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THE ECONOMICS OF NICOTINE CONSUMPTION

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ABSTRACT

The development of nicotine replacement therapies and e-cigarettes emphasize and highlight that, in tobacco demand, nicotine is one of, if not, the primary object people want. This chapter presents a simple model of utility maximization that focuses specifically on nicotine as the object of interest. It yields a derived demand for a nicotine delivery technology and predictions researchers can use to account for patterns in consumption over the life-cycle of individuals and the market as a whole. The model is informed by available evidence about the neurological effects of nicotine and differences in the relative efficiency and associated physical costs of nicotine delivery devices, and genetic differences across individuals that partly explains variation in nicotine consumption. The analysis highlights that one of the key theoretical objects of interest is the price per unit of nicotine delivered to the brain. The limited empirical literature on e-cigarettes does not measure that price. All told, economists have much to offer in modeling and empirically studying demand for the new nicotine delivery products. In addition, a range of studies could look back, reconfigure prices and measured consumption, to better explain patterns in historical time-series data on consumption and substitution across different nicotine delivery devices.

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This chapter reframes the economics of smoking and tobacco consumption to focus more specifically on the economics of nicotine. Chaloupka and Warner (2000) and DeCicca et al. (2018) review the theoretical and empirical literatures on the economics of smoking and smoking prevention. The literature they review and the broader and extensive literature on smoking and tobacco use has always recognized the central role nicotine plays (Burns, 2007; Kluger, 1996). But those literatures infrequently study demand for nicotine as the central focus. Here I refocus on the economics of nicotine because recent technological developments emphasize and highlight that, in tobacco demand, nicotine is one of, if not, the primary object people want. The new frame makes nicotine a key object of interest because entrepreneurs and scientists have developed new methods that efficiently deliver nicotine but do not require that people consume tobacco. Starting in 1984, US consumers could buy newly developed nicotine replacement therapies that deliver nicotine by chewing gum, lozenge, inhaler, and transdermal patch. The 2006 launch of e-cigarettes introduced delivery of nicotine using a battery-powered device that vaporizes liquid containing nicotine. Consumers then inhale the steam. This process is commonly known as "vaping."[1] Vaping liquids can and do contain a wide range of substances other than nicotine - primarily flavors and tetrahydrocannabinol (THC).[2] Recently, the Food and Drug Administration (FDA) has issued warnings about vaping because some people have injured their lungs or died after ingesting vapors (Pray et al. 2020).[3] Despite these cases, it is clear that the vaping technology is here to stay.

This chapter presents a simple model of utility maximization that focuses specifically on nicotine as the object of interest. It yields a derived demand for a nicotine delivery technology and predictions researchers can use to account for patterns in consumption over the life-cycle of individuals and over time for the market as a whole. The model is informed by available evidence, both positive and negative, about the neurological effects of nicotine. I draw heavily from the 2019 book titled *Neuroscience of Nicotine* that reviews evidence on neurological and physical effects of nicotine in humans and animal models (Preedy 2019). The model is also informed by evidence that nicotine delivery technologies differ quite a bit in their relative efficiency and associated physical costs. This evidence is important because it highlights that one of the key theoretical objects of interest is the price *per unit of nicotine delivered to the brain*. To date, researchers use prices of different tobacco or nicotine delivery products that are, at best, only crudely comparable. The limited empirical literature on e-cigarettes ignores factors that researchers can use to approximate the shadow price of nicotine. The model also recognizes and incorporates the newest evidence that genetic differences across individuals partly explains variation in nicotine consumption, including smoking behavior. A small but growing literature exploits genome-wide association studies that generate polygenic scores that measure the

[1] The new verb, "vape," entered the common vernacular sufficiently that, in November 2014, Oxford Dictionaries designated it as "word of the year."
[2] THC is the chemical responsible for most of marijuana's psychological effects. Evidence suggests that a substantial fraction of youth who vape do so with liquids that only contain flavors (Miech et al. 2017).
[3] As of January 2020, the Centers for Disease Control and Prevention has recorded 2,608 cases of lung injury and 60 deaths. Over 80 percent of cases involved the vaping of liquids containing THC. Only 14 percent involved the vaping of nicotine. Most people got liquids from informal sources. Current evidence suggests the illnesses might have been caused by vaping liquids contaminated with vitamin E acetate (Pray et al. 2020).

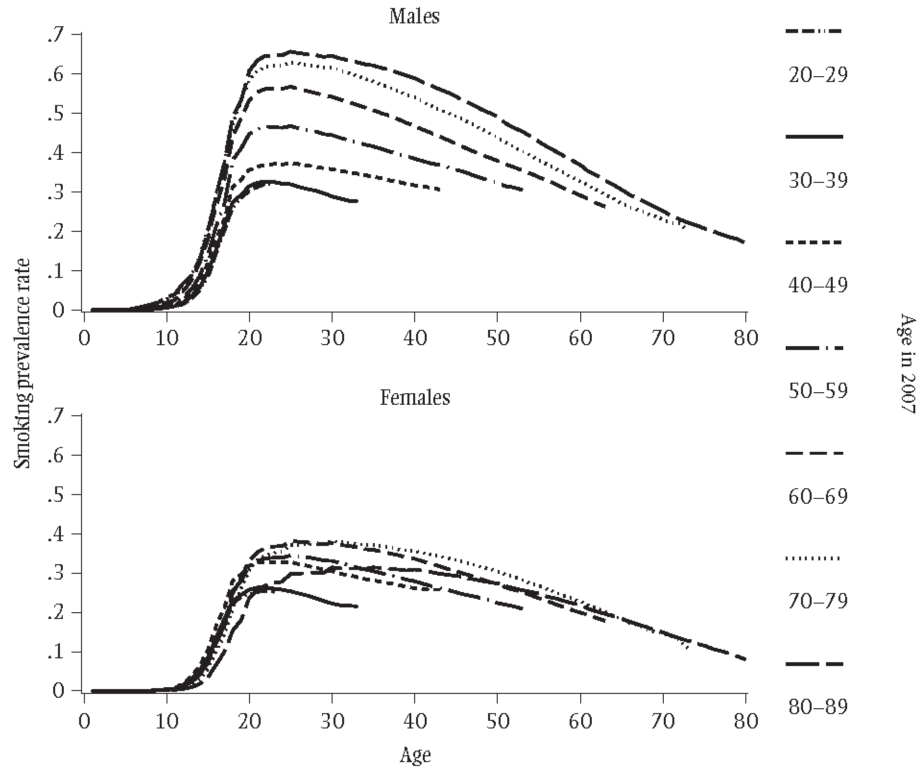
association between genetic variants and various aspects of smoking behavior. Economic models of nicotine consumption (and of a wide range of other behaviors) will increasingly control for genetic differences across individuals to estimate price elasticities of demand for nicotine and cross-price elasticities of substitution between particular nicotine delivery devices (e.g. traditional cigarettes and e-cigarettes).

