Plain Cigarette Packaging and Its Effect on Youth Smoking Rates

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Abstract

In this paper I develop a consistent modelling framework in which to consider the effect of plain cigarette packaging on youth smoking rates. Under very general assumptions I isolate two distinct effects of the policy, a value effect and diversity effect. I show that the latter effect can, under certain circumstances, overcome the former and lead to an increase in youth smoking through falling prices. Applying additional structure, I also show how government may use the tax system to offset this price effect and ensure youth smoking rates decline. The analysis presented has wider implications for the way in which government should approach the regulation of smoking and junk food.

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1 Introduction

In recent years policy makers have taken several steps to curtail youth smoking rates. These policy measures have included, but are not limited to, taxation, prohibition of tobacco advertising and public health campaigns. A recent development in the drive to reduce smoking is standardised or 'plain' cigarette packaging. Australia was the first to introduce plain cigarette packaging in December 2012 and at the time of writing remains the only country to have done so, although the policy has since been approved by MPs in the UK and the Irish Seanad (BBC News, 2015). The policy is also being considered more widely by the developed world. Despite being commonly referred to as 'plain' cigarette packaging, the policy would remove all the attractive or promotional aspects of a cigarette's packaging and intentionally make it unattractive. The current UK proposal is that, "except for the brand name (which would be presented in a standardised way), all other trademarks, logos, colour schemes and promotional graphics would be prohibited" (Barber and Conway, 2015). The new packaging would comprise of an unattractive colour scheme, prominent health warnings and graphic images of the consequences of smoking; Figure 1.1 is the current packaging proposed by the UK government. In the UK, much of the opposition to the policy rests with concerns relating to employment in the tobacco

Figure 1.1: Proposed packaging

Source: UK Department of Health

industry, illegal cigarettes and the effect on small retailers. [1] Another interesting dimension of the debate has been the insistence by some commentators (and the tobacco industry itself) that the policy will backfire. The critics of the policy claim that it will lead to some combination of falling prices, greater counterfeiting or smuggling. In Australia, the campaign against plain cigarette packaging has been led by *The Australian*; it claimed that there was a 0.3% increase in tobacco sales volume in 2013 directly following the introduction of plain cigarette packaging. The veracity of these claims has been challenged by the health lobby and the Australian government (Daube and Chapman, 2014; The Guardian, 2014). Although I make no attempt to verify these claims made by *The Australian*, the model presented here would not rule out an increase in sales following the implementation of the policy. Nevertheless, Scollo et al (2014) writing in the British Medical Journal conclude that "one year after implementation, [there is] no evidence of the major unintended consequences concerning loss of smoker patrons from small retail outlets, flooding of the market by cheap Asian brands and use of illicit tobacco predicted by opponents of plain packaging in Australia." In this paper, I restrict my attention to the effect the policy has on youth smoking rates. This is not to dismiss the other arguments, or even diminish their importance, but to concentrate on measuring the effectiveness of the policy against its stated aim. [2] Reducing youth smoking rates is important as the evidence suggests that it is during these years adult smokers begin smoking. In the UK approximately seven in ten adults who have ever smoked regularly began smoking before they were 18 years old (Department of Health, 2008). Another primary motivation for focussing on youth smoking is that youth smoking rates have increased in Australia between 2010 and 2013, reversing a declining trend. The significance of this reversal is that it has taken place despite the introduction of plain cigarette packaging and increased taxation of tobacco. Although it is not possible to assign any causality to this increase, it raises important questions about the effectiveness of the policy. In the model presented here, the policy has two distinct effects. The first effect is the *value effect* and relates to how the value of smoking is reduced by the policy. This effect is what the current research has focussed on almost exclusively and is discussed extensively in Section 2. The second effect

[1] In the UK, 70 MPs wrote an open letter to the Health Secretary, Andrew Lansley, on 29 June 2012 suggesting that the policy would endanger more than 5,500 jobs in the tobacco sector in the UK. The MPs were also concerned that the policy would make smuggling easier.

[2] A UK government consultation on the policy asked whether "plain packaging of tobacco products has merit as an initiative to reduce smoking uptake by young people." It also lists "protecting children and young people from smoking" as one of the four main areas in developing a new national tobacco control strategy (Deparment of Health, 2008).

Table 1.1: Australian smoking rates for 12–17 year olds

Smoking status	2004	2007	2010	2013
Daily	5.2	3.2	2.5	3.4
Occasional	1.5	0.9	1.3	1.6
Ex-smokers	1.7	0.9	1.6	0.3
Never smoked	91.6	95.0	94.7	94.7

Source: National Drugs Strategy Household Surveys, Australian Institute of Health and Welfare

is the reduction in product diversity available in the market, which I refer to as the *diversity effect*. This distinction between the value and diversity effect is critical in understanding why the policy may have an ambiguous effect on youth smoking and may ultimately backfire. It is the diversity effect that has ambiguous consequences for the youth smoking rate and may offset the value reduction effect of the policy. To address the central question of whether the policy will reduce youth smoking rates, I develop a search model grounded in the work of Wolinsky (1984) and Anderson and Renault (1999) on consumer search with product differentiation. In these seminal papers, a consumer has an individual specific product match with every firm which is unobservable and determined by the characteristics of the different goods. Consumers must search a firm before learning its price and their individual match, incurring a constant marginal cost each time they do so. In my model, this match value represents a consumer's match with the particular branding, flavour profile and other unobservables that are unknown to them before searching a firm. The match value is a random variable that follows a distribution known to both consumers and firms allowing them to make optimal search and pricing decisions, respectively. I make one additional assumption regarding the possible distribution of the match value in order to define the policy of plain cigarette packaging. [3] This paper contributes to the search model literature by combining aspects of the product design literature developed by Johnson and Myatt (2006) and Bar-Isaac et al (2012) with heterogeneous agents. Bar-Isaac et al (2012) model product design by allowing firms to select the variance of the match parameter

[3] I maintain the assumption that the distribution is log-concave but make the additional assumption that the distribution belongs to the location-scale family. The importance of this assumption is explained in Part II.

