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Habits and externalities

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Abstract

We develop a conceptual model characterizing two types of individuals: one myopic and the other hyperopic. A myopic individual ignores his private contributions to both a social and private negative externality, as well as the effect that his accumulation of stuff (i.e., the stock of consumption goods) has on his habit parameter. A hyperopic individual internalizes both externalities as well as his habit-formation effect. We find that the hyperopic individual consumes a greater amount of a clean good and a lesser amount of a dirty good, with the magnitude of the latter difference being greater than the magnitude of the former. Consequently, the hyperopic individual's cumulative consumption of the two goods is lower. The hyperopic individual's lower cumulative consumption also contributes to a less-persistent consumption habit. Further, we explore the extent to which the allocation of consumption across the clean and dirty goods made by an astigmatic individual (an intermediate type of individual who internalizes the private externality, as well as the habit-formation effect) diverges from the myopic individual's allocation. We consider the implications of our findings for traditional environmental tax policy as it applies to myopic and astigmatic individuals. Conceptually, we find that Pigovian tax rates in the presence of habit formation diverge from corresponding standard rates that ignore habit formation based on the difference between the magnitudes of the cumulative marginal benefit associated with habit formation and the marginal cost associated with the accumulation of stuff. Results from a simple numerical analysis demonstrate these conceptual results and more.

KEYWORDS
environmental externality, habit formation, tax policy

The chains of habit are too weak to be felt until they are too strong to be broken.
Samuel Johnson
Habit is a great deadener. Samuel Beckett

1 | INTRODUCTION

Johnson's and Beckett's aphorisms imply three things about habits—they form imperceptibly, they persist, and they negatively affect those of us who possess (or should I say, are possessed by) them. Most of us would probably agree that the first two of these implications are valid. The third one is not so much, since habits can have both negative and positive effects. Many of us suffer from the effects of bad habits, like overeating, negative thinking, laziness, and so forth. But there are also good habits that, when cultivated, improve our welfare—habits such as exercising, maintaining a healthy diet, mindfulness, and so forth. These habits extend to the consumption of actual commodities (which lead to the accumulation of "stuff") that affect our local and global environments, for example, all manner of durable goods. Some of these goods are "clean" (e.g., less-polluting) goods, such as electric vehicles and sustainably produced clothing, and some are "dirty" (more-polluting) goods, such as vehicles with internal-combustion engines and nonrecyclable appliances and furniture.[1]

This paper develops a simple conceptual theory of habit formation in the context of a standard externality model, where a habit forms imperceptibly in the consumption decisions of what we call a myopic individual. The consumption habit elicits both positive and negative welfare effects. The individual experiences a positive effect via an increase in his taste parameter associated with the consumption of both a clean and dirty good. In terms of their respective use values, the two goods are considered perfect substitutes. Their consumption in aggregate feeds a habit that heightens the individual's perceived welfare over time, which is why the habit persists.

[1]In reality, since the production and consumption of most if not all goods are associated with the emission of pollution, the distinction between these two types of goods is more accurately described as "cleaner" versus "dirtier." While we adhere to this distinction in the basic model described in Section 2 (i.e., consumption of the clean good contributes to the flow and stock of emissions, but at a lower rate than consumption of the dirty good), for expository purposes we refer to the two goods in the text as clean versus dirty.

But aggregate consumption also leads to the accumulation of stuff over time, which affects the individual's welfare negatively as he grapples with managing and storing the cumulative goods, in some cases eliciting negative intrinsic consequences as well. The accumulation of stuff can therefore be considered a private negative externality. The term "externality" is used liberally here. Technically speaking, the accumulation of stuff is not an external, third-party effect. Rather, it is an internal effect that arises due to its imperceptibility. Because it is imperceptible, and thus ignored by the individual, we model the accumulation of stuff as a common type of externality. In the organizational behavior literature this type of private externality has come to be known as an "internality," the essential feature being that it is unperceived by the individual (cf. Reimer & Houmanfar, 2017). Concomitantly, consumption of the clean good causes less of a negative externality per unit than the dirty good, for example, in the form of health damages associated with pollution caused by consumption of the two goods. Pollution is thus a social negative externality. Moreover, consuming the clean good elicits a "warm glow" effect, reflecting the added intrinsic value the individual receives from knowing that she is "doing something good for the environment."

Although the control of negative externalities has received considerable attention over time in the environmental and resource literature, the consequence of inward-looking habit formation has received comparatively little consideration.[2] Gorman (1967), Peston (1967), and Pollak (1970) provide early theoretical explorations into the modeling of habit formation, their guiding motivation being that, as Gorman puts it, "choices depend on tastes, and tastes on past choices (p. 218)."[3] More recently, numerical and empirical analyses of habit formation have been conducted in a variety of micro- and macroeconomic settings. In their meta-analysis, Havranek et al. (2017) find that, on average, studies based on microeconomic (and higher-frequency) data report lower estimates of the habit parameter in consumption than those based on macroeconomic (and lower-frequency) data.[4]

This paper's conceptual model compares the choice behavior mainly of two types of individuals: one myopic and the other hyperopic. A myopic individual ignores her private contributions to the negative welfare effects associated with both the social and private negative externality. Also ignored is the effect that the accumulation of stuff has on her habit parameter. In so doing, the myopic individual does not perceive the formation of her consumption habit. The hyperopic individual is the polar opposite. This type of individual internalizes both externalities and is cognizant of his consumption habit. We find that the hyperopic individual consumes a greater amount of the clean good and a lesser amount of the dirty good than the

[2]See Baumol and Oates (1988), and references therein, for an early, in-depth investigation of externality theory and control strategies, and Phaneuf and Requate (2017), and references therein, for a more recent, broader assessment.

[3]Peston was the first to show that when a myopic individual's utility function includes a parameter (or, habit) that depends upon previous consumption levels, the function generates consistent long-run demand functions. Gorman also investigated the nature of these functions, and described the conditions under which the corresponding utility function itself exists in the long run.

[4]Recent examples of this literature include Alvarez-Cuadardo et al. (2004), who model habit formation as a component of an intertemporal utility function, where the individual's current consumption is normalized by a reference consumption stock representing his habit. The reference stock is an exponentially declining weighted average of the individual's past consumption levels. The authors find that, in general, habit formation increases an economy's sluggishness by lowering the intertemporal elasticity of substitution. Fuhrer (2000) finds that habit formation helps explain the existence of a gradual hump-shaped response of real spending to various shocks in the US economy. Other macroeconometric studies incorporating habit formation explain consumption behavior among developed nations (Fuhrer & Klein, 2006) and the persistence of productivity shocks (Khorunzhina, 2015).

myopic individual, with the magnitude of the latter difference being greater than the magnitude of the former. Consequently, the hyperopic individual's cumulative consumption of the two goods is lower, as is his contribution to the social externality. Lower cumulative consumption also contributes to a lower habit parameter, which is indicative of a less-persistent consumption habit. Further, we find that the allocation of consumption across the clean and dirty goods made by an astigmatic individual (an intermediate type of individual who internalizes the private [but not the social] externality, as well as the habit-formation effect) diverges from the myopic individual's allocation of the two goods regardless of whether the goods are perfect or imperfect substitutes in preferences derived over aggregate and cumulative consumption. However, in the case of perfect substitutability the differences emanate from identical implied demand curves.

Regarding the design of tax policy to control the social externality caused by myopic and astigmatic individuals, we find that the adjustment to the standard Pigovian tax rate (which controls for a negative externality in the absence of habit formation) depends upon whether the marginal benefit associated with habit formation outweighs the marginal cost associated with the accumulation of stuff. To the extent that it does, the Pigovian tax rate in the presence of habit formation is lower than the standard rate.

Numerical evidence demonstrates our theoretical results, and extends our understanding of convergent trajectories among myopic and astigmatic individuals' key variables, on the one hand, and hyperopic individuals', on the other hand, as the price differential between the clean and dirty good (i.e., the clean good's price premium) widens. We find that as the price premium increases, respective demands for the clean good among the three types of individuals converge more quickly than do the demands for the dirty good. To the contrary, there is no discernible convergence between the levels of cumulative consumption and the social externality. While the social externality increases at a decreasing rate with the price premium for the three types of individuals, cumulative consumption remains constant. This constancy of cumulative consumption suggests that each individual's respective consumption habit is correspondingly maintained across an increasing price premium.

Section 2 introduces our basic model of habit formation in the presence of a negative social externality associated with aggregate consumption. Section 3 characterizes the myopic individual's decision problem, and Section 4 characterizes the hyperopic individual's problem. Section 5 compares the two, and distinguishes the astigmatic individual. Section 6 discusses the implications for tax policy, Section 7 presents our numerical results, and Section 8 concludes.

2 | THE BASIC MODEL

Consider a representative individual whose utility in any given time period, u, is governed by the following function[5]:

$$u(X, y, g, G, \hat{X}; \alpha(\hat{X}), \beta, \rho_G, \rho_{\hat{X}}, N), \tag{1}$$

where $X = x_1 + x_2$ is the individual's aggregate consumption of the clean good (x_1) and the dirty good (x_2) over a given time period, y is his consumption of a numeraire good, $g = \phi x_1$ is an

[5]To avoid unnecessary clutter, subscript t is not affixed to the model's variables, except when necessary.

attendant warm glow effect associated with consuming the clean good ($\phi > 0$), G is the stock of a negative social externality, and $\hat{X}$ the individual's stock of aggregate consumption.[6] We let $\alpha(\hat{X}) > 0$ represent the substitution parameter for X, the size of which depends upon $\hat{X}$ (described further below). Constant $\beta > 0$ denotes the substitution parameter for g, $\rho_G > 0$ the substitution parameter for G, $\rho_{\hat{X}} > 0$ the substitution parameter for $\hat{X}$, and N is the community's population size.

