal revenue is a constant times the price:

\[
MR_i(q^{i,M}_t) = \eta_i - 1 \left( \frac{q^{i,M}_t}{\mu_i} \right) = \frac{\eta_i}{\eta_i - 1} P_i(q^{i,M}_t); \quad i = A, B.
\]

This latter result implies that prices will also be rising at the rate of interest in each market:

\[
P_i(q^{i,M}_t) = e^{rt}P_i(q^{i,M}_t); \quad i = A, B.
\]

Solving for \(q^{i,M}_t\), we then get the same result as (7):

\[
q^{A,M}_t = e^{-\eta_A r t}q^{A,M}_0; \quad q^{B,M}_t = e^{-\eta_B r t}q^{B,M}_0.
\]

However, although this Hotelling rule seems the same for the planner and the monopolist, the relative prices are different, meaning that the paths do diverge. Setting marginal revenues equal to each other, we see the monopolist does not want prices to be equal in the two markets if the elasticities of demand are different:

\[
P_B(q^{B,M}_t) = \frac{\eta_B}{(\eta_B - 1)} \left( \frac{\eta_A - 1}{\eta_A} \right) P_A(q^{A,M}_t).
\]

From this result, we can prove three statements comparing monopolist resource use with the planner’s with respect to prices, quantities, and welfare:
**Theorem 1** When assumptions 1 to 3 hold, the monopolist raises the price in the market with relatively inelastic demand and lowers it in the market with relatively elastic demand compared with the optimal (planner’s) price.

**Proof.** Let $\eta_B > \eta_A > 1$. From (16), we find that $P_t^{B,M} < P_t^{A,M}$; the monopolist wants a lower price in the market with more elastic demand for all $t$. From (12) and (13), monopoly prices in each market must rise at the rate of interest; from (2) and (3), optimal prices are the same in each market and rise at the rate of interest. Thus, if $P_t^S < P_t^{A,M}$ for any $t$, it must hold for all $t$. Suppose now that the price path in market $A$ were the same as the planner’s, while that in $B$ were lower, implying greater sales in that market in every period. Over the same horizon, then, total extraction would be greater for the monopolist, thereby violating the stock constraint. (By the same logic, if $P_t^{B,M} = P_t^S$ and $P_t^{A,M} > P_t^S$ for all $t$, then the monopolist would extract less over the same horizon, implying a slack stock constraint, which violates the monopolist’s conditions for optimality.) Thus, the monopolist’s equilibrium must have higher prices than optimal in market $A$ in all periods, and prices in market $B$ must be lower than optimal.

**Corollary 2** Consumers in the market with relatively inelastic demand obtain less of the resource in each period and overall with monopoly provision, while those in the market with relatively elastic demand obtain more of the resource in each period and overall.

**Proof.** This result follows from the previous theorem: since $P_t^{A,M} > P_t^S$, then $q_t^{A,M} < q_t^{A,S}$ for all $t$. Since $P_t^{B,M} < P_t^S$, then $q_t^{B,M} > q_t^{B,S}$ for all $t$. Thus, $\int_{t=0}^{\infty} q_t^{A,M}dt < \int_{t=0}^{\infty} q_t^{A,S}dt$ and $\int_{t=0}^{\infty} q_t^{B,M}dt > \int_{t=0}^{\infty} q_t^{B,S}dt$.

**Corollary 3** Compared with the social optimum, consumers in the market with relatively elastic demand are better off under monopoly provision, as is the monopolist, while consumers in the market with relatively inelastic demand are worse off, as is society overall.

**Proof.** This result follows from the previous corollary. Consumer surplus is higher with more consumption; since $q_t^{B,M} > q_t^{B,S}$ and $q_t^{A,M} < q_t^{A,S}$ for all $t$, consumers in $B$ are unambiguously better off with monopoly provision while those in $A$ are unambiguously worse off. The monopolist is better off by definition of profit maximization, while society overall is worse off by definition of welfare maximization, since the two paths differ.