Before presenting the model, I first describe patterns in life-course cigarette smoking (because it is the technology for which data are available over the longest time span). I review those patterns in section 1.1 to lay out stylized facts the model must explain. In section 1.2, I review evidence on the neurological effects of nicotine and available evidence about the costs and benefits of nicotine consumption at each stage of life. Section 1.3 briefly reviews evidence linking genetic variation to nicotine consumption. I point interested readers to literature that describes the methods that researchers use to connect genetic variants to nicotine consumption. I also revisit the above evidence to highlight that both costs and benefits of nicotine consumption vary with individual differences in genetic makeup. In section 1.4, I briefly review the history of nicotine delivery technologies. In section 1.5, I discuss the measurement of the shadow price of a unit of nicotine. In section 1.5.1 I review evidence of biological processes that generate differences in the shadow price of a unit of nicotine delivered by a particular device. In section 1.5.2 I review how the shadow price of nicotine varies across delivery devices because the risk of degrading one's health varies with the way one ingests nicotine. Both types of factors matter and should shape how empirical researchers measure the effective price of nicotine. In section 1.6, I lay out a simple model that incorporates the costs and benefits of nicotine consumption over different parts of the life-cycle and present the full shadow price of nicotine. I discuss the simple first-order conditions and, in section 1.6.1, review some of the model's implications. In section 1.7, I briefly discuss the role of imperfect information. This discussion proposes that consumers are less likely to know (or be able to make inferences about) particular types of evidence of costs or benefits of nicotine in particular life-cycle stages. Relaxing the full information assumption also rationalizes a role for advertising in consumers' nicotine consumption decisions. Section 1.8 highlights selected evidence from the more recent empirical literature studying newer nicotine delivery technologies. Section 1.8.1 reviews evidence e-cigarettes and smoking cessation. Section 1.8.2 reviews evidence on the growing trend of simultaneous use of multiple nicotine delivery methods. Section 1.8.3 reviews the role of taxes and price in substitution between nicotine delivery methods. Section 1.8.4 relates studies that explore factors that the above model puts in the shadow price of nicotine. I conclude in section 1.9.

1.1 Life-course patterns of smoking behavior

The model of nicotine consumption must explain patterns of consumption not only of nicotine but also of traditional methods people use. Here I focus on life-cycle patterns of cigarette consumption as that was the predominant method of nicotine delivery until recently. Figure 1 plots the life-course smoking prevalence rate of seven cohorts

Figure 1. Life-cycle smoking prevalence of 7 cohorts of US men and women



Reproduced from Lillard (2015). Data source: Tobacco Use Supplement to the Current Population Survey (TUS-CPS). 1967, 1968, 1985, 1989, 1992, 1993, 1995, 1996, 1998–2003, 2006, 2007. Washington, DC: US Census Bureau.

of US men and women. Patterns for both men and women show three stylized facts the model must explain. First, most people start smoking regularly between the age of 13 and 26 (Lillard et al. 2013).[4] Second, smoking prevalence peaks around age 25. Third, after age 25, patterns of smoking prevalence begin to diverge across cohorts and especially for women. Further, as Lillard and Christopoulou and colleagues show, one observes strikingly similar patterns of life-course smoking initiation and peak smoking prevalence in ten developed and developing countries (Lillard and Christopoulou, 2015). The countries differ in their languages, cultures, policy environments, and attitudes about smoking. At the same time, one observes differences. For example, patterns for women in older cohorts differ much more relative to men than do patterns for women and men in younger cohorts. In the youngest cohorts, life-course patterns of smoking prevalence of women and men are nearly indistinguishable. Consequently, the model of nicotine consumption must be rich enough to explain the patterns observed over time, between countries, and across demographic groups. It must also explain cross-sectional and longitudinal patterns in the nicotine delivery method people choose.

The model must be informed by plausible reasons that explain why people might rationally consume nicotine. To date, the literature offers hypotheses and evidence to answer the related but different question, "Why do people smoke?" Many of the factors already identified as predictive of smoking belong in a model of the demand for nicotine. The literature has already identified

[4] Shown in multiple and independently drawn US samples (Harris, 1983; Burns et al., 1998; Lillard et al. 2013; Christopoulou and Lillard, 2016)

neurological effects of nicotine as a key factor. Researchers also suggest a role for psycho-social factors. For example, it is common to suggest that youth smoke may smoke as a form of rebellion (Jarvis 2004), to take risks (Burt et al., 2000), as a coping mechanism to deal with anxiety (Patton et al., 1998), or because it is behavior one needs to join a social group (Simons-Morton and Farhat, 2010). Jarvis (2004) (and others) also suggests that people continue to smoke (have difficulty quitting) because they get addicted to nicotine. Still other suggest that people start and continue to smoke because they are myopic, less than fully informed, or have hyperbolic discount rates (Avery et al. 2007; Lillard, 2017; Gruber and Koszegi, 2001).

1.2 Life-cycle costs and benefits of nicotine

To properly model the economics of nicotine, one must understand the costs and benefits of nicotine consumption at each age over the life-cycle. The scientific community is still discovering evidence about those costs and benefits. In this review, drawn largely from Preedy (2019), I focus on evidence from studies that use animal models to understand the neurological effects of nicotine. Observational data from humans includes selection effects that make it difficult to identify causal effects of nicotine. I also emphasize studies that expose the animals (typically rats or mice) to nicotine (or cotinine) rather than studies that expose them to tobacco smoke.[5] An obvious point bears repeating - no single survey can adequately summarize the extensive body of evidence on the effects of nicotine. This brief survey is incomplete and it is possible, even likely, that countervailing evidence exists.

With those caveats, the evidence suggests three main conclusions that broadly inform an economic model of nicotine consumption. First, exposure to nicotine results in both positive and negative neurological effects. Second, the effects vary by age of exposure and sex. Third, unsurprisingly, effects depend on the quantity consumed. Unless otherwise noted, I discuss evidence from studies that expose animals (mice, rats, and monkeys) to nicotine at various life-cycle stages.

Exposure to nicotine in utero harms fetal development (Chen et al. 2019). In animal models, exposure to nicotine reduces blood flow in the uterus, lowers the delivery of nutrients and oxygen to the fetus and results in low birth weight. Exposure to nicotine also affects the growth and development of nerve tissue, formation of synapses between neurons, causes long-lasting abnormalities in neurotransmitter signaling, and cognitive deficits in later life (Alkam and Nabeshima, 2019).

Nicotine exposure in adolescence has both negative and positive effects (Izenwasser 2019). Rats exposed to nicotine in adolescence will self-administer two to three times as much nicotine when they are adults as will rats first exposed to nicotine as adults. Evidence also suggests that effects of nicotine exposure in adolescence vary by sex. Male, but not female, rats exposed daily to nicotine as adolescents increase their loco-motor activity and, with repeated exposure, the response to nicotine neither diminishes nor increases. The latter effect, labeled sensitization in studies of psychostimulants, does occur in adults. Sensitization implies that, to get the same increase in loco-motor activity, adult male rats need less nicotine. However, other studies show that when male rats consume nicotine in adolescence, they become more sensitive to alcohol, cocaine, and amphetamines as adults. That implies that even a small experimental dose might

[5] In the section on choice of nicotine delivery method, I briefly summarize the evidence on negative effects of exposure to the by-product of each delivery method (e.g. cigarette smoke).

lead them to addiction. However, the evidence from animal studies is mixed. Some studies using mice found that nicotine administration decreased cocaine addiction (Kelley & Middaugh, 1999; Kelley & Rowan, 2004; cited in Izenwasser 2019). Bajrektarevic et al. (2019) review studies of nicotine delivered to humans using transdermal patches. Those studies find that subjects experienced improved attention, information processing, memory, perception, and vigor with minimal side effects.