Function $u(\cdot)$ is assumed increasing in X, y, and g, decreasing in G and $\hat{X}$, and is strictly quasi-concave. We can interpret the negative welfare effect of G as being health damages incurred by the individual through society's production of goods 1 and 2 to meet his (and his community's) demands for the two goods. Health damages therefore arise as a consequence of societal decision making.[7] The negative welfare effect of $\hat{X}$ represents private damages incurred through the individual's personal accumulation of stuff (e.g., stuff that requires resources to maintain and, ultimately, discard). These consumptive damages therefore arise as a consequence of private decision making.[8]

Note that, by design, we assume the clean and dirty goods are perfect substitutes in preferences derived over aggregate and (as we will see below in Equation 5) cumulative consumption, for example, the individual derives the same use value from a kWh of electricity whether it is produced from solar or traditional energy sources, and so forth.[9] The warm glow effect, g, accounts for any added intrinsic value the individual obtains from consuming the clean good (cf. Andreoni, 1990; Hartmann et al., 2017). Habit formation is assumed to occur in tandem with growth in the individual's stock of aggregate consumption, under the assumption that $\alpha'(\hat{X}) > 0$, where superscript "′" represents the corresponding first partial derivative (cf. Gorman, 1967). In other words, formation of the individual's consumption habit is driven by increases in his marginal utility from aggregate consumption per period in response to growth in the cumulative stock of his consumption goods over time. We further assume that $\alpha''(\hat{X}) < 0$, where superscript "″" represents the second-partial derivative. This latter curvature condition is meant to ensure that the individual's consumption habit does not evolve into an addiction over time.[10]

For purposes of tractability, we henceforth assume a partial double-log form of Equation (1), denoted $\tilde{u}$,

$$\tilde{u} = \alpha(\hat{X})ln(X) + ln(y) + \beta ln(g) - \sigma_G G^{\rho_G} - \sigma_X \hat{X}^{\rho_X}, \tag{2}$$

[6]Our notion of the warm glow effect is taken from Andreoni (1990).

[7]In the context of our model, we attribute the externality to individuals' consumption of the goods rather than the goods' production per se (which is plausible under market clearing).

[8]For an insightful commentary on the accumulation of stuff, see Brody (2021) and SreenIvasan and Welnberger (2018).

[9]In Section 5, we explore the implications of assuming imperfect substitution between the two goods.

[10]We follow Gorman's (1967) approach to modeling habit formation by endogenizing the individual's contemporaneous-consumption utility parameter according to the level of cumulative (or long-run) consumption, as this approach has been shown by Peston (1967) to generate consistent long-run demand functions. Other habit-formation frameworks have been proposed by, inter alia, Fuhrer (2000) and Alvarez-Cuadardo et al. (2004), who assume that an individual's current utility level is determined by contemporaneous consumption relative to a reference level of consumption, typically lagged consumption. These frameworks have been developed with the purpose of grounding macroeconometric analyses in microeconomic foundations.

where constants $\sigma_G \in (0, 1)$ and $\sigma_X \in (0, 1)$ scale variables G and $\hat{X}$, respectively, such that the individual's optimal utility level is nonnegative.[11] To restrain the convexity in G's and $\hat{X}$'s respective effects on the individual's utility level, we assume $\rho_G \in (1, 2]$ and $\rho_X \in (1, 2]$.

In each period, the individual abides by budget constraint,

$$w = y + p_1 x_1 + p_2 x_2, \tag{3}$$

where w is the individual's available, or permanent, income for the period, and $p_1 > 0$ and $p_2 > 0$ are given prices of goods 1 and 2, respectively.[12] For the purpose of tractability, we assume the individual consumes out of a permanent flow of income each period rather than from a stock of wealth. Following the literature, we assume $p_1 > p_2$, that is, that the clean good is associated with a price premium (cf. Drozdenko et al., 2011; Shi & Jiang, 2022).

Social externality G adheres to the following law of motion:

$$\dot{G} = G_0 + N[\mu_1 x_1 + \mu_2 x_2] - \nu G, \tag{4}$$

where $\dot{G}$ represents the instantaneous per-period change in the externality stock, $G_0 \geqslant 0$ is the initial externality stock, $\mu_1 > 0$ and $\mu_2 > 0$ are emissions factors for the clean and dirty goods, respectively, and $\nu \in (0, 1)$ is the externality's natural absorption rate. By virtue of x_1 and x_2 representing the clean and dirty goods, respectively, we have $\mu_2 > \mu_1$.

The individual's cumulative consumption $\hat{X}$ adheres to the following law of motion:

$$\dot{\hat{X}} = \hat{X}_0 + X - \delta \hat{X}, \tag{5}$$

where $\dot{\hat{X}}$ represents the instantaneous per-period change in the stock of cumulative consumption, $\hat{X}_0 \geqslant 0$ is the initial cumulative-consumption stock, and $\delta \in (0, 1)$ is the stock's depreciation rate.

3 | THE MYOPIC INDIVIDUAL'S DECISION PROBLEM

A myopic individual ignores, or externalizes, his private contributions to the negative welfare effects associated with G and $\hat{X}$, but not the fact that his contributions lead to growth in both stocks (by "contributions" we mean consumption of goods 1 and 2). Also ignored is the effect that his accumulation of stuff (i.e., his contributions to $\hat{X}$) has on his substitution parameter α, which is a determining factor of his marginal utility from total consumption. In so doing, the myopic individual does not perceive the formation of his consumption habit.

We therefore express the myopic individual's current-value Hamiltonian function, $\mathcal{H}^m$, as

[11]The double log is "partial" in order preserve the convexity of G's and $\hat{X}$'s effects on $\tilde{u}$.

[12]Being the numeraire, good y's price is normalized to one.

$$\mathcal{H}^m = \alpha(\bar{\hat{X}})ln(X) + ln(y) + \beta ln(\phi x_1) - \sigma_G[\bar{G}]^{\rho_G} - \sigma_X[\bar{\hat{X}}]^{\rho_X} + \lambda_G \dot{G} + \lambda_X \dot{\hat{X}} + \lambda_w[w - y - p_1 x_1 - p_2 x_2], \tag{6}$$

where $\dot{G}$ and $\dot{\hat{X}}$ are as defined in Equations (4) and (5), respectively, λ_G and λ_x are corresponding multipliers, or shadow values, and the "-" accent on G and $\hat{X}$ denotes that the individual takes these variables as given. The term λ_w similarly represents the multiplier on, or marginal utility of income associated with, the individual's per-period budget constraint. The interior optimality conditions for this problem are derived as follows[13]:

$$\frac{\alpha}{X} + \frac{\beta}{x_1} + \lambda_G N\mu_1 + \lambda_X - \lambda_w p_1 = 0, \tag{7}$$

$$\frac{\alpha}{X} + \lambda_G N\mu_2 + \lambda_X - \lambda_w p_2 = 0, \tag{8}$$

$$\frac{1}{y} - \lambda_w = 0, \tag{9}$$

$$w - y - p_1 x_1 - p_2 x_2 = 0, \tag{10}$$

$$\dot{\lambda_G} = \rho_G \sigma_G G^{\rho_G - 1} + \lambda_G[\nu + r], \tag{11}$$

$$\dot{\lambda_X} = -\alpha' ln(X) + \rho_X \sigma_X \hat{X}^{\rho_X - 1} + \lambda_X[\delta + r], \tag{12}$$

where $\dot{\lambda_G}$ and $\dot{\lambda_X}$ represent the instantaneous changes in multipliers λ_G and λ_X, respectively, and r represents the prevailing discount rate. Two transversality conditions are also assumed to be simultaneously satisfied in the optimal solution:

$$\lim_{t\to\infty} \lambda_G e^{-rt} G_t = \lim_{t\to\infty} \lambda_X e^{-rt} \hat{X}_t = 0. \tag{13}$$

We note from Equation (9) that $\lambda_w > 0$ in the optimal solution, and that Equation (10) satisfies Walras' law. Further, from Equation (11) we see that in the steady state (ss),

$$\lambda_G^{ss} = -\frac{\rho_G \sigma_G [G^{ss}]^{\rho_G - 1}}{\nu + r} < 0.$$

Hence, we choose to define $\pi = -\lambda_G$ and rewrite (11) as

$$\dot{\pi} = \rho_G \sigma_G G^{\rho_G - 1} - \pi[\nu + r]. \tag{14}$$

We also note from Equation (12) that in the steady state,

[13]We address the conditions necessary for an interior solution below.

$$\lambda_X^{ss} = \frac{\alpha' ln(X^{ss}) - \rho_X \sigma_X [\hat{X}^{ss}]^{\rho_X - 1}}{\delta + r} \lesseqgtr 0 \quad \text{as} \quad \alpha' \ln(X^{ss}) \lesseqgtr \rho_X \sigma_X [\hat{X}^{ss}]^{\rho_X - 1} [\delta + r].$$

In other words, λ_X^{ss} is positive as long as the value of the individual's marginal habit-formation effect is larger than marginal damage suffered by the individual from cumulative consumption, and nonpositive otherwise. Since the sign of λ_X^{ss} is ambiguous, we choose not to redefine λ_X, as was done with λ_G.

Combining (7) and (8) we obtain the myopic individual's implicit demand for good 1[14]:

$$x_1^m = \frac{\beta}{\Phi_m}, \tag{15}$$

where $\Phi_m = \pi N[\mu_1 - \mu_2] + \lambda_w[p_1 - p_2]$, and the "$m$" superscript denotes an optimal value for the myopic individual. Thus, since $\beta > 0$, our necessary condition for $x_1^m > 0$ is $\Phi_m > 0$, which requires $\lambda_w[p_1 - p_2] > \pi N[\mu_2 - \mu_1]$. In other words, $x_1^m > 0$ requires the shadow value of the clean good's price premium to be larger than the shadow value of the difference in the population-weighted emissions factors between the dirty and clean good. This condition is more likely to hold the smaller the community's population size and emissions-factor differential, and the larger the clean good's price premium. As anticipated, the myopic individual's demand for good 1 is positively related to the substitution parameter for the warm glow effect (β), the emissions-factor differential ($\mu_2 - \mu_1$), and externality G's shadow value (π). The individual's demand for good 1 is negatively related to the clean good's price premium and the marginal utility of income.

