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Does Intellectual Property Restrict Output? An Analysis of Pharmaceutical Markets

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Abstract

Standard analysis of intellectual property focuses on the balance between incentives for research and the welfare costs of restraining output through monopoly pricing. We present evidence from the pharmaceutical industry that output often fails to rise after patent expirations. Patents restrict output by allowing monopoly pricing but may also boost output and welfare by improving incentives for marketing, a form of nonprice competition. We analyze how nonprice factors such as marketing mitigate and even offset the costs of monopoly associated with intellectual property. Empirical analysis of pharmaceutical patents suggests that, in the short run, patent expirations reduce output and consumer welfare by decreasing marketing. In the long run, patent expirations benefit consumers, but by 30 percent less than would be implied by the reduction in price alone. Focusing only on the pricing issues of intellectual property may lead to incomplete or even inaccurate conclusions for welfare.

1. Introduction

Intellectual property (IP) spurs innovation by increasing the rewards for discovery, but it does so by granting a monopoly in the event of discovery. According to standard analysis (see Nordhaus 1969), the research and development (R&D) benefits of a patent system must be weighed against the associated output lost to patent monopolies, which reduce price competition. This analysis implies that patent expirations always lead to increased competition, lower prices, and higher market output. From this point of view, Figure 1 is surprising. The figure depicts

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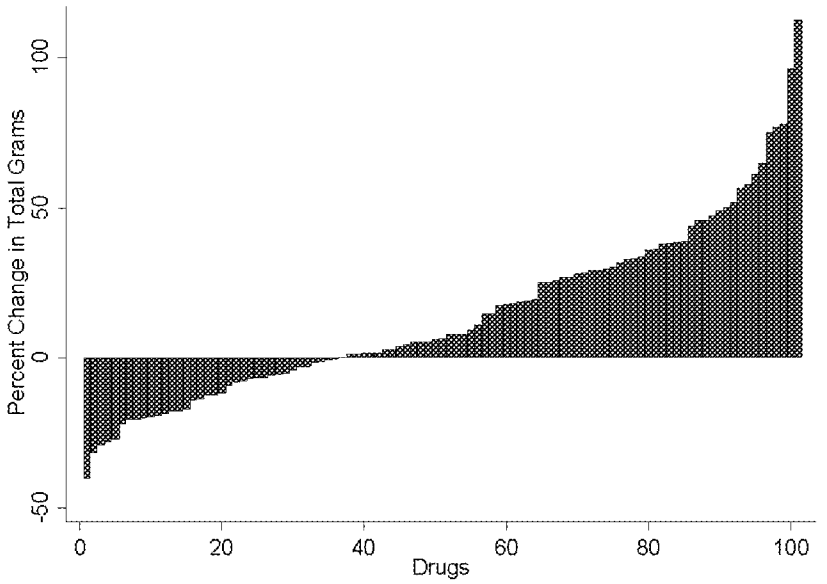

Figure 1. Effect of patent expirations on quantity sold, for a sample of prescription drugs

the percentage change in quantity—comparing the month before patent expiration with the month after—for a sample of U.S. pharmaceutical products whose patents expired between 1992 and 2002.[1] For about 40 percent of drugs, output falls after patent expiration and expands only modestly for many others.

Figure 1 suggests that there may be more to a patent expiration than the end of monopoly pricing alone, and consequently more to the welfare effects of IP protection. We argue that the standard analysis of IP must incorporate various aspects of nonprice competition, which may reinforce or mitigate the effects of monopoly pricing. For example, while monopolists have incentives to restrict quantity through higher prices, they may also have different incentives to promote their product through advertising, to provide durability of goods, and to vertically integrate with upstream or downstream firms. These forms of nonprice competition can change the efficiency impact of IP regulations by either mitigating or reinforcing the conventional effects on price competition.

Motivated by this idea, we examine the effect of marketing—a particularly important form of nonprice competition—on the static and dynamic efficiency

[1] To be specific, Figure 1 shows the percentage decline or growth in prescriptions filled (in grams) between the month before and the month after expiration. More detail on the data is given in Section 3.2.

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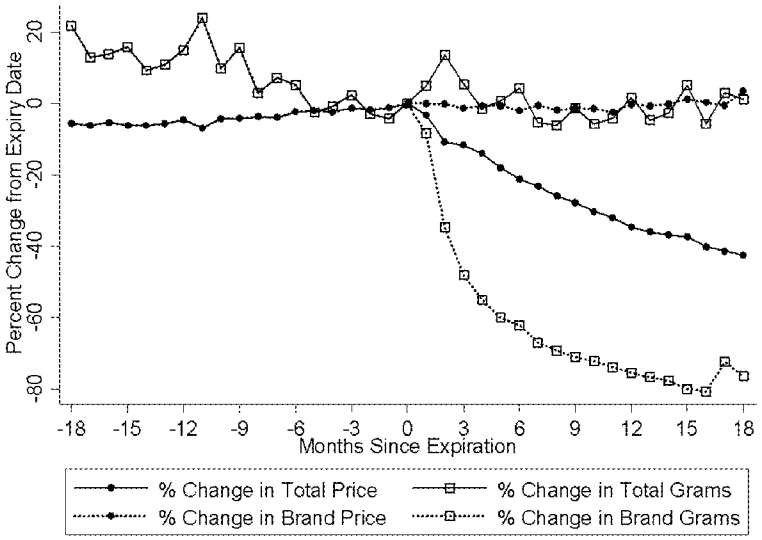

Figure 2. Mean trends in price and quantity for fully advertised drugs

of patents.[2] Patent expirations decrease the private returns to marketing, which may be limited when goods are sold at marginal cost. As a result, expirations may actually reduce output if they decrease marketing effort by enough to offset the impact of price reductions. From a normative point of view, advertising by a monopolist is valuable because it moves output toward its efficient level. Notably, this is true even if advertising is purely persuasive and provides no valuable information to consumers.

To assess the importance of these arguments more fully, we estimate the impact of marketing on welfare using patent expirations in the U.S. pharmaceuticals market between 1990 and 2003. This industry is a natural choice for empirical analysis of R&D and marketing because it is among the highest spending industries in both categories. The industry spends approximately 15 percent of sales on marketing and 16 percent of sales on R&D.[3] By comparison, about 2 and 3 percent of U.S. gross domestic product are allocated to advertising and R&D, respectively.

Figures 2 and 3 provide some illustrative data from the pharmaceutical in-

[2] Different forms of nonprice competition merit separate analyses. For example, monopoly has a range of possible effects on quality provision. Mussa and Rosen (1978) show that monopolists will overdifferentiate their product and induce a lower quality choice by consumers. Subsequent authors have demonstrated how these results can be altered or even reversed under different specifications for demand (Gabszewicz and Wauthy 2002).

[3] Many drugs have seen dramatic increases in direct-to-consumer (DTC) advertising since the change in Food and Drug Administration guidelines on such advertising in 1997.

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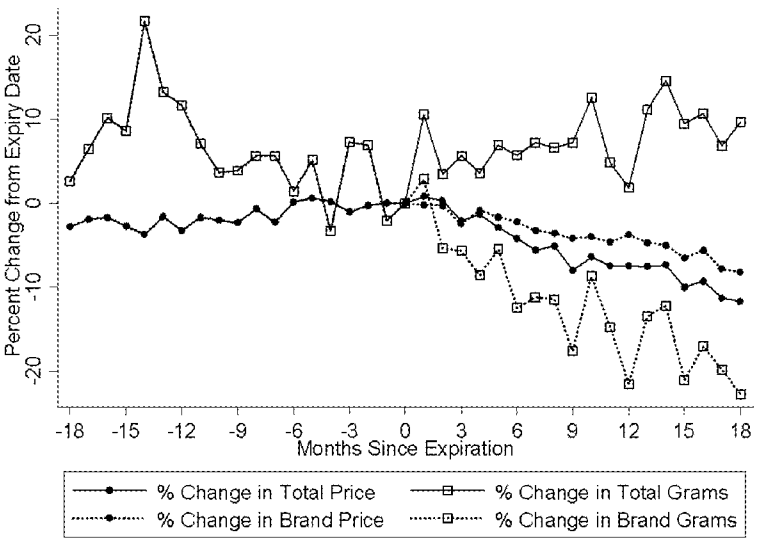

Figure 3. Mean trends in price and quantity for drugs not fully advertised

dustry. The figures are based on data—described in Section 3.2—from 101 molecules with expiring patents. Each figure depicts monthly time series, relative to the month of patent expiration, for branded quantity, branded price, total quantity, and total price, at the molecule level. Figure 2 depicts these trends for molecules that are advertised, while Figure 3 does so for molecules that are not.[4] For all drugs, price declines steadily after the month of patent expiration. For the nonadvertised drugs, quantity rises fairly steadily over this period as well. However, for the advertised drugs, quantity appears flat after patent expiration. This suggests that patent expirations have different effects for advertised drugs than for their nonadvertised peers.

To estimate these effects more formally, we use the timing of patent expirations as instruments for the price and incentives of a molecule. Changes in supply induced by patent expiration allow us to identify the demand for drugs as a function of both price and advertising effort. The estimated demand function implies that in the short run (the first 5 months), output decreases after patent expiration because the reduction in advertising more than offsets the reduction in price. This output loss is estimated to cost consumers roughly $1 million per month for each drug whose patent expires. Not until several years have elapsed

[4] Figures 2 and 3 show the percentage change between the month of patent expiration and the month shown on the *x*-axis. In all cases, price is per gram. A fully advertised drug has at least 1 month of nonzero samples dispensed, at least 1 month of nonzero promotional visits to doctors, and at least 1 month of nonzero medical journal advertisements. Drugs that do not meet these criteria are considered to be not fully advertised. The figures are discussed in more detail in Section 3.3.

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does the price effect dominate the reduction in advertising. In the long run, patent expiration increases quantity and benefits consumers, but the reduction in advertising reduces the total gain to consumers from patent expiration by about 30 percent. However, even from a long-run perspective, monopoly marketing provides benefits to consumers. We estimate that, even if advertising is purely persuasive and provides no valuable information, the value to consumers is roughly 20–25 percent of total monopoly revenue, roughly on par with the costs of marketing to firms. Therefore, even if firms did not benefit from marketing at all, it would be no worse than welfare neutral.

Our project integrates a great deal of work that has separately considered advertising and intellectual property.[5] Several papers have studied the unique aspects of pharmaceutical advertising: Rosenthal et al. (2002) study direct-to-consumer advertising, while Bhattacharya and Vogt (2003) consider how brand loyalty affects pricing under IP. In the economic analysis of IP, an equally extensive literature tackles the question of how to generate efficient R&D effort. There is a large literature analyzing the effects and desirability of public interventions affecting the speed of technological change.[6] Less effort has been devoted to studying the joint problem of advertising and IP, even though the interaction between these two factors has many important normative and positive implications, particularly for the marketing of pharmaceuticals in the United States.