Evidence suggests that exposure to nicotine (and its primary metabolite cotinine) in adulthood also has positive and negative effects (Brown and Gill, 2019; Echeverria and Zietlin, 2019; Hritcu and Mihasan, 2019). Evidence from animal models suggest that exposure to nicotine and/or nicotinic agonists have also been shown to increase receptor expression of a family of biomolecules in mammalian brains important to the growth, survival, differentiation, and maintenance of developing and mature neurons (Koskela et al., 2017). Although this effect potentially strengthens neuronal connections (Tyler, Perrett, & Pozzo-Miller, 2002) there is also evidence that it is through this process that nicotine consumption is a double-edged sword. In its role as an agonist at the nicotinic acetylcholinergic receptors (nAChR), nicotine causes the brain to release more dopamine. The process cuts two ways because the additional dopamine raises the probability of addiction but also increases overall neuronal activity in these regions in ways that improves cognition in animal models of Alzheimer's and Parkinson's disease; reduces Alzheimer type plaques; mitigates cognitive loss after brain injury; decreases neuro-inflammation associated with several neurological disorders;[6] and improves or prevents symptoms of diseases.[7] Some of these findings are supported by post-mortem autopsy of humans. An autopsy of smokers and non smokers found fewer senile plaques in female smokers and more neurofibrillary tangles in patients who had smoked more (Ulrich et al. 1997). Postmortem studies of Alzheimer patients who smoked compared to nonsmoking patients find fewer beta-amyloid peptides, which are toxic to neurons (Hritcu and Mihasan, 2019).

Echeverria and Zeitlin's (2019) survey of the effects of cotinine concludes that exposure at different ages has positive effects. They note that a broad set of studies establish that cotinine promotes higher cognitive functioning, improves memory, reduces anxiety, depression and depressive behavior, mitigates symptoms of post-traumatic stress disorder, and diminishes contextual fear in mice, rats, and monkeys.

All of the above suggests that people may demand nicotine partly because it confers positive benefits. It is likely that people learn about some, but not, of the above effects through experience.

There is evidence that people use nicotine to medicate. Even across nicotine delivery methods that differ widely in the amount of nicotine each makes available to the body, people still only consume nicotine up to a given and fairly constant ceiling (daily intake of nicotine per kilogram of body weight) (Gori and Lynch, 1985; Kozlowski et al.). Gori and Lynch argue that, because one observes the same parallel distributions of plasma nicotine and cotinine across products with all Federal Trade Commission measured nicotine levels, the pattern of ceiling nicotine levels is less likely to result from metabolic differences in the rate of excretion and more likely due to individual differences in nicotine demand and how people use each method to satisfy it. Evidence supports this observation. Smokers of low nicotine cigarettes adjust how they

[6] Alzheimer's, Parkinson's, schizophrenia, major depressive disorder, and bipolar disorder.

[7] Alzheimer's, Parkinson's, brain injury, memory impairment and neuro-inflammation

smoke low nicotine cigarettes to achieve blood nicotine levels comparable to the level they attain smoking cigarettes of higher nicotine content. (Benowitz 2001).

I note again that the above discussion barely scratches the surface of an extensive literature on the effects of nicotine and cotinine. The 50-plus surveys in Preedy (2019) cite several thousand published articles and still only represent a fraction of published work. The point for economists is to realize that strong evidence documents that people who consume nicotine (cotinine) get physiological benefits and pay health costs. Because these benefits and costs vary systematically over the life cycle, one can model them. The fact that it will be difficult or impossible for people to know or recognize some of the effects suggests that assumptions about perfect information will usually be inappropriate. Other effects people can observe through self-observation. In modeling consumption of nicotine theoretically, it is critical to review and understand those effects (as best one can) so that one can predict the theoretically optimal time path of consumption and so that one can understand how and why, in observational data, people might deviate from that optimal path.

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1.3 Genetic variation and nicotine consumption

An economic model of nicotine consumption can and should incorporate a role for genetic makeup. Since the mapping of the human genome in 2000, geneticists, neuroscientists, and social scientists have rapidly progressed in our understanding of the connection between genetic variants at particular locations on the genome, social and economic behaviors.[8] This advance includes a growing understanding of specific locations on the genome at which people differ that are associated with either observed smoking behavior or with neurological structures and functions that interacts with nicotine. In both cases, differences across people at these genetic variants (called single nucleotide polymorphisms or SNPs), predict differences in smoking behavior. The science is still evolving on understanding the complex processes that connect the SNP variants with smoking but, especially for smoking, evidence strongly suggests that genetic factors influence the number, operation, and efficiency of receptors in the brain to which nicotine attaches.

For example, studies reviewed by Namba et al. (2019) establish that the majority of SNPs associated with nicotine-related phenotypes involve nicotinic acetylcholine receptor (nAChR) genes. The nAChR genes are associated with nicotine dependence, lung cancer, other cardio-pulmonary diseases, and whether smokers successfully quit. For some of those SNPs, studies identify the likely biological pathway. For example, even before the mapping of the genome, researchers established that α4β2 nAChRs are densely expressed in the brain's dopamine reward pathway and that they directly regulate nicotine addiction and dependence (Epping-Jordan, Picciotto, Changeux, & Pich, 1999; Tapper et al., 2004). Eggan and McCallum (2019) review studies showing that, when nicotine binds with the α3β4 nAChR, nicotine likely causes the release of glutamate in the primary reward pathways. Glutamate plays a central role in processes believed to underlie how addiction develops and gets maintained (Tzschentke and Schmidt, 2003).

[8] Scientists announced the working draft of the genome, covering about 80 percent of the genome, in June 2000. The human genome project was declared to be complete in April 2003 but it covered about 92 percent of the genome to the accuracy criterion established by the project (Schmutz et al. 2004). Work continues to the present.

Genetic differences may also influence the rate at which an individual metabolizes nicotine. When nicotine metabolizes at a slower rate, an individual experiences the effect of a given input of nicotine longer. As importantly, he extracts more nicotine from a given dose than people who metabolize nicotine faster.

A full model of nicotine consumption should include the role genetics plays in how nicotine operates to create both costs and benefits not only because it is theoretically important but also because, increasingly, major social science surveys collect the data needed for empirical studies. The surveys collect individual data on both genetic variants and (some) types of nicotine consumption (usually cigarette consumption). US surveys include the Health and Retirement Study, Wisconsin Longitudinal Study, and the National Longitudinal Survey of Adolescent Health. Including data on nicotine-related genetic variants will not only capture previously unexplained individual variation associated with nicotine costs and benefits but will also allow researchers to explore whether demand for nicotine in response to policies is heterogeneous across the distribution of genetic variants.

1.4 Nicotine delivery technologies

The new focus on nicotine consumption must also explain the method consumers choose to get nicotine into their blood and brain. I label these methods as nicotine delivery technologies. The simplest way for the model to predict which method people choose is to recognize the variation in the relative costs and benefits associated with each method. A model that recognizes those differences can use temporal variation in the available nicotine delivery technologies to explain the relative demand for nicotine delivered by each method.

Incorporating this source of variation into the model has an added advantage. The new nicotine delivery technologies are recent enough that the consumption behaviors in above survey data span the whole period over which major new technologies were developed.