It is interesting to note the interplay in this model between the factors determining the size of x_1^m, on the one hand, and the necessary condition for $x_1^m > 0$, on the other hand. In particular, the same factors that individually lead to a larger value of x_1^* (e.g., the emissions-factor and price differentials), together cannot be too large in magnitude. Otherwise, the necessary condition for $x_1^m > 0$ will be violated. No such interplay confines the extent to which increases in β enlarge x_1^m.

Using (10) and (15), the myopic individual's implicit demand for good 2 is derived as

$$x_2^m = \frac{w - \frac{1}{\lambda_w} - \frac{p_1 \beta}{\Phi_m}}{p_2}. \tag{16}$$

From (16) we see that, all else equal, the factors determining whether $x_1^m > 0$, that is, that determine whether $\Phi_m > 0$, are in opposition to an interior solution for x_2^m. In other words, $x_2^m > 0$ is more likely to hold the larger the community's population size and emissions-factor differential, and the smaller the clean good's price premium. In addition, the myopic individual's permanent income level, w, must also be large enough for $x_2^m > 0$. Note that $\Phi_m > 0$ alone is not necessary for $x_2^m > 0$. Further, unlike with x_1^m, there is no confining interplay

[14]The demand is "implicit" because it is written as a function of λ_w and π. We present implicit rather than explicit demand for both goods 1 and 2 due to their convenient functional forms, and the fact that expressing the demands in their explicit forms is unnecessary for the ensuing analysis.

between the factors determining the size of x_2^m and the necessary condition for $x_2^m > 0$. Finally, as anticipated, x_2^m is negatively related to β and its own price, p_2.

As shown in Appendix A, the per-period second-order conditions ensuring a unique optimal solution to Equation (6) hold automatically under the assumption of a price premium for the clean good, that is, $p_1 > p_2$. Appendix A also proves that the problem's steady-state solution is locally saddle-point stable. We now turn to the case of a hyperopic individual, who internalizes her private contributions to the negative welfare effects associated with G and $\hat{X}$, as well as the formation of her consumption habit. In other words, the hyperopic individual solves the same decision problem as would a social planner, fully internalizing both the negative social and private externalities associated with the respective health damages and psychic damages from stuff accumulation, respectively.

4 | THE HYPEROPIC INDIVIDUAL'S DECISION PROBLEM

To account for the hyperopic individual's internalization of her private contributions to the negative welfare effects associated with G and $\hat{X}$, we must first solve the first-order differential Equations (4) and (5) to obtain the expressions governing the relationships between x_1 and x_2, on the one hand, and G and $\hat{X}$ on the other hand. The solutions for these two equations are,

$$G(x_1, x_2) = [G_0 + c_G]\mathrm{e}^{-\nu t} + \frac{N[\mu_1 x_1 + \mu_2 x_2]}{\nu}, \tag{17}$$

$$\hat{X}(x_1, x_2) = [X_0 + c_X]\mathrm{e}^{-\delta t} + \frac{x_1 + x_2}{\delta}, \tag{18}$$

where c_G and c_X represent respective constants of integration. From these two equations we obtain

$$\frac{\partial G(x_1, x_2)}{\partial x_1} = \frac{N\mu_1}{\nu} > 0 \quad \text{and} \quad \frac{\partial G(x_1, x_2)}{\partial x_2} = \frac{N\mu_2}{\nu} > 0, \tag{19}$$

$$\frac{\partial \hat{X}(x_1, x_2)}{\partial x_1} = \frac{\partial \hat{X}(x_1, x_2)}{\partial x_2} = \frac{1}{\delta} > 0. \tag{20}$$

The hyperopic individual's current-value Hamiltonian function, $\mathcal{H}^h$, is therefore expressed as

$$\begin{aligned}\mathcal{H}^h = \alpha(\hat{X}(x_1, x_2)) ln(X) + ln(y) + \beta ln(\phi x_1) - \sigma_G[G(x_1, x_2)]^{\rho_G} - \sigma_X[\hat{X}(x_1, x_2)]^{\rho_X} \\ - \pi\dot{G} + \lambda_X\dot{\hat{X}} + \lambda_w[w - y - p_1 x_1 - p_2 x_2],\end{aligned} \tag{21}$$

which results in first-order conditions (9)–(12) and transversality conditions (13) from Section 3, and new versions of first-order conditions (7) and (8) based on Equations (19) and (20),

$$\frac{\alpha}{X} + \frac{\alpha(\hat{X})' ln(X)}{\delta} + \frac{\beta}{x_1} - \frac{\rho_G N\mu_1 \sigma_G G^{\rho_G - 1}}{\nu} - \frac{\rho_X \sigma_X \hat{X}^{\rho_X - 1}}{\delta} - \pi N\mu_1 + \lambda_X - \lambda_w p_1 = 0, \tag{22}$$

$$\frac{\alpha}{X} + \frac{\alpha(\hat{X})' ln(X)}{\delta} - \frac{\rho_G N\mu_2\sigma_G G^{\rho_G-1}}{\nu} - \frac{\rho_X\sigma_X\hat{X}^{\rho_X-1}}{\delta} - \pi N\mu_2 + \lambda_X - \lambda_w p_2 = 0. \tag{23}$$

Combining (22) and (23) results in

$$x_1^h = \frac{\beta}{\Phi_h}, \tag{24}$$

where $\Phi_h = \Phi_m - N[\mu_2 - \mu_1]\rho_G\sigma_G G^{\rho_G-1}$, and the "$h$" superscript denotes an optimal value for the hyperopic individual. Similar to the myopic individual's problem, our necessary condition for $x_1^h > 0$ is $\Phi_h > 0$, which in this case requires $\lambda_w[p_1 - p_2] > [\pi + \rho_G\sigma_G G^{\rho_G-1}]N[\mu_2 - \mu_1]$. Comparing this necessary condition with that derived for Equation (15) in Section 3 we see that, all else equal, the necessary condition for $x_1^h > 0$ is less likely to hold than that for $x_1^m > 0$. This is because $\Phi_h < \Phi_m$, implying that, all else equal, Φ_h is more likely to be negative.

Just as it is for the myopic individual, the hyperopic individual's demand for good 1 is positively related to the substitution parameter for the warm glow effect (β), the emissions-factor differential ($\mu_2 - \mu_1$), and externality G's shadow value (π). The individual's demand for good 1 is negatively related to the clean good's price premium and the marginal utility of income. In addition, we see that the hyperopic individual's demand for good 1 is positively related to parameters ρ_G and σ_G and externality G itself. Each of these comparative static effects is as anticipated.

Using (10) and (24), the hyperopic individual's demand for good 2 mimics that of the myopic individual's in (16),

$$x_2^h = \frac{w - \frac{1}{\lambda_w} - \frac{p_1\beta}{\Phi_h}}{p_2}. \tag{25}$$

The comparison between the necessary conditions for $x_2^h > 0$ and $x_2^m > 0$ is, as anticipated, the reverse of that between the necessary conditions for $x_1^h > 0$ and $x_1^m > 0$. In particular, the necessary condition for $x_2^h > 0$ is more likely to hold than that for $x_2^m > 0$. This too is because $\Phi_h < \Phi_m$. And, contrary to the demand for x_1^h, the hyperopic individual's demand for x_2^h is negatively related to parameters ρ_G and σ_G and externality G itself.

As shown in Appendix B, the per-period second-order conditions ensuring a unique optimal solution to Equation (21) do not hold automatically under the assumption of a price premium for the clean good, unlike the second-order conditions for the myopic individual. These conditions therefore must be assumed to hold for a unique maximal solution to the hyperopic individual's problem. Nevertheless, Appendix B proves that the steady-state solution to the hyperopic individual's problem is locally saddle-point stable.

5 | SOME COMPARISONS

Given the results from Sections 3 and 4, we can now state the paper's first proposition.

Proposition 1. *For a small-enough price premium, (i)* $x_1^h > x_1^m$, *(ii)* $x_2^m > x_2^h$, *(iii)* $x_2^m - x_2^h > x_1^h - x_1^m$, *(iv)* $y^h > y^m$, *(v)* $\hat{X}^m > \hat{X}^h$, *(vi)* $G^m > G^h$, *(vii)* $\pi^m > \pi^h$, *(viii)* $\lambda_w^m > \lambda_w^h$, *and (ix)* $\lambda_X^h > \lambda_X^m$.

Proof. For a given λ_w and π, we see from (15) and (24) that $x_1^h > x_1^m$, and from (16) and (25) that $x_2^m > x_2^h$. Further, from (15) and (16), and using our standing assumption that $p_1 > p_2$, we see that

$$\frac{\partial x_2^m}{\partial \Phi_m} = \frac{p_1 \beta}{p_2 \Phi_m^2} > -\frac{\partial x_1^m}{\partial \Phi_m} = \frac{\beta}{\Phi_m^2},$$

which in turn implies $x_2^m - x_2^h > x_1^h - x_1^m$ as a result of our earlier finding that $\Phi_m > \Phi_h$. Via Walras' law, that is, Equation (10), and the condition of a small-enough price premium, this implies $y^h > y^m$, and by our definitions of $\hat{X}$ and G in (17) and (18), implies $\hat{X}^m > \hat{X}^h$ and $G^m > G^h$, respectively.

Now, from Equation (9), $y^h > y^m \Rightarrow \lambda_w^m > \lambda_w^h$, which is consistent with increases in the differences $x_1^h - x_1^m$ (via comparing Equation 15 with Equation 24) and $x_2^m - x_2^h$ (via comparing Equation 16 with Equation 25). Given $p_1 > p_2$, the increase in $x_2^m - x_2^h$ is greater than the associated increase in $x_1^h - x_1^m$. Hence, inequalities (i)–(iii) in Proposition 1 are strengthened, which in turn strengthens inequalities (v) and (vi). Further, using $G^m > G^h$, (14) implies that in the steady state $\pi^m > \pi^h$, which, via Equations (15), (16), (24), and (25) further strengthens inequalities (i)–(iii) in Proposition 1, which further strengthens inequalities (v) and (vi).

