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ABSTRACT

Neoclassical economic theory predicts that policies that discourage the consumption of a particular good will induce innovation in a socially desirable substitute. Evolutionary theory emphasizes the possibility of innovation waves associated with the identification of new dominant designs. We incorporate both of these possibilities in a model of the invention of new smoking cessation products, based on a new dataset of patents on such products from 1951-2004. We find that an increase in cigarette tax levels and smoking bans had no discernible impact on the industry-wide rate of invention in smoking cessation products. It does appear, however, that dominant designs did have substantial positive innovation effects. More specifically, the introduction of the nicotine gum and patch are estimated to have increased the rate of patenting activity in smoking cessation products by 60 and 79 percent, respectively, subject to a 10 percent rate of decay. Finally, these products had larger innovation effects at the firm level than among individual inventors.

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1. Introduction

Cigarette smoking is the leading preventable cause of death in the United States. According to the Center for Disease Control (CDC), smoking is responsible for approximately one in five deaths annually, or about 443,000 deaths per year. In the last several decades, technology has provided effective and affordable ways for heavily addicted smokers to "break the habit." Smoking cessation products, mainly comprised of nicotine replacement therapies, have been at least partially responsible for a decrease in smoking rates from more than 42% to less than 20% of American adults over the past forty years.

More generally, there are numerous public policy problems for which we look to new technology for solutions. The most prominent of these is global climate change, where it seems clear that significant damage will be avoided at reasonable economic cost only if new low-carbon or carbon-free technologies can be deployed at massive scale. There is currently an active debate as to whether and how public policy might foster the desired innovation. The economic literature on induced innovation provides an explicit framework to consider the mechanisms by which specific policies might increase the rate of innovation in particular areas, and to estimate the empirical magnitude of such inducement effects. We take the experience of the public health problem of smoking, and the development of new technologies to deal with it, as a case study that may inform this larger question of the factors that influence the development of new, socially desirable technologies. The imposition of taxes on cigarettes and bans on smoking in public places are loosely analogous to policies that have or might be implemented in other areas. At the same time, we also explore the role that factors not apparently controlled by policy may have played in the rate and direction of invention related to smoking cessation. We use an evolutionary model of the technological change process to introduce explicitly the importance of transformative inventions in spurring overall technological advance.

The body of this paper will be organized as follows. Section II explores public policy as a source for induced innovation. Section III introduces the neoclassical and evolutionary hypotheses about the rate of innovation for smoking cessation products. Section IV discusses the quantitative and qualitative data used in this empirical study. Section V describes our estimation techniques and presents the results of our econometric analysis. Finally, Section VI concludes our exploration of the causal link between the rules of the market and the marketplace of ideas.

2. Public Policy and Induced Innovation

Public policies are designed to achieve multiple social goals. We can identify three main types of policy aims that might alter the course of technological change. The first type of policy aims to change the actual innovation system, but remains neutral with respect to the specific types of innovation that it might encourage. Examples of this type of policy range from changes in the patent system to R&D subsidies and tax credits, among others (Jaffe, 2000). In addition, we can pinpoint specific pieces of legislation such as the Bayh-Dole Act of 1980 which gave research universities and small businesses the right to patent inventions that resulted from government funding (Mowery et al, 2004), the establishment of the Court of Appeals of the Federal Circuit by Congress in 1982 which presides over patenting activity (Kortum and Lerner, 1999), and a 1991 law that increased patent application fees and made the United States Patent and Trademark Office (USPTO) an almost fully user-fee funded agency (Sanyal, 2003), which have had various effects on the rate of innovation.

A second type of public policy focuses on achieving a certain social goal by encouraging a specific type of innovation. For example, the Orphan Drug Act (ODA) of 1983 was designed to incentivize the development of pharmaceutical products used to treat rare diseases in small, relatively unprofitable consumer markets. Yin (2008, 2009) found that the legislation mostly induced innovation within ODA-qualifying subdivisions for non-rare diseases, which deviated from the primary goals of the legislation. Furthermore, the author considered the counterfactual and estimated that 10 percent of the induced innovation might have occurred in the absence of the legislation. In either case, the study showed that firms did respond to incentives; however, the resulting inventive output was only tangentially related to the social goal of the legislation.

The third category of public policies are those that focus on achieving some social goal other than innovation but which (perhaps unintentionally) induce innovative activity among other responses. In the energy and environment sector, Jaffe and Palmer (1997) concluded that environmental compliance standards increased R&D spending at the firm level, but did not necessarily induce inventive output in the form of successful patent applications. In a related study, Popp (2003) found that the Clean Air Act of 1990, which instituted a market for sulfur dioxide (SO_2) permits, enhanced the efficiency of "scrubbers," or flue gas desulfurization units. Most recently, Johnstone et al (2008) found that different types of environmental policy instruments had a significant positive effect on patent counts for new sources of renewable energy. Similarly, in the health sector, Finkelstein (2004) showed that policies designed to increase the usage of preexisting vaccines induced a 2.5-fold increase in clinical trials for new vaccines. In the most ambitious project of this nature, Acemoglu et al (2006) concluded that the introduction of Medicare did not induce pharmaceutical innovation by showing that an increase in drug consumption by the elderly did not correspond with an increase in FDA drug approvals for treatments for diseases that affect the elderly. Finally, Acemoglu and Finkelstein (2008) demonstrated that the shift from full labor cost to partial cost reimbursement for hospitals under the Medicare Prospective Payment System (PPS) caused substantial increases in capital-labor ratios and a corresponding decrease in labor inputs. This empirical finding perfectly supports the induced innovation hypothesis – as the relative price of labor increased, hospitals economized the use of this factor of production. In addition, the authors found that the PPS also encouraged the adoption of a wide range of new medical technologies.