Until recently, people got nicotine from tobacco by smoking (cigarettes, cigars, pipes, water pipes), chewing, or sniffing it.[9] A seventh delivery technology, gum, became commercially available in the US in 1984.[10] The FDA approved an eighth delivery technology, the transdermal patch, as a way to deliver drugs through the skin in 1979 but did not approve it as a way to deliver nicotine until 1992. In 1996 and 1998, the FDA approved a ninth and tenth delivery technology, the nicotine nasal spray and a nicotine inhaler respectively (CDC 2000). In 1999, the FDA approved the sale of an eleventh delivery technology, nicotine sublingual tablets. In 2002, the FDA approved a twelfth delivery technology - a nicotine lozenge. In 2006, firms introduced vaping to US consumers, counted here as the thirteenth nicotine delivery technology. Finally, in 2010, the FDA approved the fourteenth technology, a nicotine mouth spray.

1.5 Defining the shadow price of nicotine

The shadow price of nicotine is the pecuniary and non pecuniary cost of a unit of nicotine delivered successfully into the blood stream (brain). The pecuniary cost of a unit of delivered nicotine equals the price of a standard unit of a nicotine product (cigarettes, cigars, nicotine

[9] A much rarer delivery method was a tobacco smoke enema described in Sydenham (1809).

[10] A medicated-chewing-gum was commercially introduced in 1928 (Conway 2003). It was adapted to deliver nicotine in 1971 (Brantmark et al. 1973; Fernö 1973) but not commercially launched until 1978.

liquid) divided by the amount of nicotine that a consumer actually gets when he consumes that product. The non pecuniary cost is the social cost (or desirability) of a given nicotine delivery mechanism. The shadow price of a unit of nicotine delivered by device *j* at time *t*, SP_{Nt}^{j}, is given by:

$$SP_{Nt}^{j} = \frac{P_{Nt}^{j}}{(\theta_j N_j)} + Soc_t^j \qquad (1.1)$$

where the first term measures the money price per unit of delivered nicotine. The numerator, P_{Nt}^{j}, is the price of a unit of the nicotine containing product delivered by device *j*. The denominator is the amount of nicotine delivered to the blood when a person uses delivery method *j*. It is raw nicotine in product j, N_j, times the fraction that gets absorbed into a person's blood, θ_j, under normal use That is, θ_j, measures the efficiency of the nicotine delivery device. Across products, $\theta_j N_j$ varies substantially. For a given product, $\theta_j N_j$ is usually, but not always constant over short time spans. However, even for a given product, $\theta_j N_j$ can differ over time. The introduction of low nicotine cigarettes is an obvious example.

The second term, Soc_t^j, is an index of the social desirability associated with a particular nicotine delivery technology. No single data source measures social desirability but some researchers use approximations of it. For example, Kim and Shanahan (2003) find that when smoking stigma is higher in a given state, smokers are more likely to quit. DeCicca et al (2008) use a similar index in a model of smoking. More generally, the social desirability index could (should) not only be a function of public sentiments about particular types of smoking (e.g. sentiment against cigar smoke) but also advertising of all types that try to create a positive image in the public's mind about particular nicotine delivery devices. Further, manufacturers actively seek to place tobacco products into films, television programs, and video games to shape viewer's attitudes about the products. Evidence suggests the product placements have the intended effects. Gibson and Maurer (2000) show that viewers have more positive attitudes about smoking when a lead movie actor is shown smoking. Glass (2007) shows that video game players, experimentally assigned to play games in which branded products appear, are more likely to rate products as good, and do so more quickly, than are players assigned to play games in which no products appear. These observations suggest that, when constructing the shadow price of each nicotine delivery device, economists should try to capture the broader factors of social stigma, advertising, and product placement that belong in the shadow price.

Below I will explicitly derive a third component of the shadow price. That term will capture, in monetary units, the life-time health cost of increasing consumption of nicotine by one unit at time t. For now, define the price of a unit of delivered nicotine at time *t* as the lowest available price across all nicotine delivery methods that are available.

1.5.1 Efficiency of nicotine delivery

The efficiency of the nicotine delivery device, θ_j, is largely determined by the part of the body which primarily absorbs the nicotine. When a consumer smokes cigarettes or vapes, he absorbs nicotine mostly through his lungs. People who chew tobacco, use moist snuff (snus), nicotine inhalers, lozenges, or mouth spray, or smoke cigars, pipes or water pipes absorb most of their nicotine through the buccal mucosal membranes (i.e. in the mouth). People who use nasal spray and dry snuff absorb nicotine through the nasal mucous membranes. The transdermal patch delivers nicotine through skin.

Table 1 lists, for each product, the amount of nicotine in the usual dose, the peak nicotine level a consumer experiences, and the fraction of nicotine that is absorbed (termed bioavailability). These technologies also differ in how rapidly the body absorbs nicotine. Speed of absorption depends not only on the site in the body but also, for tobacco products, on the pH of the tobacco. For example, the body delivers nicotine to the brain more slowly when it is mostly absorbed through the buccal mucosa compared to the alveolar surfaces of the lung (Benowitz, 1988). Partly because of this, when people burn tobacco or use an inhaler, the absorption rate varies with whether or not, and how deeply, one inhales.

Benowitz (1993) documents how several of the delivery methods differ in the associated nicotine absorption rate. He compares nicotine absorption from smokeless tobacco, cigarettes, oral snuff, and nicotine gum. People absorb nicotine from smokeless tobacco more slowly than from cigarette smoke but the two methods produce similar peak venous levels. Nicotine blood

Table 1. Nicotine bioavailability and physical harm associated with delivery methods

Delivery method	Absorb. site	Dose (avg.)	Nicotine (mg) /dose	Peak (ng/ml)	Bioavailability (percent)	Harm[a]
Cigarettes[1]	Lungs	1 g	1.0	25.9	80-90	99.6
Small cigars[2]	Mouth	1 cigar	5.8-8.2/g	21.4	75-99	67
Pipes[3]	Mouth	1 bowl	14.4/g	4	29[b]	21
Cigars[4]	Mouth	1 cigar	12.0/g	3.4-5.2	29	15
Water pipes[5]	Mouth	12.5 g	32	11.7	8	14
Smokeless tobacco[1]	Mouth	7.9 g	4.5	14.5	3.4	12
Snuff[1]	Nose	1.4 g	3.6	18.5	14	---
E-cigarettes[6]	Lungs	1 dose	15.9/ml	9	91	4
Patch[7]	Skin	1 patch	15/16 hr	11-14	75-100	2
Gum[7]	Mouth	1 piece	2.0	7.5	78	2
Lozenge[7]	Mouth	1 piece	4.0	10.8	79	2
Nasal spray[7]	Nose	1 dose	1.0	5-8	60-80	2
Inhaler (deep)[7]	Lungs	1 dose	3.9	34.2	56	2
Inhaler (shallow)[7]	Mouth	1 dose	4.0	32.0	51	2

[a] Estimated by Nutt et al. (2014) using multiple criteria decision analysis; ranked relative to harm associated with cigarettes. Study did not include snuff.
[b] Bioavailability rate of cigar smokers.
Sources: [1] Benowitz (1993), Holm et al. (1992), Temple (1976) ; [2] Armitage et al. (1978), Claus et al. (2018); [3] McCusker and McNabb (1982); [4] Fant and Henningfield (1998), Hoffmann and Hoffmann (1998); [5] Jacob et al. (2011); [6] St. Helen et al. (2015), Yingst et al. (2019); [7] Hukkanen et al. (2005), Molander et al. (1996)

levels drop quickly when a person stops smoking a cigarette, but stay elevated during and after a person chews tobacco. The nicotine in average doses of chewing tobacco (7.9 g) and snuff (2.5 g) were 4.5 and 3.6 mg, respectively, and 1.0 mg per 1 gram of tobacco in the average cigarette.