Hence, for any values of π^m and π^h such that $\pi^m > \pi^h$, and any values of λ_w^m and λ_w^h such that $\lambda_w^m > \lambda_w^h$, inequalities (i)–(vi) in Proposition 1 hold. Because the expressions for x_1^m, x_1^h, x_2^m, and x_2^h in (15), (16), (24), and (25) do not depend upon λ_X, the inequalities (i)–(vi) hold for any values of λ_X^m and λ_X^h. As shown in Technical Appendix B, $\lambda_X^h > \lambda_X^m$. □

As Proposition 1 indicates, relative to a myopic individual a hyperopic individual consumes a greater amount of the clean good and a lesser amount of the dirty good, with the magnitude of the latter difference being greater than the magnitude of the former. Consequently, the hyperopic individual's cumulative consumption of the two goods is lower, as is his contribution to the social externality (or, to put it another way, a community of hyperopic individuals produces a lower level of the social externality than a community of myopic individuals).

As a corollary to Proposition 1, we can also characterize an individual whose degree of "sightedness" lies between myopia and hyperopia, which, as described earlier in Section 1, we have labeled an astigmatic individual. In our specific context, an astigmatic individual internalizes his private contributions to the private external effect associated with $\hat{X}$, as well as the formation of his consumption habit. But, unlike the hyperopic individual, the astigmatic individual ignores the negative welfare effect associated with his contribution to social externality G.

Corollary 1. *Under the assumptions of our model, in particular perfect substitution between the clean and dirty goods in preferences derived over aggregate and cumulative consumption, an astigmatic individual exhibits the same implicit demand functions as a myopic individual.*

Proof. The astigmatic individual's current-value Hamiltonian function, H_a, is expressed as

$$H_a = \alpha(\hat{X}(x_1, x_2))ln(X) + ln(y) + \beta ln(\phi x_1) - \sigma_G[\bar{G}]^{\rho_G} - \sigma_X[\hat{X}(x_1, x_2)]^{\rho_X} \\ - \pi\dot{G} + \lambda_X\dot{\hat{X}} + \lambda_w[w - y - p_1x_1 - p_2x_2],$$

resulting in first-order conditions (9)–(12) and transversality conditions (13) from Section 3, and new versions of first-order conditions (7) and (8),

$$\frac{\alpha}{X} + \frac{\alpha(\hat{X})'ln(X)}{\delta} + \frac{\beta}{x_1} - \frac{\rho_X\sigma_X\hat{X}^{\rho_X-1}}{\delta} - \pi N\mu_1 + \lambda_X - \lambda_w p_1 = 0, \quad (26)$$

$$\frac{\alpha}{X} + \frac{\alpha(\hat{X})'ln(X)}{\delta} - \frac{\rho_X\sigma_X\hat{X}^{\rho_X-1}}{\delta} - \pi N\mu_2 + \lambda_X - \lambda_w p_2 = 0. \quad (27)$$

Combining (26) and (27) results in Equations (15) and (16). □

The equivalence of the myopic and astigmatic individuals' implied demand functions is driven by the perfect-substitutability assumption of x_1 and x_2 in preferences derived over aggregate and cumulative consumption. This assumption effectively neutralizes the astigmatic individual's internalized habit-formation effect (i.e., there is no marginal gain in utility associated with substituting one good for the other through endogenized parameter $\alpha(\hat{X}(x_1, x_2))$ in the problem's Hamiltonian function).[15] Nevertheless, it is important to point out that because these are implicit demand functions, the solutions to the individuals' respective decision problems will differ, as indicated by comparing the myopic individual's optimality conditions (7) and (8) with the astigmatic individual's (26) and (27). We explore these differences further in Sections 5, 6, and 7.

It is relatively easy to see how relaxing the perfect-substitutability assumption can distinguish an astigmatic individual's implicit demand function from a myopic individual's, and, ultimately, the consumption levels of the clean and dirty goods. Let $\gamma_i \in [0, 1]$, $\sum_i \gamma_i = 1$, $i = 1, 2$ represent proportionality factors for goods 1 and 2, respectively, and consider Corollary 2.

Corollary 2. *Under the assumption of imperfect substitutability in preferences derived over aggregate and cumulative consumption, the astigmatic individual's consumption level of the clean good exceeds the myopic individual's when the clean good's substitution parameter exceeds the dirty good's, that is, when $\gamma_1 > \gamma_2$, for a given level of aggregate consumption.*

[15]Below, where we explicitly explore the effects of imperfect substitutability, we assume that the astigmatic individual maintains perfect substitutability in the stuff-accumulation effect (i.e., there continues to be no marginal gain from substituting one good for the other through the effect associated with $\sigma_X[\hat{X}(x_1, x_2)]^{\rho_X}$ in the problem's Hamiltonian function). This assumption reflects the belief that individuals do not distinguish their preferences defined over clean from dirty goods in terms of how they accumulate the two types of goods over time, that is, stuff is stuff regardless of whether it is clean or dirty.

Proof. First, note that introducing imperfect substitutability into the myopic individual's preferences results in Equations (9)–(13) and new versions of conditions (7) and (8):

$$\frac{\alpha\gamma_1}{X}+\frac{\beta}{x_1}-\pi N\mu_1+\lambda_X-\lambda_w p_1=0,$$
$$\frac{\alpha\gamma_2}{X}-\pi N\mu_2+\lambda_X-\lambda_w p_2=0,$$

which in turn result in new versions of Equations (15) and (16), respectively, defined as

$$\ddot{x}_1^m=\frac{\beta}{\ddot{\Phi}_m}, \tag{28}$$

$$\ddot{x}_2^m=\frac{w-\frac{1}{\lambda_w}-\frac{p_1\beta}{\ddot{\Phi}_m}}{p_2}, \tag{29}$$

where the "¨" accent denotes a solution value for the case of imperfect substitution, and

$$\ddot{\Phi}_m=\Phi_m-\frac{\alpha[\gamma_1-\gamma_2]}{X}, \tag{30}$$

where Φ_m is as defined in Equation (15).

The astigmatic individual's decision problem likewise results in Equations (9)–(13) and new versions of conditions (26) and (27),

$$\frac{\alpha\gamma_1}{X}+\frac{\alpha(\hat{X})'\gamma_1 ln(X)}{\delta}+\frac{\beta}{x_1}-\frac{\rho_X\sigma_X\hat{X}^{\rho_X-1}}{\delta}-\pi N\mu_1+\lambda_X-\lambda_w p_1=0, \tag{31}$$

$$\frac{\alpha\gamma_2}{X}+\frac{\alpha(\hat{X})'\gamma_2 ln(X)}{\delta}-\frac{\rho_X\sigma_X\hat{X}^{\rho_X-1}}{\delta}-\pi N\mu_2+\lambda_X-\lambda_w p_2=0, \tag{32}$$

which in turn result in a new versions of Equations (15) and (16), respectively, as

$$\ddot{x}_1^a=\frac{\beta}{\ddot{\Phi}_a}, \tag{33}$$

$$\ddot{x}_2^a=\frac{w-\frac{1}{\lambda_w}-\frac{p_1\beta}{\ddot{\Phi}_a}}{p_2}, \tag{34}$$

where,

$$\ddot{\Phi}_a=\ddot{\Phi}_m-\frac{\alpha(\hat{X})'[\gamma_1-\gamma_2]ln(X)}{\delta}. \tag{35}$$

For a given λ_w, ϕ, and X, we see from (28)–(30) and (33)–(35) that if $\gamma_1>\gamma_2$, then from (30) and (35) we have $\ddot{\Phi}_m>\ddot{\Phi}_a$, implying $\ddot{x}_1^a>\ddot{x}_1^m$ and $\ddot{x}_2^m>\ddot{x}_2^a$. Following the same logic as presented in the proof of Proposition 1, we see from Equations (28) and (29) that

$$\frac{\partial \ddot{x}_2^m}{\partial \ddot{\Phi}_m} = \frac{p_1 \beta}{p_2 \ddot{\Phi}_m^2} > -\frac{\partial \ddot{x}_1^m}{\partial \ddot{\Phi}_m} = \frac{\beta}{\ddot{\Phi}_m^2},$$

which in turn implies $\ddot{x}_2^m - \ddot{x}_2^a > \ddot{x}_1^a - \ddot{x}_1^m$ as a result of our earlier finding that $\ddot{\Phi}_m > \ddot{\Phi}_h$. Note that $\ddot{x}_2^m - \ddot{x}_2^a > \ddot{x}_1^a - \ddot{x}_1^m$ in turn implies that $\ddot{X}^m > \ddot{X}^a$, which strengthens the claim in Corollary 2. Also, via Equation (10), and the condition of a small-enough price premium, $\ddot{x}_2^m - \ddot{x}_2^a > \ddot{x}_1^a - \ddot{x}_1^m$ implies $\ddot{y}^a > \ddot{y}^m$, and by our definitions of $\hat{X}$ and G in (17) and (18), implies $\ddot{\hat{X}}^m > \ddot{\hat{X}}^a$ and $\ddot{G}^m > \ddot{G}^a$, respectively. Moreover, from Equation (9), $\ddot{y}^a > \ddot{y}^m \Rightarrow \ddot{\lambda}_w^m > \ddot{\lambda}_w^a$, which is consistent with increases in the differences $\ddot{x}_1^a - \ddot{x}_1^m$ (via comparing Equations 28 and 30 with Equations 33 and 35), and $x_2^m - x_2^h$ (via comparing Equations 29 and 30 with Equations 34 and 35). Given $p_1 > p_2$, the increase in $\ddot{x}_2^m - \ddot{x}_2^a$ is greater than the associated increase in $\ddot{x}_1^a - \ddot{x}_1^m$. Hence, the claim in Corollary 2 is again strengthened. Lastly, using $\ddot{G}^m > \ddot{G}^h$, (14) implies that in the steady state $\ddot{\pi}^m > \ddot{\pi}^h$, which, via Equations (28)–(30) and (33)–(35) further strengthens the claim in Corollary 2. □

Therefore, relaxing the assumption of perfect substitutability between the clean and dirty goods leads to differential habit-formation effects (and correspondingly different implied demand functions) between the myopic and astigmatic individuals, that is, there are now added marginal gains from internalizing the habit- formation effect associated with substituting one good for the other. To the extent that the marginal gain in consumption of the clean good exceeds the dirty good, that is, $\gamma_1 > \gamma_2$, the astigmatic individual, who endogenizes the habit-forming effect, chooses to consume more of the clean good and less of the dirty good than does the myopic individual.