within some interval; high and low variance would represent niche and broad products, respectively. When firms are heterogeneous in value, the product design strategy is a mapping from the firm's objective value to the product design variance space. In equilibrium, high quality firms choose broad product designs while low quality firms choose niche designs. The underlying idea here is that low quality firms compensate for their quality by making their designs as niche as possible. This is optimal since niche designs will appeal to some agents enough for them to overlook the low quality. An important distinction in my model is that product design is not endogenous and so firms do not choose design alongside price. This means there is a single variance parameter corresponding to the match value for all firms. The variance of the match parameter changes only in response to the policy. By restricting the ability of firms to choose their own design and display branding, the policy reduces the variance of the match parameter. Armstrong et al (2009) consider heterogeneity where a particular firm is prominent in the market and sampled first by all consumers, while Arbatskaya (2007) considers a more extreme environment in which all searches are ordered. Particular attention is paid to how an agent's search behaviour is determined by their search costs and how firm's react when we allow for search cost heterogeneity. In contrast, Anderson and Renault (2006) consider a world in which there is a monopoly firm that can use advertising to be informative about their product's price or characteristics and model heterogeneity as differences in an agent's reservation price for the good. For simplicity I do not consider prominence and consumer heterogeneity in search costs. Furthermore, advertising has been banned in the markets considering the introduction of plain cigarette packaging and so plays no role in my model. Instead, consumer heterogeneity in my model takes the form of two distinct groups of *insiders* and *outsiders*. The insiders are adult smokers who are assumed to be addicted (always make a purchase) and whose search decisions affect the equilibrium price. The outsiders are young smokers and differ from the insiders in that they receive a free first match and have the outside option of not smoking (exiting the market). In Part I, I present the search model outlined above and state a sufficient condition for which the price of cigarettes is decreasing when product variety falls. This theorem is due to Anderson and Renault (1999) and is a potentially counter-productive result when reducing youth smoking rates is one of the principal concerns of policy makers. Additionally, I characterise the two possible youth smoking equilibria that can arise. In Part II, I disentangle the two effects of the policy to show why it has ambiguous effects on the youth smoking rate. By making additional assumption in Part III, I am able to derive successful policy conditions that could be used by a well informed policy maker to adjust the taxes on cigarettes to offset any fall in prices. The contribution of this paper to the policy debate is that it develops a consistent framework in which to model the effects of the policy. What is more, the research currently being used to support the policy of plain cigarette packaging is problematic. Much of the research outlined in Section 2 attempts to show, rather predictably, that by making the packaging unattractive the policy reduces the value of smoking. The danger is in concluding that this reduction in value necessarily means a reduction in adult or youth smoking. These papers fail to consider the policy's general equilibrium effects on the market, i.e. the response of firms and consumers to the reduced product diversity and value.

2 Health Literature Review and The Value Effect

In the absence of any substantial empirical evidence on the effects of plain cigarette packaging, much of the justification has focussed on the behavioural and psychological effects of making the packaging unattractive in deterring young people from taking up smoking. I briefly summarise the health literature on the effects of plain cigarette packaging below. Wakefield et al (2013) surveyed 536 smokers living in the Australian state of Victoria in November 2012 and conclude that plain cigarette packaging reduces a smoker's perceived quality and satisfaction of smoking as well as increases the frequency and intensity of negative thoughts associated with smoking. [4] Hogarth et al (2015) attempt to evaluate the effect the policy has on the tobacco seeking behaviour of smokers. They sampled the responses of adult smokers in a nominal Pavlovian to instrument transfer procedure and found that branded packs "primed a greater percentage of tobacco-seeking." They conclude that "plain packaging may reduce smoking in current smokers by degrading cue-elicited tobacco-seeking." Brose et al (2014) supports both of these conclusions, suggesting that "standardised cigarette packaging may reduce acute (hedonic) craving and is associated with more negative perceptions than branded packaging with less prominent health warnings." Maynard et al (2015) conduct a randomised control study on smokers to assess the impact replacing current UK branded packs with Australian packaging has on their behaviour as well as the utility they obtain from smoking. They conclude that smokers "reduce ratings of

[4] These negative thoughts include the perceived harm of smoking, quitting, quitting priority and intention to quit.

the experience of using the cigarette pack, and ratings of the pack attributes, and increase the self-perceived impact of the health warning, but do not change smoking behaviour, at least in the short term." This research draws attention to the fact that addiction plays a key role in the behaviour of adults smokers, which I return to in my model. Moodie et al (2011) go further, suggesting that the policy may help reduce tobacco consumption among smokers aged between 18–35 years, and in particular women in this age group. They recruited 140 volunteers in Scotland to smoke cigarettes from plain packets and their regular packets for a fortnight at a time and surveyed them on their attitudes to smoking over this period. [5] Thrasher et al (2011) ran auction experiments with adult smokers to determine how their valuation varies with packaging design. They report that bids fell as the packaging was made more unattractive and in the case of prominent health warnings, the fall in demand was statistically significant. They conclude "results suggest that prominent health warnings with graphic pictures will reduce demand for cigarettes." Additionally, they write "regulators should not only consider this type of warning label, but also plain packaging policies for tobacco products." All of the studies presented here highlight the value effect of the policy; this is how the policy reduces an individual's value from smoking. Essentially all of these studies are asking smokers "how does your value of smoking change when you smoke from plain cigarette packets?" I take as given that the policy reduces the value of smoking to all individuals in my model and consider this the consensus view of the health literature. However, what is problematic with some of these papers is the suggestion that plain cigarette packaging will lead to a reduction in smoking rates or demand as a result of this value effect. This conclusion is the result of a partial equilibrium analysis since it ignores the response of consumers and firms to the reduced diversity in the market. Reducing diversity causes individuals to alter their search behaviour since the benefits of searching are reduced by the policy. Firms take this change in search behaviour into account, as well as the direct reduction in their market power when setting their prices after the introduction of the policy. If prices go down as a result of the policy, it is no longer the case that the reduction in value is enough to ensure smoking rates will decline.

[5] It is worth noting that the attrition rate was very high and only 48 correctly responded to the surveys, and only 18 participated in a post-study interview.

Part I

The Search Model

3 Consumers

In this section I outline the optimal behaviour of adult smokers and young individuals. There are two disjoint populations of adult smokers and young individuals of size N_A and N_Y, respectively. The utility of consumer l from smoking cigarette brand i is given by

$$u_{li} = v - p_i - t + \mu\epsilon_{li} \tag{3.1}$$

and is common to both populations. The value of smoking is v, the price of cigarette brand i is p_i, the tax on all cigarettes is t and the final term is the random match between consumer l and cigarette brand i. The match between a consumer and a cigarette brand is unknown to the consumer before she searches that firm. I assume that ϵ is mean zero and independent and identically distributed according to the probability density function f (with corresponding cumulative density denoted by F) on the support $[A, B]$. Note that since ϵ is mean zero, it must be the case that $A < 0$ for all non-trivial distributions. I also assume that f is log-concave and belongs to the location-scale family of distributions. [6] This match value between an individual and a brand corresponds to how much a consumer values the packaging, flavour profile of the cigarette and so on, all of which is unknown to a consumer before searching the firm. Consumers in this model search sequentially and incur a cost c each time they wish to discover a cigarette brand's price and their match value with the particular brand. Consumers are only able to purchase a particular brand if they have searched that firm and are able to recall previous matches at no additional cost. One fundamental difference between adult smokers and young individuals in my model is that adult smokers are assumed to be addicted to smoking and will always make a purchase. This assumption rules out changes to the adult smoking rate and relates back to the idea that the policy may reduce the value adult smokers obtain

[6] These restrictions includes many familiar distributions, namely the normal, uniform, logistic, Laplace and extreme value distributions. The restrictions are important in the proof of Theorem 1, in the definition of the policy in Part II and allow me to assume that ϵ is mean zero without loss of generality. In Part III of this paper I discuss the special case of the uniform distribution.

from smoking but does not alter their behaviour (Maynard et al, 2015). In contrast, young individuals are not assumed to be addicted to smoking and have an outside option normalised to $\bar{u} = 0$. They each receive a free first match with a randomly selected brand of cigarettes before any search takes place. [7] This free first match represents the idea that at some point a youth will be offered a cigarette to try, learning its price and their individual match with the particular brand. After this initial match, a young individual then chooses whether to begin smoking that brand, searching the other brands in the market, or not smoking at all and exiting the market. Consider a symmetric equilibrium where all firms choose a price p^*. [8] Suppose a consumer currently holds a best offer x (match value), if she chooses to search another firm to obtain a match z, her highest offer is z if $z > x$ and x otherwise. Her gain in consumption utility is weakly increasing with every search and is given by

$$\Delta u = \begin{cases} \mu\left(z - x\right), & \text{if } z > x \\ 0, & \text{otherwise} \end{cases}.$$

