Too slow a change? Deep habits, consumption shifts and transitory tax

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Abstract

This paper studies shifts in the consumption bundle when consumption is subject to habit formation, and consumers do not internalize this habit formation process. Habits are good-specific, or 'deep', and cause persistence in good-specific consumption. In addition, at the aggregate level, habits act as benchmark against which consumption is evaluated. I establish that a rapid transition is optimal if the persistence effect is relatively strong, and determine the path of taxes or subsidies that implements this transition, both when goods are produced competitively and when they are produced by monopolists. To explore the quantitative implications of the model I consider the introduction of a 10 percent charge on a subset of goods. I find that consumption adjusts inefficiently fast; implementing first-best adjustment requires a transitory discount of up to 60 percent of the cost increase.

Keywords: habit formation, projection bias, consumption shifts, optimal taxation

JEL classifications: D11, D62, H21, H23

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1 Introduction

A rapidly expanding literature in behavioral economics documents how consumer preferences and rationality deviate from 'standard' neoclassical assumptions.[1] Preferences for instance, are shaped by context and reference points. I consider the specific case of habit formation, where utility from consumption depends on habits (Frederick and Loewenstein, 1999; Rabin, 2002). As habits only slowly catch up with actual consumption, consumption patterns become persistent. People however have difficulty anticipating such future preference changes. This is known as projection bias, and implies individuals do not appropriately internalize the effects of current consumption decisions on future demand and welfare (Frederick and Loewenstein, 1999; Loewenstein et al., 2000; DellaVigna, 2009). Against this backdrop, a question arises whether fiscal policies can improve welfare by correcting this habit internality. This question has relevance especially where policymakers foresee or manage a change in consumption patterns.

Several imminent changes in consumption patterns can be identified across the globe. In 2014, droughts and water shortages were reported from Australia to California and Tehran to São Paulo. Many of these areas have a long history with droughts. Yet, more intensive agriculture and population growth increase the difficulty of dealing with ensuing water shortages. In California for instance, water shortages during the 2011-2017 drought led farmers to increasingly rely on the already dwindling groundwater stock, and reservoir water levels fell below 60 percent of average levels (State of California, 2015; The New York Times, 2015). Combating water shortages and preventing an irreversible depletion of groundwater resources required, and will continue to require, a substantial reduction in water use by the agricultural sector and households.

More generally, both in the past and future, people's diets have and will be subject to constant shocks and changes. Examples are numerous here. Collapsing ocean fish stock will force consumers to shift their diets away from the most-prized species. So-called 'fat' and 'sugar' taxes have been the subject of debate in many countries. Several government have introduced such taxes, as a measure to induce consumers to adopt a healthier diet.[2] Similar examples can be found in other areas. For instance, congestion and more stringent local pollution policies will require urbanites to abandon their gas-guzzling vehicle for a more efficient one, shift to public transport or even a bicycle. Stringent climate policies can contribute to this trend, and bring an end to an era of cheap energy.

When habits cause consumption persistence, such shifts in consumption patterns will not come about from one day to another. Rather, following a shock to relative goods prices, consumption, and habits, will only gradually adjust. In this context, the question is whether from a welfare

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[1]For example Rabin (2002), Tirole (2002), DellaVigna (2009) and Samson (2014).

[2]See for instance The Washington Post (2012) and The Guardian (2016). Smed (2012) discusses the specific case of the Danish fat tax (which was later scrapped).

perspective, such a shift in consumption patterns is too slow, or still too fast. Correspondingly, is a policy that further smooths this change in consumption welfare-improving, or should policy be used to implement a faster transition?

In this paper, I answer this question. I put forward a simple model of habit formation. In this model, a representative consumer forms habits at the level of individual goods. These good-specific habits cause persistence in consumption patterns. At the aggregate level, habits form a benchmark against which consumption is evaluated. This benchmark, which slowly adjust to consumption, causes any increase in utility due to an increase in the consumption level to fade over time; as the consumer get used to a higher consumption level she loses (part of) her appreciation for it. The consumer does not internalize that current consumption affects future habits and thereby future demand and welfare. Consumption decisions may therefore deviate from the optimal path, which is defined as the path that maximizes welfare, taking into account the endogenous formation of habits.