Next, we briefly examine the tax-policy implications of our results for the myopic and hyperopic individuals.

6 | IMPLICATIONS FOR TAX POLICY

In the standard externality problem, where the effects of habit formation are ignored by the regulator, the Pigovian tax rate is set equal to the marginal damage associated with optimal production or consumption of the good causing the externality. In our model, where consumption of two different types of goods contribute to the externality (i.e., where the goods are nonuniformally mixed), the regulator must formulate two separate tax rates, one applied to the myopic individual's consumption of good 1, the other to his consumption of good 2 (recall that the myopic individual ignores the social externality in the formulation of his decision

[16]Note that because he fully internalizes the private and social externalities plus the habit-formation effect, the hyperopic individual's solution values are first-best. Thus, tax rates are inapplicable for the hyperopic individual. Rather, the hyperopic individual's solution values serve as benchmarks for the derivation of this model's Pigovian tax rates.

problem).[16] In the standard case, these consumption (or "downstream") tax rates for goods 1 and 2, respectively, would be,

$$\tau_1^S = \frac{\rho_G N\mu_1\sigma_G[G^h]^{\rho_G-1}}{\lambda_w \nu}, \tag{36}$$

$$\tau_2^S = \frac{\rho_G N\mu_2\sigma_G[G^h]^{\rho_G-1}}{\lambda_w \nu}, \tag{37}$$

where the "S" superscript denotes the standard case, and we note that $\tau_1^S/\tau_2^S = \mu_1/\mu_2$ and $\tau_2^S > \tau_1^S$, reflecting the fact that $\mu_2 > \mu_1$. As Equations (36) and (37) indicate, the standard tax rates are set equal to the marginal damages associated with consumption of the clean and dirty goods evaluated at their respective first-best, or hyperopic, levels. Note that, because he internalizes both the habit-forming and stuff-accumulation effects, leaving only the social externality uninternalized, the standard rates, τ_1^S and τ_2^S, serve as the astigmatic individual's Pigovian rates.

In our case, the myopic individual's Pigovian tax rate for good 1 (which accounts not only for his contribution to the social externality but also his contribution to the private externality and habit-formation effect) is instead derived by comparing Equation (7) with (22) (and using Equation 36), and that for good 2 by comparing Equation (8) with (23) (and using Equation 37), resulting in

$$\tau_1^m = \tau_1^S - \tau_{HF}^m, \tag{38}$$

$$\tau_2^m = \tau_2^S - \tau_{HF}^m, \tag{39}$$

where the "m" superscript in this context denotes that the Pigovian tax is applied to the myopic individual's choices of goods 1 and 2, but set according to the marginal damages incurred by the (first-best) hyperopic individual, and

$$\tau_{HF}^m = \frac{\rho_X\sigma_X[\hat{X}^h]^{\rho_X-1} - \alpha'(\hat{X}^h)ln(X^h)}{\lambda_w\delta} \lesseqgtr 0 \quad \text{as} \quad \rho_X\sigma_X[\hat{X}^h]^{\rho_X-1} \lesseqgtr \alpha'(\hat{X}^h)ln(X^h). \tag{40}$$

As indicated in Equation (40), the term t_{HF}^m accounts for the marginal effect of the individual's habit formation, which consists of two counterposing factors. One factor, $[\rho_X\sigma_X[\hat{X}^h]^{\rho_X-1}]/\delta > 0$ represents the cumulative marginal benefit associated with habit formation. The other, $[\alpha'(\hat{X}^h)ln(X^h)]/\delta > 0$ denotes the marginal cost associated with the accumulation of stuff. Clearly, t_{HF}^m is positive when the former factor outweighs the latter, and is negative otherwise.

From Equations (38) and (39) we note that, unlike with the standard tax rates in (36) and (37), $\tau_1^m/\tau_2^m = \mu_1/\mu_2$ solely in the special case of $\tau_{HF}^m = 0$, but still $\tau_2^m > \tau_1^m$ by $\mu_2 > \mu_1$. This leads to the paper's second proposition.

Proposition 2. $\tau_i^m \lesseqgtr \tau_i^S$ as $\tau_{HF}^m \gtreqless 0$, $i = 1, 2$.

Proof. The proposition follows directly from Equations (38)–(40). □

Proposition 2 informs us that the adjustment to the standard tax rate depends upon whether the myopic individual's (uninternalized) cumulative marginal benefit associated with habit formation outweighs the marginal cost associated with the accumulation of stuff. To the extent that it does, the Pigovian tax rates in the presence of habit formation are lower than their corresponding standard tax rates that ignore the formation of a consumption habit. In this case, the former rates could actually be negative, indicating that it is optimal to subsidize the myopic individual to encourage him to exploit the net marginal benefit associated with his habit formation. To the contrary, that is, to the extent that the myopic individual experiences a larger marginal cost associated with the accumulation of stuff than marginal benefit from habit formation, the Pigovian tax rates will exceed their corresponding standard rates. This, in turn, will lead to lower levels of aggregate and cumulative consumption and lower levels of both the private and social externalities.

7 | NUMERICAL ANALYSIS

Our numerical analysis targets the sensitivity of the paper's main steady-state results to the size of the price differential, $p_1 - p_2$, particularly regarding the full set of results presented in Proposition 1.[17] The analysis is demonstrative, since empirical data with which to calibrate the numerical model is currently unavailable. For this exercise, we make two assumptions. One is the functional form of the habit parameter, α, which we define as

$$\alpha(\hat{X}) = \alpha_0 + \kappa_0 \hat{X}^{\kappa},$$

where $\alpha_0 > 0$ represents the individual's baseline substitution parameter for variable X, and $\kappa_0 \in (0, 1)$ and $\kappa \in (0, 1)$ are the habit-formation proportionality and substitution parameters, respectively.

Second, for a baseline simulation of the numerical model, Table 1 presents the specific values assigned to the parameters previously defined in Section 2. Each of the values in Table 1 is consistent with their respective restrictions imposed in Section 2. In particular, we note the relatively small values for adjustment factors σ_G and σ_X, which ensure positive utility values in the optimal solutions for the myopic and hyperopic individuals. The price premium for x_1 is \$0.03 per unit (or roughly 4%), and the difference between x_2's and x_1's emissions factors is 0.1 (roughly 15%). Lastly, $\phi = 0.75$ represents a relatively large warm-glow effect, 0.75 utils per logged unit of x_1.

Table 2 presents our corresponding steady-state results for the myopic, astigmatic, and hyperopic individuals under our standing assumption of perfect substitutability in preferences derived over aggregate and cumulative consumption of the clean and dirty good; results based on the optimality conditions derived in Sections 3–5. We note that each of the nine conditions included in Proposition 1 holds in this baseline simulation. In particular, x_1^h exceeds x_1^m (by roughly 9.5%), and x_2^m exceeds x_2^h (by over 12%), leading to the result that $x_2^m - x_2^h > x_1^h - x_2^h$. These results in turn drive the hyperopic individual's higher warm glow and utility levels, as

[17] GAMS v. 33.2.0 x86 64bit/MS Windows was used for the ensuing analysis.

TABLE 1 Parameter values.

Parameter[a]	Initial value
α_0	0.35
κ_0	0.05
κ	0.005
β	0.005
σ_G	5E − 11
σ_X	5E − 7
ρ_G	1.5
ρ_X	1.5
w	75
p_1	0.73
p_2	0.70
μ_1	0.65
μ_2	0.75
ν	0.0005
G_0	15
$\hat{X}_0$	10
δ	0.03
r	0.03
ϕ	0.75
N	5

[a]Parameters w, p_1, and p_2 are denominated in dollars. All other parameters are denominated in generic units.

well as his lower emissions and cumulative consumption levels.[18] As anticipated, results for the astigmatic individual fall between the myopic and hyperopic individuals.[19]

As Table 2 indicates, the conditions described in Section 6 regarding optimal tax policy hold in this simulation exercise as well. We see that the standard tax rates (which equal the Pigovian rates for the astigmatic individual) satisfy the conditions $\tau_1^S/\tau_2^S = \mu_1/\mu_2$ and $\tau_2^S > \tau_1^S$. Since $\tau_{HF}^m > 0$, $\tau_i^S > \tau_i^m$, $i = 1, 2$, which is consistent with Proposition 2. Interestingly, the value of τ_{HF}^m (which reflects the net marginal benefit of habit formation) is large enough in our numerical example to cause the Pigovian rates for the myopic individual to represent subsidies rather than taxes, that is, $\tau_1^m < \tau_2^m < 0$.

[18]Note that the relatively large values for G and $\hat{X}$ represent perpetuity values. Also, the values for G are each summed over the community populations of five individuals.

[19]Not shown is the unexpected result that the astigmatic individual's utility level slightly exceeds the hyperopic individual's when not rounded to two decimal points.

TABLE 2 Baseline numerical results for myopic, astigmatic, and hyperopic individuals.