Hence, she has an expected utility gain from searching given by

$$\begin{aligned} \mathbb{E}\left[\Delta u\right] &= \mu \int_x^\infty \left(\epsilon - x\right) f\left(\epsilon\right) d\epsilon \\ &= \mu g\left(x\right). \end{aligned}$$

In equilibrium the expected gain from searching must equal the marginal cost of search c. The threshold value at which consumers stop search $\hat{x}$ is implicitly defined by

$$g\left(\hat{x}\right) = \frac{c}{\mu}. \tag{3.2}$$

It is worth noting that $g\left(x\right)$ is positive and decreasing over its domain. What is more, the derivative $g'\left(x\right) = -\left[1 - F\left(x\right)\right]$ and $\lim_{x \to A} g\left(x\right) = -A > 0$. The value $\hat{x}$ will define a cutoff strategy for adults in the model whereby they will search sequentially until they receive a match

[7] Each brand is chosen with equal probability $1/n$ where n is the number of firms.

[8] In this paper I restrict my attention to symmetric equilibria where all firms charge the same price and have an equal market share. This follows from the fact that all firms are ex-ante identical, that is they differ only in their individual match with a consumer.

higher than or equal to $\hat{x}$. [9] If they search all n firms and receive no match greater than $\hat{x}$, they will choose to purchase from the firm with the highest match. In this paper I consider only interior solutions $\hat{x} \in [A, B]$, i.e. when the cutoff is located in the support of the distribution. This is important to note since $\hat{x}$ is not bounded from below and $\hat{x} < A$ corresponds to a degenerate equilibrium in which no agent chooses to search and firms charge infinite prices (see Diamond, 1971). The condition for an interior equilibrium is given by $c < \mu (\mathbb{E}[\epsilon] - A)$ and is explained in more detail by Anderson and Renault (1999). The equilibrium behaviour of young individuals will depend on the parameters of the model. Since young individuals retain the outside option, there are two possible cases:

1. **Search:** If the lowest acceptable match is below the adult search threshold, young individuals with an initial match below $\hat{x}$ search. They continue searching while their best match is below $\hat{x}$, but only smoke if one of the n matches gives utility above the outside option.

2. **No search:** If the lowest acceptable match exceeds $\hat{x}$ then no young individual searches. Those whose initial match is below the lowest acceptable match exit, while those whose initial match exceeds it smoke the brand they were matched to initially.

4 Firms

In this section I consider the equilibrium pricing strategy for firms. There are $n \in \mathbb{N}_{>1}$ firms competing in the market, producing one brand and choosing only their price. [10] I assume that firms only consider the adult population of smokers when setting prices. This assumption has important implications for the youth smoking market, namely, firms do not take into account how their prices affect the decision of young people to smoke or not. This relates to the notion of young individuals being outsiders; their search decisions do not affect prices at all. My

[9] Formally, write the utility of searching one more time given j searches as $U_S^j = v - p^* - t + \mu \max\{x_1, \ldots, x_j\} + \mu g(\max\{x_1, \ldots, x_j\}) - c$. This function is weakly increasing in the number of searches. This ensures that an agent will always find it worthwhile searching if they do not possess a match exceeding $\hat{x}$.

[10] It is worth noting that I do not consider market entry or exit, and treat the number of firms competing in the market as fixed. While this assumption is useful in simplifying the model, it is somewhat plausible in the case of the tobacco industry where sizeable barriers to entry exist. In some sense the analysis presented here is short-run in nature and the model would predict firms exiting in the long-run following the introduction of plain cigarette packaging. This follows directly from Proposition 3 of Anderson and Renault (1999): the optimal number of firms is increasing in $\hat{x}$.

justification for this assumption centres on the current law in the UK regarding the sale of cigarettes to minors and the relatively small number of youth smokers. The Criminal Justice and Immigration Act 2008 can be used to strip any retailer found to have sold tobacco products to a person under the age of 18 twice in any two year period of its licence to sell tobacco products to anyone for up to one year. [11] What is more, in 2013 the UK youth smoking rate for those aged 11–15 was only 3% corresponding to approximately 100,000 individuals (Fuller and Hawkins, 2014). A young person is classed as a regular smoker if they smoke at least one cigarette per week. In contrast, there are an estimated 9.4 million adult smokers in the UK (Orchard, 2014). This implies that youth smokers represent approximately 1% of smokers in the UK; it is also very likely that they represent a much smaller fraction in terms of sales given that one cigarette a week is enough to qualify as a youth smoker. Given this assumption, I define a firm's demand in an identical way to Anderson and Renault (1999). Suppose that all firms but i set their price equal to p^*. I define the probability that firm i 's match value exceeds a consumer's threshold value $\hat{x}$ as

$$\Pr(x > \hat{x}) = 1 - F(\hat{x} + \Delta),$$

where $\Delta = (p_i - p^*)/\mu$ is the standardised price premium of firm i. Demand for firm i will be the sum of all the adults whose match with firm i whilst searching is the first to exceed the reservation value $\hat{x}$, and the adults for whom firm i had the highest match value after searching all n firms given none exceeded $\hat{x}$ (comebacks)

$$D_i(p_i, p^*) = N_A \left\{ \frac{1}{n} \left[1 - F(\hat{x} + \Delta)\right] \left[\frac{1 - F(\hat{x})^n}{1 - F(\hat{x})}\right] + \int_{-\infty}^{\hat{x}+\Delta} F(z - \Delta)^{n-1} f(z)\, dz \right\}. \tag{4.1}$$

The first term follows from the fact the firms are sampled according to the geometric series

$$\frac{1}{n} + \frac{F(\hat{x})}{n} + \frac{F(\hat{x})^2}{n} + \ldots + \frac{F(\hat{x})^n}{n}.$$

[11] The particular legislation can be found in §4.11.143 of the Criminal Justice and Immigration Act 2008.

Maximising firm i 's demand with respect to their own price, the symmetric equilibrium price is [12]

$$p^*(\mu, c, n) = \frac{\mu}{f(\hat{x})\left[\frac{1 - F(\hat{x})^n}{1 - F(\hat{x})}\right] - n\int_{-\infty}^{\hat{x}} f'(z)\, F(z)^{n-1}\, dz}. \tag{4.2}$$

It is worth noting here that the price of cigarettes depends only on diversity μ, the cost of search c and the number of firms in the market n. For notational convenience I write $p^*(\mu, c, n) = p^*$ from here on. The reason price is independent of the value of smoking v and taxation t is that these things are uniform across all firms and so cannot affect price in a symmetric equilibrium. Given the assumption that adult smokers are addicted and must make a purchase (even if they never obtain a match exceeding $\hat{x}$), v and t cannot influence search behaviour. In a sense they only have *level effects* and not search or competition effects.