Within this latter category, analysts have tried to determine whether different policy approaches to a given substantive goal (e.g. cleaning up the air) are more or less likely to induce innovative responses. There is both a theoretical and empirical literature, for example, on "market-based" policies such as taxes or subsidies versus "command and control" policies such as specific performance standards. Unfortunately, neither theory nor empirical analysis has been conclusive in this debate. In this paper, we do not start from any particular presumption about what policies may have been more effective, but merely analyze the policies that were enacted in a framework that allows for all possible inducement effects.

3. Cigarette Taxes and Smoking Cessation Products

In the previous section, we observed that policies that encourage the use of existing products can also promote innovation in related technologies (Finkelstein, 2004). This paper addresses the converse relationship as its main research question. Do policies that discourage the use of existing technologies induce innovation in socially desirable substitutes? In particular, does an increase in cigarette taxes induce innovation in the market for smoking cessation products? Cigarette taxes have primarily been imposed to generate revenue, since they were first levied prior to the health warnings regarding cigarette smoking. However, economists have clearly demonstrated that an increase in cigarette taxes leads to a decrease in cigarette consumption given several individual and location fixed effects (Baltagi and Levin, 1986;

Flewelling et al, 1992; Peterson et al, 1992; Lewit et al, 1997; Ringel and Evans, 2001; Tauras, 2004, 2006).

Starting from the demonstrated responsiveness of cigarette consumption to cigarette prices, and given the addictive nature of smoking, it seems reasonable to presume that an increase in the price of cigarettes should increase the demand for smoking cessation products (Tauras and Chaloupka, 2003; Tauras et al, 2005). If firms are choosing potential research products based on profit-maximization, then an increase in the demand for smoking cessation products should incentivize the development of new smoking-cessation products. Regulatory policies such as restrictions on workplace smoking that make smoking less convenient should have similar effects. In this paper, we do not measure or model explicitly the market demand for smoking cessation products, but simply investigate empirically the possible impact on smoking-cessation invention from economic forces that could push people toward smoking cessation.[1]

Recent advances in evolutionary economics tell us a different story about the innovation process. The general reasoning described above that connects cigarette taxes or bans with profit potential from new smoking cessation products is rife with uncertainty. Firms will not know the magnitude or timing of possible increases in demand for cessation products. In addition, they will not even be able to estimate probabilities regarding the actual payoffs if they were to invest resources in developing new cessation products. Thus, without denying the general tendency described above, the evolutionary paradigm recognizes that markets are evolutionary and firms are adaptive (Nelson and Winter, 1982). Therefore, we should consider the possibility that firms do not necessarily respond in ways explicable through the profit-maximization mechanism, but rather follow a set of routines and abide by certain decisions rules. In the context of our study, it may be that firms continuously engage in a certain amount of research related to smoking cessation, and adjust their investments in that research only occasionally and in response to general environmental signals rather than specific predictions based on prices and markets.

This paradigm suggests that perhaps innovation follows a path generated by its own inertia. In addition, we might be able to observe certain predictable and repeating patterns in the rate and direction of innovation in a particular industry. There are two main possibilities to

[1] At some point, policies or other forces that reduce the number of smokers would eliminate the demand for smoking cessation products, since if there are no smokers then nobody needs to quit. Given that the number of smokers worldwide is huge and still growing, we do not think that this ultimate possibility is relevant for our analysis of past experience in the industry.

explore. First, we must consider that inventive output might respond to the quantity of existing inventions. One important feature of technological change is path dependency (Arthur, 1994). In other words, innovation is a cumulative process in which the outputs in time period t_i also function as the inputs in time period t_{i+1}. This model is driven by increasing returns to innovation, which simply means that past invention begets future invention. Therefore, we might expect the number of innovations per year to increase exponentially due to the increasing supply of knowledge and a constantly expanding choice set of possible input combinations.

Second, we must consider that the rate and direction of innovation responds to the quality of previous technological change. Therefore, we might observe short explosions of innovative activity, rather than gradual change over time. These periods of sharp increase might be triggered by the introduction of a keystone technology by one firm, which then spurs a wave of imitation by other firms. Eventually, innovation slows down once the market has selected a “dominant design” and this trough continues until a new and improved design is developed. These observed cycles follow an evolutionary algorithm of differentiation, imitation, and selection, which is similar to the “windows of opportunity” described in the management literature (Anderson and Tushman, 1990; Tyre and Orlikowski, 1994).

These two paradigms are by no means mutually exclusive. It is possible that cigarette taxes and other policies in the government’s anti-smoking agenda can explain broad trends in innovation, but deviations from these neoclassical predictions might represent something other than random noise around a static equilibrium. Evolutionary models in economics offer a unique perspective from which to understand specific patterns in innovation as an endogenous component of a complex adaptive system. The empirical goal of this study is to integrate both models to develop a more comprehensive understanding of the innovation process.

4. Data and Methods

4.1. Patent Statistics

Our dependent variable is the number of U.S. patents granted for smoking cessation products, tabulated by the year in which the application was made. Economists have relied on patent statistics as a measure of innovation for decades because they are detailed, precise, and easily observed. Of course, patent statistics are far from perfect indicators of the rate of invention. Not all inventions are patented, and the significance or importance of patents varies enormously. In addition, when used as an indicator of the rate of invention over time, there are irresolvable questions of timing—there will be a lag between some economic or institutional stimulus and when a researcher begins a project; a lag between when the project begins and when it ends; and a lag until the patent application is filed.