We can show that the price path for relatively inelastic market $A$ gets shifted up, while that of $B$ gets shifted down, compared with the planner’s path. The dual to this result is that the extraction path for market $B$ gets shifted up, while that of $A$ gets shifted down, compared with the planner’s. However, either market could still be the larger than the other, depending again on the relative demand parameters.
To solve for the complete system of extraction, we must combine the first-order conditions with the stock constraint. Cumulative extraction for each market is the same function of initial resource sales, the interest rate, and its own market elasticity as we saw for the planner’s problem:

$$\int_{t=0}^{\infty} e^{-\eta_i r_t} q_0^{i,M} dt = \frac{q_0^{i,M}}{r \eta_i}. \quad (17)$$

However, the initial extraction terms will differ for the monopolist. From (16) we solve for initial extraction in $B$ in terms of that in $A$:

$$q_0^{B,M} = \mu_B \left( \frac{\eta_B}{(\eta_B - 1) \eta_A} \right)^{-\eta_B} \left( \frac{q_0^{A,M} \eta_B}{\mu_A} \right) \eta_B. \quad (18)$$

Then, substituting this result with (17) into the stock constraint (4), we arrive at the equation determining the monopolist’s optimal $q_0^{A,M}$:

$$q_0^{A,M} + \frac{\mu_B}{\eta_A r} \left( \frac{\eta_B}{(\eta_B - 1) \eta_A} \right)^{-\eta_B} \left( \frac{q_0^{A,M} \eta_B}{\mu_A} \right) = K_0. \quad (19)$$

Recall that $\mu$ represents the relative size of the market. From (10) and (19), we can also observe that as $\mu_B \to 0$ and one market shrinks to nothing, $q_0^{A,M} \to q_0^{A,S}$, and we are back in the Stiglitz world, where the monopolist behaves like the planner in providing to a single market.

### 2.3 Total Extraction with Two Markets

We have shown that the extraction paths of the planner and the monopolist diverge when facing two markets with different elasticities. But what does this imply for the path of total extraction and thereby the rate of depletion of the single resource?

**Theorem 4** When assumptions 1 to 3 hold, total extraction by the monopolist is greater than that by the planner in the initial period.

**Proof.** From (9) and (17) we can rewrite the stock constraint (4) as

$$\frac{q_0^{A,j}}{r \eta_A} + \frac{q_0^{B,j}}{r \eta_B} = K_0 \quad (20)$$

for $j = S, M$. Solving for $q_0^{B,j}$, we get

$$q_0^{B,j} = \eta_B r K_0 - \frac{\eta_B q_0^{A,j}}{\eta_A}, \quad (21)$$
which lets us write the total initial extraction $Q_0$ for each actor, $j$, as

$$Q_0^j = \eta_B r K_0 + \left(1 - \frac{\eta_B}{\eta_A}\right) q_0^A j . \quad (22)$$

Subtracting the planner’s initial extraction from the monopolist’s, we see that the difference is positive:

$$Q_0^M - Q_0^S = \left(1 - \frac{\eta_B}{\eta_A}\right) (q_0^A M - q_0^A S) , \quad (23)$$

since $\eta_B > \eta_A$ implies that $q_0^A M < q_0^A S$.

Although the monopolist contracts supply in the market with less elastic demand, it expands it in the market with more elastic demand, with the net effect being an initial increase in total supply.

**Corollary 5** The monopolist follows a faster extraction path than the planner.

**Proof.** The previous theorem states that total extraction is higher for the monopolist initially, but it cannot be so indefinitely, else the stock constraint would be violated. Thus, at some point the extraction paths must cross, with the monopolist’s total extraction being less than the planner’s in later periods. Therefore, the monopolist’s extraction path must be steeper.

In other words, the monopolist will tend to be less “conservationist” than the planner. Furthermore, we see from (23) that this tilting of the total extraction path must be greater when the market elasticities diverge to a greater extent.

### 2.4 Monopolist Extraction with Arbitrage

Does arbitrage between the two markets eliminate the monopolist’s incentive to behave differently than the planner? If the markets can resell to each other, a single equilibrium price will result. Let $P_t^1 = P_A(q_t^A) = P_B(q_t^B)$. Whereas in the segregated markets case we worked with inverse demand, in this case we will simplify the expressions as a function of the common price $P_t^1$. With our constant-elasticity demand, we can write $q_t^i = \mu_i(P_t^1)^{1-\eta_i}$. In other words, at any price the monopolist faces a single, unified demand schedule of

$$Q_t^1 = \mu_A(P_t^1)^{-\eta_A} + \mu_B(P_t^1)^{-\eta_B} ,$$

which no longer displays constant elasticity. The point elasticity is now

$$\bar{\eta}_t = -\frac{dQ_t}{dP_t} = \frac{\eta_A \mu_A(P_t^1)^{-\eta_A} + \eta_B \mu_B(P_t^1)^{-\eta_B}}{\mu_A(P_t)^{-\eta_A} + \mu_B(P_t)^{-\eta_B}} ,$$

which collapses to a constant as $\mu_i \to 0$ or $\eta_A \to \eta_B$.
The monopolist’s new problem is

$$\max_{P^1_t} \int_{t=0}^{\infty} P^1_t Q(P^1_t)e^{-rt}dt - \lambda \left( \int_{t=0}^{\infty} Q(P^1_t)dt - K_0 \right).$$