The paper proceeds as follows. Section 2 considers the impact of nonprice competition on the welfare effects of patents and outlines the full impact of patents on static and dynamic welfare. Section 3 estimates demand as a function of price and advertising and infers changes in welfare from marketing and patent expiration. Section 4 concludes and discusses future research.

2. Marketing and Intellectual Property

From a positive point of view, IP protection has ambiguous effects on quantity provided, depending on the strength of incentives to market. Normatively, the static costs (or benefits) of patents depend on whether patent protection moves quantity toward or past the efficient level.

2.1. The Welfare Effects of Patents

Define W_M and W_C as the annual level of aggregate welfare (social surplus) under monopoly and competitive provision of an invention, respectively. The

[5] Kaldor (1949) provides a seminal analysis of advertising along both positive and normative dimensions. Dixit and Norman (1978) and Telser (1962) provide an initial discussion of the meta-preference approach to welfare analysis of advertising developed formally and systematically by Becker and Murphy (1993). There are also summary treatments of advertising in Tirole (1988), Shapiro (1982), Schmalensee (1987), and Bagwell (2005).

[6] Representative treatments include Nordhaus (1969), Loury (1979), Wright (1983), Judd (1985), Gilbert and Shapiro (1990), Klemperer (1990), Horstman, MacDonald, and Slivinski (1985), Gallini (1992), Green and Scotchmer (1995), and Scotchmer (2004).

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net present value of welfare associated with a patent of length τ years is then given by

$$W(\tau) = \nu(\tau)W_M + [\nu(\infty) - \nu(\tau)]W_C.$$

Here, $\nu(\tau)$ is the date-zero present value of a claim that pays \$1 for τ years. The net present value of profits associated with this patent is given by

$$\pi(\tau) = \nu(\tau)\pi_M,$$

where π_M represents monopoly profits. To represent technological investment induced by IP protection, define the increasing, differentiable, and strictly concave function $m(r)$ as the probability of discovering an invention, as a function of R&D investment r. The privately optimal R&D associated with a patent of length τ maximizes expected profits:

$$r(\tau) = \arg\max_r m(r)\pi(\tau) - r. \tag{1}$$

This implies that increases in the profits expected from discovery also stimulate marketing activity, because innovators expect greater rewards (Nordhaus 1969). Therefore, innovation is complementary with all investments that stimulate profits, including marketing.

This level of R&D induces the expected social surplus:

$$ES(\tau) = m[r(\tau)]W(\tau) - r(\tau). \tag{2}$$

The dynamically optimal patent length that maximizes expected welfare is therefore given by the following first-order necessary condition:

$$r_\tau[m_r W(\tau) - 1] \geq m(-W_\tau). \tag{3}$$

The marginal gains from increasing R&D levels through IP (the left-hand side) are made up of the extra R&D induced by the patent extension, r_τ, multiplied by the net social value of that extra R&D, $m_r W(\tau) - 1$, which consists of the marginal social gain from more invention net of research spending. The optimal patent life equates this marginal benefit of an extension with the marginal cost of the extension, which is the welfare cost of an additional year of monopoly (on the right-hand side). The marginal cost of patent expiration—the loss of welfare once the technology has been discovered—is given by the static welfare effect,

$$\frac{dW}{d\tau} = \frac{d\nu}{d\tau}(S_M + \pi_M - S_C),$$

where S_M and S_C are consumer surplus under monopoly and competition, respectively. Patents are costly on the margin whenever $S_M + \pi_M < S_C$; this is the condition for static deadweight loss from monopoly. Below we demonstrate that marketing lowers the relative cost of patents and that it can sometimes lower cost to zero or below. In such cases, infinite patent length is desirable.

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2.2. *Positive Effects of Advertising under Patent Monopoly*

We first show that advertising limits and sometimes fully offsets the quantity-restricting effects of patent monopoly. Consider the standard monopoly profit-maximization model:[7]

$$\max_{p,A} Q(p, A)p - \text{MC} \times Q(p, A) - A.$$

For simplicity, consider the constant elasticity demand function, $Q(p, A) = A^{\varepsilon}p^{-\gamma}$. Monopoly equilibrium with advertising exists and is well defined when demand is elastic to price and inelastic to advertising: $\gamma > 1$ and $0 < \varepsilon < 1$.[8] The optimal price is given by the standard Lerner markup condition:

$$[p]{:}p = \frac{c\gamma}{\gamma - 1}.$$

The first-order condition for optimal advertising equates the marginal value of marketing to its marginal cost, according to

$$[A]{:}\frac{dQ}{dA}(p - c) = 1.$$

This expression demonstrates why perfectly competitive firms have no incentives to advertise. Without a markup, it is not valuable to stimulate more quantity.

Using the constant elasticity form, the first-order condition for advertising can be rewritten as

$$\varepsilon p^{-\gamma}(p - c) = A^{1-\varepsilon}.$$

Combining the two first-order conditions, the equilibrium level of advertising is given by $A^{1-\varepsilon} = \varepsilon c[1/(\gamma - 1)]$. The monopoly quantity can be written as

$$Q^{\text{M}} = c^{-\gamma}\left(\frac{\gamma}{\gamma - 1}\right)^{-\gamma} A^{\varepsilon} = c^{-\gamma}\left(\frac{\gamma}{\gamma - 1}\right)^{-\gamma}\left[\varepsilon c\left(\frac{1}{\gamma - 1}\right)\left(\frac{c\gamma}{\gamma - 1}\right)^{-\gamma}\right]^{\varepsilon/(1-\varepsilon)}.$$

By comparison, the competitive level of quantity is given by $Q^{\text{C}} = c^{-\gamma}$. And the monopoly quantity in the absence of marketing would be $Q^{\text{M0}} = c^{-\gamma}[\gamma/(\gamma - 1)]^{-\gamma}$. It will always be true that $Q^{\text{M0}} < Q^{\text{M}}$ and that marketing leads to higher

[7] The static model is useful and appropriate for advertising. However, a more dynamic approach may be needed for the analysis of other types of nonprice competition, like quality, that influence research and development.

[8] The condition on the price elasticity is standard. The condition on the advertising elasticity follows as a corollary of the Dorfman-Steiner theorem. Observe that

$$\pi = pq - cq - A = pq\left(1 - \frac{cq}{pq} - \frac{A}{pq}\right) = pq\left(1 - \frac{c}{p} - \frac{\varepsilon}{\gamma}\right) = pq\frac{(1 - \varepsilon)}{\gamma}.$$

Nonnegative profits imply that $\varepsilon < 1$.

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quantity provision in the marketplace.[9] However, Q^M may be higher or lower than Q^C, depending on the configuration of parameters.

Observe that $Q^M/Q^C = [\gamma/(\gamma - 1)]^{-\gamma} A^{\varepsilon} = (c/p)^{\gamma} A^{\varepsilon}$. The higher the price markup, the greater the restriction in quantity; this is the standard incentive effect of monopoly, encapsulated by the first term. However, monopolists restrict quantity less when the responsiveness of demand to marketing (ε) is higher.

To take a few concrete examples, monopoly quantity is nearly 50 percent higher than competitive quantity for the parameters $c = .1$, $\gamma = 1.6$, and $\varepsilon = .9$; under this scenario, more than half of revenue (.9/1.6) is spent on marketing. In contrast, for $c = .1$, $\gamma = 1.6$, and $\varepsilon = .5$, monopoly quantity is more than 80 percent below competitive quantity, and less than one-third of revenue (.5/1.6) is spent on marketing.

This implies that marketing can partially or completely offset monopoly pricing and can even overcorrect for the quantity distortions of monopoly, depending on the strength of incentives to market. Note that the analysis so far is strictly positive in nature, as the competitive level of quantity may be equal to or below the efficient level.

2.3. Normative Analysis of Patents with Advertising

The cost of monopoly is the reduction in quantity suffered by consumers. In the absence of advertising, this is easy to calculate: the quantity provided after patent expiration is assumed to be the competitive and efficient level; the difference between the monopoly quantity and the postexpiration quantity yields the social cost.

The introduction of marketing makes the situation more complex for two reasons. First, competition may increase or decrease quantity. Second, since competition may not produce the efficient level of quantity, the competitive level of output cannot be used as a simple benchmark for efficiency. Nonetheless, the competitive level of quantity can usually help bound the welfare costs of patents, as we show.

In general, the welfare effects of patents are a priori ambiguous because their quantity effects are ambiguous. Recall from Section 2.2 that patent expiration has offsetting effects on quantity. Patent expiration increases quantity by lowering the market price but decreases it by reducing market advertising. Ultimately, the welfare effects depend on the value of changes in quantity and (sometimes) on the direct consumption value of changes in advertising. The ambiguous effect on quantity thus creates ambiguity for the welfare effects of patents. Moreover, the same forces that move quantity in opposite directions—namely, price cuts and advertising reductions—also move consumer welfare in opposite directions. Therefore, patents may help or harm consumers, depending on the shape of the demand and cost curves of a particular industry.

[9] Suppose not. In this case, $A^{\varepsilon} < 1$, which implies that $A < 1$ and that, on the margin, $D_A < 0$. This cannot be an equilibrium.