Variable[a]	Myopic	Astigmatic	Hyperopic
α	0.40	0.40	0.40
x_1	8.94	9.10	9.79
x_2	21.26	19.73	18.62
X	30.20	28.83	28.42
y	53.59	54.55	54.81
g	6.71	6.83	7.35
G	247,577	237,096	233,332
$\hat{X}$	1340	1294	1281
π	1.22E − 6	1.20E − 6	1.19E − 6
λ_X	−0.23E − 3	−0.23E − 3	−0.22E − 3
λ_w	0.0187	0.0183	0.0182
$\tilde{u}$	5.329	5.330	5.330
τ_1^S	–	0.013	–
τ_2^S	–	0.015	–
τ_{HF}^m	0.048	–	–
τ_1^m	−0.035	–	–
τ_2^m	−0.033	–	–

[a]Variables y and λ_w are denominated in dollars, and variables g, π, λ_X, and $\tilde{u}$ are denominated in utils. All other variables are denominated in generic units.

Figure 1 presents our results for the clean and dirty goods (i.e., x_1^m, x_2^m, x_1^h, and x_2^h) from the simulation of a widening price premium—a premium ranging from slightly over 2% (\$0.015) to slightly over 15% (\$0.105). As anticipated, we see that as the price premium increases, demands for the clean good among the myopic and hyperopic individuals decrease, and demands for the dirty good increase. Whereas the demands for the dirty good show only a slight asymptotic tendency as the price premium increases, the demands for the clean good exhibit a strong tendency. These latter demands begin to coincide at a price premium of roughly \$0.03, which is the premium assumed for the baseline steady-state solutions (refer to Table 1).[20]

Figure 2 presents our results for the negative externality (i.e., G^m and G^h) associated with a widening price premium. In this case, the levels of a myopic and hyperopic community's negative externality exhibit no discernible asymptotic relationship. The difference between the two communities' rising externality levels is constant across the range of price premiums. The externality levels increase with the price premium as myopic and hyperopic individuals substitute away from the clean good to the dirty good.

[20]Results for the astigmatic individual are available from the author upon request for Figures 1–3. As expected, the astigmatic individual's solution values for x_1^a, x_2^a, G^a, and $\hat{X}^a$ lie between those of the myopic and hyperopic individuals in relation to a widening price premium.

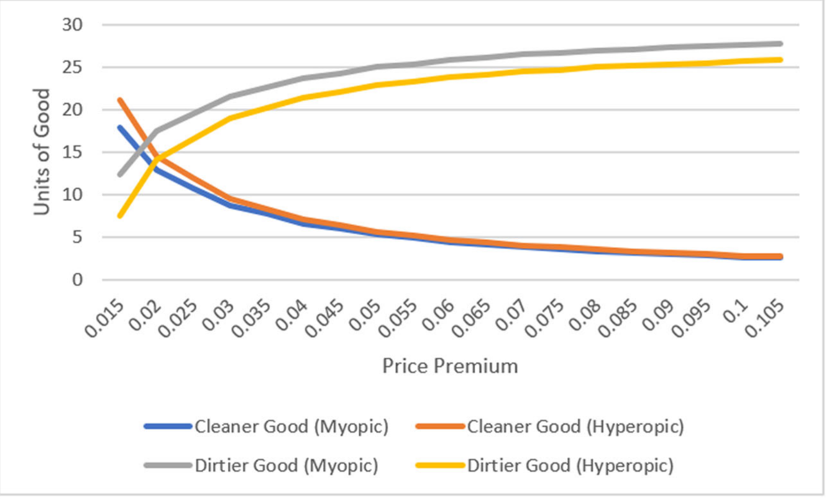

FIGURE 1 Myopic and hyperopic individuals demand for the clean and dirty goods.

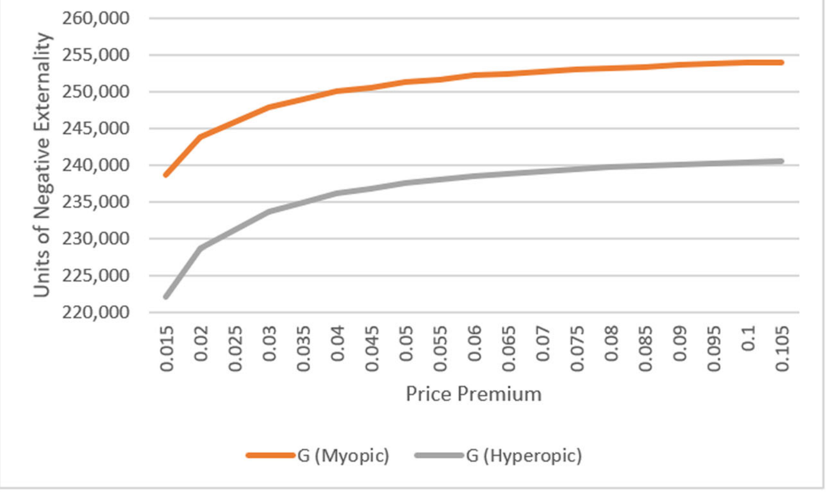

FIGURE 2 Myopic and hyperopic community levels of negative externality.

Taken together, the results in Figures 1 and 2 suggest that the shrinking gap between the hyperopic and myopic individuals' clean-good consumption levels (as the clean good's price premium increases) is not strong enough to noticeably expand the gap between the two individuals' respective contributions to the social externality. This result is consistent with the smaller amounts of the clean good consumed by two individuals (relative to the dirty good) at the study's baseline steady state, which are slightly under 30% and slightly over 34% for the myopic and hyperopic individuals, respectively.[21]

[21]As mentioned previously, our numerical results are meant to be demonstrative, since there are no known empirical estimates available of the percentages of clean goods consumed by different types of individuals.

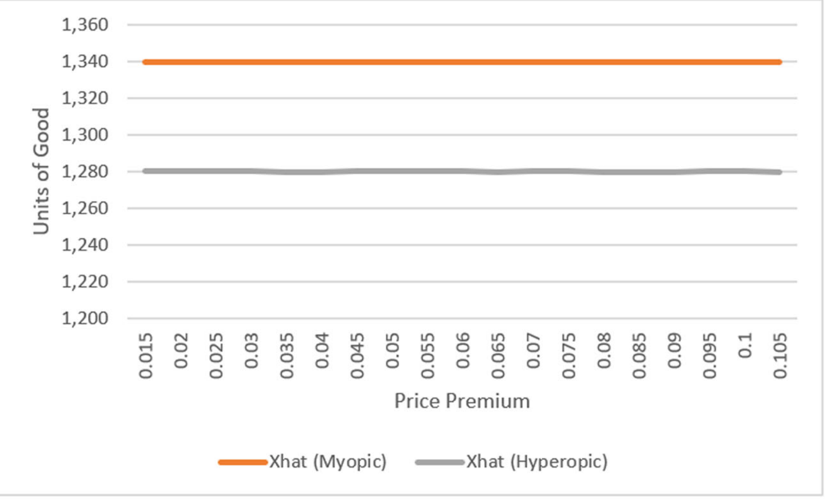

FIGURE 3 Myopic and hyperopic cumulative consumption levels.

Lastly, Figure 3 presents similar results for cumulative consumption (i.e., $\hat{X}^m$ and $\hat{X}^h$) in relation to a widening price premium. In this case, not only is the difference between the two individuals' cumulative consumption levels constant, but the respective levels themselves are held constant across the increasing price premium.

The constancy of cumulative consumption is a consequence of the high degree of substitutability between the clean and dirty goods. Under these circumstances, both the myopic and hyperopic individuals sustain the levels of their consumption habits through time. They do so in the presence of societal and private externalities that effectively temper gains in their welfare levels caused by their habit formations.

8 | SUMMARY AND CONCLUSIONS

In this paper, we have developed a conceptual model characterizing the choice behavior of two types of individuals: one myopic and the other hyperopic. A myopic individual ignores his private contributions to the negative welfare effects associated with both a social and private negative externality. Also ignored is the effect that his accumulation of stuff has on his habit parameter. In so doing, the myopic individual does not perceive the formation of his consumption habit. The hyperopic individual is the polar opposite. He internalizes both types of externalities, and is cognizant of his consumption habit.

We find that the hyperopic individual consumes a greater amount of the clean good and a lesser amount of the dirty good, with the magnitude of the latter difference being greater than the magnitude of the former. Consequently, the hyperopic individual's cumulative consumption of the two goods is lower, as is his contribution to the social externality. Lower cumulative consumption also contributes to a lower habit parameter, which is indicative of a less-persistent consumption habit. We also find that an astigmatic individual (an intermediate type of individual who internalizes the private (but not the social) externality, as well as the habit-formation effect) consumes a greater amount of the clean good and a lesser amount of the dirty good than a myopic individual, with the magnitude of the latter difference being greater than the magnitude of the former.

Regarding the design of tax policy to control the social externality, we find that the adjustment to the standard Pigovian tax rates (which control for a negative externality in the absence of habit formation) depends upon whether the marginal benefit associated with habit formation outweighs the marginal cost associated with the accumulation of stuff. To the extent that it does, the Pigovian tax rates in the presence of habit formation are lower than the standard tax rates that ignore the formation of a consumption habit. The former rates could actually be negative, indicating that it is optimal to subsidize the myopic individual to encourage him to exploit the net marginal benefit associated with his habit formation. To the contrary, that is, to the extent that the myopic individual experiences a larger marginal cost associated with the accumulation of stuff than marginal benefit from habit formation, the Pigovian tax rates will exceed their corresponding standard rates. This, in turn, will lead to lower levels of aggregate and cumulative consumption and lower levels of both the private and social externalities.

Numerical evidence supports our theoretical results, and extends our understanding of convergent trajectories among the myopic and hyperopic individuals' key variables as the price differential between the clean and dirty good, that is, the clean good's price premium, widens. We demonstrate that as the price premium increases, the demands for the clean good among the myopic and hyperopic individuals converge more quickly than do the demands for the dirty good. On the contrary, there is no discernible convergence between the levels of cumulative consumption and the social externality. While the social externality increases at a decreasing rate with the price premium for both types of individuals, cumulative consumption remains constant. This constancy of cumulative consumption suggests that the individuals' consumption habits are correspondingly maintained across an increasing price premium.