As all goods are subject to habits, habits provide no reason to subsidize consumption of one good relative to another in steady state. However, habits do affect the optimal adjustment path of consumption towards a new bundle. This optimal transition is faster the stronger are habits at the good-specific level vis-a-vis the aggregate level. At the good-specific level, the consumer prefers to consume goods she has a high habit in. As a consequence, as she does not internalize that current consumption affects future habits, she keeps 'too high' habits for those goods consumption shifts away from. A faster transition thus improves welfare. At the aggregate level however, the transition offers an opportunity to manage the habit benchmark against which consumption is evaluated. A slow transition, which implies the consumer consumes to a relatively 'inefficient' bundle for a longer period of time, lowers this benchmark, and is thus beneficial.

The optimal consumption path can be implemented by temporary, or transitory, fiscal policy. A positive tax on those goods consumption shift away from speeds up the transition, while a subsidy slows it down. The exact path of taxes and subsidies then depends on whether goods are produced under perfect competition or by monopolists. In the latter case, forward-looking producers invest in habits. An anticipated drop in demand reduces the value of this investment, and increases the markup charged by monopolists. This price response speeds up the transition to the new consumption bundle compared to the competitive market. Hence, I find that while taxes might still be called for under perfect competition, transitory subsidies are always required to implement the optimal consumption path under monopolists.

To illustrate the mechanisms and quantify effects, I evaluate the implications of an unanticipated shock to production costs. More specifically, I consider the introduction of a 10 percent charge on 'unhealthy foods', which induces consumption to shift to away from these goods. Here I determine the transition when goods are produced by perfectly competitive firms or monopolists,

as well as the optimal transition. I find the latter to be relatively slow; relative consumption drops by about 11 percent at the onset of the shift, and it takes more than 10 years for the economy to converge to the new steady-state. Implementing this path requires sizable policy intervention; initial charges are set to about 40 to 60 percent of the long-run optimal charge. Appropriately managing this transition reduces transition costs by up to 5 percent. Immediately setting the charge at the long run level however has the advantage of being simple and straightforward to implement. I propose two alternative simple policy rules which generate welfare levels close to the one under the optimal path.

The remainder of this paper is structured as follows. Section 2 discusses the relevant literature. The model is introduced in Section 3. Section 4 discusses the equilibrium, including the steady state. The transition path towards this steady state is discussed in Section 5. Optimal steady-state adjustment and policy are presented in Section 6, and Section 7 deals with the numerical application. Section 8 concludes. Detailed derivations, proofs, a model extension, and further details to Section 7 can be found in Appendices A through C.

2 Literature

Early theoretical contributions on habit formation have been made by Pollak (1970), Ryder and Heal (1973), Becker and Murphy (1988) and Abel (1990). The work by Pollak (1970), and later Carroll (2000) and Hiraguchi (2008), focuses on the properties of demand functions with habit formation. The implications of habit formation have been explored in fields as diverse as asset pricing (Abel, 1990; Constantinides, 1990; Campbell and Cochrane, 1999), growth (Ryder and Heal, 1973; Carroll et al., 2000; Alvarez-Cuadrado et al., 2004; Alonso-Carrera et al., 2005), addiction (Becker and Murphy, 1988), life cycle consumption and savings (Cremer et al., 2010; Koehne and Kuhn, 2014) and the relationship between income and happiness (Layard, 2006; Choudhary et al., 2012). In these fields, habits have been put forward as an explanation for multiple 'puzzles', such as the equity premium puzzle (Abel, 1990; Constantinides, 1990; Campbell and Cochrane, 1999), the observation that growth Granger causes savings (Carroll and Weil, 1994; Carroll et al., 2000) and the Easterlin paradox (Choudhary et al., 2012). Including habits in monetary policy and DSGE models allows these models to capture certain features of the macroeconomy, such as the gradual response of real spending to shocks (Fuhrer, 2000) and counter-cyclical markups (Ravn et al., 2006). Also empirical research generally confirms the presence of habit formation in consumption. Bronnenberg et al. (2012) for instance, find that endogenous brand preferences explain 40 percent of the geographic variation in market shares. Carrasco et al. (2005) test for habits formation in food, services and transport. They find evidence for habits in food and services; accounting for individual fixed effects, a 1 percent increase in past consumptions of food and services increases

current consumption by 0.72 and 0.14 percent respectively.[3]