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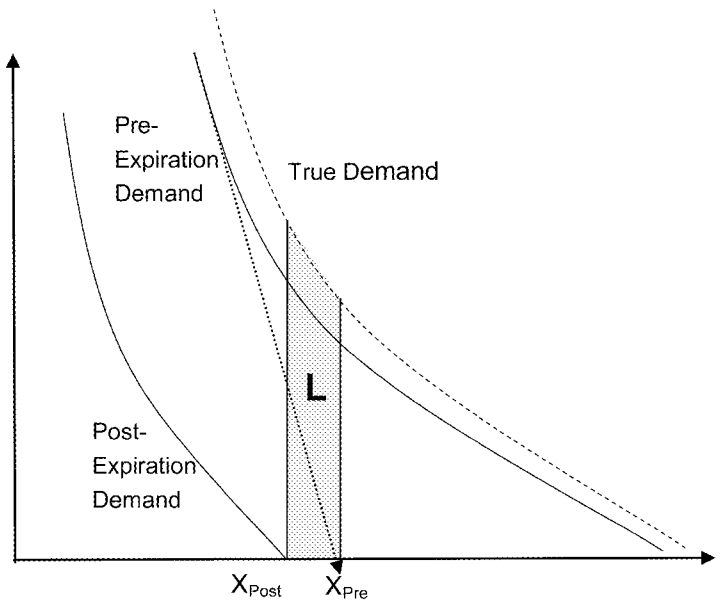

Figure 4. Welfare effects of patent expiration under informational advertising

2.3.1. Advertising as Information

We first consider the welfare effects of patents when advertising provides valuable information about a product but does not add value to the product itself or provide direct utility to consumers. In this case, advertising does not affect the true value of a good to consumers but does move perceived value toward the true value. Let $p(x, a)$ represent the inverse demand as a function of quantity (x) and advertising (a). Price falls in quantity but rises in advertising. We denote by $p(x)$ the full-information demand curve defined by

$$\lim_{a \to \infty} p(x, a) = p(x), \forall x.$$

The change in welfare due to patent expiration is given by the change in true social surplus, which is evaluated at the true, fully informed demand curve. We define this as

$$\Delta_{\text{Info}} \equiv S_{\text{C}} - S_{\text{M}} = \int_{x_{\text{M}}}^{x_{\text{C}}} p(q)dq - (p_{\text{C}}x_{\text{C}} - p_{\text{M}}x_{\text{M}}). \quad (4)$$

Figure 4 illustrates this argument for the case in which patent expiration reduces quantity. The change in quantity is evaluated along the true demand curve, which differs from the observed demand curves both before and after patent

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expiration. In this case, the welfare cost of patent expiration is given by the area L, which measures the welfare loss from patent expiration, assuming zero marginal cost of production, and yields the consumer surplus associated with the additional quantity consumed under monopoly.

Since advertising moves observed demand toward the true demand curve, we can use observed consumer surplus as a lower bound on the true consumer surplus, according to

$$\int_{x_M}^{x_C} p(q)dq \geq \int_{x_M}^{x_C} p(q, a_M)dq.$$

On the basis of this inequality, our empirical analysis uses the observed change in consumer welfare as a bound on the true change in welfare. In particular, we construct the estimator

$$\tilde{\Delta}_{\text{Info}} \equiv \int_{x_M}^{x_C} p(q, a_M)dq - (p_C x_C - p_M x_M), \tag{5}$$

where $\tilde{\Delta}_{\text{Info}} \leq \Delta_{\text{Info}}$ if and only if patent expiration increases quantity. Therefore, the estimator is a lower bound, in absolute value, on the true increase in welfare.

2.3.2. Advertising as Persuasion

Some forms of advertising seek to persuade rather than inform. An example is the provision of in-kind prescribing incentives to physicians. Informational advertising moves demand toward its fully informed level. Purely persuasive advertising moves demand above its true level and may create socially excessive consumption.[10] To separate this case from that of advertising as consumption, suppose further that advertising confers no direct consumption benefits on physicians or patients.

The welfare effects of persuasive advertising depend on the strength of marketing incentives and whether these boost quantity past its efficient level. While persuasive advertising always pushes the demand curve above its efficient level, it does not always push equilibrium quantity past this point. Figure 5 illustrates this case, in which market demand, D_M, exceeds the true demand curve, D_T. Region L shows welfare loss due to patent monopoly with persuasive advertising, and the combined regions L′ and L show this loss for patent monopoly without advertising. Even though demand is pushed past its efficient level, the monopolist does not choose to boost demand by so much that the equilibrium quantity exceeds its efficient level, X_C. As a result, the "inefficient" growth in demand actually reduces deadweight loss due to underutilization. Therefore, even persuasive advertising partially offsets the monopoly restriction on quantity and thus improves social welfare.

[10] If advertising is only partially persuasive and fails to increase demand above its true level, the analysis is substantially similar to the case of advertising as information.

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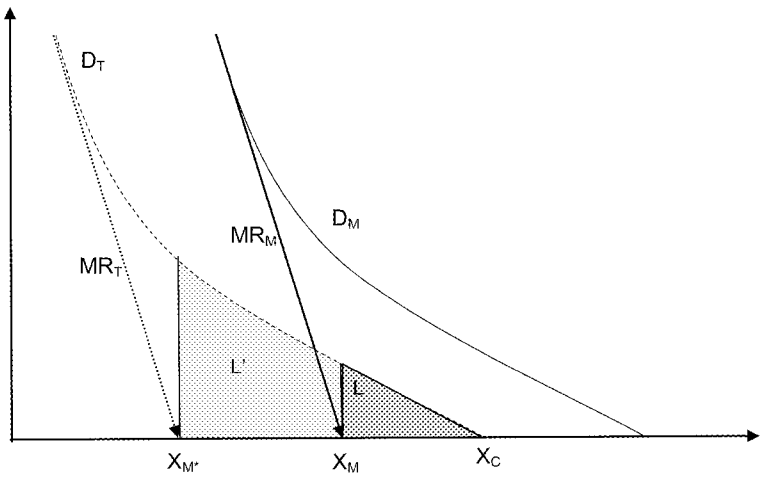

Figure 5. Welfare effects of patent expiration under persuasive advertising

Implicit in this last point is the premise that advertising cost must be strictly less than the additional consumer surplus generated by the growth in utilization. This is a straightforward implication of profit-maximizing behavior by the monopolist, who will never spend more than the incremental value created for consumers. An alternative case is one in which demand rises by so much as to push equilibrium quantity past X_C. In this case, advertising may create static welfare loss because of overutilization.

Empirically, the only difference with persuasive advertising is that the competitive demand curve coincides with the true demand and lies below the monopoly demand curve. Therefore, the competitive demand curve serves as the best approximation of true demand.

In this case, we use the estimator

$$\tilde{\Delta}_{\text{Pers}} \equiv \int_{x_M}^{x_C} p(q, a_C)dq - (p_C x_C - p_M x_M). \tag{6}$$

Observe that

$$\tilde{\Delta}_{\text{Pers}} = \tilde{\Delta}_{\text{Info}} + \int_{x_M}^{x_C} [p(q, a_C) - p(q, a_M)]dq.$$

The latter expression implies that $\tilde{\Delta}_{\text{Pers}} < \tilde{\Delta}_{\text{Info}}$. Intuitively, when we assume that advertising is persuasive, we are implicitly assuming that the true demand for the product is lower than in the informational advertising case. Under persuasive advertising, therefore, patent expiration benefits consumers less. As before, this

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estimator is a lower bound on the true absolute change in welfare due to patent expiration.

2.3.3. Advertising as Consumption

Suppose that advertising confers utility through two channels. The first is direct: exposure to advertising produces utility. For example, pharmaceutical companies may provide perquisites to consumers (in the form of samples) or to physicians (in the form of gifts or in-kind transfers). The second operates through complementarity with consumption. Advertising may increase the true value of and consumers' willingness to pay for a product. That is, consumers may derive more utility from using a heavily advertised product. In this case, the consumer welfare effect of patent expiration satisfies

$$\Delta_C \equiv S_C - S_M = V(a_C) + \int_0^{x_C} p(q, a_C)dq - V(a_M) - \int_0^{x_M} p(q, a_M)dq - (p_C x_C - p_M x_M). \tag{7}$$

The terms $V(a_C)$ and $V(a_M)$ represent the direct utility value of competitive and monopoly advertising levels, respectively. When advertising has consumption value, patent expiration can raise output while still lowering welfare: the decline in price raises output and welfare, but the reduction in advertising has a direct negative effect on welfare.

These results are illustrated by Figure 6, which depicts the change in gross surplus that occurs at patent expiration when advertising provides utility. In that case, patent expiration lowers price and shifts demand inward. Regions G and L show the respective gain and loss in gross social surplus attributable to a simultaneous reduction in advertising and price. The welfare impact is ambiguous and depends on the sizes of G and L. When advertising has value in itself, therefore, care must be taken when inferring changes in welfare from changes in output. For example, it is possible that the optimal patent life is infinite, even when patent expiration increases output.

Another possibility is differential marketing to consumers with different willingness to pay. While price discrimination may be difficult, discrimination through marketing is much easier. This applies to the promotion of drugs to doctors, called "detailing" in pharmaceutical markets. Differential advertising across doctors and markets may act as a form of price discrimination. Since advertising cannot be resold, it is more easily implemented than traditional forms of price discrimination. Thus, advertising may shrink pricing inefficiencies and thereby lower the marginal cost of patent extension. Discriminatory advertising may lower or even remove the deadweight losses associated with patent monopolies.

When advertising has consumption value, it is necessary to estimate the direct

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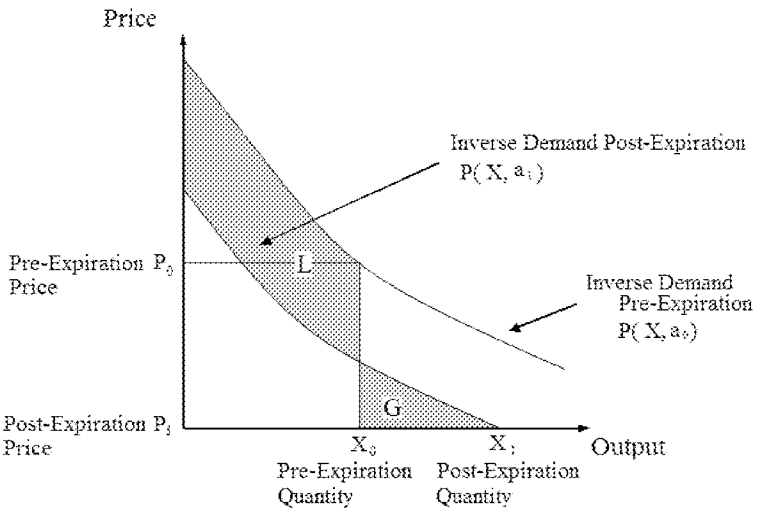

Figure 6. Welfare effects of patent expiration under advertising as consumption

utility of advertising in order to capture the full value of patent expiration. In the absence of this estimate, we can say that consumers benefit less from patent expiration whenever they derive consumption value from advertising.

3. Empirical Analysis

This section investigates the empirical impact of pharmaceutical marketing on consumer welfare. Our approach is to use patent expirations as a means of identifying the demand curve for pharmaceuticals, where demand depends on both price and advertising effort. These estimates are then used to calculate how much patent expiration benefits (or costs) consumers.

We focus on direct-to-physician marketing, which accounts for about 86 percent of all pharmaceutical marketing (Kaiser Family Foundation 2003). We estimate the value of marketing under the alternative models of advertising as information (Section 2.3.1) and advertising as persuasion (Section 2.3.2). We do not have the data necessary to estimate the direct utility value of such marketing to consumers or physicians. If this exists, it will further increase the value of marketing and reduce the cost of patents.

We begin by presenting our empirical model and approach to welfare estimation. We then describe our data and present descriptive analyses of the relationships between patent expiration, quantity changes, and marketing effort. Next, we discuss our approach to measuring advertising and lay out our identification strategy. We finish with our estimated models and welfare effects.