For example, suppose that cigarette taxes increase substantially in a given year t_i, which triggers investment in R&D for smoking cessation technologies in year t_{i+j}. The R&D process might take as long as k years before firms can complete and submit their patent applications. In this case, the magnitude of the invention lag in years equals $j+k$. And of course there is no reason why either j or k would be the same for all firms. This means that any attempt to determine the empirical significance of different causal factors through time series analysis of patent statistics must not be interpreted too literally.[2]

Patent statistics for this empirical study were collected by application date from the USPTO website and the Google Patents database. When collecting patent data, the researcher can filter search results by either sub-class or keyword. The former approach returns a surplus of results that share a similar method of delivery but perform incongruous therapeutic purposes, while the latter will inevitably underestimate patent counts due to omitted keyword bias. Smoking cessation products in particular are difficult to locate because they exist in a variety of different forms (such as liquids, solids, and even computer programs), which makes sub-class searches extremely difficult. Therefore, we performed a series of keyword searches to maximize

[2] Theoretically, firms could anticipate changes in taxes or other inducers, creating the possibility of observed negative lags.

our signal-noise ratio.[3] This technique is generally recommended in the empirical literature (Dekker et al, 2010).[4]

The time series for this analysis extends from 1951-2004. While patent statistics are available up to the present, we truncate the time series since patent applications can take up to six years to be approved. Figure 1 displays the total number of patent counts for smoking cessation products by application date. These patent counts range from 0 to 21 new applications per year, with a total of 342 patent applications overall. We observe a steep decline in patent counts after 1997, which might represent market saturation due to the clinical success and commercial domination of the nicotine gum and patch.[5] Working with a relatively small number of observations exposes our vulnerability to the confounding effects of random noise in the data. However, since we were able to read through every patent application that was collected for this study, we can assume greater accuracy in the dependent variable.

We must also consider the likelihood that patent counts in a given industry will be influenced by trends in overall patenting activity. Therefore, we constructed a second dependent variable to represent the patent share of the smoking cessation industry. Patent shares are calculated by dividing the total number of patent counts in a given industry by the total number of patents in that year, which inherently controls for these general trends in inventive output. Figure 2 shows the patent share for smoking cessation products by application date, which follows a similar pattern as the patent counts data. The USPTO Patent Database is the only source that provides aggregated patent statistics by application date from 1964 to the present.

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[3] To ensure a representative (if not complete) sample of patents for smoking cessation products, we exploited an exhaustive list of keywords by therapeutic purpose, material inputs, and product types. For each keyword, we recorded the first 250 results in the Google Patent database and omitted any duplicates. For quality assurance, we searched for the same keywords in the USPTO database and recorded any remaining unique results. This exercise involved many judgment calls, and there is no perfect method for achieving a completely unbiased sample. In order to preserve objectivity, our search criteria stated that the patent application must clearly demonstrate that smoking cessation was one of the primary motivations for inventing the given technology, and one of the primary functions and/or applications of the invention. Some patents described methods to reduce the incidence of several dangerous activities with negative health effects, and these were recorded as long as smoking was listed as one of the primary behaviors to be modified. This search excluded several products that reduced the harmful effects of smoking, or potentially reduced exposure products (PREPS), which have become popular over the last decade but have not been clinically proven to break the habit of cigarette smoking.

[4] Many of the patents fall into easily recognizable categories, but one described a tubular coin receptacle that was designed to illustrate the potential monetary rewards of quitting the habit of smoking, otherwise known as a “ciggie bank” (U.S. Patent Application No. 10/291,727 (2002)).

[5] In addition, a series of mergers among pharmaceutical companies might have led to a reassessment of new drug development. Furthermore, companies started to produce potentially reduced exposure products (PREPS), such as the electronic cigarette, which reduce nicotine and tar consumption but cannot claim smoking cessation benefits in patent applications.

Although this generates fewer observations, we can see from Figure 1 that this shortened time series still covers most of the patenting activity in the smoking cessation industry.

4.2. Cigarette Taxes

Currently, the government levies both state and federal taxes on cigarettes, with more frequent increases at the state level. We expect that firms will respond to total cigarette excise taxes, which equals the sum of state and federal tax levels, because they are developing smoking cessation aides for a national market. However, it is possible that marginal state and federal tax increases can each have independent effects on innovative activity since they are associated with different complementary effects, such as media coverage and advocacy campaigns.

We collected cigarette tax data from 1951-2004 from *The Tax Burden on Tobacco*, which is a historical compilation of data from the tobacco industry published by Orzechowski and Walker, an economic consulting firm. This dataset reports annual federal tax levels along with average state tax levels weighted by cigarette sales. Excise taxes are measured in a given quantity of dollars and cents added on to the original retail price of a pack of cigarettes, as opposed to a percentage of total retail prices. Since these cigarette tax levels are reported in nominal terms, we construct this explanatory variable by calculating the real tax level for any given year in 2009 dollars.[6] Figure 3 displays the state, federal, and total cigarette tax levels in real terms for the entire time series.

Cigarette taxes are one part of a much larger public policy effort to reduce the level of tobacco smoking (Warner, 1977; Chaloupka, 1995). For example, state and local governments have passed several pieces of legislation that ban smoking in public places over the past few decades. The primary goal of this legislation is to reduce nonsmoker exposure to second-hand smoke; however, these policies also make smoking more inconvenient for existing smokers and protect highly suggestible nonsmokers from adopting the dangerous habit. These important unintended consequences have been found to have a significant negative effect on both adult and teenage demand for cigarettes (Wasserman et al, 1991; Tauras, 2006).

An online database maintained by Americans for Nonsmokers' Rights (ANR), an anti-smoking advocacy group, contains a chronological list of these smoking bans from 1990-

[6] Real tax levels were generated by the Inflation Calculator from the Bureau of Labor Statistics.

present.[7] Each observation provides the state or municipality associated with the smoke-free provision, reports the corresponding population of this geographic area at the time the legislation was passed, and indicates whether the provision guarantees 100% smoke-free air in workplaces, restaurants, bars, or some combination of the three. Using this information, we calculate the percentage of the total U.S. population protected by some type of 100% smoke-free law for any given year t as follows:

$$\theta_t = \frac{\sum_{t=1990}^{2004} x_t}{\mu_t} \qquad [1]$$

where θ_t represents the percentage of the total U.S. population covered by smoke-free provisions in year t, x_t represents the total cumulative number of people protected by smoke-free provisions in year t from 1990 to 2004, and μ_t represents the Census estimate of the total US population in year t from 1990 to 2004.[8] The expected sign of this explanatory variable is unclear. We can imagine a positive sign in the case that smoke-free provisions decrease the demand for smoking, and thus increase the demand for smoking cessation products. However, we can also imagine that firms might interpret smoke-free provisions as "substitute" methods for quitting smoking that lower the residual demand for cessation products.