Benowitz (1993) estimated average systemic bioavailability of nicotine to be 12.0 percent, 14.0 percent, and 3.4 percent for cigarette smoke, oral snuff, and chewing tobacco, respectively. When people smoke small cigars, peak plasma nicotine and bioavailability is approximately the same as cigarettes (Claus et al. 2018). Peak plasma nicotine is lower for cigars because cigar smokers seldom inhale (Fant and Henningfield, 1998; Hoffmann and Hoffmann, 1998).

By contrast, Yingst et al. (2019) estimate that, when people vape using e-cigarettes, they get an average of 1.33 mg of nicotine and 93.8% of the inhaled dose. They concluded that e-cigarettes can deliver levels of nicotine comparable to or higher than typical tobacco cigarettes, with similar systemic retention. The bioavailability of nicotine is roughly the same as e-cigarettes when delivered by transdermal patches (though absorption is slower) while bioavailability of other nicotine replacement therapies - gum, lozenges, and nasal spray - is at least ten percentage points lower (Hukkanen et al. 2005). Molander et al. (1996) estimate that, when people use nicotine inhalers, they absorb nicotine either via their mouth (if they do not inhale) or lungs (if they inhale). On average, these two methods exposed people to 4.00 and 3.87 mg of nicotine respectively. Mean peak plasma level was 32.0 and 34.2 ng/ml respectively. On average, bioavailability of nicotine from an inhaler was 51 and 56 percent respectively.

1.5.2 Physical cost associated with nicotine delivery devices

The last column of Table 1 lists a physical harm index for each technology. The index, described in Nutt et al. (2014), ranks each method by the physical harm associated with it. Briefly, a group of experts ranked twelve product types according to a weighted average of 14 types of harm each might cause. The broad set of harm criteria include harm that the consumer experiences, harm to close family members (e.g. people exposed to second-hand smoke), community, and the broader society (e.g. loss of productivity). The group rated harm in terms of mortality and morbidity, injury to others, economic losses and environmental harm.

Although the Nutt et al. harm index is cross-sectional, the underlying data varies over time. One can use them to construct a time-varying index and use it to explain the share of nicotine consumers get from each technology. Christopoulou and Lillard (2016) use something that crudely approximates such an index and provide evidence that it adds predictive power. They standardize cigarette consumption by the average number of cigarettes consumed and the average tar content of the cigarettes. They show that the standardized smoking prevalence rate better predicts a given cohort's smoking related future mortality (in thirty years) than the unadjusted rate.

Note also that the degradation of health also unfolds over time. Table 2 draws on evidence,

Table 2. Disease prevalence at age 60, by smoking status, age started

	Heart disease		Rheumatoid arthritis		COPD	
Group	Men	Women	Men	Women	Men	Women
Smokers (13-17)	16	12	10	11	4	12
Smokers (18-22)	11	9	8	11	4	7
Non smokers	5	5	5	8	2	3

Source: Chen (2003)

reported in Chen (2003), on how smokers and non smokers differ in the prevalence of three of the most common diseases associated with smoking – rheumatoid arthritis, heart disease, and chronic obstructive pulmonary disease (COPD) which includes chronic bronchitis and emphysema.

Chen (2003) reports that, at age 30, there are few differences in the prevalence of all three diseases among smokers and non smokers of both sexes. By age 40, the prevalence rate of all three diseases among smokers exceed rates of non smokers. The differences continue to grow so that, by age 60 the prevalence rate of the diseases of smokers exceeds that of non smokers by between 37 and 300 percent (see Table 2).

In sum, all three components of the shadow price vary with device-specific and individual-specific factors. Economists can exploit that variation to predict the fraction of people who use a particular nicotine delivery device and how much nicotine people consume.

1.6 A model of lifetime utility with nicotine

The model assumes that individuals seek to maximize their lifetime utility. In every period, consumers choose how much to consume of the composite good and their mental and physical health. To produce mental and physical health, consumers choose nicotine and medical inputs. Each person discounts his future utility by each his consumption rate of time preference. In a given period, a person's (remaining) life-time utility is given by:

$$U_t = \sum_{t=0}^{T} U[C_t, M_t, H_t; \varphi(g)]e^{-\beta t} \qquad (1.2)$$

where C_t denotes the composite consumption good; M_t and H_t denote the mental and physical health production functions, respectively; $\varphi(g)$ is the function that translates genetic make-up into preferences; and β denotes the consumption rate of time preference.

Health of each type is a function of the stock carried from the previous period and investments of nicotine, N_t, and purchased health inputs, I_t, (e.g. medical care). Note that the effect of nicotine on each type of health varies systematically with a person's genes associated with the processing and interactions with nicotine, $N_t(g_N)$. In each period, mental and physical health is given by:

$$\begin{aligned} M_t &= m\big(M_{t-1}, N_t(g_N), I_t; d_M\big(t, Age_t, f(g)\big), \varepsilon_t\big) \\ H_t &= h\big(H_{t-1}, N_t(g_N), I_t; d_H\big(t, Age_t, f(g)\big), \eta_t\big) \qquad (1.3) \end{aligned}$$

where $d[\cdot]$ is a depreciation process specific to each type of health. ε_t and η_t denote shocks to mental and physical health respectively.

This structure allows a person's mental health and physical health to evolve differently over various life-cycle periods. For example, while most youth are physically robust during puberty, the hormonal changes that occur during those years can affect their mental health. Similarly, at older ages, physical health may decline faster than mental health. The two types of health are likely to co-evolve and may follow similar trends. In addition, each type of health depreciates at a rate that depends on calendar time (e.g. to capture changes in medical technology), age, A_t, genetic make-up, $f(g)$, and accumulated mental and physical health.

Available evidence, reviewed above, suggests that nicotine can affect mental and physical health positively and negatively depending on when a person consumes it (or gets exposed to it).

Consequently, the marginal effects of nicotine and purchased health inputs vary with the age (or calendar time) at which a person consumes them. I fix the initial levels for mental and physical health (M_0; H_0) and end conditions (M_T; H_{min}) respectively. As in Grossman (1972), a person dies if his physical health falls below some minimum (H_{min}) but a person can reach the end of life with high or low mental health.

Consumers cannot consume more than their resources allow at exogenously given prices and a rate of interest, r. Resources available every period are given by:

$$A_t = (1 + r)A_{t-1} - P_{ct}C_t - P_{Nt}N_t - P_{It}I_t \qquad (1.4)$$

where P_{Ct}, P_{Nt}, and P_{It} denote the price of consumption, nicotine, and health inputs respectively. The equilibrium also depends on initial and end conditions for assets (A_0 and A_T respectively).