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3.1. Model and Approach to Welfare Estimation

The basic framework for this analysis is the following demand function:

$$\ln x_{it} = \beta_0 + \beta_1 \ln p_{it} + \beta_2 \ln a_{it} + \phi_i + M(t) + \varepsilon_{it}. \tag{8}$$

In this equation, p_{it} is the price of molecule i in month t, x_{it} is the corresponding quantity of the molecule, and a_{it} is a measure of advertising. There is also a molecule fixed effect, ϕ_i, and a polynomial time trend, $M(t)$. We are particularly interested in using the demand function to ascertain the effects of patent expiration on quantity and on welfare. It is straightforward to assess the quantity effects, but estimating the welfare changes (in terms of consumer surplus) requires more discussion.

The demand function (and its associated inverse demand) implies forms for the changes in consumer surplus presented in Section 2.3. Consider first the cost of quantity restriction alone, which would be present without advertising. Suppose that $p(q)$ represents demand at the consumer's true valuation of the good. Monopoly quantity is given by x_M. Finally, define by x_C' the counterfactual quantity that would obtain under competition if prices changed but advertising remained at its monopoly level. If dp/p is the percentage change in price due to patent expiration, we can define $x_C' \equiv x_M[1 + (dp/p)\,\varepsilon]$. The cost of quantity restriction to the consumer is then defined by

$$\int_{x_M}^{x_C'} p(q)dq - p_C x_C' - p_M x_M. \tag{9}$$

Substituting in the logarithmic form for the inverse demand function and integrating yields the final expression:

$$\Delta_Q = \exp\left[\frac{-\beta_0 - \phi_i - M(t = -1) - \beta_2 \ln(a_M)}{\beta_1}\right] \times \left(\frac{\beta_1}{1 + \beta_1}\right)\left[x_C'^{(1+1/\beta_1)} - x_M^{1+1/\beta_1}\right] - (p_C x_C' - p_M x_M). \tag{10}$$

The time trend is evaluated at $t = -1$, the last month of patent protection. This expression can be calculated in the short run and the long run by calculating x_C' according to either the short-run or long-run reduction in price due to patent expiration. This distinction allows us to calculate either the short-run or long-run change in welfare.

The short-run price change is defined as the change observed in the first few months immediately following patent expiration. Since the long-run price change due to patent expiration is unobserved by us, we estimate it by assuming that the long-run competitive price is equal to marginal cost. The demand curve then implies an associated long-run quantity, based on the estimated price elasticity

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of demand. Further details on the methods for estimating short- and long-run consumer surplus appear in the Appendix.

In the case of informational advertising, the true expected change in consumer surplus is given by

$$\Delta_{\text{Info}} = \int_{x_M}^{x_C} p(q)dq - (p_C x_C - p_M x_M). \tag{11}$$

This differs from Δ_Q in its use of the equilibrium competitive quantity x_C that includes the effects of both price and advertising changes. Above, we defined the conservative bound on this quantity:

$$\tilde{\Delta}_{\text{Info}} = \int_{x_M}^{x_C} p(q,\ a_M)dq - (p_C x_C - p_M x_M). \tag{12}$$

The functional form of the demand curve provides an explicit expression for this term:

$$\begin{aligned}\tilde{\Delta}_{\text{Info}} = \exp\left[\frac{-\beta_0 - \phi_i - M(t = -1) - \beta_2 \ln(a_M)}{\beta_1}\right] \\ \times \left(\frac{\beta_1}{1+\beta_1}\right)(x_C^{1+1/\beta_1} - x_M^{1+1/\beta_1}) - (p_C x_C - p_M x_M).\end{aligned} \tag{13}$$

Next, the value to consumers of monopoly-level informational advertising can be obtained as

$$\text{InfoAdvValue} = \tilde{\Delta}_Q = \tilde{\Delta}_{\text{Info}}. \tag{14}$$

Finally, consider the case of persuasive advertising. Recall that the value of patent expiration in this case is given by $\tilde{\Delta}_{\text{Pers}} \equiv \tilde{\Delta}_{\text{Info}} + \int_{x_M}^{x_C} [p(q,\ a_C) - p(q,\ a_M)]dq$. The functional form of the demand curve then implies

$$\begin{aligned}\tilde{\Delta}_{\text{Pers}} = \tilde{\Delta}_{\text{Info}} + \exp\left[\frac{-\beta_0 - \phi - M(t = -1)}{\beta_1}\right] \\ \times \left(\frac{\beta_1}{1+\beta_1}\right)\left(1 - a^{-\beta_2/\beta_1}\right)\left(x_C^{1+1/\beta_1} - x_C^{1+1/\beta_1}\right).\end{aligned}$$

As above, the value to consumers of monopoly-level persuasive advertising can then be obtained as

$$\text{PersAdvValue} = \tilde{\Delta}_{\text{Pers}} - \tilde{\Delta}_Q.$$

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Table 1
Monthly Molecule-Level Variables

Variable	Definition
Quantity	Grams of the drug sold by retailers
Price	Revenues divided by grams sold
Journal Advertising	Total cost of journal advertising space
Detailing Visits	Visits to physicians by pharmaceutical representatives
Samples	Drug samples dispensed to physicians
Generic Competitors	Competing producers of the molecule

Source. The data for Generic Competitors are from the MIDAS database produced by IMS Health; all other data are from IMS Health's Generic Spectra database.
Note. All variables are available monthly, 36 months prior to and after expiration. Revenues are for retail and hospital channels and are converted to reflect ex-manufacturer prices and quantities. No adjustments are made for confidential rebates to health plans.

3.2. Data

The IMS Health Generic Spectra database contains data on 101 unique molecules whose patents expired between 1992 and 2002.[11] Table 1 lists our variables. IMS collects data on both revenue and grams sold. Revenue data are collected at the retail level (through both retail and hospital pharmacies) and at the wholesale level. IMS then estimates the wholesale price paid to the pharmaceutical company. Therefore, in the case of a patented drug, this can be thought of as the price paid to the monopolist rather than the price paid by insured or uninsured consumers. We also have three measures of direct-to-physician advertising: monthly expenditures on medical journal advertisements, monthly detailing visits, and the number of drug samples dispensed by representatives to doctors.

Price, quantity, and advertising data are available separately for the branded and generic producers of the molecule and for the overall market. Total market price is constructed as total revenues divided by total grams, and similarly for the branded and generic prices. In estimating market demand, we use total market prices and quantities.

Table 2 reports a breakdown of the 101 molecules by therapeutic class and advertising status. We consider a drug to be fully advertised if some advertising activity is reported for it in each of our three advertising categories, and not fully advertised if it does not. Not surprisingly, advertising effort is much greater for heavily used drugs: drugs not fully advertised account for about 28 percent of the molecules but less than 10 percent of total revenues.

[11] The full data include 106 molecules, but five are excluded. We exclude Aventyl (Eli Lilly, patent expiration in July 1992), Prinivil (Merck, patent expiration in June 2002), and Betoptic (Alcon, patent expiration in June 2000) because generic sales for these drugs include other branded products, which creates a measurement problem. We also dropped Bumex (Roche, patent expiration in January 1995) and Toradol (Roche, patent expiration in May 1997), both of which had a duplicate formulation in the data.

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Table 2
Types of Molecules Represented in IMS Generic Spectra Database, by Number of Drugs

Two-Digit U.S.C. Category	Not Fully Advertised	Fully Advertised	Total
Analgesics		4	4
Anesthetics	2		2
Antiarthritics		7	7
Hemostat modifiers		2	2
Antihistamines		1	1
Anti-infectives	2	3	5
Antimalarials		1	1
Neurological treatments	2	4	6
Gastrointestinal drugs		6	6
Bile therapy		1	1
Beta blockers		2	2
Cardiac agents	2	4	6
Antineoplasm	3	3	6
Ace inhibitors	2	14	16
Antihyperlipidemic		3	3
Antifungal agents		2	2
Diabetes therapy		3	3
Diuretics	1	1	2
Hormones	1	2	3
Musculoskeletal	2	1	3
Ophthalmic		3	3
Psychotherapeutics	4	6	10
Sedatives		2	2
Tuberculosis therapy	1		1
Antiviral		2	2
Immunologic		2	2
Total	22	79	101

Note. Fully advertised drugs have, at some point in their life span, nonzero advertising in each of three advertising categories: journal advertising, detailing visits, and samples. U.S.C. = Uniform System of Classification.

3.3. Descriptive Analysis

An initial examination of the data reveals some interesting patterns that suggest the interplay of quantity restriction and advertising effects.

3.3.1. Patent Expiration and Changes in Quantity

Figure 1 demonstrates that for about 40 percent of drugs, the total market quantity consumed declines in the short run immediately after patent expiration. This suggests that patent expiration is doing more than simply removing the monopolist's incentive to restrict quantity.

Figure 7 depicts trends in price (per gram) and quantity for the average drug as a function of time until (or after) the month of expiration. As others have noted, before expiration, price tends to rise and quantity to fall over time. Bhattacharya and Vogt (2003) argue that this occurs because a drug is an ex-

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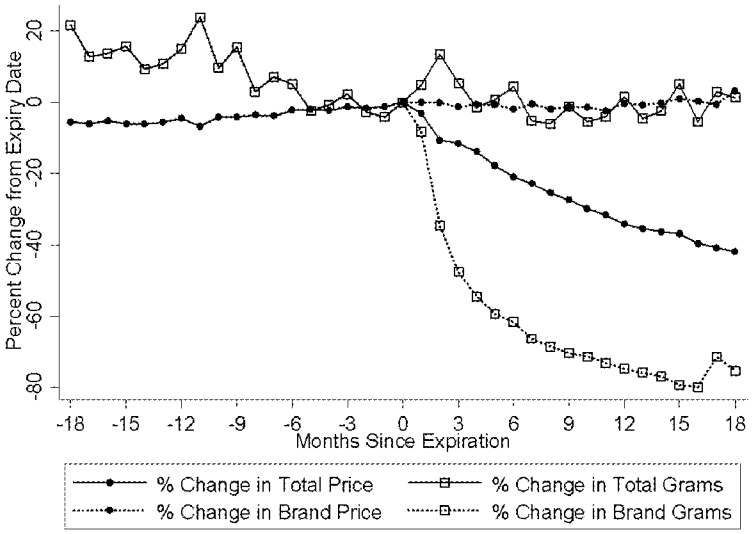

Figure 7. Trends in price and quantity for the average drug

perience good in the sense that consumers have to use it before they can judge its value. Therefore, inducing more use by lowering the price can lead to permanent increases in consumption by creating loyal customers. The incentive to win more customers is highest early in the life of the patent and erodes as the month of expiration looms. This is consistent with the trends in price and quantity prior to expiration.