Empirical evidence from psychology and behavioral economics indicates that consumers are not fully rational with respect to observing and anticipating the habit formation process. Instead, individuals suffer from projection bias, i.e. they fail to fully anticipate preference shifts (Frederick and Loewenstein, 1999; Loewenstein et al., 2000; Conlin et al., 2007).[4] This opens up room for welfare-improving policy intervention. Ljungqvist and Uhlig (2000) for instance, show that habits provide a rationale for procyclical taxes, as such taxes counter the tendency to build up 'too high' habits during booms. In the context of growth, Alonso-Carrera et al. (2005), Turnovsky and Monteiro (2007) and Monteiro et al. (2013) characterize the income and consumption tax rates that implement the optimal path of consumption as the economy transitions to the balanced growth path. In Cremer et al.'s (2010) two-period model with retirement, habit formation and myopia cause overconsumption and undersaving in the first period of life. A tax on first-period consumption and a lump-sum transfers then implements the first-best allocation. If lump-sum transfers are infeasible, the second-best policy will also have redistributive implications. This paper contributes to this literature, which evaluates the implications of habit formation for optimal (tax) policy when consumers do not fully internalize the habit formation process.[5]

With the exception of the work by Ravn et al. (2006), the theoretical research cited above assumes habits form at the level of aggregate consumption instead of individual goods. Hence, this research cannot address the implications of habit formation for shifts *within* the consumption bundle. To my knowledge, I am the first to evaluate the potential policy implications of habit formation when habits are formed at the good-specific level. The distinction between aggregate (superficial) and good-specific (deep) habits was first made by Ravn et al. (2006), who studies the implications of the latter. When habits form at the level of individual goods, strategic behavior by firms becomes relevant; a central result of Ravn et al. (2006) is that deep habits give rise to countercyclical markup behavior. In Ravn et al. (2010), the authors more closely assess the pass-through of marginal cost shocks and establish that pass-through is increasing in the persistence of

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[3]See also Dynan (2000), Ravina (2005), Dubé et al. (2010), Alvarez-Cuadrado et al. (2012), Atkin (2013) and Verhelst and Van den Poel (2014). All except Dynan (2000) find evidence for habit formation. This literature is discussed in more detail in Section 7.

[4]From a modeling perspective, projection bias blurs the distinction between habit formation when habits are formed internally and own past consumption acts as a reference point, or externally, where the reference point depends on past consumption of a peer group (also known as 'catching up with the Joneses'). In both cases, external habits and internal habits with projection bias, the consumer does not internalize the habit formation process. For this reason, both the literature on, and policy implications of, internal and external habit formation are relevant to this paper and thus considered. See also Section 3.

[5]More generally, I contribute to a broader literature in 'behavioral public economics', which evaluates the policy implications of non-standard (behavioral) assumptions. Examples of such behavioral assumptions include projection bias considered here, but also hyperbolic discounting, reference-dependent preferences, overconfidence, and limited attention (DellaVigna, 2009). See for instance O'Donoghue and Rabin (2006) on optimal policy under hyperbolic discounting and Bernheim and Rangel (2007) and Dalton and Ghosal (2011) for a general discussion.

cost shocks, and may even exceed a 100 percent. Such 'excessive' pass-through is also a feature of my setup, and will tend to speed up shifts within the consumption bundle.

The deep habits specifications formulated by Ravn et al. (2006), and subsequently used by Doi and Mino (2008), Ravn et al. (2010) and Nakamura and Steinsson (2011), do not separate the two effects of habit formation; the presence of good-specific habits reduces (steady-state) welfare whenever habits lead to persistence in consumption, and vice versa. I propose a specification that separates these two effects. This allows me to more closely evaluate the importance of these effects and their relative strength in determining the optimal adjustment path of consumption. In addition, my specification unites the deep habits approach of Ravn et al. (2010) with the mainstream aggregate habits specification adopted by for instance Abel (1990) and Monteiro et al. (2013).

As argued in the introduction, consumption patterns can change for many reasons. Several of those reasons relate to resource scarcity and environmental externalities. In this context, this paper contributes to a more specialized literature that assesses the optimal time path of environmental taxes, and carbon taxes in particular. In this literature, numerous rationales for time-varying taxes have been proposed, ranging from innovation externalities (Acemoglu et al., 2012; Gerlagh et al., 2009) to issues related to resource scarcity and the so-called green paradox (Ulph and Ulph, 1994; Sinn, 2008). Here, this paper provides an additional, previously uninvestigated, rationale for time-varying environmental taxes: habits. Appendix B explicates how the framework can be extended to and interpreted in this context.