The model yields a first-order condition showing that, to consume nicotine optimally, consumers consider three key factors. First, consumers must consider whether and how nicotine affects current mental and physical health. Second, consumers must consider whether and how a change in current health affects the evolution of future health. Third, consumers must balance the benefits of nicotine against the price they pay, in terms of money and degraded mental or physical health. The first-order condition for nicotine is given by:

$$\left[\frac{\partial U(\cdot)}{\partial M_t} e^{-\beta t} + \sum_{k=t+1}^{T-1} \frac{\partial U(\cdot)}{\partial M_k} \prod_{j=t}^{k-1} \left(\frac{\partial M_{j+1}}{\partial M_j}\right) e^{-\beta k}\right] \frac{\partial M_t}{\partial N_t} + \left[\frac{\partial U(\cdot)}{\partial H_t} e^{-\beta t} + \sum_{k=t+1}^{T-1} \frac{\partial U(\cdot)}{\partial H_k} \prod_{j=t}^{k-1} \left(\frac{\partial H_{j+1}}{\partial H_j}\right) e^{-\beta k}\right] \frac{\partial H_t}{\partial N_t} - \lambda P_{Nt} = 0 \qquad (1.5)$$

The terms inside the upper and lower brackets respectively capture the sum of the marginal utility from increasing mental and physical health by one unit. This sum consists of the direct marginal utility from changing health today plus the cumulative marginal utility of health in each future period that accrues if and when a change in current health affects future health. Although I have subsumed it here, remember that the model allows the health effect of nicotine to vary systematically with individual differences in genetic make-up.

To estimate empirically the consumption of nicotine, one needs to identify which terms in (1.5) constitute marginal benefits and which terms constitute marginal costs. P_{Nt} is the marginal cost of a (delivered) unit of nicotine. But, as noted above, the effect of nicotine on mental and physical health likely varies over the life course. So it is not obvious whether the two other terms are costs or benefits. The terms in brackets are both positive (utility increases with improvements in mental and physical health) so consumption of nicotine increases utility only when nicotine improves mental or physical health, i.e. when $\left({}^{\partial M_t}/_{\partial N_t}, {}^{\partial H_t}/_{\partial N_t} > 0\right)$ respectively.

Note also that absolute value or sign of these derivatives can change with technological shocks. The introduction of filtered cigarettes, discovery of combination chemotherapy as a cancer treatment, and development of e-cigarettes are three examples of such shocks. These technological shocks have generally been to reduce the negative effects associated with particular nicotine delivery methods. The temporal variation in them offers empirical researchers a way to revisit demand for nicotine and changes in demand for particular nicotine delivery methods.

Collecting the negative terms, one can restate the shadow price of a unit of nicotine, across all *J* nicotine delivery devices available at time *t*, as:

$$P_{Nt} = min\left(SP^{j}_{Nt}\right) = min\left(\frac{P^{j}_{Nt}}{(\theta_j N_j)} + Soc^{j}_{t} - \sum_{k=t}^{T} \frac{\partial \mathcal{H}_k(\cdot)}{\partial N_{jt}} v(\mathcal{H}_k)(1+r)^{-(k-t)}\right) \forall\, j \in J \quad (1.6)$$

Where the last term captures all of the degradations in mental and physical health associated with nicotine consumption delivered by device j. The term $v(\mathcal{H}_k)$ is the money value of an improvement in health at every age. Note that this value is also likely to vary over time. People who demand nicotine will choose delivery method *j* in year *t* if it satisfies (1.6).

1.6.1 Implications

The above model yields several testable predictions. It predicts who will demand nicotine, how much they will demand, and the nicotine delivery method they will choose. I list a few here.
Initiation: Unlike the Becker and Murphy (1988) model of rational addiction, this model yields testable predictions about who is likely to start smoking. Because nicotine is known to reduce anxiety and mood swings and because the health costs of smoking take a long time to accumulate, the model predicts that youth going through puberty are more likely to start smoking. The model also predicts that any shock to mental health (e.g. marital problems, divorce, unemployment, natural disasters) will also lead people to start smoking or, in the case of former smokers, relapse and re-start.
Level/intensity of nicotine consumption: A nice feature of the model is that people the previous finding about a ceiling on consumption of nicotine flows from the biological processes that naturally imply decreasing productivity of marginal units of nicotine. In addition, because nicotine is used to affect mental and physical health, it implies a natural ceiling on consumption. Such ceilings are observed in data on cigarette consumption.

This observation suggests that changes in technology that lower the shadow price of nicotine will lead to only marginal changes in any given individual's nicotine consumption but will increase the aggregate consumption of nicotine because it will induce people, previously priced out of the nicotine market by the negative health effects, to consume again.
Choice of delivery device: The model also predicts the factors that will determine the nicotine delivery device a new consumer will choose in any given period. The driving factor is the shadow price of getting nicotine from a particular device. As noted, the shadow price varies over time with the money price, the bioavailability of nicotine a device delivers, the social costs (or benefits) associated with a particular device, and the mental and health degradation suffered when using the device. Variation in each of these factors yields testable predictions.

For example, a reduction in the money price of a particular delivery device that does not change the medical effects of nicotine will increase the share of nicotine delivered by the cheaper delivery device. A reduction in the health degradation costs of a particular delivery device will also shift demand to the lower health cost delivery device. That prediction is not unique to this model. It flows from basic economic theory but the prediction is repeatedly borne out as new technologies reduced the health costs of consuming nicotine. For example, the introduction of filtered cigarettes in 1954 led to a dramatic substitution from plain-tipped to filter-tipped cigarettes (Hammond and Garfinkel, 1964). While the market for e-cigarettes and nicotine vaping liquids is still developing, similar patterns are emerging (Marynak et al. 2017).

The model also points to factors that can explain recent empirical findings that the price elasticity of smoking participation is falling in recent years (Hansen et al. 2017). While the money price of cigarettes has been steadily increasing since about 1983 (Lillard et al. 2013), the development of new nicotine delivery devices has caused a change in the composition of people who choose to smoke cigarettes.

Substitution between delivery devices: The model also predicts patterns of substitution between nicotine delivery devices (among individuals who choose to consume nicotine). Note that model predicts the conditions under which there will continue to be a market for traditional nicotine delivery devices (cigarettes, cigars, snus, chewing tobacco, snuff, water pipes). Those markets will persist if people face relatively low social stigma when they use a particular device and when there is a social benefit to using a particular device. These aspects of the shadow price of each device vary with advertising, public perceptions (social norms), information, and marketing (product placement) that can vary across demographic groups and regions. For example, in rural areas there is less social stigma associated with chewing tobacco.

More generally, the model suggests that it would be useful to revisit basic data on the sale of different nicotine delivery methods, adjust them to reflect the bioavailability of nicotine and the negative health effects associated with each. A model of demand for nicotine would then use temporal and individual variation in those factors and social stigma associated with each type of device to predict patterns of and changes in consumption and demand for each device. The growing availability of data that include not only consumption but also individual genetic makeup means that researchers can also capture individual heterogeneity in demand for nicotine that arises because of individual differences in genetic variants associated with nicotine consumption.

Smoking cessation: The model also predicts that decisions to quit smoking depend principally on the underlying mental and physical health conditions affected by nicotine. Economic factors such as information and taxes induce marginal smokers to quit. As observed above, nicotine can improve or degrade physical health and these effects vary over the life-cycle. Consistent with the patterns shown in Figure 1, most people start smoking between the ages of 13 and 25, a period during which youth experience large hormonal changes, mood swings, and significant transitions in life situations. Note that, in most cases, these conditions persist for some number of years. That year-on-year persistence means the underlying demand for nicotine also persists year-on-year. The consequence of that persistence is the appearance of addiction (as posited in Becker and Murphy (1988). However, in this model people demand not because they are addicted but because the underlying conditions persist. Conversely, the model predicts that people will quit when those conditions get resolved (or can be treated in other ways).