After patent expiration, the price of the branded drug remains largely unchanged, even rising slightly, while the price of generic forms falls precipitously. The deviations from the typical expectations we have about patent expiration seem at least correlated with advertising. Drugs that are not fully advertised, according to the definition above, tend to behave according to the standard theory of monopoly. Compare Figures 2 and 3, which show trends for fully advertised and not fully advertised drugs, respectively. Trends for the less advertised drugs look fairly standard: after patent expiration, quantity increases and remains at a permanently higher level. Moreover, the price of the branded drug decreases after expiration, although it always remains higher than the generic price. In contrast, for the more advertised drugs, the brand price steadily increases after expiration, and total market quantity ends up decreasing after expiration, after a brief initial rise.

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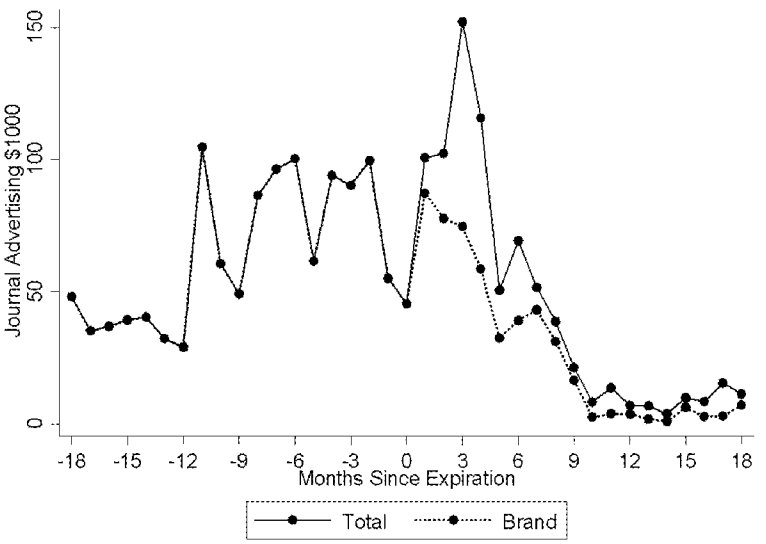

Figure 8. Mean monthly spending on journal advertising for the average molecule and the average branded molecule.

3.3.2. Trends in Advertising

Figures 8, 9, and 10 document trends in journal advertising, detailing visits, and samples dispensed. Advertising expenditures decline throughout the life of the product, since the payoff to advertising declines with the length of the patent horizon. At the month of patent expiration, there is a short-lived jump in advertising, as generic firms spend some effort publicizing their product. In percentage terms, this jump is most pronounced in the case of journal advertising but still occurs for samples dispensed and detailing visits.

3.4. Measurement of Advertising

The nature of these three types of advertising activities differs considerably. Ideally, we would like to estimate the impact of prices and the independent impact of all three forms of direct-to-physician advertising.[12] However, we lack enough identifying variation to estimate the impacts of all three measures. Therefore, we focus on the estimates using samples dispensed, which account for almost two-thirds of direct-to-physician advertising expenditures (Kaiser Family Foundation 2003). In contrast, journal advertising accounts for roughly 2 percent of spending, with detailing visits accounting for the rest.

[12] The IMS Generic Spectra database does not contain information on DTC advertising, which makes up approximately 14 percent of total advertising spending (Kaiser Family Foundation 2003).

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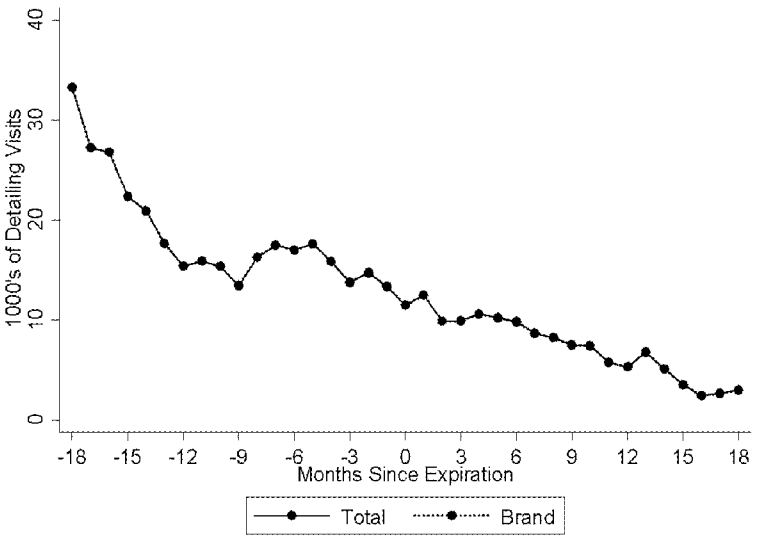

Figure 9. Mean monthly visits by pharmaceutical company representatives for the average molecule and the average branded molecule.

An additional empirical reason to study samples instead of detailing visits is the issue of attribution to specific molecules. It is clear how to assign samples dispensed by a manufacturer to a particular brand. Apportioning detailing visits is much more ambiguous. This is consistent with our finding that the standard errors on detailing effects are consistently larger (by nearly an order of magnitude) than the corresponding errors on journal advertisements or samples dispensed.

To be sure, a drawback of focusing on a single advertising measure is the exclusion of other marketing activities. However, analyzing a single marketing activity ought to provide quantitatively generalizable insights. In a simple model, the marginal dollar spent on every marketing activity ought to be equally valuable in terms of generating additional units of demand.[13] Therefore, the demand response generated by a dollar of spending on journal advertising ought to be roughly comparable to the response generated by a dollar spent on detailing or a dollar spent on dispensing samples. The elasticities on individual activities are related, according to $\varepsilon_{A_i} = \varepsilon_A \sigma_{A_i}$, where ε_A is the elasticity on total advertising, ε_{A_i} is the elasticity on advertising activity i, and σ_{A_i} is the share of activity i in total advertising spending.

This helps clarify the effect of focusing on one type of advertising. If other

[13] To be specific, if demand depends on two advertising activities, according to (p, A_1, A_2), where A_1 and A_2 are both denominated in dollars, profit maximization implies that $\partial D/\partial A_1 = \partial D/\partial A_2$.

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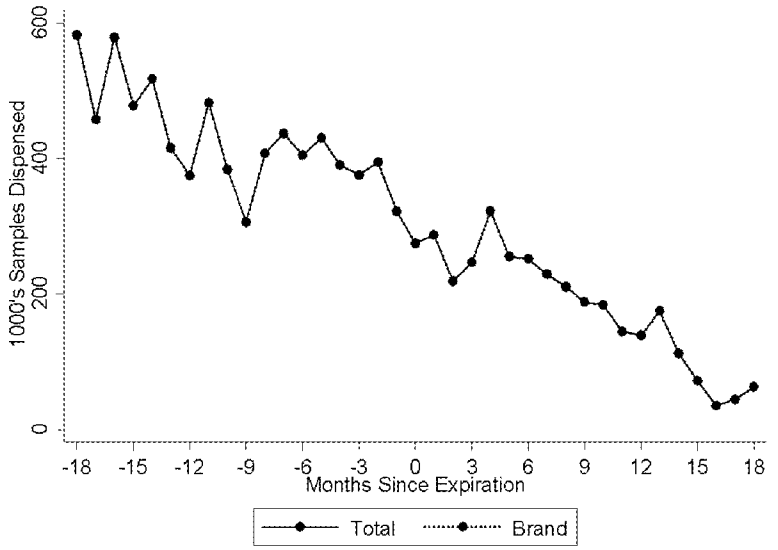

Figure 10. Mean monthly samples dispensed by pharmaceutical company representatives for the average molecule and the average branded molecule.

forms of advertising change at patent expiration, an omitted variables problem ensues. If all forms of marketing are positively correlated, the estimated elasticity on activity i, $\hat{\varepsilon}_{A_i}$, will be biased toward the total elasticity ε_A. If correlation is perfect, $\hat{\varepsilon}_{A_i}$ will equal ε_A itself. In our context, therefore, we know that the estimated elasticity on samples will lie between the true elasticity on samples and the true total advertising elasticity. The bias is bounded above by $|\varepsilon_A - \varepsilon_{A_i}| = \varepsilon_A |1 - \sigma_{A_i}|$. To be conservative about the value of advertising, we assume that all forms of advertising are perfectly correlated and that the bias is maximized. As a result, we treat the elasticity on samples as if it were the elasticity on total advertising and assume that $\hat{\varepsilon}_{A_i} = \varepsilon_A$. This weakly understates the value of advertising.

3.5. Identification

3.5.1. Approach

To identify the demand for drugs, our approach is to isolate movements along the demand curve, as distinct from shifts of the curve itself. The general strategy is to treat large changes in price and advertising sufficiently close to the date of expiration as being related to the patent expiration and not to shifts in the demand curve. The trend breaks in price, advertising, and quantity are then used to calculate demand elasticities.

To lay out this approach, consider first a formulation that treats advertising

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effort as exogenous. This involves estimating the following first- and second-stage equations via instrumental variables regressions:

$$\ln p_{it} = \alpha_0 + \alpha_1 \text{Expired}_{it} + \alpha_2 \ln(a_{it}) + \phi_i + M_p(t) + \eta_{it}, \quad (15)$$

and

$$\ln x_{it} = \beta_0 + \beta_1 \ln p_{it} + \beta_2 \ln a_{it} + \phi_i + M_x(t) + \varepsilon_{it}. \quad (16)$$

Price (p_{it}) is a function of advertising (a_{it}), a molecule fixed effect (ϕ_i), and a polynomial in month ($M_p(t)$). Quantity (x_{it}) depends on price, advertising, a molecule fixed effect, and a polynomial in month ($M_x(t)$). The expiration variable identifies the within-molecule break in the polynomial trend that occurs at expiration for changes in price and quantity. These trend breaks, which imply percentage changes in price and quantity, are then implicitly used to estimate the demand elasticity. Breaks in trend at the date of expiration are attributed to the expiration itself; they are assumed to be independent of unobserved changes in demand and used to estimate movement along the demand curve. Later, we present some evidence in favor of this identifying assumption.