In addition to cigarette taxes and smoking bans, we identified three structural breaks in the policy environment that might have signaled significant changes in the demand for smoking cessation products:

- The 1964 Report of the Surgeon General was the first public declaration of the adverse health effects of tobacco use, specifically estimating a 70 percent increase in the mortality rate of smokers over non-smokers.[9] We should expect that this public health report significantly altered the direction of innovation (Warner, 1977).
- A 1996 ruling allowed smoking cessation products to be sold over-the-counter. Previously, these products were prescribed by physicians and supplemented with

[7] For full chronological listing, please visit: [http://www.no-smoke.org/pdf/EffectivePopulationList.pdf]
[8] Every effort was made to minimize double-counting, a certain degree of which is inevitable given independent and overlapping state and municipality legislative schedules.
[9] Information on the 1964 Surgeon General's Report was collected from the National Library of Medicine at the National Institutes of Health: [http://profiles.nlm.nih.gov/NN/Views/Exhibit/narrative/smoking.html]

counseling, but we would expect that producers face greater incentives to innovate when there are fewer transaction costs associated with consuming their product.

- The 1998 Tobacco Master Settlement Agreement entitled 46 states to recover damages from the four largest tobacco companies for smoking-related Medicare and Medicaid expenditures by establishing tort liability. The settlement also established the American Legacy Fund, a tobacco control advocacy group, along with an anti-smoking advertising campaign. Theory and empirical evidence have demonstrated that targeted advertising campaigns have a significant negative effect on the demand for smoking (Hamilton, 1972; Hu et al, 1995; Saffer and Chaloupka, 2000).

We should also consider two important endogenous changes in the market for smoking cessation products. Nicotine replacement therapies are the most popular smoking cessation products, and clinical studies suggest that they are also the most effective method for quitting. The first nicotine replacement therapy, Nicorette Gum, was marketed in 1984 (Hu et al, 2000). We recall from the previous section that evolutionary models assume that the rate of innovation is a function of the quality of previous innovations. If this hypothesis is correct, then we should expect to see an increase in patenting after the introduction of nicotine gum, which represents the first dominant design in the market. By this logic, the sale of nicotine patches starting in 1992 should have a comparable stimulatory effect on patenting behavior.

There were also many policy changes over this period that affected incentives to patent generally (Kortum and Lerner, 1999). Rather than model these explicitly, we use the patent share measure as the dependent variable in some regressions to sweep out any effects of policy changes that relate to the patent system as a whole.

5. Estimation

5.1. Patent Counts

The first set of regressions attempts to explain changes in the rate and direction of patent counts from 1951-2004. We begin with the following basic linear OLS model:

$$Y_t = \alpha_{t-1} + \beta_1 \ln(TAX_{t-1}) + \beta_2 POP_{t-1} + \sum_{i=1}^{n} \gamma_i EVO_{i,t-1} + \sum_{i=1}^{k} \rho_i X_{i,t-1} + \varepsilon_{t-1} \qquad [2]$$

where Y_t represents patent counts in a given year t by application date. *TAX* represents real cigarette tax levels and *POP* represents the percentage of the U.S. population covered by 100%

smoke-free air provisions. *EVO* represents a vector of evolutionary variables controlling for the introduction of the nicotine gum in 1984 and nicotine patch in 1992. To reflect the temporary boost to innovation that may be generated by the introduction of a transformative new technology, we construct these evolutionary variables using a decay function. The given variable takes a value of 0 before the technology was developed, 1 during the year of its introduction, and then decreases at a constant rate thereafter:

$$EVO_{\tau} = EVO_{\iota} * \left(1 - \frac{\delta}{100}\right)^{\tau - \iota} : \iota > \tau \qquad [3]$$

where δ represents the rate of decay in percentage terms, τ represents the current year and ι represents the year of introduction. Finally, *X* represents a vector of binary time dummy variables that control for the Surgeon General Report of 1964, the sale of NRTs over-the-counter in 1996, and the Tobacco Master Settlement Agreement in 1998.[10]

The inherently cumulative nature of the invention process suggests that invention in year *t,* in addition to being affected by the drivers included in equation (2), is also affected by the rate of invention in previous years. In principle, this process should be modeled explicitly,[11] but it is difficult to get very far with such modeling in a single time series. Hence we do not explicitly introduce the effect of lagged invention rates into the model, but we do correct for the autocorrelation of the error that is suggested by such a model using the Prais-Winsten generalized least squares estimation technique.

Another issue with equation (2) is that linear relationships are commonly seen as less plausible than the constant-elasticity relationships that would be captured by a log-log formulation. We cannot use a simple log-log formulation, because the dependent variable is sometimes zero. Instead, we estimate the related non-linear model:

$$Y_t = \exp[\alpha_{t-1} + \beta_1 \ln(TAX_{t-1}) + \beta_2 POP_{t-1} + \sum_{i=1}^{n} \gamma_i EVO_{i,t-1} + \sum_{i=1}^{k} \rho_i X_{i,t-1}] + \varepsilon_{t-1} \qquad [4]$$

[10] There may well be lags of unknown duration in the effect of any of our regressors on the rate of invention. Given our limited data, we are not in a position to estimate these lags, and so look simply for effects in year *t* related to values in *t-1*.

[11] See, e.g., Caballero and Jaffe (1993)

Taking the log of both sides shows that the parameters of the exponential model can be interpreted as elasticities just as if a log-log linear model had been estimated.[12]

5.2. Patent Shares

The previous model only considers factors that are endogenous to the market for smoking cessation products. However, it is possible that the dependent variable is being significantly influenced by exogenous factors that affect overall patenting activity. Therefore, the second set of regressions takes as its dependent variable the *share* of all patents represented by patents on smoking cessation technologies, thereby eliminating the effects of factors that affect the overall rate of patenting. For these regressions, we use the log of the logistic transformation of the share data, thereby also providing estimates with a convenient parametric interpretation.