3 Model

I consider a simple setup in which a representative consumer consumes a variety of goods $c_i(t)$, with $i \in [0, 1]$ and where t denotes time. The consumer forms habits $h_i(t)$ over the same varieties. These good-specific, or 'deep', habits cause persistence in consumption decisions: demand for good $c_i(t)$ is increasing in habit $h_i(t)$. Consumption and habits are aggregated into $C(t)$ and $H(t)$. The representative consumer's instantaneous utility $U(t)$ at time t increases in effective consumption $C(t)$, and $C(t)$ relative to a benchmark, the aggregate habit $H(t)$. The higher this benchmark, the lower is utility from consumption. Hence, the aggregate habit causes some degree of hedonic adaptation: the utility gain from a permanent increase in consumption (partly) fades out over time as consumers become accustomed to the higher consumption level.[6] Note that in the remainder, I omit time from notation when convenient.

Instantaneous utility reads

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[6]The hedonic treadmill, or hedonic adaptation, is a concept from psychology which describes the tendency for humans to quickly return to a relatively stable level of happiness following a major positive or negative life event (Frederick and Loewenstein, 1999).

$$U(t) = \frac{\left(C(t)^{1-\gamma}\left(\frac{C(t)}{H(t)}\right)^{\gamma}\right)^{1-\sigma}}{1-\sigma}, \tag{1}$$

where $\sigma > 0$ is the (negative) elasticity of marginal utility when habits are exogenous. The parameter γ is the aggregate habit strength, and measures the importance of the aggregate habit benchmark in utility. Here I set $\gamma \in [0,1]$. Effective consumption is an aggregate of consumption over a variety of goods c_i. The importance of each variety in C depends on (endogenous) good-specific consumption weights w_i. These weights in turn depend on habits; a higher good-specific habit relative to the aggregate habit increases the weight of a good c_i in C:

$$C(t) = \left[\int_0^1 w_i(t)c_i(t)^{\frac{\eta-1}{\eta}} di\right]^{\frac{\eta}{\eta-1}}, \tag{2}$$

and

$$w_i(t) = \left(\frac{h_i(t)}{H(t)}\right)^{\frac{\theta}{\eta}}. \tag{3}$$

Here, η is the instantaneous elasticity of substitution across varieties and $\theta \in [0,1)$ is the good-specific habit strength. Deep habits, at the level of individual varieties, increase demand for specific varieties as they increase these varieties' weight in the consumption aggregate. Note that the aggregation from c_i to C preserves linear homogeneity: a proportional increase in all c_i translates into an equiproportional increase in C. The aggregate habit is a measure for the effective consumption level the consumer is accustomed to and defined as follows

$$H(t) = \left[\int_0^1 w_i(t)h_i(t)^{\frac{\eta-1}{\eta}} di\right]^{\frac{\eta}{\eta-1}}. \tag{4}$$

H is linearly homogeneous in good-specific habits h_i which implies consumption weights are independent of the scaling of the habit. A proportional increase in all habits h_i thus reduces utility only through an increase the aggregate habit benchmark H; it does not alter effective consumption C. Similarly, a shift in good-specific habits, keeping the aggregate habit H constant, only affects utility through its effect on the good-specific consumption weights w_i and effective consumption C. Such a shift in good-specific habits will increase effective consumption C if it brings the pattern of habits more in line with the pattern of consumption.[7] If consumption and habits are uniform across varieties, we have $H = h_i$, $w_i = 1$ and $C = c_i$.

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[7]This can be illustrated by the following example. Consider a consumption bundle that is high in vegetables and low in meat. Then effective consumption C derived from this bundle is higher if the consumer is used to this high vegetable, low meat diet, than if she were used to a low vegetable, high meat diet. Both diet habits however, could resemble the same standard of living, i.e. the same H.

Good-specific habits slowly catch up with consumption:

$$\dot{h}_i(t) = \xi \left(c_i(t) - h_i(t) \right), \tag{5}$$

where the dot denotes a time derivative and $\xi > 0$ is the adjustment speed of the habit. In steady-state, habits have converged to actual consumption: $h_i = c_i$. From (2) and (4) it then also follows that in steady state, the aggregate habit equals effective consumption: $H = C$.