(24)

The new first-order condition is

$$Q(P^1_t)e^{-rt} + P^1_t Q'(P^1_t)e^{-rt} - \lambda Q'(P^1_t) = 0,$$

which simplifies to

$$P^1_t \left( 1 - \frac{1}{\bar{\eta}_t} \right) = e^{rt} \lambda.$$

The rate of change in the price path is then

$$\frac{\dot{P}^1_t}{P^1_t} = r - \frac{\dot{\eta}}{\bar{\eta}} \left( \frac{1}{\bar{\eta}_t - 1} \right).$$

Since we assume $\eta_B > \eta_A > 1$, then $\bar{\eta}_t > 1$. Thus, whether the price rises faster or slower than the interest rate depends on whether the total elasticity is rising or falling:

$$\dot{\eta} = -\frac{\dot{P}^1_t}{P^1_t} \left( \frac{(\eta_B - \eta_A)^2 \mu_A \mu_B (P^1_t)^{-(\eta_A + \eta_B)}}{(\mu_A (P^1_t)^{-\eta_A} + \mu_B (P^1_t)^{-\eta_B})^2} \right) < 0.$$

Since the effective elasticity falls as the price rises, in equilibrium $P^1_t > e^{rt}P^1_0$. In other words, with an arbitrage constraint, the monopolist will choose a steeper price path than the planner: the monopolist prefers to lower prices in relatively elastic periods and raise prices in relatively inelastic ones, resulting in lower initial prices and higher ones later on. A steeper price path over the same time horizon with the same stock constraint implies that the monopolist’s initial price must be lower than the planner’s: $P^1_0 < P^S_0$. This in turn implies that starting consumption is greater in both markets: not only $q^1_B > q^{B,S}_0$, but also $q^1_A > q^{A,S}_0$. Thus, total extraction is greater at the beginning, and the monopolist is again less conservationist than the planner. This result is similar to that of ? and others who note that if the elasticity of demand increases over time, the monopolist picks a more conservationist path relative to the social planner. However, these increases are modeled as exogenous changes to an elasticity that is otherwise constant with respect to price within any period. Here, by presenting overall demand as the sum of distinct markets each with constant elasticities of demand, we arrive at an effective elasticity that is decreasing in price, and thus decreasing over time. Thus, our example corresponds to the extension by ? and ?), who consider a stationary demand schedule with elasticity increasing in consumption.

In summary, without arbitrage, the monopolist will follow the optimal (Hotelling) rule for the price paths but will differ from the social planner with respect to the
relative prices between markets. With arbitrage, the monopolist’s relative prices between markets coincide with the planner’s, but as a consequence the monopolist’s price path is distorted. In both cases, the existence of two markets with different elasticities causes the monopolist to behave differently from the planner and, overall, to follow a steeper path of depletion. A caveat to this conclusion comes from \textit{?}), who notes that when the price of a resource is projected to rise faster than the interest rate, speculators will seize the opportunity and buy the resource, causing its current price to increase until, with no storage costs, the price is projected to rise no faster than the interest rate. Thus, when there is arbitrage both between time periods and among markets, the monopolist is further restricted in its ability to control prices, as speculation may limit increases to the rate of interest. One can only conclude that the monopolist’s equilibrium price path will rise at least as steeply as that of the social planner.

\subsection{2.5 Other Demand Functions}

We recognize that the results under constant-elasticity demand may be special. In particular, they require the further assumption that demand not be inelastic; else, the monopolist would choose to sell only a tiny amount of the resource at a near-infinite price (Tullock 1979). If we relax the constant-elasticity assumption, we can allow for demand curves with inelastic portions—as long as demand becomes elastic for small enough quantities,\footnote{The linear demand curve is the classic example of this type.} as that is still necessary for an equilibrium with nontrivial production.

We can generalize our results somewhat by relaxing the assumption about the demand specification.\footnote{Although we maintain the assumption of no extraction costs, this restriction is less important.} Specifically, we no longer require demand to be constant; however, we still need to assume either that demand is always elastic, or if partly inelastic, that at some sufficiently low quantity the elasticity becomes greater than 1.