The model predicts the pattern in the life-course smoking prevalence in Figure 1. The emerging field of Magnetic Resonance Imaging and Functional Magnetic Resonance Imaging is accumulating evidence that the adolescent brain is still maturing through adolescence and into young adulthood. Paus (2005) observes that "Smooth flow of information throughout the brain depends, to a great extent on the structural integrity and maturity of white-matter pathway." That maturation process slows significantly after age 25, consistent with peak smoking prevalence around age 25 for men and women across multiple cohorts shown in Figure 1 (and in multiple developed countries) (Lillard 2015; Lillard and Christopoulou 2015). The model predicts that smokers will quit as underlying conditions get resolved as they age and mature. Any factors that raises anxiety or stress will reduce the probability a smoker quits or cause ex-smokers to smoke again. These predictions are consistent with findings that rates of smoking increase when unemployment rates increase (Everding and Marcus, 2020; De Vogli and Santinello, 2005). The same will be true for other life-course shocks (divorce, death of loved ones, chronic illnesses etc). These observable and plausibly exogenous events affect mental health and, through that mechanism, the demand for nicotine.

1.7 Deviations from full information

The above model assumes people possess full information about things they are unlikely to know. Because the model allows the effect of nicotine to vary with life-cycle age, it generates specific predictions about whether and at what ages uninformed people will consume too little or too much nicotine. For example, during the 1950s and earlier, doctors and consumers knew much less about how smoking affects fetal brain development and cognition in the short and long run. Consequently, less informed pregnant women smoked more than they would have under full information. On the flip side, neuroscientists are still trying to understand the potentially positive effects of nicotine on loco-motor activity, concentration, reducing depression, formation of beta amyloid plaques, neuro-inflammation, onset and progression of Alzheimer's and Parkinson's disease. If those connections are true then uninformed people may be consuming too little nicotine.

The empirical evidence is mixed on how much nicotine consumption deviates from the optimal level because people are not fully informed. Viscusi (1990) finds that smokers and nonsmokers overestimate the lung cancer risk of cigarette smoking. Lillard (2017) shows that smokers are more likely to quit when exposed to articles about the health risks of smoking published in popular consumer magazines. If, as in Viscusi's study, people overestimate their risks, providing full information would increase smoking.

The model predicts that less than fully informed people will alter their consumption of nicotine when they get new information that they believe (regardless of whether or not the information is scientifically valid). One can similarly study how demand for nicotine (from particular devices) varies with information on the relative risks of using each device (a la the harm index shown in Table 1) to first the assumption that people hold accurate beliefs and then to test how their consumption varies with the arrival of new information.

1.8 Interpreting existing literature

The recent empirical literature has begun to describe whether the use of e-cigarettes is associated with higher rates of smoking cessation, patterns of use and dual use of traditional and newly emerging nicotine delivery devices. An even smaller literature models demand for nicotine replacement therapies, e-cigarettes (vaping liquids), and the effects of prices and emerging taxes and usage bans on e-cigarettes and vaping liquids on substitution between traditional cigarettes and e-cigarettes. Finally, I relate a strand of the empirical literature that explores factors that broadly fit the social cost factor in the shadow price I describe above. I briefly review these literatures, relate them to the model, and highlight areas that researchers might measure better the theoretically indicated factors.

1.8.1 E-cigarette and smoking cessation

Recent studies show with both longitudinal and cross-sectional data that people who use e-cigarettes smoked fewer cigarettes on the average day, were twice as likely to attempt to quit smoking cigarettes, and 1.6 to 8 times more likely to have quit cigarettes in the past 30 days as non users of e-cigarettes (Berry et al. 2019; Johnson et al. 2019; Zhu et al. 2017). Hajek et al. (2019) conclude that smokers assigned to use e-cigarettes were more likely to abstain from smoking after one year than smokers assigned to nicotine replacement therapies.

1.8.2 Patterns of "polytobacco" consumption and substitution

While a growing number of studies try to predict the nicotine delivery device(s) consumers choose (especially e-cigarettes), few studies try to explain whether, when, and how people consume multiple tobacco products (polytobacco use) and substitution patterns even though a growing fraction of tobacco consumers use multiple product types. Researchers may devote less attention to polytobacco use because the vast majority of nicotine consumers smoke cigarettes. Connolly and Alpert (2008) track relative sales shares of cigarettes, small cigars, roll-your-own tobacco, and moist snuff from 2000-2007. Consumers predominantly choose cigarettes but trends were towards other nicotine delivery types. From 2000 to 2007, the cigarette sales share fell from 89.2 to 82.7 percent. Sales of moist snuff increased from 9.1 to 13.6 percent. Interestingly, Connolly and Alpert use the weight of tobacco in each product to create what they call "cigarette pack equivalent" units but they do not adjust for differences in the bioavailability of nicotine. Smokers who use other tobacco products are more likely to be young adult males, never married, living in the West, have tried to quit smoking before (Lee et al., 2014). The higher polytobacco use in the West is consistent with there being regional differences in the social stigma associated with use of smokeless tobacco.

A burgeoning literature studies tries to understand the relationship between use of e-cigarettes and consumption of regular cigarettes. The vast majority of these studies use cross-sectional survey data so they only describe associations. Their focus is on two aspects of substitution. First, do youth who use e-cigarettes later smoke cigarettes or use both products simultaneously. Second, do established cigarette smokers use e-cigarettes to quit or to continue smoking (dual use). Using cross-sectional data, Warner (2016) finds that, among grade 8, 10, and 12 never smokers 48, 43, and 25 percent respectively used e-cigarettes. Available longitudinal evidence suggests that, after controlling for observables, youth who reported using e-cigarettes were no more likely to use cigarettes one year later than youth who did not use e-cigarettes (Conner et al. 2018). About half of e-cigarette users jointly used cigarettes (11.5 percent), cigars (7.7 percent), and cigars and water pipes (5.2 percent) (King et al. 2018). Using data from five nationally representative cross-sectional surveys, Levy et al. (2019) find associations that suggest that youth are substituting e-cigarettes for cigarettes. They find that the rate of vaping among youth is increasing, the rate of decline in smoking prevalence increased, and the proportion of daily smokers among past 30-day smokers is falling. However, in at least one longitudinal study, researchers did not find evidence of substitution. Sweet et al. (2019) use longitudinal data to track consumption behavior of people who, at baseline, were consumed only cigarettes or e-cigarettes and people who used both cigarettes and e-cigarettes. They measured consumption of these two products 6, 12, and 18 months after the baseline interview. After six months, abstinence from cigarette smoking among dual users was double that of cigarette smokers. The differences did not persist to the 12 or 18-month follow-up. At 18 months, the groups did not differ in either their consumption of cigarettes or in quit attempts. Delnevo et al (2016) use cross-sectional data to report that e-cigarette experimentation is most common among current cigarette smokers and young adults, but that former smokers who quit in the past year were four times more likely to use e-cigarettes on a daily basis compared to daily cigarette smokers. Older smokers were also more likely to be daily e-cigarette users.

No study adjusts for the relative efficiency of each nicotine delivery type or for the full shadow price associated with each. That is a fruitful area for future research.