To identify the effects of endogenous advertising effort, we extend the strategy above, which relies on changes in price and quantity at the precise moment of patent expiration. In reality, however, the effect of expiration is not immediate. Competitors enter slowly and at an uncertain pace because of the vagaries of the Food and Drug Administration's approval process and nonpatent entry barriers like fixed startup costs. If expiration has lagged effects, we can obtain more identifying variation. We adapt the expiration window strategy by considering the lagged effect of expiration in addition to the immediate effect. Formally, we implement this by the following model:

$$\ln(p_{it}) = \alpha_0 + \alpha_1 \text{Expired}_{it} + \alpha_2 \text{ExpiredLag}_{it} + \phi_i + M_p(t) + \eta_{it}, \quad (17)$$

$$\ln(a_{it}) = \delta_0 + \delta_1 \text{Expired}_{it} + \delta_2 \text{ExpiredLag}_{it} + \phi_i + M_a(t) + \omega_{it}, \quad (18)$$

and

$$\ln(x_{it}) = \beta_0 + \beta_1 \ln(p_{it}) + \beta_2 \ln(a_{it}) + \phi_i + M_x(t) + \varepsilon_{it}. \quad (19)$$

As before, Expired_{it} is a dummy variable for the month immediately following expiration. The variable ExpiredLag_{it} is a dummy for the lagged effect of expiration: we consider specifications using 2 months, 3 months, 4 months, and 5 months after expiration; these produce similar results, as shown below.

3.5.2. Validity Tests

The identification strategy rests on the validity of using patent expiration as an instrument for estimating the demand for pharmaceuticals. The instrument is valid if patent expiration has no direct effects on the demand curve. It seems reasonable to assume that consumers do not derive direct utility from a molecule's being on or off patent, even if they may value using branded drugs over

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generics. However, there may be indirect effects of patent expiration on demand if expiration causes competitors to respond strategically. For example, monopolistic competitors may manipulate prices or marketing in response to a patent's expiration.

To investigate the importance of this behavior, we run the following regression:

$$\ln(S_{jm}) = \eta_0 + \eta_1 \text{Expired}_{im} + M_S(t) + \phi_i + \kappa_{jm}. \quad (20)$$

The dependent variable is a measure of strategic behavior—measured as competitors' prices, or marketing activity—for either the manufacturer's own molecule or the molecule's competitors. We define the set of competitors as molecules in the same (five-digit Uniform System of Classification) therapeutic class. The explanatory variable $M_S(t)$ is a quartic in months until the expiration of the patent on molecule i,[14] and ϕ_i is a fixed effect for molecule i. Intuitively, these regressions assess whether patent expirations affect pricing or advertising decisions for a molecule's competitors.

Table 3 presents the results. Patent expirations reduce price and marketing effort for the on-patent molecule, as expected. However, for price and the three marketing measures, there is no effect on the behavior of competitors. With the exception of the price regression, the effects for competitors are more precisely estimated than the own-molecule effects, which suggests that the competitor regressions would be precise enough to detect the own-molecule effects and that wider confidence intervals cannot explain the difference in significance. Finally, the molecules being studied represent 30 percent of class-level grams sold, on average. Therefore, if patent expiration has no effects on competitors, one would expect the class-level effects to be about 30 percent as large as the own-molecule effects. One can never reject this hypothesis statistically for any of the four measures; moreover, six of the eight point estimates are within one-half of a standard deviation of that 30 percent level.

3.6. Naive Estimates with Exogenous Advertising

We first present the three-stage least squares coefficients that treat advertising as exogenous in Table 4, which reports results for four versions of the model and estimates equations (15) and (16). Models 1 and 2 include samples dispensed as a measure of advertising and differ with respect to the form of the polynomial time trend. Models 3 and 4 include all three measures of direct-to-physician marketing in our data.

The estimated price elasticities are just above 1.0 in the fully specified model and around 1.5 in the model with samples alone. The theory of monopoly predicts that the absolute value of the demand elasticity equals the inverse of the monopoly markup. In the case of drugs, the long-run price of generic equivalents tends to be approximately 10–20 percent of the brand price at the date

[14] We obtained similar results using cubic and quadratic specifications.

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Table 3
Effect of Patent Expiration on the Manufacturer's Own Molecule, the Entire Class, and Competitors' Molecules

Dependent Variable	Own Molecule	Entire Class	Competitor Molecules
ln(Price):			
Expired for 1 month	−.020*	−.016	.160
	(.009)	(.023)	(.161)
Expired for 5 months	−.079**	−.022	−.071
	(.018)	(.016)	(.103)
N	4,063	6,097	3,766
ln(Samples):			
Expired for 1 month	.010	−.012	−.044
	(.155)	(.084)	(.087)
Expired for 5 months	−.342*	−.079	.040
	(.155)	(.080)	(.072)
N	3,313	5,066	4,487
ln(Visits):			
Expired for 1 month	−.166+	−.038	.073
	(.097)	(.080)	(.095)
Expired for 5 months	−.188+	−.124*	−.024
	(.100)	(.062)	(.055)
N	4,562	5,912	5,363
ln(Journal):			
Expired for 1 month	.192	.133	.006
	(.169)	(.092)	(.093)
Expired for 5 months	−.433**	−.131+	.026
	(.131)	(.075)	(.083)
N	2,364	5,173	4,529

Note. Robust standard errors are in parentheses. Regressions for the entire class measure quantities in the same five-digit Uniform System of Classification therapeutic class as the molecule with the expiring patents. Regressions for competitor molecules measure class-level quantities minus the molecule itself.
+ Significant at 10%.
* Significant at 5%.
** Significant at 1%.

of expiration (Grabowski and Vernon 1992). This implies that the demand elasticity at expiration is predicted to be between 1.10 and 1.25. These numbers lie within 1 standard deviation of all four estimates.

The first-stage estimates suggest that patent expiration immediately lowers price by 6–10 percent. This is predicted to raise quantity by slightly more. One month after patent expiration, the model predicts that quantity will be about 9.5 percent higher. This number is largely invariant across the four specifications. In the long run, however, price typically falls by 80 percent (Grabowski and Vernon 1992). Given the likely demand elasticities, therefore, patent expiration increases quantity by more than 80 percent in the long run.

In the models with only samples dispensed, the naive advertising elasticity is around .12–.13. Including the other measures of marketing lowers this number, but the combined effect of increasing all marketing measures proportionally results in a similarly sized response.

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Table 4

Estimated Demand Elasticities for Drugs, with Naive Model of Advertising

	Model 1		Model 2		Model 3		Model 4	
	ln(Price)	ln(Grams)	ln(Price)	ln(Grams)	ln(Price)	ln(Grams)	ln(Price)	ln(Grams)
Expired for 1 month	−.063**		−.065**		−.096**		−.094**	
	(.020)		(.020)		(.020)		(.020)	
log Total price (revenues/gram)		−1.501**		−1.467**		−1.018**		−1.041**
		(.558)		(.534)		(.387)		(.399)
log Total samples dispensed	.062**	.130**	.061**	.126**	.031**	.051**	.028**	.049**
	(.003)	(.035)	(.003)	(.033)	(.005)	(.015)	(.005)	(.014)
log Total detailing visits					.049**	.077**	.051**	.079**
					(.008)	(.024)	(.007)	(.025)
log Total journal advertising					.036**	.038*	.035**	.038*
					(.004)	(.016)	(.004)	(.016)

Note. Values are three-stage least squares coefficients and standard errors using dummies for 1 month since expiration as an instrument for ln(Price). All equations include molecule-specific fixed effects. The time trend for models 1 and 3 is cubic in month; the time trend for models 2 and 4 is quartic in month. For models 1 and 2, $N = 2{,}276$; for models 3 and 4, $N = 1{,}034$.

* Significant at 5%.

** Significant at 1%.

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Table 5
Estimated Model of Advertising and Pharmaceutical Demand

	Model 1			Model 2		
	ln(Price)	ln(Samples)	ln(Grams)	ln(Price)	ln(Samples)	ln(Grams)
Expired for 1 month	−.015	.313*		−.027	.257+	
	(.023)	(.133)		(.023)	(.134)	
Expired for 5 months	−.131**	−.566**		−.100**	−.417**	
	(.023)	(.132)		(.024)	(.139)	
log Total price (sales/gram)			−1.004*			−.937+
			(.480)			(.530)
log Total samples			.318**			.360*
			(.117)			(.142)

Note. Values are three-stage least squares coefficients and standard errors using dummies for months since expiration as instruments for ln(Price) and ln(Samples). All equations include molecule-specific fixed effects. For model 1, the time trend is cubic in month, the Cragg-Donald statistic is 3.95 (size = 20%), and the Stock-Wright statistic is 16.7 ($p = .0002$). For model 2, the time trend is quartic in month, the Cragg-Donald statistic is 3.241 (size > 25%), and the Stock-Wright statistic is 15.06 ($p = .0005$). $N = 2{,}276$ for all equations.

+ Significant at 10%.
* Significant at 5%.
*** Significant at 1%.

3.7. *The Full Model of Advertising*

The full model treats advertising as an outcome variable, as specified in equations (17), (18), and (19). The results are given in Table 5, which reports estimates from two models, one using a cubic polynomial in month and one using a quartic. The results are reasonably stable across the two specifications. The price elasticity of demand is estimated to be at or near unity, while the advertising elasticity ranges from .32 to .36. Both sets of estimates imply that, for the average molecule, total quantity falls by about 5 percent on net after 5 months of patent expiration. Our price elasticity estimates continue to be within 1 standard deviation of 1.10 and 1.25.

Theory also provides predictions on the size of the advertising elasticity; the ratio of advertising to price elasticities ought to equal the share of advertising in sales (Dorfman and Steiner 1954).[15] To calibrate the elasticity, we need to calculate the share of advertising in sales for on-patent molecules. Unfortunately, our data do not contain expenditures on samples, but we can calculate the advertising share in revenues indirectly. The overall share of marketing expenditures in total pharmaceutical revenue is approximately 14 percent (Kaiser Family Foundation 2003). About 75 percent of total revenues belong to drugs that are currently on patent (Hughes, Moore, and Snyder 2002). Assuming that marketing is negligible for generics and off-patent drugs, this implies that marketing is about 19 percent of revenues for the relevant drugs.

[15] The Dorfman-Steiner theorem follows most simply from the analysis of a static monopoly maximization problem.

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Finally, our sample of drugs is more heavily marketed than the average drug, in part because these drugs are selected to have sales throughout their product lifecycle. As such, they will tend to be more successful than average. To calibrate this difference, we compare marketing expenditures on detailing in our data to those for the average on-patent drug. Overall, 29 percent of marketing expenditures are for detailing (Kaiser Family Foundation 2003). Since marketing expenditures are approximately 19 percent of on-patent drug spending, this implies that 5.5 percent of on-patent drug revenues are spent on detailing. In our data, we estimate that 6.8 percent of revenues are spent on detailing while drugs are on patent.[16] Along this dimension, marketing effort is roughly 24 percent higher for our drugs. Applying this correction would imply that marketing is roughly 23 percent of revenues for our drugs. Theory predicts that the price elasticity ranges from 1.10 to 1.25. These price elasticities coupled with our rough estimates of the revenue share spent on advertising imply total advertising elasticities between .25 and .29. Our estimates are slightly higher, but fairly close, and not statistically distinguishable from these crude predictions.