Theorem 4.1. *Suppose f is log-concave on $[A, B]$ and we have an interior equilibrium. Then on any interval such that $f'(\hat{x}) \leq 0$, p^* is increasing in μ.*

Theorem 1 is due to Anderson and Renault (1999) and is proved in Appendix B. It provides a region in which a reduction in product diversity will reduce the equilibrium price for sure. Any change to μ has both a direct and indirect effect. A reduction in μ represents a weakening of a firm's market power directly, but since agents reduce their search activity, it allows firms to increase prices somewhat. When there is sufficiently high diversity, reducing diversity leads to a fall in prices as the market power effect dominates the reduction in search activity effect. [13] Theorem 1 is fundamental in explaining why the policy may backfire and I will return to it in Part II.

5 Youth Smoking Equilibrium

In this section I explain the two possible youth smoking equilibria that may arise and the conditions required for each of them. Recall that every young individual receives a free first match, denoted by x_0, before having the option to begin smoking the brand they were matched

[12]For a detailed discussion of this optimisation see Appendix A or Section 3 of Anderson and Renault (1999).

[13]There may exist regions outside this where prices are also decreasing with diversity, however, characterising them with a closed form expression is difficult without further restrictions.

to initially, searching the remaining firms at a marginal cost c or exiting the market. The key distinction from adults is that young individuals retain the outside option after search begins. Let the lowest acceptable match be

$$x_M = \frac{p^* + t - v}{\mu}. \tag{5.1}$$

This is the match value that gives a young person utility equal to the outside option $\overline{u} = 0$. Equivalently, the utility from accepting a best current match x is $\mu (x - x_M)$. Suppose a youth currently holds a best match x and considers searching one more firm, whose match is z. Because she can always exit, the relevant fallback is the better of smoking the best discovered brand and taking the outside option. The expected gross gain from another search is therefore

(5.2)

$$H(x) = \mathbb{E}\left[\max\{0, \mu(\max\{x, z\} - x_M)\} - \max\{0, \mu(x - x_M)\}\right] = \begin{cases} \mu g(x_M), & x < x_M \\ \mu g(x), & x \geq x_M \end{cases}.$$

Thus, when the best discovered match is below x_M, the current cigarette offer has no value as a fallback and the expected gain from search is computed relative to the outside option. A youth searches whenever $H(x) \geq c$.

Search

Search occurs when the lowest acceptable match is below the search stopping threshold:

$$x_M \leq \hat{x}, \quad \text{or equivalently} \quad p^* \leq v - t + \mu\hat{x}. \tag{5.3}$$

Since g is decreasing and $g(\hat{x}) = c/\mu$, this condition implies $\mu g(x_M) \geq c$. A youth with a current best match below $\hat{x}$ searches; a youth with a current best match at least $\hat{x}$ accepts that match. The youth smoking rate in this case is

$$\rho_S = 1 - F(x_M)^n. \tag{5.4}$$

The only youths who never smoke are those whose best match after all n possible matches is still below x_M.

No Search

No search occurs when the lowest acceptable match exceeds the adult search threshold:

$$x_M > \hat{x}, \quad \text{or equivalently} \quad p^* > v - t + \mu\hat{x}. \tag{5.5}$$

In this case, for any $x < x_M$ the expected gain from search is $\mu g(x_M) < c$, while for any $x \geq x_M$ the expected gain from search is below the marginal search cost because $x > \hat{x}$. Thus no young individual searches. The youth smoking rate is

$$\rho_N = 1 - F(x_M). \tag{5.6}$$

It does not depend directly on the number of firms in the market. [14] At the boundary $x_M = \hat{x}$, youths with a current best match below x_M are indifferent between searching and exiting. The smoking rate at this boundary therefore depends on the tie-breaking rule. I assign the weak inequality to the search case in 5.3.

Part II

The Policy of Plain Cigarette Packaging

6 How The Policy is Defined

In this section I define the policy in the context of my model, explaining the distinction between the value and diversity effects. From there I make statements about the effectiveness of the policy and give sufficient conditions to reduce the youth smoking rate in the general case of a log-concave, location-scale distribution. Before this, I explain the importance of the distribution of the match parameter belonging to the location-scale family. A random variable X is said to belong to the location-scale family when its CDF

$$F_X(x|a,b) = \Pr(X \leq x|a,b)$$

[14] The youth smoking rate depends on the number of firms in the market only through its effect on the equilibrium price p^*.

is a function only of $(x - a)/b$,

$$F_X(x|a,b) = F\left(\frac{x-a}{b}\right)$$

for all $a \in \mathbb{R}$ and $b \in (0, \infty)$. A familiar example would be the normal or uniform distributions, with the interpretation that a represents a location change, while b represents a scale change. In the case where we have mean zero and unit variance, a represents the mean and b represents the standard deviation of the transformed variable. I now make explicit the assumption that the distribution of the match value ϵ has mean zero and unit variance without loss of generality for my analysis (this transformation has welfare implications). [15] With this normalisation in mind, I define the policy in the following way.

Definition. *The policy of plain cigarette packaging is a location-scale transformation of the distribution of the match parameter. That is the government transforms the match value from* ϵ *to* $Y = -\gamma + \sigma\epsilon$ *where* $\gamma > 0$ *and* $\sigma \in (0,1)$. *The transformed variable belongs to the same distribution family as* ϵ, *but instead has mean* $-\gamma$ *and variance* σ^2. *Consider the utility of the agent after the introduction of the policy*

$$\begin{aligned} u'_{li} &= v - p_i - t + \mu(-\gamma + \sigma\epsilon_{li}) \\ &= \underbrace{(v - \mu\gamma)}_{v'} - p_i - t + \underbrace{\mu\sigma}_{\mu'} \epsilon_{li} \end{aligned}$$

where $v' < v$ *and* $\mu' < \mu$. [16]

The natural interpretation of this is that the policy simultaneously reduces the value of smoking and product diversity. The justification for this reduction in value follows on from the health research presented in Section 2 (Thrasher et al, 2011; Wakefield et al, 2013; Hogarth et

[15] This is without loss of generality since it involves an increasing linear transformation of the utility function. This would change the value of the parameters in the model if the true distribution of the match value is not mean zero with unit variance. In fact, the assumption of location-scale implicitly means that we are always estimating the same distribution but changing the "physical units" of measurement as we change the parameters a and b.

[16] I denote variables after the introduction of the policy with a prime, that is to say a' is the value of a after the policy has been introduced.

al, 2015; Maynard et al, 2015), meanwhile the reduction in diversity is a consequence of the reduction in product variety available.

7 Theoretical Impact of The Policy

In this section I present the main results of my analysis. In Lemma 2 I state the necessary local condition for the policy to *always* reduce youth smoking. The condition states that youth smoking must be increasing in both the value of smoking and product diversity. To be clear, if this condition is violated the policy may still reduce youth smoking, but not for all parameters $(v, \mu, c, n, t, \gamma, \sigma)$. Proposition 3 takes this result and shows that the policy is ambiguous in general, since the youth smoking rate is not always increasing in diversity. I also provide conditions that restrict the responsiveness of prices to ensure youth smoking is increasing in diversity.

Lemma 7.1. *A necessary local condition for the policy to reduce youth smoking throughout the parameter space is* $\partial\rho/\partial v > 0$ *and* $\partial\rho/\partial\mu > 0$.