The specification above allows me to disentangle two effects of habits. First, θ measures the degree to which habits cause persistence in good-specific consumption. The higher is θ, the more responsive is the consumption weight w_i to a change in good-specific habits h_i. Then, as will become clear in the next section, a higher θ implies greater persistence in consumption patterns. If $\theta = 0$, such consumption choices are independent of good-specific habits, and (2) collapses to the standard Dixit-Stiglitz specification. Second, γ measures the degree to which, over time, consumers adapt to changes in effective consumption C. The higher is γ, the more important is the aggregate habit benchmark in welfare. If $\gamma = 1$, changes in consumption do not lead to long-term utility gains or losses. With $\gamma = 0$, aggregate habits do not affect utility from C.

For production, I assume a constant returns to scale production technology, where the production of each good requires $\delta_i > 0$ units of labor. Total labor supply, L, is fixed, so that the labor market equilibrium reads as follows

$$L = \int_0^1 \delta_i c_i(t) di. \tag{6}$$

In addition to the direct labor cost of production, producers may face a good-specific production tax. I denote the wage rate by p_L. To the producer, the total cost of producing one unit of c_i then equals $\delta_i p_L(t) \tau_i(t)$ where $\tau_i(t)$ is the gross tax rate; for $\tau_i(t) > 1$, good i production is subject to a positive tax, and good i is subsidized if $\tau_i(t) < 1$. Tax receipts are rebated though a lump-sum transfer (which is negative in case total receipts are negative).

Finally, I make two assumptions regarding the rationality of the consumer and producers:

Assumption 1 The representative consumer is subject to strong projection bias, i.e. it does not internalize the effect of current consumption on future habits.

Projection bias is a form of limited rationality where individuals do not (fully) anticipate future changes in preferences (Loewenstein et al., 2000; Samson, 2014). As a consequence, in the face of changing preferences, the individual is unable to fully optimize its consumption decisions. In the context of the current framework, this implies that demand is a function of the goods' current prices and habits, but not on future expected prices.

Assumption 2 Producers are forward-looking and atomistic.

Contrary to the consumer, producers do anticipate that current consumption affects future demand through habits. Hence, they adjust their optimization accordingly. Their atomistic size however implies that even though producers internalize the direct effect of $c_i(t)$ on the evolution of the good-specific habit $h_i(t)$, they do not internalize the subsequent effect on the aggregate habit $H(t)$.[8] As we will see below, habits affect the price charged by monopolists. If markets are perfectly competitive, goods are always sold at marginal costs.

Catching up with the Joneses   In terms of modeling, the internal habit formation framework presented above is virtually equivalent to a setup which instead features 'catching up with the Joneses', as in Abel (1990), Alvarez-Cuadrado et al. (2004) and Alonso-Carrera et al. (2005). In such a setup, $h_i(t)$ represents an external habit, i.e., a reference point based on (past) consumption in the peer group. To the individual consumer, this habit is exogenous. With a representative consumer, one can show h_i still evolves according to (5).[9] In the remainder of the paper, I continue to interpret h_i as an internal habit where the consumer does not internalize the habit formation process. All results and policy recommendations continue to apply if habits are instead formed externally as described above.

4   Equilibrium

The representative consumer maximizes instantaneous utility while taking habits as given. This gives demand

$$c_i(t) = \left(\frac{p_i(t)}{P(t)} \right)^{-\eta} \left(\frac{h_i(t)}{H(t)} \right)^{\theta} C(t), \tag{7}$$

where p_i is the price of good i and

$$P(t) = \left[\int_0^1 \left(\frac{h_i(t)}{H(t)} \right)^{\theta} p_i(t)^{1-\eta} di \right]^{\frac{1}{1-\eta}} \tag{8}$$

is the price of effective consumption. Demand for good i decreases in the price of good i and increases in effective consumption C. For given aggregate habit H, a higher good-specific habit h_i

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[8]This implication is akin to the notion that monopolistically competitive firms internalize the effect of output on the good-specific price, but not on the aggregate price level in the economy.