5.3. Results

Table 1 displays the results of the regressions using patent counts as the dependent variable. The first four columns show the linear model using Prais-Winsten standard errors to control for autocorrelation; the last column presents the NLLS results for the exponential version with Newey-West standard errors. We can see that cigarette taxes and smoking bans appear not to have had a significant effect on patenting activity, even when we isolate them on the right-hand side of the equation. Furthermore, the coefficients on both policy variables are surprisingly negative when we include all relevant explanatory variables and time dummies. The evolutionary variables had a positive effect on innovation, significant at the 10 percent level in the linear model and highly significant in the exponential model.[13] As expected, the Surgeon General Report of 1964 had a highly significant positive impact on smoking cessation product innovation, while the 1996 law allowing the sale of NRTs over-the-counter had a marginally significant positive effect. However, the Tobacco Master Settlement had an unexpected negative and insignificant effect on patenting behavior. Note that the magnitude of the coefficients from the linear and non-linear models cannot be compared to each other, but the qualitative pattern of

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[12] Estimation of equation (4) by NLLS also produces consistent parameter estimates for a wide range of assumptions about the stochastic process that underlies the integer nature of the patent variable. See Hausman, Hall and Griliches (1984).

[13] The reported results are based on using a 10% annual decay rate for the evolutionary effects as represented in equation (3). We also experimented with using annual decay rates of 20% and 30%. The overall fit is poorer with these higher decay rates, but the qualitative picture given by the results (including the negative but insignificant effect of the tax and smoking ban variables) is the same.

effects is the same in both formulations. We return to interpretation of the magnitude of the coefficients below.

Table 2 presents the results from the estimation based on the share of smoking cessation patents among all patents. We were able to identify consistent data for all patents beginning only in 1964,[14] so our time series is shortened slightly, but with little loss of meaningful variance because the there were almost no smoking cessation patents before 1964. In general, the share results are quite consistent with the results based on patent counts. Columns (1) and (2) show that cigarette taxes and smoking bans once again have no significant impact on patenting activity. The evolutionary variables remain the only regressors with real explanatory power and were highly significant at the 1 percent level. The log-log interpretation suggests that the introduction of the nicotine gum and patch each increased the rate of innovation in smoking cessation products by 60 and 79 percent, respectively, subject to a 10 percent rate of decay. The Surgeon General Report of 1964 drops out of the model because of the lack of observations before its issuance.

Table 2 also explores whether the inventive environment as modeled here affected different kinds of potential inventors differently. We distinguish those patents assigned to corporations and those retained by individuals. Column (3) shows that the evolutionary variables had a significant positive innovation effects at the firm level. These results are consistent with our previous results and evolutionary theory. However, Column (4) shows that dominant designs did not induce innovation among individual inventors. Instead, smoking bans had a slightly negative effect on individual patents, which is highly significant at the 1 percent level. One possible explanation for this divergence is that individuals do not participate in industry-wide cycles due to limited access. More generally, the evolutionary model attempts to explain decision making within firms; we do not have a corresponding model of the decision behavior of individuals acting outside of organized firms.

The signs and statistical significance of the coefficients in the regressions gives a clear qualitative picture of the relative importance of the effects. But they do not convey a clear sense of the magnitude of the effects. This question is investigated in Figure 4, which presents counter-factual simulations of the rate of smoking-cessation patenting based on the estimated model. In

[14] We are dating our smoking cessation patents by year of application, and we were not able to find PTO data on the number of patents tabulated by date of application before 1964.

other words, we can examine what the dependent variable would have been in the absence of the effects of interest using the coefficients from the patent counts model above. Each line in Figure 4 represents our fitted linear model with the value of one particular regressor equal to zero; comparing these lines to the base case gives an indication of the quantitative importance of the omitted variable. We observe that the counterfactual series in the absence of one or both of the evolutionary variables represent the least patenting activity, which further suggests that they had the largest innovation effects. Indeed, had the gum and patch not been introduced, the results indicate that the cumulative total of smoking cessation patents over the time period would have been reduced by 40%. Conversely, the fact that the counterfactual series without cigarette taxes or smoking bans are so close to the actual fitted series suggests that these policy variables had no significant impact on the rate of innovation in smoking cessation products.

6. Summary and Conclusions

The purpose of this study was to explore the causal link between public policy and induced innovation. Theory tells us that policies that discourage the use of existing technologies should induce socially desirable innovation. However, our empirical evidence suggests that cigarette taxes and smoking bans appear to have had no industry-wide impact on the rate of innovation for new smoking cessation products. Given that inflation-adjusted taxes fell for much of the period, this is perhaps not surprising, but the results certainly do not provide support for an empirically large induced innovation effect from taxes.

Our empirical results are more consistent with an evolutionary model of the pace of invention. The recursive evolutionary algorithm of differentiation, selection, and amplification is embedded in the decay model that we introduced. The development of the first nicotine gum and patch were the only explanatory variables to remain highly significant and maintain the same sign through the entire empirical analysis. As expected, the introduction of these dominant technologies had a positive effect on the rate of innovation in the smoking cessation industry. Of course, the impact of these two technologies is hardly conclusive with respect to the broader significance of the evolutionary model, and the appearance of these transformative technologies remains itself unexplained. Nonetheless, we hope that these findings will provide clues about how to incorporate evolutionary models in empirical research.

From a policy perspective, our empirical results suggest that the primary determinant of smoking cessation product innovation was innovation itself. In order to successfully induce future socially desirable innovation, the challenge will be to find a way to generate a new dominant design. Further research can explore exactly what happened in 1984 and 1992 when the nicotine gum and patch were developed and try to understand what role external factors, including public policy, may have played in triggering these developments. Until such research advances, it will be impossible to say much with respect to the public policy implications of the evolutionary model. For example, current political discourse is centered on a potential excise tax on soda and junk food, and on carbon taxes to address climate change. The innovation effects of these policies cannot be derived from this analysis.