Proof. The differential of the youth smoking rate with respect to v and μ is

$$d\rho = \frac{\partial\rho}{\partial v}dv + \frac{\partial\rho}{\partial\mu}d\mu.$$

The total change in the youth smoking rate can be decomposed as follows [17]

$$\begin{aligned}\rho\left(v', \mu'\right) - \rho\left(v, \mu\right) &= \rho\left(v', \mu'\right) - \rho\left(v, \mu'\right) + \rho\left(v, \mu'\right) - \rho\left(v, \mu\right) \\ &= \int_{v}^{v'} \frac{\partial\rho\left(v, \mu'\right)}{\partial v}dv + \int_{\mu}^{\mu'} \frac{\partial\rho\left(v, \mu\right)}{\partial\mu}d\mu.\end{aligned}$$

Recall that the change to v and μ from the policy is $v' - v = -\mu\gamma$ and $\mu' - \mu = \mu\left(\sigma - 1\right)$ where $\gamma > 0$ and $\sigma \in (0, 1)$. Since $v' < v$ and $\mu' < \mu$, I write

$$\rho\left(v', \mu'\right) - \rho\left(v, \mu\right) = -\int_{v'}^{v} \frac{\partial\rho\left(v, \mu'\right)}{\partial v}dv - \int_{\mu'}^{\mu} \frac{\partial\rho\left(v, \mu\right)}{\partial\mu}d\mu.$$

Since the policy reduces both v and μ, a negative partial derivative with respect to either

[17] Note that I omit the other arguments for notational convenience and $\rho\left(v, \mu\right)$ is $\rho\left(v, \mu, c, n, t\right)$.

parameter can make the corresponding policy change increase youth smoking locally. Thus the policy can reduce youth smoking throughout the parameter space only if both $\partial\rho/\partial v > 0$ and $\partial\rho/\partial\mu > 0$. □

The decomposition in Lemma 2 has the interpretation that we can consider the policy as two distinct changes: the government first reduces diversity and then reduces the value of smoking, or vice versa. This demonstrates that the risk of the policy lies in whether the diversity effect, if negative, can undo the reduction in youth smoking caused by the value effect. In a loose sense this is most likely when individuals do not find the new standardised packaging very unattractive and there is a substantial reduction in product variety. In this context we would expect a small value effect and a large diversity effect. This situation is problematic for policy makers since the policy cannot affect diversity ex-ante. What is more, even if we allow government to choose the design γ in some compact interval, the final value effect also depends on how much consumers care about the match value through μ. Even if government makes the packaging as unattractive as possible, it does not determine how this changes a consumer's value of smoking.

Proposition 7.2. *The effect of the policy on youth smoking rates is ambiguous. The reduction in value works to reduce youth smoking. The reduction in diversity reduces youth smoking if $\partial p^*/\partial\mu < x_M$ and can increase youth smoking if this condition fails.*

Proof. Away from the boundary $x_M = \hat{x}$, the youth smoking rate can be written compactly as

$$\rho = \begin{cases} 1 - F\left(x_M\right)^n, & x_M \leq \hat{x} \\ 1 - F\left(x_M\right), & x_M > \hat{x} \end{cases}.$$

From Lemma 2 we know that youth smoking always falls if $\partial\rho/\partial v > 0$ and $\partial\rho/\partial\mu > 0$. Taking the partial derivative with respect to the value gives

$$\frac{\partial\rho}{\partial v} = \begin{cases} -n\frac{\partial x_M}{\partial v} f\left(x_M\right) F\left(x_M\right)^{n-1}, & x_M \leq \hat{x} \\ -\frac{\partial x_M}{\partial v} f\left(x_M\right), & x_M > \hat{x} \end{cases}$$

and makes clear that the sign of the effect depends on the sign of $\partial x_M/\partial v$. Computing this partial derivative from 5.1 gives

$$\frac{\partial x_M}{\partial v} = -\frac{1}{\mu} < 0.$$

and it is straightforward to see that the youth smoking rate is increasing in the value of smoking, i.e. $\partial \rho / \partial v > 0$ in both equilibria. This allows us to conclude that reducing the value of smoking acts to reduce the youth smoking rate. I now turn my attention to the diversity effect of the policy. Taking the partial derivative with respect to μ gives

$$\frac{\partial \rho}{\partial \mu} = \begin{cases} -n \frac{\partial x_M}{\partial \mu} f(x_M) F(x_M)^{n-1}, & x_M \leq \hat{x} \\ -\frac{\partial x_M}{\partial \mu} f(x_M), & x_M > \hat{x} \end{cases}$$

The sign of this effect depends on the sign of $\partial x_M / \partial \mu$. Computing this partial derivative gives

$$\frac{\partial x_M}{\partial \mu} = \frac{\mu \frac{\partial p^*}{\partial \mu} - (p^* + t - v)}{\mu^2} = \frac{\frac{\partial p^*}{\partial \mu} - x_M}{\mu}.$$

The diversity effect reduces youth smoking if $\partial x_M / \partial \mu < 0$, or equivalently if

$$\frac{\partial p^*}{\partial \mu} < x_M.$$

This condition is not guaranteed since t and v are free parameters and independent of $\partial p^* / \partial \mu$. This proves the proposition. □

The ambiguity comes from two channels. Reducing the value of smoking raises the lowest acceptable match x_M and unambiguously reduces youth smoking. Reducing diversity has both a direct effect on how much utility a match generates and an indirect price effect. If prices are very responsive to changes in diversity, firms will cut prices aggressively and offset the fall in the value of smoking and unobservables to individuals. Proposition 3 makes explicit the risks of the policy and demonstrates why it does not always reduce youth smoking. By making the packaging of cigarettes uniform, government will reduce product diversity and weaken a firm's market power. If prices fall when diversity is reduced, the fall in prices could offset the other effects of the policy. By making the market more competitive, the policy may have the perverse effect of increasing youth smoking if the equilibrium price is responsive enough.

Claim. *Increasing taxation reduces youth smoking in both equilibria.*

Proof. The partial derivative of the youth smoking rate with respect to the tax on cigarettes is

$$\frac{\partial \rho}{\partial t} = \begin{cases} -n \frac{\partial x_M}{\partial t} f\left(x_M\right) F\left(x_M\right)^{n-1}, & x_M \leq \hat{x} \\ -\frac{\partial x_M}{\partial t} f\left(x_M\right), & x_M > \hat{x} \end{cases}$$

and $\partial x_M / \partial t$ determines the sign. Computing this partial derivative gives

$$\frac{\partial x_M}{\partial t} = \frac{1}{\mu} > 0.$$

Hence, the youth smoking rate is decreasing in cigarette taxes. □

The effect of increasing taxes should be unsurprising and follows from it being mathematically symmetrical to a reduction in the value of smoking. Increasing taxes raises the lowest acceptable match and reduces youth smoking in either regime.

Part III

Uniformly Distributed Match with a Continuum of Firms

8 Successful Policy Conditions

In this section I impose further structure on the model in order to derive additional analytic results. The two assumptions made here are

1. the match value follows a uniform distribution with mean zero and unit variance, that is $\epsilon \sim U\left[-\tau, \tau\right]$ where $\tau = \sqrt{3}$, and
2. there are a continuum of firms in the market ($n \to \infty$).