Table 1 summarizes the results for the relative prices and paths for the generalized example, using the same methods as previous sections. It reveals that the difference in incentives between the planner and the monopolist still relies on the difference in elasticities between the two markets, with some additional subtleties.
With segregated markets, differences between constant elasticities shifted the price paths, but the rate of increase remained constant at the interest rate. With changing elasticities, the monopolist no longer follows the r-percent rule. If demand elasticity declines with consumption, then over time it rises as consumption falls; since $\eta_t^i > 1$ in equilibrium, this implies that the monopolist’s price paths rise at less than the interest rate when markets are segregated. If, on the other hand, demand elasticity increases with consumption (decreases over time), the monopolist will want price paths that rise faster than the rate of interest.

The monopolist’s behavior under perfect arbitrage depends on how the average of the demand elasticities changes. Since the price is the same in both markets under arbitrage, we can define general demand as $Q(P) = q^A(P) + q^B(P)$. Average demand elasticity can be written as the weighted average of individual elasticities:

$$\bar{\eta}_t = \frac{-\partial Q}{\partial P} = \frac{-\partial q^A}{\partial P} + \frac{\partial q^B}{\partial P} = \frac{\eta^A q^A + \eta^B q^B}{Q}.$$  

Next, we see how the average elasticity responds to a price increase:

$$\frac{\partial \bar{\eta}_t}{\partial P} = \frac{\partial \eta^A q^A}{\partial P} + \frac{\partial \eta^B q^B}{\partial P} - \frac{(\eta^A - \eta^B)^2 q^A q^B}{P Q}.$$  

The last term means that the change in the average elasticity will always be less than the average change in the individual elasticities. This general result implies that for other demand functions as well, the monopolist follows a steeper price path in an arbitrage situation than on average in a situation where it can discriminate between markets. Thus, the monopolist follows a more conservationist extraction path when markets are segregated compared with the planner, the monopolist tends to be more conservationist if elasticities are greater than 1 and increasing with the price (declining with consumption).

### 3 An Application to the Market for Antibiotics

The results in this paper are particularly useful in illuminating policymaking with respect to patent-protected antibiotics. Antibiotic effectiveness can be considered an exhaustible resource (??). Selective pressure placed by antibiotics on bacteria that are susceptible to them ensures that antibiotics become less effective with use. Many antibiotics are sold both for treatment of bacterial infections in humans and for growth promotion in animals. In fact, almost half the 50 million pounds of U.S.-produced
antibiotics is used in farm animals (of which 80% is used to help animals grow faster and the rest is used to treat disease), and 40,000 pounds is sprayed on fruit trees (?). There is growing evidence that antibiotic use for growth promotion in animals also contributes to the pool of resistant pathogens that put humans at risk.

The sale of antibiotics for growth promotion in animals is the subject of a contentious policy debate. Recognizing the impact of antibiotics in nonhuman, subtherapeutic applications on the overall level of bacterial resistance in the environment, many countries in Europe have banned the use of antibiotics for these purposes. However, antibiotics continue to be used in farm feed and agriculture in the United States. Although the animal industry and the pharmaceutical industry are largely in favor of continued use of antibiotics for growth promotion, this policy is strongly opposed by the medical profession as well as by many environmental groups concerned about increasing bacterial resistance to antibiotics.

At first glance, it may appear that a pharmaceutical firm that owns a patent on an antibiotic would have sufficient incentives to care that the use of antibiotics for growth promotion could potentially impact its market for sales in humans. Typically, the growth promotion market contributes only a small percentage (in the order of 10 to 20%) of revenues, but the market for antibiotics in humans is far larger. Naturally, one is perplexed by the question of why firms acting in their own self-interest would jeopardize their profitable human drugs market to retain a much smaller agricultural market.

The answer is that very often, the firms that make antibiotics for human use are different from those that make these drugs for growth promotion. For instance, Synercid, a powerful new antibiotic manufactured by Aventis, is based on the same chemical compound as Virginiamycin, an antibiotic that has been sold by Pfizer for growth promotion for many years. Further, many firms make antibiotics that, though different, are derivatives of the same basic chemical entity. For instance, there are currently at least four firms that make quinolones, a class of powerful antibiotics (of which Ciprofloxacin is the best known member) both for use in human treatment and for growth promotion. The resource embodied in the effectiveness of a class of antibiotics is thus available to several pharmaceutical firms that produce antibiotics for both markets. Although resistance may be an inevitable consequence of antibiotic use, suboptimal increases in resistance may be attributed to the fact that antibiotic effectiveness is a common property resource. Since no single firm has an incentive to take into full consideration the effect of its sales of antibiotics on the overall level of future antibiotic effectiveness, the classic externality problem arises where there

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5 For instance, Bayer has patent rights to a number of antibiotics in the class of fluoroquinolones, of which Ciprofloxacin is the best known. Bayer also sells fluoroquinolones for growth promotion in poultry. Recently, the Food and Drug Administration ordered Bayer to stop selling fluoroquinolones for use in animals, a decision based on the perception that this use may lead to increasing fluoroquinolone resistance in Campylobacter pylori, which causes infections in humans. However, Bayer has challenged this decision and continues to sell in both markets.
may be too much antibiotics sold from a societal perspective. From an economic perspective, the price of antibiotics sold for growth promotion may not adequately reflect the true social cost of resistance associated with such use, and it is likely that the use of antibiotics used for growth promotion in food animals would be less prevalent if farmers were to face the full resistance costs of such use.