There are limitations to the analysis that impel further research into the consequences of externality-causing behavior in the presence of consumption-habit formation. Foremost among them is the need to better comprehend the link between a given individual's consumption habits and his contributions to both private and social externalities. In the best-case scenario, this would entail individual-level surveys and field experiments designed to ferret out the motivations driving an individual's consumption habits, and the extent to which the individual is cognizant of the links between his habits and his environmental footprint. For example, to what extent do lovers of fast food associate their fast-food habit with negative environmental consequences? To what extent do habitual travelers account for the impact of their globe-trotting tendencies on climate change?

Understanding these types of linkages—between one's consumption habits and environmental footprint—from a granular, behavioral perspective may enable the formation of public policies to mitigate both private and social externalities through the use of more subtle "nudges" than the use of the proverbial sledgehammer of taxation (Thaler & Sunstein, 2009). For example, human-interest awareness stories about individuals who are voluntarily working to reduce consumption habits that exacerbate private and social externalities could be given more nationwide attention. The goal here would be to recalibrate social norms away from a mass consumption ethic, ironically to harness the habit that many of us share when it comes to consuming social media. Effective messaging could potentially go a long way toward helping us reduce the impacts of the habits we form, whether we do so knowingly or not.

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The author has no conflicts of interest (financial or nonfinancial) to report regarding this paper and the research conducted to produce it.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no data sets were generated or analyzed during the current study.

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APPENDIX A: SUFFICIENCY AND STABILITY CONDITIONS FOR MYOPIC INDIVIDUAL'S PROBLEM

Totally differentiating first-order conditions (7)–(10) results in the bordered-Hessian matrix:

$$\bar{H}^m = \begin{bmatrix} 0 & -p_1 & -p_2 & -1 \\ -p_1 & -\frac{\alpha}{X^2} - \frac{\beta}{x_1^2} & -\frac{\alpha}{X^2} & 0 \\ -p_2 & -\frac{\alpha}{X^2} & -\frac{\alpha}{X^2} & 0 \\ -1 & 0 & 0 & -\frac{1}{y^2} \end{bmatrix},$$

from which,

$$\left|\bar{H}_2^m\right| = -p_1^2 < 0, \tag{A1}$$

$$\left|\bar{H}_3^m\right| = p_1\left[\frac{\alpha}{X^2}[p_1 - p_2]\right] - p_2\left[\frac{\alpha}{X^2}[p_1 - p_2] - p_2\frac{\beta}{x_1^2}\right] > 0, \tag{A2}$$

$$\left|\bar{H}_4^m\right| = -\left[\frac{\alpha}{X^2}\frac{\beta}{x_1^2}\right] - \frac{1}{y^2}\left|\bar{H}_3^m\right| < 0, \tag{A3}$$

where all variables are evaluated at their optimal levels, and the inequality in (A2) comes about via $p_1 > p_2$. Equations (A1)–(A3) satisfy the second-order conditions for a unique maximum solution to problem (6).

To check the problem's local stability conditions, we begin by noting the following from (15) and (16):

$$\frac{\partial x_1^m}{\partial \pi} = \frac{-\beta N\left[\mu_1 - \mu_2\right]}{\Phi_m^2} > 0 \quad \text{and} \quad = \frac{\partial x_2^m}{\partial \pi} = -\frac{p_1}{p_2}\frac{\partial x_1^m}{\partial \pi} < 0, \tag{A4}$$

which implies

$$-\frac{\partial x_2^m}{\partial \pi} > \frac{\partial x_1^m}{\partial \pi}, \tag{A5}$$

by $p_1 > p_2$.

To check for local stability, we evaluate the four-dimensional system of Equations (4), (5), (14), and (12) at the optimal solution, expanded here to account for (A4) and (A5),

$$\dot{G} = G_0 + N[\mu_1 x_1(\pi) + \mu_2 x_2(\pi)] - \nu G, \tag{A6}$$

$$\dot{\hat{X}} = \hat{X}_0 + x_1(\pi) + x_2(\pi) - \delta \hat{X}, \tag{A7}$$

$$\dot{\pi} = \rho_G \sigma_G G^{\rho_G - 1} - \pi[\nu + r], \tag{A8}$$

$$\dot{\lambda_X} = -\alpha'(\hat{X}) ln(x_1(\pi) + x_2(\pi)) + \rho_X \sigma_X \hat{X}^{\rho_X - 1}. \tag{A9}$$

The associated Jacobian matrix of this system, denoted J_E^m, is written as

$$J_E^m = \begin{bmatrix} -\nu & 0 & \Psi & 0 \\ 0 & -\delta & \Gamma & 0 \\ \Lambda & 0 & -[\nu + r] & 0 \\ 0 & \Omega & -\frac{\alpha'\Gamma}{X} & \delta_r \end{bmatrix},$$

where (i) $\Psi = \mu_1 \frac{\partial x_1}{\partial \pi} + \mu_2 \frac{\partial x_2}{\partial \pi} < 0$ as a result of $\mu_2 > \mu_1$ and (A5), (ii) $\Gamma = \frac{\partial x_1}{\partial \pi} + \frac{\partial x_2}{\partial \pi} < 0$ from (A5), (iii) $\Lambda = \rho_G[\rho_G - 1]\sigma_G G^{\rho_G - 2} > 0$, and (iv) $\Omega = -\alpha'' ln(X) + \rho_X[\rho_X - 1]\sigma_X \hat{X}^{\rho_X - 2} > 0$. From matrix J_E^m we obtain $Trace\left(J_E^m\right) = -2\nu < 0$ and $|J_E^m| = [\delta + r][\delta\Psi\Lambda - \nu\delta[\nu + r]] < 0$, indicating that the system is locally saddle-point stable (Wainwright & Chiang, 2004).

To visualize the system's dynamics, we provide two phase diagrams. In Figure A1 we present the dynamics between externality G and its shadow value π. The $\dot{\pi} = 0$ curve corresponds to steady-state equality $\pi[\nu + r] = \rho_G \sigma_G G^{\rho_G - 1}$, with slope,

$$\left.\frac{\partial \pi}{\partial G}\right|_{\dot{\pi}=0} = \frac{\rho_G[\rho_G - 1]\sigma_G G^{\rho_G - 2}}{\nu + r} > 0, \tag{A10}$$

and the $\dot{G} = 0$ curve corresponds to steady-state equality $\nu G = G_0 + \mu_1 x_1(\pi) + \mu_2 x_2(\pi)$, with slope,

$$\left.\frac{\partial \pi}{\partial G}\right|_{\dot{G}=0} = \frac{\nu}{\Psi} < 0, \tag{A11}$$

where Ψ is previously defined. As we see, the diagram's (saddle-point) stable manifold follows a northwest-southeast route. We also note that the slopes of both the $\dot{\pi} = 0$ and $\dot{G} = 0$ curves are unaffected by changes in $\hat{X}$ and λ_X.

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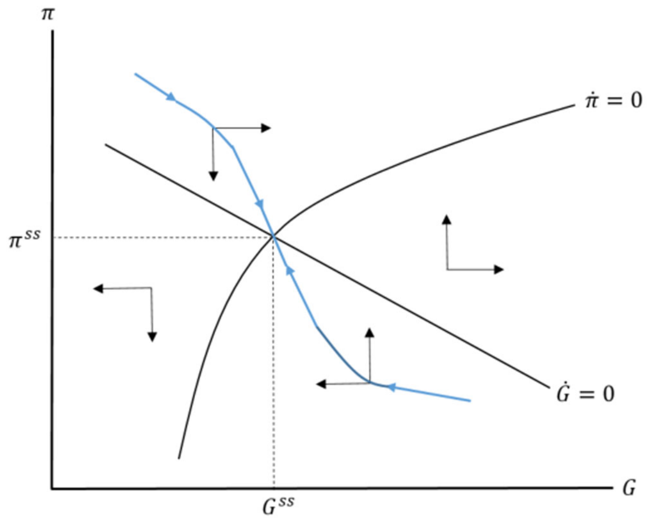

FIGURE A1 Phase diagram of the relationship between $\dot{\pi}$ and $\dot{G}$ for myopic individual.

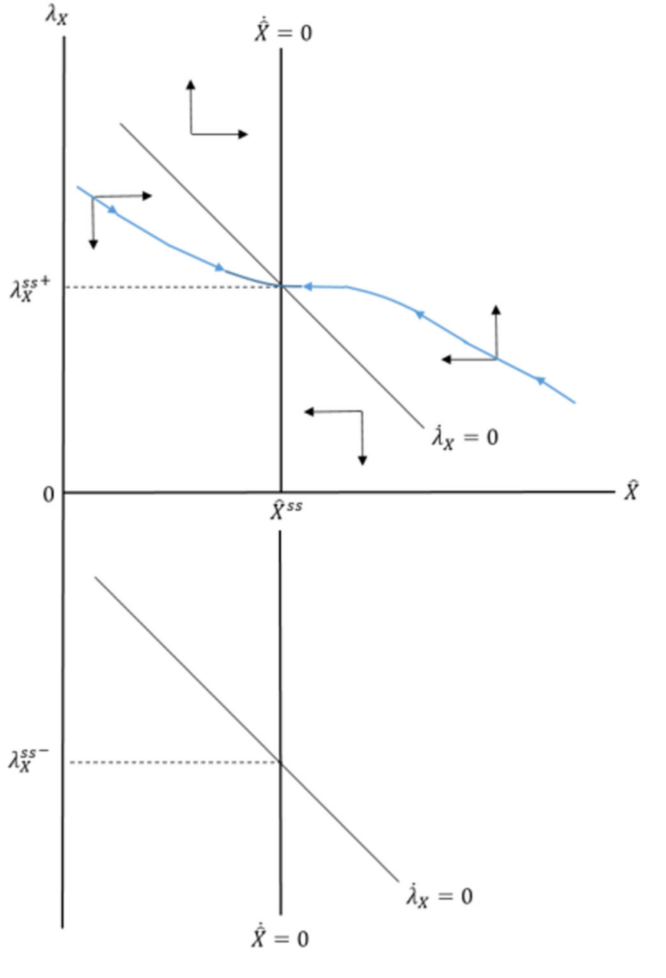

FIGURE A2 Phase diagram of the relationship between $\dot{\lambda}_X$ and $\dot{\hat{X}}$ for myopic individual.