The note to Table 5 presents weak-instrument diagnostics. For the purpose of diagnosing weak instruments, Stock and Yogo (2005) derive critical values for use with the Cragg-Donald statistic. Unlike the conventional *F*-test for weak instruments, their methods are applicable to cases with multiple included endogenous regressors. In particular, they show that the Cragg-Donald statistic can be used to infer maximum Wald test sizes. For example, they show that a Cragg-Donald statistic above 3.95 implies that a Wald test at the 5 percent level will have a maximum size of 20 percent—that is, it will be rejected no more than 20 percent of the time. A typical threshold for declaring instruments to be strong is a maximum size of 10 percent.

As Table 5 demonstrates, the maximum test sizes lie above this threshold and thus indicate weak instruments. To address this problem, we report the Stock-Wright *S*-statistic, which is a weak-instrument-robust procedure for testing hypotheses concerning the coefficients on the included endogenous regressors (Stock and Wright 2000). According to the Stock-Wright statistic, we can reject the null hypothesis that the coefficients on price and advertising are jointly zero in our models. Nonetheless, care should be taken in interpreting our confidence intervals, as our standard errors are likely to be biased downward.

3.7.1. Consumer Surplus from Patent Expiration

Estimating the full demand functions allows us to infer the changes in consumer surplus associated with patent expiration, quantity restriction, and monopoly marketing. Conceptually, we estimate three kinds of welfare changes: cost of quantity restriction, cost of patents, and value of monopoly marketing. The

[16] We assume that each detailing visit costs $138 (Neslin 2001). We then calculate total spending on detailing as a fraction of total revenue for each month and compute the mean fraction for all on-patent drug-months.

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second and third types of welfare change are estimated in both the persuasive and informational advertising cases.

The cost of quantity restriction is the consumer's cost of the higher prices induced by patents.[17] The overall cost of patents, on the other hand, combines this cost with the consumer value of increased output due to more advertising.[18] Theoretically, the cost of quantity restriction must always be positive. But the cost of patents may be positive or negative, as shown in our theoretical discussion. Finally, the value of monopoly marketing is the value to consumers of the marketing induced by patents, holding price fixed.[19]

In our benchmark estimation, we define the short run as the first 5 months after patent expiration:[20] the price and advertising changes that take place over this initial period define short-run costs. The long-run welfare changes are the total gains that would accrue to consumers in a long-run steady state. These are computed using the following results: in the long run, competition drives price to marginal cost and advertising effort to zero. Since long-run generic prices are about 10–20 percent of monopoly prices, we assume that in the long run, price falls by 90 percent and advertising falls by 100 percent. More detail on the calculation of these consumer surplus changes appears in the Appendix.

The consumer surplus calculations depend on the price elasticity, the advertising elasticity, and the short-run impact of patent expiration on price. Our model estimates all three of these underlying quantities and allows calculation of consumer surplus. Table 6 lists the estimated change in consumer surplus associated with each model estimate.

The per-molecule cost of quantity restriction to consumers is \$1.9–\$2.4 million in the short run. This means that 5 months after patent expiration, consumers receive about \$2 million of additional value per month (from one molecule) from the reduction in price alone. This value rises to about \$12.7 million in the long run. In other words, the price reduction delivered by a competitive market, compared to the last month of a patent monopoly, would yield at least \$12.7 million of value to consumers per month.

These calculations do not account for the effect of patents in encouraging advertising and thus increasing quantity. Accounting for the effects on advertising, patent expiration has small positive or even negative effects on consumers in the short run. In the long run, consumers still benefit from patent expiration, but by less than the cost of quantity restriction alone. In the long run, competition creates \$8.1–\$9.5 million of additional value for consumers per month. This is approximately 30 percent lower than the value created by the price reduction

[17] This is given by equation (13), evaluated at the value of x_C that would obtain if patent expiration had no impact on marketing effort. The evaluation procedure is described in Section A1.

[18] This is given by equation (13), evaluated at the actual competitive value of x_C. The evaluation procedure for the informational advertising case appears in Section A2. Section A3 provides details for the persuasive advertising case.

[19] This is given by equation (14).

[20] Below we demonstrate the robustness of our results to 1-month, 2-month, 3-month, and 4-month definitions of the short run.

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Table 6
Estimated Change in Consumer Surplus for Price and Advertising Changes

	Model 1	Model 2
Short-run cost of quantity restriction ($/month)	2,400,000	1,900,000
Long-run cost of quantity restriction ($/month)	12,700,000	12,700,000
Informational advertising:		
Short-run patent cost ($/month)	−1,000,000	−1,200,000
Long-run patent cost ($/month)	9,500,000	8,300,000
Value to consumers of monopoly marketing (% of revenue)	20	25
Persuasive advertising:		
Short-run patent cost ($/month)	−1,000,000	−1,200,000
Long-run patent cost ($/month)	8,800,000	8,100,000
Value to consumers of monopoly marketing (% of revenue)	22	26

Note. Costs of quantity restriction represent the costs of monopoly restrictions on quantity alone. Patent costs measure the total welfare impact of patents under alternative views of advertising. The short run is a 5-month period, while the long run assumes that, under competition, advertising goes to zero and prices go to marginal cost.

alone. The marketing induced by patents generates consumer surplus approximately equal to 22–26 percent of total pharmaceutical spending. Earlier, we roughly estimated that firms spend about 23 percent of total revenues for the marketing of on-patent drugs in our sample. Therefore, the value of marketing to consumers alone—excluding the value to firms—is approximately equal to its cost.

Note also that the estimates are fairly similar for the cases of persuasive and informational advertising. Under persuasive advertising, we assume that the true value of the product is lower than under informational advertising. As a result, the cost of patent monopoly is also somewhat lower and the value of monopoly-induced marketing relatively higher. These are, however, modest differences, as Table 6 indicates. By and large, the welfare effects of advertising do not hinge on the precise model of advertising adopted. Finally, our estimates do not incorporate the direct consumption value of marketing, if any. Consumption value lowers the social cost of patents and raises the value of monopoly marketing.

The implications of weak instruments for these estimates are not clear. Relative bias in an exactly identified instrumental variables (IV) model is undefined, as is the expected value of the IV coefficient (Staiger and Stock 1997). In the absence of clear econometric evidence, it is useful to reiterate the finding that the coefficient estimates agree with the simple economic theory of pricing and advertising by monopolists. At a minimum, therefore, our numbers can be thought of as extensions of this simple theory, calibrated to real-world data on advertising expenditures and price markups.

3.7.2. Class-Level Results

Both marketing and price reductions increase quantity for a molecule itself, but their welfare benefits might be smaller if they steal business from competitors rather than generate new consumption among untreated patients. By replacing

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Table 7
Effect of Price and Marketing on Class-Level Quantity

	Model 3			Model 4		
	ln(Price)	ln(Samples)	ln(Grams)	ln(Price)	ln(Samples)	ln(Grams)
Expired for 1 month	−.059+	−.003		.267**	.298*	
	(.031)	(.112)		(.101)	(.143)	
Expired for 5 months	−.029	−.366**		.015	−.431**	
	(.033)	(.121)		(.104)	(.146)	
log Total samples of molecule			.209+			−.055
			(.123)			(.455)
log Class-level price						−.464
						(.721)
log Price in rest of class			−1.348*			
			(.577)			

Note. Three-stage least squares standard errors are in parentheses. All models include molecule-specific fixed effects. The time trend for all models is quartic in month. Class-level price is defined as total dollar sales per grams sold in the class, and Samples is monthly samples dispensed for the molecule. For model 3, the Cragg-Donald statistic is 1.702 (size > 25%), the Stock-Wright statistic is 3.25 (p = .20), and N = 3,217. For model 4, the Cragg-Donald statistic is 3.236 (size > 25%), the Stock-Wright statistic is .516 (p = .773), and N = 2,024.

+ Significant at 10%.
* Significant at 5%.
** Significant at 1%.

molecule-level quantity and price in our earlier models with measures of class-level quantity and price, we can gain some insight into this issue. We analyze the entire therapeutic class, including the expiring molecule itself, and separately analyze the rest of the class, excluding the molecule with the expiring patent.

Table 7 displays the results of this approach. It is analogous to the models reported in Table 5 in that it estimates equations (17), (18), and (19) at the level of the therapeutic class. Table 7 shows that marketing effort and price reductions for a particular molecule increase class-level consumption but have no statistically detectable effect on consumption in the rest of the class. On average, expiring molecules comprise 30 percent of class-level grams sold. Therefore, if advertising only increases the consumption of the advertised molecule and has no impacts on competitors, the estimated advertising effects should be roughly 30 percent as large as they were in Table 5. This would suggest a class-level advertising elasticity between .09 and .11. Our point estimate is considerably larger than this, although we cannot statistically reject values smaller than these levels because of the width of the confidence interval. Taking the point estimates at face value, though, would suggest positive spillovers from a molecule to its competitors. Positive spillovers are consistent with the decrease in marketing effort and the increase in molecule-level price (as reported in Bhattacharya and Vogt 2003) that occur as patent expiration approaches. In any event, there is no evidence of market stealing in our data. This argues in favor of our welfare-calculation

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approach, which treats own-molecule quantity growth as a pure welfare gain rather than theft of competitors' market share.

A caveat to the results in Table 7 concerns the apparent presence of weak instruments, which likely widen the confidence intervals further around the coefficients of interest. The Cragg-Donald statistics imply that underrejection of hypothesis tests is likely (Stock and Yogo 2005). They imply that hypothesis tests at the 5 percent level are likely to be rejected 25 percent of the time or more; this suggests that the significance levels reported might be too low. Moreover, unlike in Table 5, hypothesis tests that are robust to weak instruments—using the Stock-Wright *S*-statistic—fail to reject the hypothesis that the price and advertising coefficients are jointly zero. As such, these results should be viewed as suggestive. We cannot detect effects of market stealing, but this may be because of a lack of power and instrument strength.

3.8. Sensitivity Analyses

We analyzed the sensitivity of our results to changes in the dynamics of patent expiration. The models above were identified using the month of patent expiration and 5 months after patent expiration as instruments. We also explored using 4 months, 3 months, and 2 months after expiration as a second instrument. Using the shorter-run estimates tends to reduce both the size and precision of the price-elasticity estimates, most of which are statistically indistinguishable from zero. However, the advertising elasticities remain stable. The value of advertising relative to revenues rise somewhat, as does the magnitude of some of the welfare effects. The results appear in Tables 8 and 9.