With these additional assumptions, I derive successful policy conditions for reducing youth smoking rates. These conditions are lower bounds for the tax changes required and how unattractive the new packaging needs to be. The uniform distribution assumption gives us

$f(x) = 1/2\tau$ and $F(x) = x + \tau/2\tau$. This assumption gives the expected gain from searching one more time

$$g(x) = \frac{1}{2\tau}\int_x^\tau (\epsilon - x)\, d\epsilon = \frac{1}{4\tau}(\tau - x)^2. \tag{8.1}$$

Solving for the equilibrium stopping rule where $g(\hat{x}) = c/\mu$ gives

$$\hat{x} = \tau - \sqrt{\frac{4\tau c}{\mu}}. \tag{8.2}$$

The probability of receiving a match below this threshold is given by

$$F(\hat{x}) = 1 - \sqrt{\frac{c}{\tau\mu}}. \tag{8.3}$$

The next step is to find the equilibrium price. When there exists a continuum of firms, the equilibrium price becomes

$$\lim_{n\to\infty} p^* = \mu\frac{[1 - F(\hat{x})]}{f(\hat{x})}$$

and in the particular case of the uniform distribution, using 8.3, is

$$p^* = 2\sqrt{\tau c \mu}. \tag{8.4}$$

What is immediately obvious from expression 8.4 is that prices are increasing in diversity for all parameter values. This is a special case and follows directly from Theorem 1; since the derivative of the PDF of a uniform distribution is zero everywhere, prices will always be increasing in diversity. The lowest acceptable match x_M does not depend on the distributional assumption directly, except through its effect on price. With a continuum of firms, the corrected youth smoking rate is

$$\rho = \begin{cases} 1, & x_M \leq \hat{x} \\ 1 - F(x_M), & x_M > \hat{x} \end{cases}.$$

Recall that after the introduction of the policy $\mu' = \mu\sigma$ and $v' = v - \mu\gamma$ where $\sigma \in (0,1)$ and $\gamma > 0$. From the expression of the equilibrium price 8.4, the new equilibrium price when diversity falls would be $p^{*\prime} = \sqrt{\sigma}p^*$. Let us first consider a no search equilibrium. In this case government will wish to increase the lowest acceptable match, so the successful policy condition is $x'_M > x_M$. This gives the tax condition

$$\Delta t > \left(\sigma - \sqrt{\sigma}\right) p^* + (1 - \sigma)(v - t) - \mu\gamma, \tag{8.5}$$

while the packaging condition is

$$\gamma > \frac{1}{\mu}\left[\left(\sigma - \sqrt{\sigma}\right) p^* + (1 - \sigma)(v - t)\right]. \tag{8.6}$$

These conditions are lower bounds on tax changes and packaging unattractiveness that reduce youth smoking when the economy remains in the no search regime. Finally consider the successful policy condition when the government finds itself in the search equilibrium. Since $\rho = 1$ in this equilibrium with a continuum of firms, the policy must move the economy into the no search regime. The condition is $x'_M > \hat{x}'$ or, equivalently, $p^{*\prime} + t' - v' > \mu'\hat{x}'$. Rearranging this policy condition gives the tax condition

$$\Delta t > v - t - \mu\gamma + \mu\sigma\tau - 2\sqrt{\sigma}p^*, \tag{8.7}$$

and the packaging condition

$$\gamma > \frac{1}{\mu}\left(v - t + \mu\sigma\tau - 2\sqrt{\sigma}p^*\right). \tag{8.8}$$

This analysis raises interesting questions regarding how government should implement the policy given it has the ability to choose taxes and/or the unattractiveness of the packaging design. An obvious question that arises is "why doesn't government simply increase taxes to infinity, or make the packaging design as unattractive as possible?" These policy responses would be optimal in a world where the government's only objective is to reduce youth smoking. In reality government may have welfare considerations as well as youth smoking targets. In this model adults are addicted and will always smoke, consequently increasing taxes heavily or making the packaging highly unattractive would reduce their welfare significantly. The conditions presented here should be seen as a way for governments to prevent the policy of plain cigarette packaging leading to more youth smoking through price effects. The optimal policy for government will depend on their social welfare or loss function.

9 Simulation Exercise

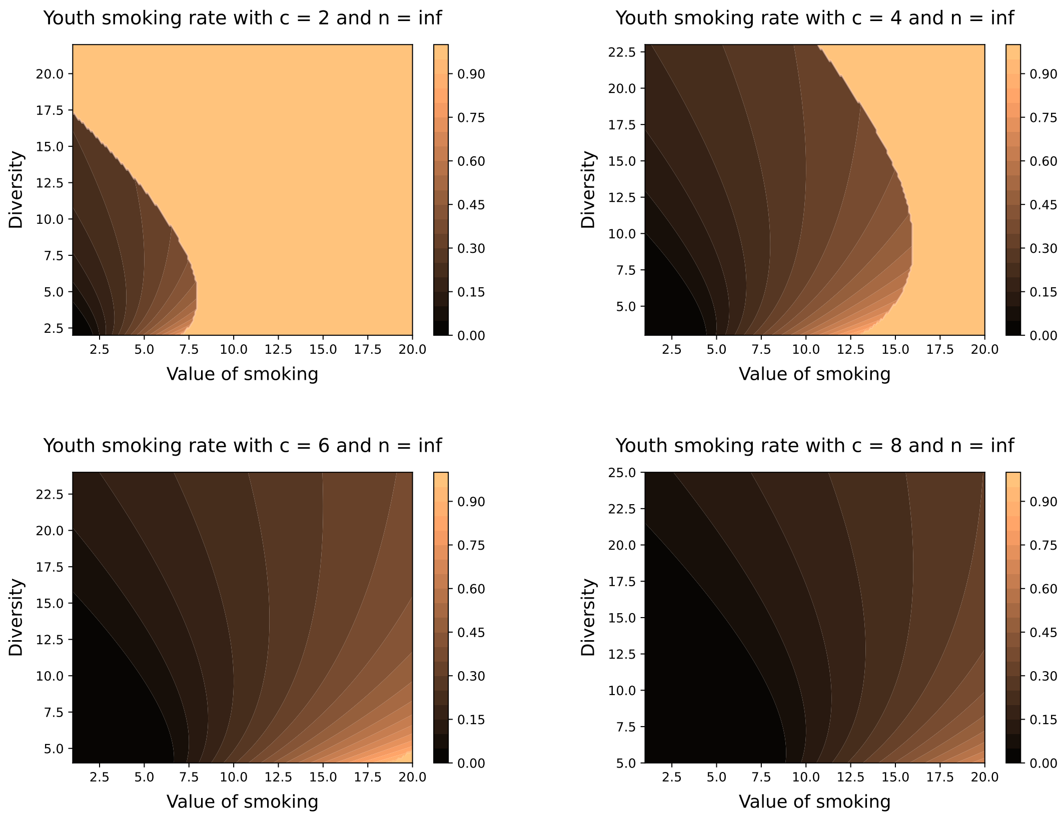
In this section, I maintain assumptions (1) and (2) and present simulations of the youth smoking rate plotted against smoking value and product diversity. Figure 7.1 presents simulations for four different search costs $c = \{2, 4, 6, 8\}$, where value is increasing along the x -axis and diversity along the y -axis. Note that in each simulation $v = [1, 20]$ while the interval for diversity is not fixed. This is a consequence of restricting my attention to interior equilibria only, where the condition $c < \mu (\mathbb{E}[\epsilon] - A)$ is satisfied. Hence, as search costs increase, the lowest level of diversity producing an interior equilibrium must also increase. For any combination of value and diversity, the policy of plain cigarette packaging moves the youth smoking equilibrium in a southwesterly direction. In the corrected continuum case the search region appears as a plateau where $\rho = 1$. It is straightforward to see from Figure 9.1 why the policy may still backfire in the no search region: if the reduction in diversity lowers equilibrium prices enough, it can reduce the lowest acceptable match and increase youth smoking. The corrected boundary between the search and no search regions is sharper because, with a continuum of firms, any young individual who searches eventually finds an acceptable match.