The evolutionary model is, however, at least suggestive of a possible role for other government policies to move the innovation process in socially desired directions. If it is true that the invention rate is dependent on the occurrence of transformative inventions, and that the normal economic signals of price and demand do not necessarily bring forth such transformative inventions, then perhaps there is a role for government to jumpstart the evolutionary process by funding research and creating a market for new products. For example, the development of digital computing and communications technology was seeded in important ways by government purchases of early computer and communications technology for military and space purposes; current commercial applications would not likely have developed or developed as quickly without this non-economic source of initial demand (Mowery, forthcoming). If society desires to nudge innovation in particular directions, then technology evolution should be embraced, and product lifecycles allow the government to play a key role at the origin of innovation.

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Figure 1. Patent Counts for Smoking Cessation Products by Application Date

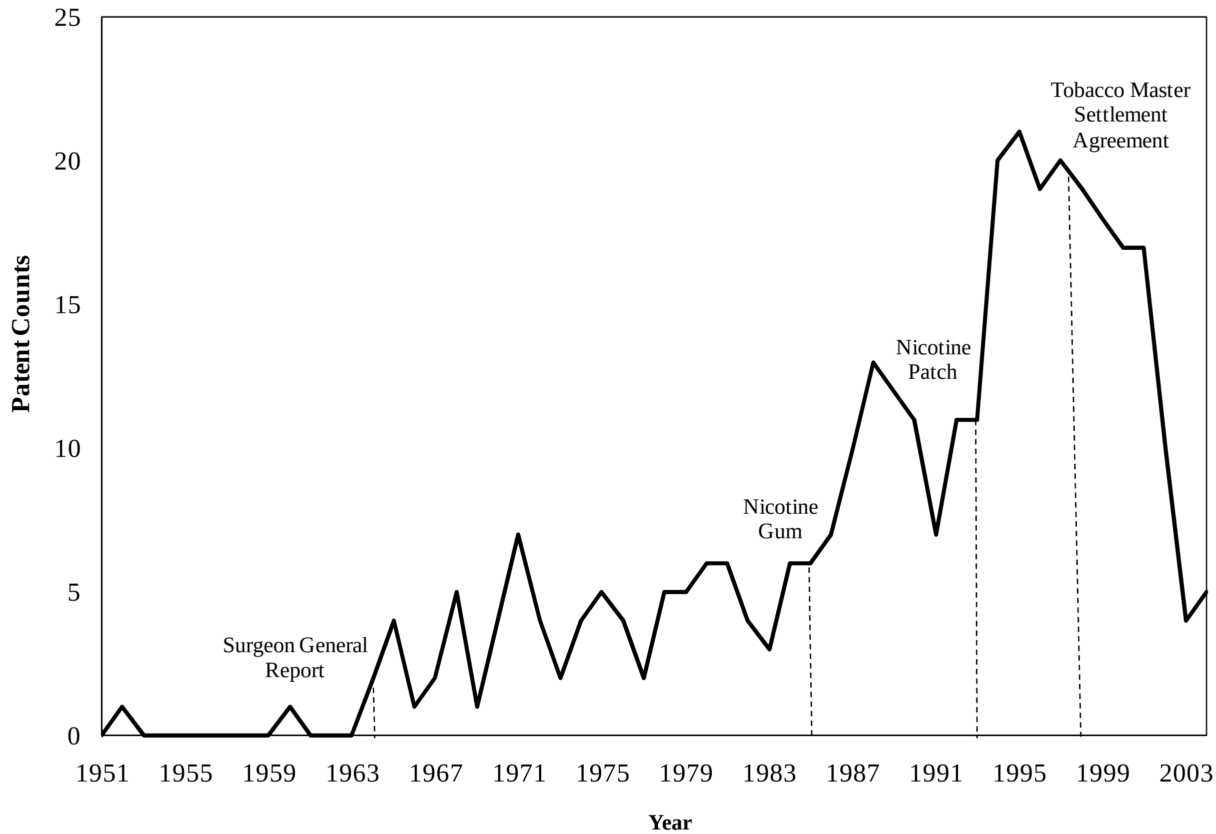


Figure 2. Patent Share for Smoking Cessation Products by Application Date

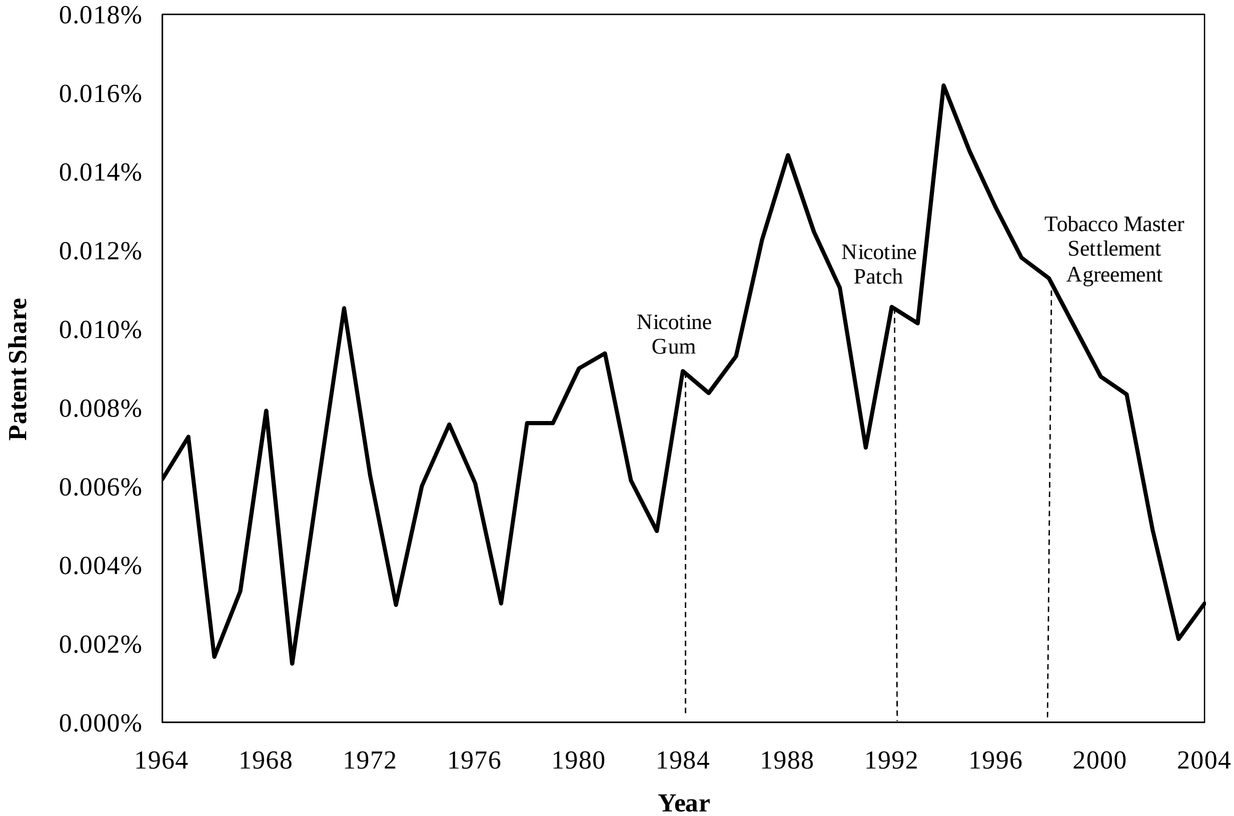


Figure 3. Real Cigarette Tax Levels

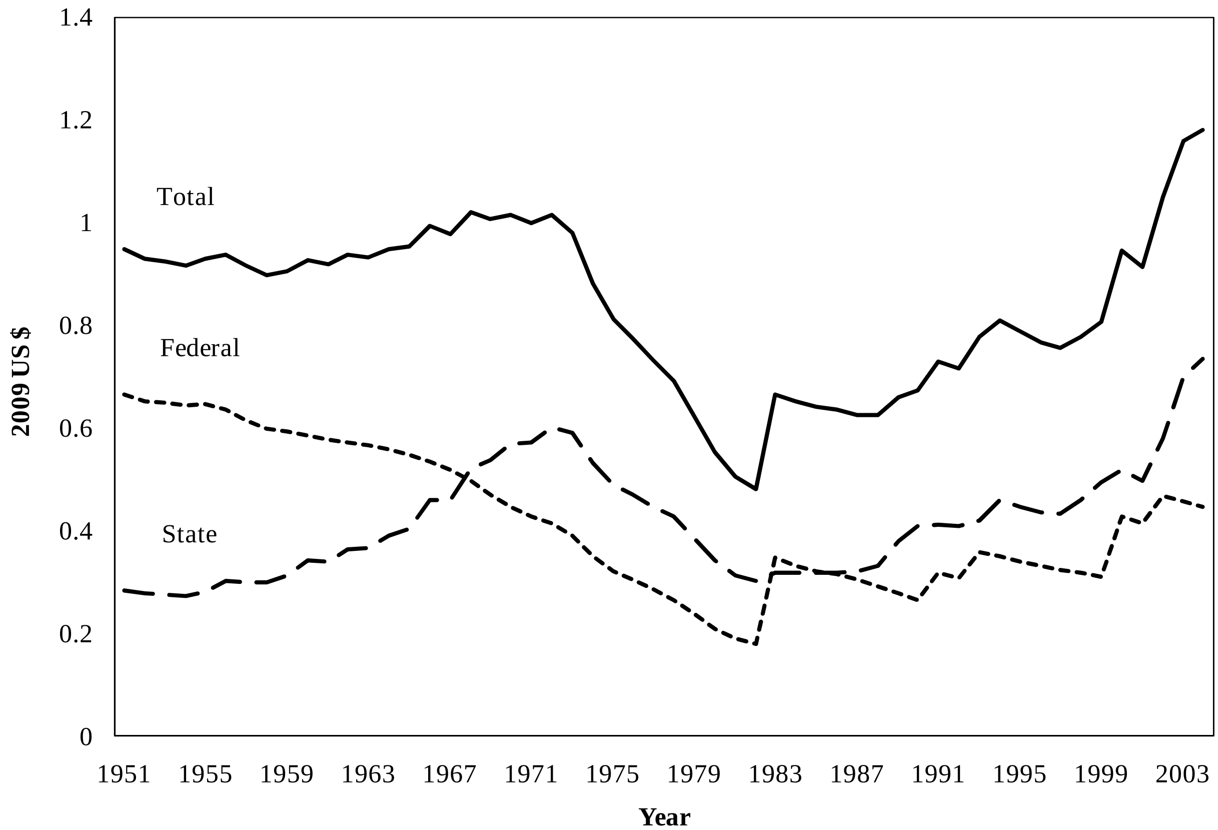
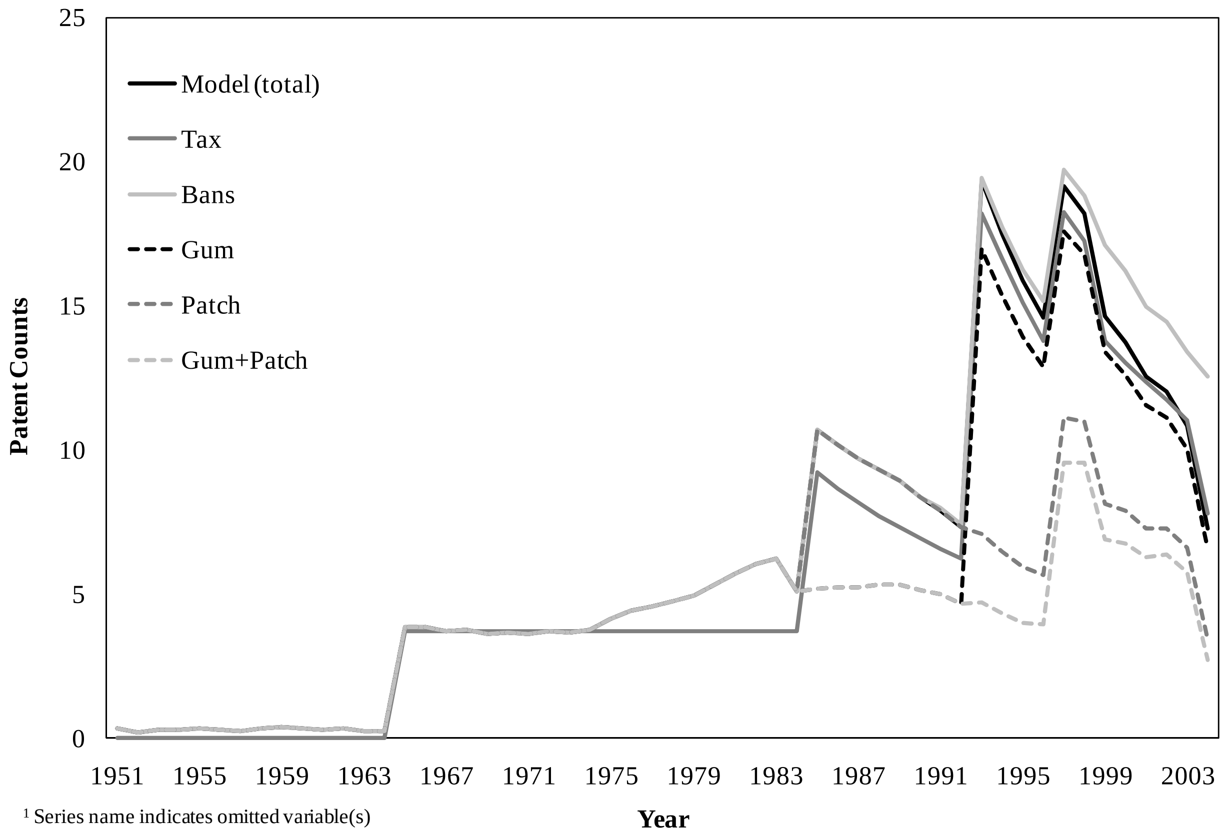