Second, we analyzed the impact of line extensions, or the launch of redesigned molecules by the original patent holder, in an effort to retain some patent protection. We limited our analysis to those 37 molecules without any line extensions. Both the price elasticity and advertising elasticity rise in absolute value, and the price elasticity becomes borderline insignificant. However, the welfare calculations are little changed. The value of marketing is about 19 percent of revenue. Considering monopoly advertising lowers the cost of patents by approximately 30 percent. Both these numbers are extremely similar to our preferred estimates.

4. Conclusion

Conventional wisdom analyzes optimal patent design as a trade-off between innovation incentives and static welfare. While this trade-off is real, it paints an incomplete picture. Patents have a variety of effects on static welfare, some of which can be positive. We demonstrated that patents improve the efficiency of marketing incentives and generate static value for consumers in this respect. Theoretically, this effect can mitigate or even fully offset the standard monopoly losses from patents. In the specific context of the market for pharmaceuticals, we estimated that monopoly marketing generates value for consumers that par-

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Table 8

Robustness of Demand Analyses to Dynamics of Patent Expiration Effects

	Model 5			Model 6			Model 7		
	ln(Price)	ln(Samples)	ln(Grams)	ln(Price)	ln(Samples)	ln(Grams)	ln(Price)	ln(Samples)	ln(Grams)
Expired for 1 month	.041	.395^{+}		.019	.394*		.001	.331*	
	(−.036)	(.209)		(−.027)	(.160)		(−.024)	(.142)	
Expired for 2 months	−.12**	−.319							
	(.036)	(−.209)							
Expired for 3 months				−.121**	−.413*				
				(.028)	(.161)				
Expired for 4 months							−.127**	−.426**	
							(.024)	(.141)	
log Total price (sales/gram)			−.817			−.837			−.802
			(−.544)			(−.529)			(−.53)
log Total samples			.39^{+}			.382*			.395*
			(.206)			(.163)			(.163)

Note. Values are three-stage least squares coefficients and standard errors using dummies for months since expiration as instruments for ln(Price) and ln(Samples). All equations include molecule-specific fixed effects. For all models, the time trend is cubic in month. For model 5, the Cragg-Donald statistic is 1.71 (size > 25%) and the Stock-Wright statistic is 14.02 ($p = .0009$); for model 6, the Cragg-Donald statistic is 2.82 (size > 25%) and the Stock-Wright statistic is 16.4 ($p = .0003$); for model 7, the Cragg-Donald statistic is 2.99 (size > 25%) and the Stock-Wright statistic is 18.6 ($p = .00009$). $N = 2{,}276$.

$^{+}$ Significant at 10%.

* Significant at 5%.

** Significant at 1%.

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Table 9
Estimated Change in Consumer Surplus for Changes in the Dynamics of Patent Expiration Effects

	Model 5	Model 6	Model 7
Short-run cost of quantity restriction ($/month)	2,300,000	3,100,000	3,500,000
Long-run cost of quantity restriction ($/month)	12,900,000	17,100,000	18,700,000
Informational advertising:			
Short-run patent cost ($/month)	−700,000	−1,900,000	−2,600,000
Long-run patent cost ($/month)	7,100,000	9,900,000	10,000,000
Value to consumers of monopoly marketing (% of revenue)	35	32	36
Persuasive advertising:			
Short-run patent cost ($/month)	−700,000	−1,900,000	−2,600,000
Long-run patent cost ($/month)	7,100,000	9,800,000	9,900,000
Value to consumers of monopoly marketing (% of revenue)	35	33	37

Note. Costs of quantity restriction represent the gains to consumers from the short-run and long-run reductions in price resulting from patent expiration. Costs of patents represent the short-run and long-run gains to consumers from patent expiration, which include the reductions in both price and advertising effort.

tially offsets the costs of monopoly pricing. Moreover, the value of advertising to consumers is roughly on par with its cost to firms; this suggests that, even if advertising generated no private value for firms, it would be approximately welfare neutral. These estimates are robust to views of advertising as persuasive rather than informational.

The paper suggests several avenues of future research. First, other forms of nonprice competition should be studied in the IP context. Quality provision, for instance, differs somewhat from marketing in that monopolies may or may not have stronger incentives for quality. Future research should clarify the link between patents and product quality and the welfare implications for consumers.

Second, using patent expirations as an exogenous increase in competition may prove useful as a means of testing theories of market structure or estimating demand parameters in other markets. For example, our data shed light on the often-debated question of whether increased competition reduces advertising. When branded drugs have to compete with identical generic substitutes, advertising effort decreases, as does utilization. Other predictions about the effects of market structure on industry conduct may be tested in a similar manner.

Third, our findings may alter the welfare interpretation of generic entry upon patent expiration. Generic entry clearly lowers price, but it also reduces advertising. It is necessary to consider both effects to capture the full value (or cost) of generic entry. At a minimum, our analysis suggests that considering price reductions alone leads to an upward bias in the estimation of welfare effects.

In general, little is known about efficient patent design in the presence of nonprice competition. More work is needed to better understand this issue, particularly in industries such as the U.S. market for pharmaceuticals, where output declines often result from patent expirations.

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Appendix

Methods for Calculating Consumer Surplus

A1. Cost of Quantity Restriction

In the text, we derived an explicit expression for the cost of quantity restriction, consistent with the econometric specification of the demand curve:

$$\Delta_Q = \exp\left[\frac{-\beta_0 - \phi_i - M(t = -1) - \beta_2 \ln a_m}{\beta_1}\right] \times \left(\frac{\beta_1}{1 + \beta_1}\right)\left(x_{c0}^{1+1/\beta_1} - x_m^{1+1/\beta_1}\right) - (p_C x_{c0} - p_M x_M). \tag{A1}$$

We define x_M as the quantity in the last month of patent protection, at $t = -1$.[21] Conceptually, x_{c0} is the quantity that would obtain in the absence of a patent but holding advertising fixed at its monopoly level.

For the short-run consumer surplus calculation, we use the change in price associated with the short-run expiration of the patent, or α_1 from the first-stage estimating equation. This leads to

$$x_c^{\text{short run}} = x_m(1 + \alpha_1\beta_1), \tag{A2}$$

and

$$p_C^{\text{short run}} = p(x_c^{\text{short run}}; a_m). \tag{A3}$$

Operationally, p is calculated as the fitted empirical inverse demand function, evaluated at the date of patent expiration, or

$$p_C^{\text{short run}} = \frac{\exp\left[\ln x_c^{\text{short run}} - \beta_0 - \phi_i - M(t = -1) - \beta_2 \ln a_m\right]}{\beta_1}. \tag{A4}$$

Note that here and elsewhere, we fix the inverse demand curve at its monopoly level when calculating p_C.[22] This is in order to focus on valuing the change in quantity rather than changes in the equilibrium inverse demand curve. Our quantitative conclusions concerning the relative importance of advertising, compared to revenues, are largely insensitive to this assumption, which uniformly affects the levels of all the consumer surplus calculations.

The long-run consumer surplus uses the quantity and price that would be associated with marginal cost production. Since marginal cost is 90 percent lower than the last observed monopoly price, the long-run competitive values can be obtained as

[21] Here and elsewhere, x_c is defined as x_m multiplied by the percentage change in quantity implied by the expiration of the patent. This percentage change is defined as the percentage change in price associated with expiration multiplied by the price elasticity of demand.

[22] We take the same approach when calculating Δ_Q under persuasive advertising.

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$$x_c^{\text{long run}} \equiv x_m[1 - .9(\beta_1)], \tag{A5}$$

and

$$p_C^{\text{long run}} = p(x_c^{\text{long run}}; a_m). \tag{A6}$$

A2. Consumer Surplus with Informational Advertising

In this case, consumer surplus can be written as

$$\tilde{\Delta}_{\text{Info}} = \int_{x_M}^{x_C} p(q, a_M)dq - (p_C x_C - p_M x_M). \tag{A7}$$

The form of the demand function allows us to rewrite this as

$$\tilde{\Delta}_{\text{Info}} = \exp\left[\frac{-\beta_0 - \phi_i - M(t = -1) - \beta_2 \ln a_M}{\beta_1}\right] \times \left(\frac{\beta_1}{1 + \beta_1}\right)\left(x_C^{1+1/\beta_1} - x_M^{1+1/\beta_1}\right) - (p_C x_{c0} - p_M x_M). \tag{A8}$$

This is similar to the expression above but with a term for advertising added. We use samples in the last month of patent protection in order to estimate $\ln a_M$; since we are estimating the fitted demand function, it is appropriate to use the advertising measure that is included in the regression. We now define the short-run prices and quantities as

$$x_c^{\text{short run}} = x_m(1 + \alpha_1\beta_1 + \alpha_2\beta_2), \tag{A9}$$

and

$$p_C^{\text{short run}} = p(x_c^{\text{short run}}; a_m). \tag{A10}$$

The long-run prices and quantities are

$$x_c^{\text{long run}} \equiv x_m[1 - .9(\beta_1) - 1.0(\beta_2)], \tag{A11}$$

and

$$p_C^{\text{long run}} = p(x_c^{\text{long run}}; a_m). \tag{A12}$$

A3. Consumer Surplus with Persuasive Advertising

In this case, consumer surplus can be written as

$$\tilde{\Delta}_{\text{Pers}} = \tilde{\Delta}_{\text{Info}} + \int_{x_M}^{x_C} [p(q, a_C) - p(q, a_M)]dq. \tag{A13}$$

This can be operationalized as

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$$\tilde{\Delta}_{\text{Pers}} = \tilde{\Delta}_{\text{Info}} + \exp\left[\frac{-\beta_0 - \phi - M(t = -1)}{\beta_1}\right] \times \left(\frac{\beta_1}{1 + \beta_1}\right)\left(1 - a_{\text{M}}^{-\beta_2/\beta 1}\right)\left(x_{\text{C}}^{1+1/\beta_1} - x_{\text{M}}^{1+1/\beta_1}\right). \tag{A14}$$

We use samples in the last month of patent protection in order to estimate a_{M}; since we are estimating the fitted demand function, it is appropriate to use the advertising measure that is included in the regression. We now define the short-run prices and quantities as

$$x_{\text{c}}^{\text{short run}} = x_{\text{m}}(1 + \alpha_1\beta_1 + \alpha_2\beta_2), \tag{A15}$$

and

$$p_{\text{C}}^{\text{short run}} = p(x_{\text{c}}^{\text{short run}};\ a_{\text{m}}). \tag{A16}$$

The long-run prices and quantities are

$$x_{\text{c}}^{\text{long run}} \equiv x_{\text{m}}[1 - .9(\beta_1) - 1.0(\beta_2)], \tag{A17}$$

and

$$p_{\text{C}}^{\text{long run}} = p(x_{\text{c}}^{\text{long run}};\ a_{\text{m}}). \tag{A18}$$

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