Part IV

Conclusion

In this paper I set out to develop a model in which to evaluate the effect of plain cigarette packaging on youth smoking rates. What I have succeeded in showing is that there exist many non-trivial situations in which the policy could increase youth smoking rates through the price effect. While there is little debate about whether the policy reduces the value of smoking to smokers, something I take into account, very little thought has been given to the general equilibrium effects of the policy prior to this. By reducing the diversity of products on the market, the policy strips cigarette companies of their market power and creates a more competitive landscape. Restricting the degree to which companies can differentiate themselves

Figure 9.1: Simulations of the youth smoking rate for different search costs



Note: the code used to produce these simulations is included in Appendix C.

using branding, for what is arguably a homogeneous good, is likely to lead to a commoditisation of tobacco products and a decline in profits across the industry. This fact explains why tobacco companies have challenged the policy aggressively and threatened countries considering the policy with legal action. Herein lies the tension between competition policy and health policy – making the market more competitive reduces prices, which in turn may entice more young people into smoking. In situations with high initial diversity, equilibrium prices are decreasing in the policy (Theorem 1). However, this is not the only effect since there is also a reduction in the value of smoking caused by the unattractive packaging and a reduction in the utility derived through unobservables due to reduced diversity. The major stumbling block is whether the price effect could offset any of these beneficial reductions in smoking utility, a question that has so far evaded the policy debate. Although the suggestion that the policy may backfire seems like a boon to the tobacco industry, my analysis suggests that the correct policy prescription should be some combination of plain cigarette packaging and price controls. These price controls may come in the form of offsetting tax adjustments or minimum cigarette prices, the latter being an issue debated for alcohol pricing in the UK. Making additional assumptions in Part III, I establish straightforward successful policy conditions that could be used by a well informed policy maker to gauge the effectiveness of the policy and calculate any required tax adjustment. Another central insight of my analysis is that policy makers should focus on price controls as well as value reducing policies, and only implement policies that affect product diversity after careful consideration. This conclusion justifies the use of effective health campaigns that directly lower the utility smokers obtain from smoking, as well as the high taxes on tobacco products in the developed world. These conclusions are of importance to similar policies being considered for junk foods and alcohol. Any policy that alters product diversity in the market, especially if it acts to commoditise the good, has the risk of reducing prices. There are some obvious extensions to the model that should be considered in any future research on the policy. The model presented here is static and does not consider market entry or exit for firms, or generational change over time; this extension would permit a long-run analysis of the effects. In time, as more data becomes available, future research should concentrate on an empirical assessment of the policy.

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Appendix

A Equilibrium price

The equilibrium price is obtained by maximising the firm's demand function with respect to its own price and given a symmetric price equilibrium. Demand for firm i is given by

$$D_i\left(p_i, p^*\right) = N_A \left\{ \frac{1}{n}\left[1 - F\left(\hat{x} + \Delta\right)\right] \left[\frac{1 - F\left(\hat{x}\right)^n}{1 - F\left(\hat{x}\right)}\right] + \int_{-\infty}^{\hat{x}+\Delta} F\left(\epsilon - \Delta\right)^{n-1} f\left(\epsilon\right) d\epsilon \right\}$$

In a symmetric equilibrium, the demand for firm i will be

$$D_i\left(p^*, p^*\right) = \frac{N_A}{n}.$$

The first derivative of the demand function with respect to own firm price is

$$\begin{aligned} \frac{\partial D\left(p_i, p^*\right)}{\partial p_i} &= N_A \left\{ -\frac{f\left(\hat{x} + \Delta\right)}{n\mu} \left[\frac{1 - F\left(\hat{x}\right)^n}{1 - F\left(\hat{x}\right)}\right] + \frac{1}{\mu} F\left(\hat{x}\right)^{n-1} f\left(\hat{x} + \Delta\right) \right. \\ & \left. -\frac{1}{\mu} \int_{-\infty}^{\hat{x}+\Delta} \left(n-1\right) F\left(\epsilon - \Delta\right)^{n-2} f\left(\epsilon - \Delta\right) \phi\left(\epsilon\right) d\epsilon \right\} \end{aligned}$$

and evaluating this at the symmetric equilibrium gives

$$\begin{aligned} \left.\frac{\partial D\left(p_i, p^*\right)}{\partial p_i}\right|_{p_i = p^*} &= \frac{N_A}{\mu} \left\{ -\frac{f\left(\hat{x}\right)}{n} \left[\frac{1 - F\left(\hat{x}\right)^n}{1 - F\left(\hat{x}\right)}\right] + F\left(\hat{x}\right)^{n-1} f\left(\hat{x}\right) \right. \\ & \left. - \int_{-\infty}^{\hat{x}} \left(n-1\right) F\left(\epsilon\right)^{n-2} f\left(\epsilon\right)^2 d\epsilon \right\}. \end{aligned}$$

The final two terms in parenthesis can be combined using integration by parts with limits as follows

$$F\left(\hat{x}\right)^{n-1} f\left(\hat{x}\right) - \int_{-\infty}^{\hat{x}} \left(n-1\right) F\left(\epsilon\right)^{n-2} f\left(\epsilon\right)^2 d\epsilon = \int_{-\infty}^{\hat{x}} f'\left(\epsilon\right) F\left(\epsilon\right)^{n-1} d\epsilon \tag{A.1}$$

allowing us to rewrite the derivative as

$$\left.\frac{\partial D\left(p_i,p^*\right)}{\partial p_i}\right|_{p_i=p^*}=\frac{N_A}{\mu}\left\{-\frac{f\left(\hat{x}\right)}{n}\left[\frac{1-F\left(\hat{x}\right)^n}{1-F\left(\hat{x}\right)}\right]+\int_{-\infty}^{\hat{x}}f'\left(\epsilon\right)F\left(\epsilon\right)^{n-1}d\epsilon\right\}.$$

A profit maximising firm will choose to set its price equal to

$$\begin{aligned}
p^* &= \frac{-D\left(p^*,p^*\right)}{\left.\frac{\partial D\left(p_i,p^*\right)}{\partial p_i}\right|_{p_i=p^*}} \\
&= \frac{-N_A/n}{\frac{N_A}{\mu}\left\{-\frac{f\left(\hat{x}\right)}{n}\left[\frac{1-F\left(\hat{x}\right)^n}{1-F\left(\hat{x}\right)}\right]+\int_{-\infty}^{\hat{x}}f'\left(\epsilon\right)F\left(\epsilon\right)^{n-1}d\epsilon\right\}} \\
&= \frac{\mu}{f\left(\hat{x}\right)\left[\frac{1-F\left(\hat{x}\right)^n}{1-F\left(\hat{x}\right)}\right]-n\int_{-\infty}^{\hat{x}}f'\left(\epsilon\right)F\left(\epsilon\right)^{n-1}d\epsilon}.
\end{aligned}$$

B Proof of Theorem 1

This proof follows directly from Proposition 2 of Anderson and Renault (1999) and is presented here for completeness.