One solution to the market failure problem is to give a single firm broad patents or intellectual property rights (IPR) over antibiotics sold for both purposes. This could potentially solve the open-access problem in essentially the same way as privatizing a fishery could solve the problem of overexploitation of fish stocks. However, the results of this paper indicate that to the extent that the elasticity of antibiotics sold for growth promotion is greater than that for antibiotics sold for treatment in humans,\textsuperscript{6} patent-protected pharmaceuticals may be encouraging the overuse of antibiotics in animals and too quickly depleting the stock of antibiotic effectiveness. Furthermore, consumers of antibiotics for human treatment may be worse off under a broader IPR regime that gives more monopoly power to the pharmaceutical manufacturer while consumers of antibiotics for growth promotion may be better off under the new regime. These considerations will have to be examined carefully before altering IPR regimes for antibiotics to solve the open-access problem.

### 3.1 Other Applications

The difference in the pattern of extraction between the monopolist and the social planner in this model relies on a difference in elasticities between the two markets. Otherwise the results collapse to those of \textsuperscript{a} and \textsuperscript{b}). The practical importance of the model, then, lies in the empirical difference in elasticities between markets. Take the case of oil and natural gas. These resources are arguably difficult to arbitrage between different markets because of the extent of vertical integration in these markets, as well as the ability to (in the case of oil) refine the commodity into different compounds that are sold in different markets. Due to contradictions among studies that attempt to measure them, these elasticities are difficult to bound, much less state authoritatively. If one could at least distinguish markets with low elasticity of demand from those with relatively elastic demand, there is scope for applying the results of this analysis in a qualitative manner.

In the case of natural gas, from surveys by \textsuperscript{a} and \textsuperscript{b}) one can conclude that the long-run elasticities for natural gas for commercial and for electrical use are 1 and 0.72, suggesting that a monopolist would ration gas for electricity use in order to oversupply commercial use. Similarly, if the short-run elasticities of oil are indicative of their

\textsuperscript{6}We can justify this characterization on two grounds. First, there are many substitutes for antibiotic use in growth promotion (including nonantibiotic inputs, such as better on-farm hygiene) but not for human treatment. Second, the price of antibiotics sold in humans is typically an order of magnitude greater than that sold for animal use.
relative long-run elasticities, a truly effective oil cartel would constrain production of oil for commercial use (less elastic demand) in favor of overproduction for residential heating (more elastic demand). Of course, in reality, the Organization of Petroleum Exporting Countries (OPEC) suffers from defections, and natural gas distribution and other natural monopolies are regulated. Our analysis would suggest that these imperfect monopoly situations are fortunate, as, contrary to much of the literature, our model suggests that the monopolist does not face inherent constraints on its ability to exert market power. Thus, there may be potentially serious social welfare consequences associated with unregulated monopolistic control over a resource.

4 Conclusion

This paper illustrates an important extension to the literature on the extraction of a depletable resource by a monopoly. We find that the ability to extract at zero marginal cost and sell in two constant-elasticity markets, with or without arbitrage between them, leads a monopolist to extract a resource at a faster-than-optimal rate. This result suggests that when a monopolist is able to price-discriminate between two sets of consumers, then the group with relatively elastic demand is better off, and the group with relatively inelastic demand is worse off with monopoly provision than under the social planner. Overall, there may be significant welfare losses associated with unregulated monopoly provision.

Needless to say, our assumption of iso-elastic demand, though a “natural first approximation” (Stiglitz 1976), is restrictive and the assumption of exogeneity of the resource stock needs to be tested. Indeed, incorporating the ability of resource owners to expand the supply of resource through exploration and innovation may prove a particularly fruitful avenue of research, as models that incorporate an endogenous stock of resource, without the potential for two markets (Gaudet and Lasserre 1988), indicate that the monopolist extracts too slowly. This suggests that a model incorporating the potential for both discovering new stock of the resource and selling it in multiple markets may yet vindicate the monopolist.