[9]More specifically, let j be the indicator for the consumer, such that $c_{ji}(t)$ is the time t good i consumption of individual $j \in [0,J]$. Then (2) can be rephrased as $C_j(t) = \left[\int_0^1 w_i(t) c_{ji}(t)^{\frac{\eta-1}{\eta}} di \right]^{\frac{\eta}{\eta-1}}$. (3)-(5) still apply, where in (5) c_i is now redefined as $c_i(t) \equiv \int_0^J c_{ji}(t) dj$. In a representative consumer setting, $C_j(t)$ then collapses to $C(t)$ as in (2).

increases the weight of consumption c_i in C (see (2)). As a consequence, demand increases in the good-specific habit. This in turn also increases the weight of the good i price in the price aggregate P. In the remainder, I take effective consumption as the numeraire, and thus normalize $P = 1$. Through the representative consumer budget constraint, expenditures C must equal income: $C(t) = \left[p_L(t)L + \int_0^1 \pi_i(t)di + \Omega(t) \right]$, where $\Omega(t) = \int_0^1 (\tau_i(t) - 1)\,\delta_i p_L(t) c_i(t) di$ is a lump-sum transfer.

On the producer side, price-setting is straightforward if markets are perfectly competitive. In this case we have

$$p_i(t) = \delta_i p_L(t) \tau_i(t). \tag{9}$$

If the producers are monopolists in their respective goods, each chooses a series of prices that maximizes its firm value V_i, which is equal to the present value of profits, discounted according to market interest rates $V_i(t) = \int_t^\infty e^{-\int_t^v r(x)dx} c_i(v) \left[p_i(v) - \delta_i p_L(v) \tau_i(v) \right] dv$, with c_i given by (7). Producers anticipate that a reduction in the current prices does not only increase current sales, but also, through habits, future demand and profits. Setting a low price to build habit can thus be considered an investment in future profits. Hence, habits are expected to reduce markups, which is confirmed by the following result for the monopolist pricing rule:[10]

$$p_i = \frac{\eta}{\eta - 1} \left[\delta_i p_L(t) \tau_i(t) - \xi \kappa_{h_i}(t) \right], \tag{10}$$

where

$$\kappa_{h_i}(t) = \int_t^\infty e^{-\int_t^v (r(x)+\xi)dx} \frac{\theta}{\eta} \frac{c_i(v)}{h_i(v)} p_i(v)\, dv, \tag{11}$$

and I require $\eta > 1$ to ensure positive steady-state markups. The standard monopolistic competition pricing rule now includes a habit discount, $\xi \kappa_{h_i}$. The size of this discount depends on the shadow value of the habit to the monopolist, κ_{h_i}, multiplied by the direct effect of an increase in consumption on the future habit, ξ. The monopolist sets a low price if investing in the habit is valuable, i.e. if the shadow value of the habit is high. This is the case if (future) demand is very sensitive to the habit (high $\theta c_i/h_i$) and prices are high (high p_i). A low elasticity of substitution η then implies markups are high, and a large share of this price constitute pure profits. Future returns are discounted at a rate $r + \xi$, where a higher discount rate reduces the shadow value of the habit. This is due to the fact that a low persistence of the habit (high ξ) reduces the marginal effect of an increase in c_i today on habits further in the future, while higher discount rates reduce the present value of a given flow of returns.

Habits do not only lead to lower markups, but also to time varying markups. This can be seen as follows. Suppose that p_i is constant, and we initially have $h_i < c_i$. Then as habits catch

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[10]See Appendix A.1 for detailed derivations.

up with consumption, c_i/h_i falls and so does the shadow value of the habit. This increases the monopolist's price according to (10) and is thus inconsistent with the constant price just assumed. The interest rate r is determined endogenously by the consumption Euler equation, which ensures optimal smoothing of (expected) marginal utility over time: $r(t) = \rho - \mathbb{E}^{rc} \left[\frac{d}{dt} \left(\frac{dU(t)}{dC(t)} \right) / \frac{dU(t)}{dC(t)} \right]$, where $\mathbb{E}^{rc} [\cdot]$ is the expectation from the perspective of the representative consumer.[11]

4.1 Steady state

The economy is in steady state if prices, consumption and habits are constant over time. Then, by (5), for all goods $i \in [0, 1]$, habits must equal consumption: $c_i^* = h_i^*$. Here, the star indicates we are in steady state. Then, by (2) and (4), it follows that in steady state also the aggregate habit equals effective consumption: $C^* = H^*$, and the market interest rate equals the rate of time preference ρ. Then, the good i steady-state price under perfect competition equals

$$p_i^* = \delta_i p_L^* \tau_i^*. \tag{12}$$

To the monopolist, the steady-state shadow value of the habit is

$$\kappa_{h_i}^* = \frac{1}{\rho + \xi} \frac{\theta}{\eta} p_i^*, \tag{13}$$

which with (10) gives the following steady state price:

$$p_i^* = \delta_i p_L^* \tau_i^* \frac{\eta}{\eta - 1} \left[\frac{\rho + \xi}{\rho + \xi \left(1 + \frac{\theta}{\eta - 1} \right)} \right]. \tag{14}$$