Proof. Consider the reciprocal of the equilibrium price and make substitutions using 3.2 and A.1 to arrive at

$$p^* = \frac{c/g(\hat{x})}{f(\hat{x})\left[\frac{1-F(\hat{x})^n}{1-F(\hat{x})}\right] - nf(\hat{x})F(\hat{x})^{n-1} + n(n-1)\int_{-\infty}^{\hat{x}} f(\epsilon)^2 F(\epsilon)^{n-2}\,d\epsilon}$$

$$\frac{1}{p^*} = \frac{1}{c}\underbrace{\frac{g(\hat{x})}{1-F(\hat{x})}}_{a(\hat{x})}\underbrace{\left(\begin{array}{c} f(\hat{x})[1-F(\hat{x})^n] - nf(\hat{x})F(\hat{x})^{n-1}[1-F(\hat{x})] \\ +n(n-1)[1-F(\hat{x})]\int_{-\infty}^{\hat{x}} f(\epsilon)^2 F(\epsilon)^{n-2}\,d\epsilon \end{array}\right)}_{b(\hat{x})}$$

The derivative of this expression with respect to μ is

$$-\frac{\partial p^*}{\partial \mu}\left(\frac{1}{p^*}\right)^2 = \frac{1}{c}\frac{\partial \hat{x}}{\partial \mu}\left[a'(\hat{x})\,b(\hat{x}) + a(\hat{x})\,b'(\hat{x})\right]$$

$$\frac{\partial p^*}{\partial \mu} = -\frac{(p^*)^2}{c}\frac{\partial \hat{x}}{\partial \mu}\left[a'(\hat{x})\,b(\hat{x}) + a(\hat{x})\,b'(\hat{x})\right].$$

□

Proof. To show that $a'(\hat{x}) < 0$ it suffices to consider the log-concavity of $g(\hat{x})$ [18] which implies

$$\frac{\partial}{\partial \hat{x}}\left\{\frac{g'(x)}{g(x)}\right\} < 0.$$

Since the derivative $g'(\hat{x}) = -[1-F(\hat{x})]$, it follows that

$$\frac{\partial}{\partial \hat{x}}\left\{\frac{g(\hat{x})}{1-F(\hat{x})}\right\} = a'(\hat{x}) < 0.$$

[18] This follows from $g(x)$ being the integral of a log-concave function.

□

Proof. All that remains is to establish when $b(\hat{x})$ is decreasing in $\hat{x}$. The derivative of $b(\hat{x})$ is

$$\begin{aligned} b'(x) &= f'(\hat{x})\left[1-F(\hat{x})^n\right] - nf(\hat{x})^2 F(\hat{x})^{n-1} - nf'(\hat{x}) F(\hat{x})^{n-1}\left[1-F(\hat{x})\right] \\ &\quad -n(n-1) f(\hat{x})^2 F(\hat{x})^{n-2}\left[1-F(\hat{x})\right] + nf(\hat{x})^2 F(\hat{x})^{n-1} \\ &\quad -n(n-1) f(x) \int_{-\infty}^{\hat{x}} f(\epsilon)^2 F(\epsilon)^{n-2}\, d\epsilon \\ &\quad +n(n-1) f(x)^2 F(x)^{n-2}\left[1-F(\hat{x})\right] \end{aligned}$$

and collecting the terms leaves

$$\begin{aligned} b'(\hat{x}) &= f'(\hat{x})\left[1-F(\hat{x})^n\right] - nf'(\hat{x}) F(\hat{x})^{n-1}\left[1-F(\hat{x})\right] \\ &\quad -n(n-1) f(x) \int_{-\infty}^{\hat{x}} f(\epsilon)^2 F(\epsilon)^{n-2}\, d\epsilon. \end{aligned}$$

Factorising the first two terms gives

$$\begin{aligned} b'(\hat{x}) &= f'(\hat{x})\left[1-F(\hat{x})\right]\left\{\frac{1-F(\hat{x})^n}{1-F(\hat{x})} - nF(\hat{x})^{n-1}\right\} \\ &\quad -n(n-1) f(x) \int_{-\infty}^{\hat{x}} f(\epsilon)^2 F(\epsilon)^{n-2}\, d\epsilon \\ &= f'(\hat{x})\left[1-F(\hat{x})\right]\left\{\sum_{j=0}^{n-1}\left[F(\hat{x})^j - F(\hat{x})^{n-1}\right]\right\} \\ &\quad -n(n-1) f(x) \int_{-\infty}^{\hat{x}} f(\epsilon)^2 F(\epsilon)^{n-2}\, d\epsilon. \end{aligned}$$

It is clear that this is negative whenever $f'(\hat{x}) < 0$. □

C Simulation Code

```
"""Generate youth smoking-rate simulations for the thesis.

The model uses a uniform match distribution with mean zero and unit variance
and the corrected youth outside-option search rule.
"""

from pathlib import Path
import math

import matplotlib.pyplot as plt
import numpy as np


OUT_DIR = Path("SimulationFigures")
TAU = math.sqrt(3)
VALUE_GRID = np.arange(1, 20.0001, 0.1)
TAX = 0
SEARCH_COSTS = (2, 4, 6, 8)


def uniform_cdf(x):
    return np.clip((x + TAU) / (2 * TAU), 0, 1)


def simulate(search_cost):
    min_mu = math.ceil(search_cost / TAU)
    mu_grid = np.linspace(min_mu, min_mu + 20, 100)
    rho = np.zeros((len(mu_grid), len(VALUE_GRID)))

    for i, mu in enumerate(mu_grid):
        x_hat = TAU - math.sqrt((4 * TAU * search_cost) / mu)
        price = 2 * math.sqrt(TAU * search_cost * mu)

        for j, value in enumerate(VALUE_GRID):
            x_m = (price + TAX - value) / mu
            if x_m <= x_hat:
```

```
                rho[i, j] = 1
            else:
                rho[i, j] = 1 - uniform_cdf(x_m)

    return mu_grid, rho



def save_figure(search_cost):
    mu_grid, rho = simulate(search_cost)

    fig, ax = plt.subplots(figsize=(5.8, 4.55), dpi=100)
    levels = np.linspace(0, 1, 21)
    contour = ax.contourf(
        VALUE_GRID,
        mu_grid,
        rho,
        levels=levels,
        cmap="copper",
        vmin=0,
        vmax=1,
    )
    fig.colorbar(contour, ax=ax, pad=0.05)
    ax.set_title(
        f"Youth smoking rate with c = {search_cost} and n = inf",
        fontsize=15,
        pad=16,
    )
    ax.set_xlabel("Value of smoking", fontsize=14, labelpad=8)
    ax.set_ylabel("Diversity", fontsize=14, labelpad=8)
    ax.set_xlim(VALUE_GRID.min(), VALUE_GRID.max())
    ax.set_ylim(mu_grid.min(), mu_grid.max())
    fig.tight_layout(pad=1.6)

    OUT_DIR.mkdir(exist_ok=True)
    output_stem = f"search-cost-{search_cost}"
    fig.savefig(OUT_DIR / f"{output_stem}.pdf")
    fig.savefig(OUT_DIR / f"{output_stem}.eps", format="eps")
    plt.close(fig)
```

```
def main():
    for search_cost in SEARCH_COSTS:
        save_figure(search_cost)


if __name__ == "__main__":
    main()
```