1.8.3 Effects of taxes, price, and policies on choice of nicotine delivery device

Economists inspired the vast literature on how decisions to consume tobacco respond to price and policy changes. The literature is large and growing for the obvious reason that legislatures have the authority to regulate nicotine product markets. While public health researchers have suggested authorities should tax nicotine, until now, taxes and policies are aimed not at nicotine but at particular nicotine delivery devices. States are rapidly adopting taxes aimed a e-cigarettes and vaping liquids. As of early 2020, 22 states have adopted taxes on e-cigarettes and vaping liquids. The form of those taxes varies widely from levies on the wholesale price of the liquids to excise taxes based on the volume of the vaping liquid sold, without regard to the nicotine content of the liquids.

Several recent working papers evaluate how smoking behavior and use of e-cigarettes varies with the introduction or cross-sectional variation in e-cigarette taxes. These studies are limited by the use of cross-sectional data, The above model implies that this organization of regulation likely reduces welfare because it pays little or no attention to the costs and benefits of ***delivered nicotine***. The above model offers useful ways to measure the effective tax on different products that have the potential to yield better predictions

To date, no studies relate the relative share of sales of different devices to differences and changes in the effective price of delivered nicotine suggested above in equation (1.6). If the above model assumptions are correct, existing empirical research suffers from specification and omitted variable bias. With that caveat in mind, existing evidence generally supports the prediction of basic economics that consumers will substitute toward less expensive nicotine delivery devices.

Agaku and Alpert (2014) describe trends in the share of tobacco sold in different forms and relate trends in sales to federal and state taxes on various products. They show that the relatively higher tax on cigarettes is likely inducing nicotine consumers to substitute to cigars and other nicotine delivery devices. Cotti, Nesson, and Tefft (2018) find that households buy fewer cigarettes and e-cigarettes when cigarette excise taxes increase (suggesting the two devices are complements). They also find that increases in the shadow price of cigarettes (cigarette smoke-free air laws) decrease cigarette purchases, but that similar laws about use of e-cigarettes do not affect either cigarette or e-cigarette purchases. This evidence is difficult to interpret because the laws banning e-cigarette use are relatively rare, new, and it is unclear how strictly they are enforced.

Evidence suggests that consumers substitute between at least some of the nicotine delivery devices. Studies have estimated positive and statistically significant cross-price elasticities of sales and consumption between cigarettes and e-cigarettes using market sales data (Zheng et al. 2017; Stoklosa et al. 2016) and longitudinal data (Cantrell et al. 2019). Huang et al. (2018) also estimate positive and statistically significant cross-price elasticities of demand between cigarettes and little cigars, loose tobacco, pipe tobacco, and dissolvable lozenges. They find that cigarettes and cigars are complements in consumption. Similarly, Zheng et al. (2017) use market level data and product prices to conclude that consumers treat cigarettes as complements with large cigars, smokeless tobacco, and roll-your-own tobacco. None of these studies adjusts prices for the bioavailability of nicotine from each device or the social and health costs associated with each device.

1.8.4 Literature related to the shadow price of nicotine: price, taxes, advertising, and smoking bans

The above model posits that the use of a particular nicotine delivery device depends on the shadow price of using each device. As noted above, no published study measures either price or tax in the way that is theoretically indicated above – the price or tax per unit of delivered nicotine (bioavailable nicotine) from each device. In a similar way, the literature does not frame advertising in terms of creating a social cost/benefit of using particular devices. A large literature explores social perceptions of smoking and implicitly frames it in the way the above model frames it. In the context of e-cigarettes, Amin et al. (2020) review literature that explores how social perceptions of e-cigarettes is associated with intentions to use or actual use of e-cigarettes. They conclude that social perceptions increase intentions to use and actual use of e-cigarettes. So this possible factor in the shadow price has potential to improve our understanding of nicotine consumption. Although there is a huge literature trying to determine whether cigarette advertising induces people to smoke cigarettes, it is rife with statistical challenges that prevent inferences of causality. Two articles worth mentioning are Avery et al. (2007) and Dave et al. (2019). Avery et al. (2007) finds credible evidence that, when smokers see more magazine advertising of nicotine replacement products (as a group), they are more likely to attempt to quit and successfully quit. Dave et al. (2019) uses a similar strategy to find that exposure to e-cigarette advertising on television is associated with a higher probability that smokers quit. In the context of the above model, it is unclear if the advertising should be considered as information consumers currently lack or as part of the shadow price of consumption. Both studies uses advertising data that appeared during periods when the particular nicotine delivery devices were relatively new. That fact suggests that manufacturers might have advertised to inform not persuade consumers.

One can treat bans on the use of particular nicotine delivery devices as an increase in the shadow price. Indeed, a marketing strategy of firms selling snus is that users no longer need to spit tobacco juice produced when they chew tobacco. Some evidence supports the idea that such bans belong in the shadow price. For example, Cotti, Nesson, and Tefft (2018) find that, in states and localities that ban cigarette smoking in public places (cigarette smoke-free air laws) households buy fewer cigarettes. However, similar laws about use of e-cigarettes do not affect either cigarette or e-cigarette purchases. This evidence is difficult to interpret because the laws banning e-cigarette use are relatively rare, new, and it is unclear how strictly they are enforced.

Regardless, the economics of nicotine consumption and the choice of a growing number of nicotine delivery systems, can profitably measure the shadow price as fully as is feasible. In so doing, researchers can gain greater power to predict who consumes what, when, and with what device.

1.9 Conclusion

The advent of new methods to deliver nicotine has highlighted the central role demand for nicotine plays and has always played in markets for tobacco products. Because new delivery devices have separated nicotine from tobacco, consumers can satisfy their demand for nicotine with fewer physical costs associated with smoking, chewing, or using powdered tobacco. This chapter highlights some of the neuroscience of nicotine that establishes both positive and negative effects of nicotine on physical and mental health. I propose a life-cycle model of consumption that lets utility be a function of mental and physical health and in which mental and physical health vary with the consumption of nicotine. The model predicts that individuals will consume nicotine differently over different life-cycle stages according to whether or not nicotine has net benefits that exceed costs (discounted to the present). The value of the model is that it predicts when individuals will start and stop using nicotine, ties those predictions to underlying evidence from neuroscience, and can be tested empirically. The model also differs from existing models because it posits that consumers pay attention to three specific costs when they decide whether to consume and how much to consume nicotine. The first innovation is to posit that money price of nicotine should be measured in terms of the price per unit of nicotine actually delivered into the bloodstream by a given nicotine delivery device. By measuring price in this way, researchers will be able to directly compare price elasticities of demand across very different nicotine delivery devices. Similar adjustments to taxes are needed. The second innovation is to formally recognize, as others previously have, that social stigma, advertising, and social approbation and condemnation figure into the shadow price. The latter is partly a function of portrayals of use of each device in movies and television. It is also something that varies by social group. The third component of the shadow price is the accumulated degradation of health associated with a unit of nicotine consumption delivered by a particular device. Those costs vary tremendously across devices and over time for a given nicotine delivery device (e.g. filtered versus unfiltered cigarettes).

The model yields a host of testable predictions for which data exist or could be constructed with existing data. Tests of those predictions will reveal whether the model assumptions need to be revisited or not. The results of those tests will also help researchers better understand patterns of initiation, intensity of use, substitution, and cessation.

It is important to recognize that people get benefits and pay costs when they consume nicotine. Researchers need to delve more deeply to understand who benefits from consuming nicotine, how they benefit, and whether the new delivery devices lower the costs of consuming nicotine to justify government interventions into the new market for nicotine. That task remains for researchers to pursue.

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