Figure 4. Simulation of Patent Counts Model [1]



[1] Series name indicates omitted variable(s)

Table 1. Patent Count Regressions, 1951-2004

	(1) Patent Counts$_t$[a]	(2) Patent Counts$_t$[a]	(3) Patent Counts$_t$[a]	(4) Patent Counts$_t$[a]	(5) Patent Counts$_t$[b]
ln(Taxes)$_{t-1}$	3.575	3.603	3.609	-3.447	-0.591
	(5.246)	(5.481)	(5.593)	(2.620)	(0.558)
Smoking Bans $_{t-1}$		-0.00215	-0.00150	-0.131	-0.007
		(0.0316)	(0.0322)	(0.108)	(0.021)
Nicotine Gum (1984) $_{t-1}$[c]			-0.00498	5.509**	0.692**
			(0.426)	(2.487)	(0.311)
Nicotine Patch (1992) $_{t-1}$[c]			0.380	12.24**	1.118***
			(0.425)	(4.961)	(0.320)
Surgeon General (1964) $_{t-1}$				3.664***	2.720***
				(0.667)	(0.583)
Over-the-counter (1996) $_{t-1}$				5.519**	0.543***
				(2.595)	(0.192)
TMSA (1998) $_{t-1}$				-0.742	0.068
				(3.565)	(0.355)
Constant	5.580	5.600	5.567	0.0403	-1.303**
	(3.885)	(4.066)	(4.153)	(0.303)	(0.558)
Observations	54	54	54	54	54
R^2	.	.	.	0.766	0.903

Robust standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
[a] Prais-Winsten AR(1) linear regression.
[b] Nonlinear regression with Newey-West (1) standard errors on the exponential model.
[c] Variables subject to 10% rate of decay.

Table 2. Patent Share Regressions, 1964-2004

	(1) ln(Patent Shares) $_t$ (Total) [a]	(2) Patent Shares $_t$ (Total) [b]	(3) Patent Shares $_t$ (Individual) [b]	(4) Patent Shares $_t$ (Corporation) [b]
ln(Taxes)$_{t-1}$	-0.832*	-0.0377	-0.155	-0.0230
	(0.430)	(0.0239)	(0.0963)	(0.0194)
Smoking Bans $_{t-1}$	-0.0193	-0.000756	-0.0123***	0.000891
	(0.0116)	(0.000592)	(0.00311)	(0.000604)
Nicotine Gum (1984) $_{t-1}$	0.596***	0.0474***	0.0670	0.0336**
	(0.198)	(0.0164)	(0.0624)	(0.0162)
Nicotine Patch (1992) $_{t-1}$	0.788***	0.0639***	0.125*	0.0580***
	(0.190)	(0.0199)	(0.0635)	(0.0142)
Over-the-counter (1996) $_{t-1}$	0.134	0.00191	0.0729	-0.00886
	(0.120)	(0.0119)	(0.0530)	(0.0102)
TMSA (1998) $_{t-1}$	-0.0712	-0.0158	0.133	-0.0157
	(0.340)	(0.0174)	(0.0936)	(0.0173)
Constant	-9.967***	0.0550***	0.212***	0.0105**
	(0.162)	(0.00773)	(0.0317)	(0.00492)
Observations	41	41	41	41
R^2	0.563	0.619	0.359	0.580

Robust standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
[a] The dependent variable represents the log of the logistic transformation of patent shares.
[b] Coefficients and standard errors were each multiplied by a factor of 1,000 for ease of comparison.