In Figure A2 we similarly present the dynamics between cumulative consumption $\hat{X}$ and its shadow value λ_X. The $\dot{\lambda}_X = 0$ curve corresponds to steady-state equality $\lambda_X[\delta + r] = \alpha'(\hat{X})ln(X) - \rho_X \sigma_X \hat{X}^{\rho_X - 1}$, with slope,

$$\left.\frac{\partial \lambda_X}{\partial \hat{X}}\right|_{\dot{\lambda}_{X=0}} = \frac{\alpha'' ln(X) - \rho_X[\rho_X - 1]\sigma_X \hat{X}^{\rho_X - 2}}{\delta + r} < 0, \tag{A12}$$

and the $\dot{\hat{X}} = 0$ curve corresponds to steady-state equality $\delta\hat{X} = X_0 + X$, with slope,

$$\left.\frac{\partial \lambda_X}{\partial \hat{X}}\right|_{\dot{\hat{X}}=0} = \infty. \tag{A13}$$

Here, we recall from Section 3 that because the sign of λ_X^{ss} is indeterminate, we must represent outcomes for both possible signs, λ_X^{ss+} and λ_X^{ss-}. As shown in the diagram for λ_X^{ss+}, the system's stable manifold follows an east–west route. Although not shown (to reduce clutter), an identical route is followed for the case of λ_X^{ss-}. Further, while the slopes of both the $\dot{\lambda}_X = 0$ and $\dot{\hat{X}} = 0$ curves are unaffected by changes in G, the former's slope flattens as π increases (since $\alpha''\Gamma/[X[\delta + r]] > 0$).

APPENDIX B: SUFFICIENCY AND STABILITY CONDITIONS FOR HYPEROPIC INDIVIDUAL'S PROBLEM

Totally differentiating first-order conditions (9), (10), (22), and (23) results in the bordered-Hessian matrix,

$$\bar{H}^h = \begin{bmatrix} 0 & -p_1 & -p_2 & -1 \\ -p_1 & \Theta_1 & \Theta_2 & 0 \\ -p_2 & \Theta_2 & \Theta_3 & 0 \\ -1 & 0 & 0 & -\dfrac{1}{y^2} \end{bmatrix},$$

where

$$\Theta_1 = -\frac{\alpha}{X^2} - \frac{\beta}{x_1^2} + \frac{\alpha''}{\delta^2} + \frac{\alpha'}{\delta X} - \frac{\rho_G[\rho_G - 1]\mu_1^2 \sigma_G G^{\rho_G - 2}}{\nu^2} - \frac{\rho_X[\rho_X - 1]\sigma_X \hat{X}^{\rho_X - 2}}{\delta^2},$$

$$\Theta_2 = -\frac{\alpha}{X^2} + \frac{\alpha''}{\delta^2} + \frac{\alpha'}{\delta X} - \frac{\rho_G[\rho_G - 1]\mu_1\mu_2 \sigma_G G^{\rho_G - 2}}{\nu^2} - \frac{\rho_X[\rho_X - 1]\sigma_X \hat{X}^{\rho_X - 2}}{\delta^2},$$

$$\Theta_3 = -\frac{\alpha}{X^2} + \frac{\alpha''}{\delta^2} + \frac{\alpha'}{\delta X} - \frac{\rho_G[\rho_G - 1]\mu_2^2 \sigma_G G^{\rho_G - 2}}{\nu^2} - \frac{\rho_X[\rho_X - 1]\sigma_X \hat{X}^{\rho_X - 2}}{\delta^2}.$$

We see that the $\alpha'/\delta X > 0$ term is the only positive term included in each of these three equations. Its inclusion precludes us from definitively signing Θ_1, Θ_2, and Θ_3. Nevertheless, we see that $|\Theta_3| > |\Theta_2| > |\Theta_1|$ by $\mu_2 > \mu_1$.

From matrix $\bar{H}^h$ we obtain

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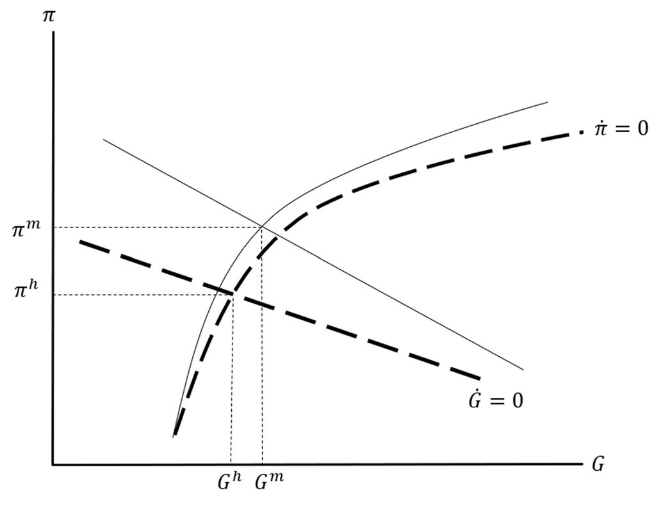

FIGURE B1 Phase diagram of the relationship between $\dot{\pi}$ and $\dot{G}$ for the hyperopic individual.

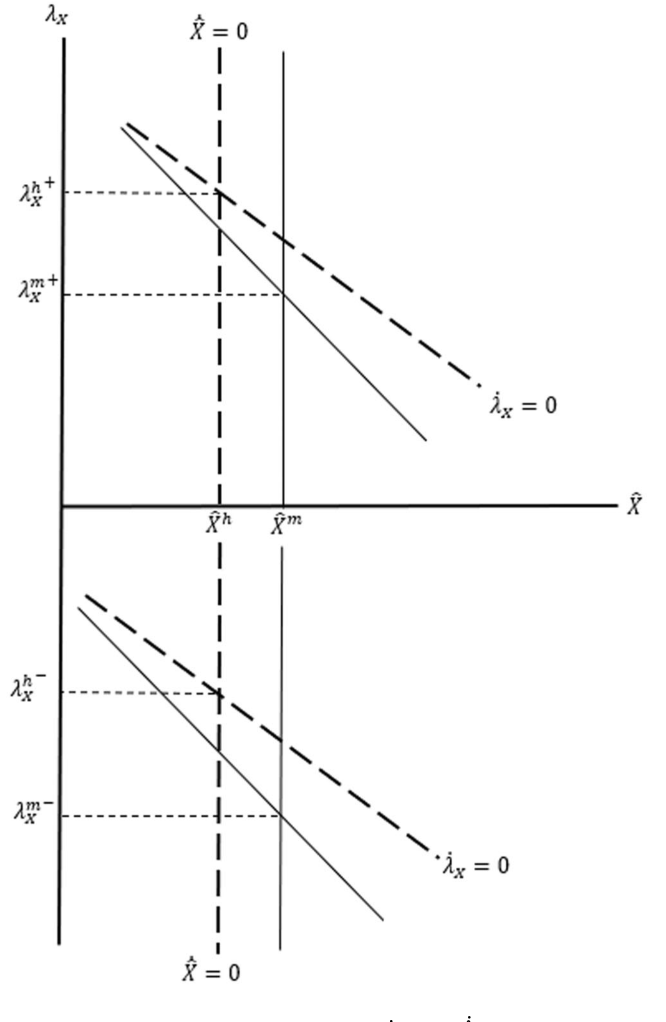

FIGURE B2 Phase diagram of the relationship between $\dot{\lambda}_X$ and $\dot{\hat{X}}$ for the hyperopic individual.

$$\left|\bar{H}_2^h\right| = -p_1^2 < 0, \tag{B1}$$

$$\left|\bar{H}_3^h\right| = p_1[p_2\Theta_2 - p_1\Theta_3] - p_2[p_2\Theta_1 - p_1\Theta_2], \tag{B2}$$

$$\left|\bar{H}_4^h\right| = \Theta_2^2 - \Theta_1\Theta_3 - \frac{1}{y^2}\left|\bar{H}_3^h\right|, \tag{B3}$$

where all variables are evaluated at their optimal levels. Although we cannot definitively sign (B2), the term $p_1[p_2\Theta_2 - p_1\Theta_3] > 0$ by $p_1 > p_2$ and $\mu_2 - \mu_1$. And the difference $\Theta_2^2 - \Theta_1\Theta_3 = 0$ in (B3). Hence, if $\left|\bar{H}_3^h\right| > 0$, then $\left|\bar{H}_4^h\right| < 0$, as required.

Regarding the local stability of the hyperopic individual's steady-state solution, we can appeal to the fact that the same four-dimensional system of equations defining the myopic individual's dynamics, (A6)–(A9), also defines the hyperopic individual's. Thus, the hyperopic individual's steady-state solution is also locally saddle-point stable.

Consistent with Proposition 1, we can account for attendant shifts in the phase diagrams' curves in Figures A1 and A2.

Regarding changes in Figure A1's curves, we note that results (vi)–(viii) of Proposition 1, along with (A4), (A6) evaluated at $\dot{G} = 0$, and (A11), indicate that the $\dot{G} = 0$ curve shifts leftward and its slope decreases in magnitude relative to the myopic individual's. Further, results (vi) and (vii) of Proposition 1, along with (A8) evaluated at $\dot{\pi} = 0$ and (A10), indicate that the $\dot{\pi} = 0$ curve shifts rightward and its slope decreases. These changes lead to new steady-state values for G and π, and are depicted in Figure B1.

Figure B2 depicts the changes associated with Figure A2's curves.

Result (v) of Proposition 1 indicates that the $\dot{\hat{X}} = 0$ curve shifts leftward. Results (i)–(iii) and (v) of Proposition 1, along with (A12), indicate that the slope of the $\dot{\lambda}_X = 0$ curve decreases in magnitude. As with Figure B1, these changes lead to new steady-state values for $\hat{X}$ and λ_X.