Even though habits reduce the monopoly markup in steady state, the markup remains positive.[12] As I abstract from saving and assume labor supply is fixed, consumption decisions are fully determined by *relative* prices. In the remainder of the paper, for ease of exposition and to stress this point, I will mostly focus on prices and quantities of a good i relative to some 'base' good $b \in [0, 1]$. From (7), steady-state relative consumption then reads

$$c_i^{R*} = \left(p_i^{R*} \right)^{-\frac{\eta}{1-\theta}}, \tag{15}$$

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[11] Since none of the theoretical results in the remainder of the text rely on whether the consumer's expectations with respect to the evolution of H are rational or not, I make no further assumptions here. If the consumer does not anticipate the evolution of H, which is the assumption I consider most in line with Assumption 1, then $r(t) - \rho = \sigma \dot{C}(t)/C(t)$.

[12] The monopoly markup is positive if $\frac{\eta}{\eta-1} \frac{\rho+\xi}{\rho+\xi\left(1+\frac{\theta}{\eta-1}\right)} > 1$. This condition can be rearranged to $\rho > \xi(\theta - 1)$. As $\theta < 1$ and $\rho, \xi > 0$, this condition is always satisfied.

with $c_i^R \equiv c_i/c_b$ and $p_i^R \equiv p_i/p_b$. The steady-state relative price is independent of market structure:

$$p_i^{R*} = \delta_i^R \tau_i^{R*}, \tag{16}$$

where δ_i^R and τ_i^R are defined in line with c_i^R and p_i^R. Then by (6) I arrive at the following solution for steady-state consumption of good i:

$$c_i^* = c_i^{R*} \left[\int_0^1 \delta_i c_i^{R*} di \right]^{-1} L. \tag{17}$$

In turn

$$C^* = \left[\int_0^1 \left(c_i^{R*} \right)^{\frac{\eta-1+\theta}{\eta}} di \right]^{\frac{\eta}{\eta-1+\theta}} \left[\int_0^1 \delta_i c_i^{R*} di \right]^{-1} L, \tag{18}$$

and

$$U^* = \frac{(C^*)^{(1-\gamma)(1-\sigma)}}{1-\sigma}. \tag{19}$$

The steady state is interior and unique only if demand is strictly concave in the good-specific habit, i.e. only if $\theta < 1$. This condition is easily derived from (7). For a given set of prices, consumption scales with the habit at degree θ. If relative consumption, c_i^R, rises by 1 percent, future habits follow, and in turn future relative consumption goes up by an additional θ percent. The long run increase in c_i^R is then bounded only if $\theta < 1$.

This observation is mirrored in the result for the long run price elasticity of demand. With good-specific habit formation, the long run price elasticity of demand exceeds the short run one. This can be seen by comparing equations (7) and (15). From (7), the (absolute value of) the short run price elasticity of demand is equal to the instantaneous elasticity of substitution across goods: $\varepsilon_p^{SR} = \eta$. In the long run, this price elasticity of (relative) demand is $\varepsilon_p^{LR} = \eta/(1-\theta)$ (see (15)). In the absence of good-specific persistence ($\theta = 0$) these elasticities are equal. For positive θ, the long run shift in consumption in response to a permanent change in relative prices exceeds the short run one: $\varepsilon_p^{LR} > \varepsilon_p^{SR}$. If $\theta = 1$, ε_p^{LR} is unbounded, implying that, in the long run, goods act as perfect substitutes. As a consequence, not all goods may be consumed in steady state, and the relevant steady state would depend on initial values of the h_i. As stated in Section 3, I assume $\theta \in [0,1)$, which rules out such indeterminacy.

A change in the steady-state C will only affect steady-state utility if the aggregate habit strength, γ, lies below 1 (see (19)). If $\gamma = 0$, aggregate habits do not affect utility for a given level of effective consumption C. If $\gamma = 1$, utility only depends on the level of effective consumption relative to the habit: C/H. As habits catch up with consumption, welfare will then always return to a stable long-run level.

Finally, in steady state, due to uniform markups, the relative price p_i^R is independent of whether goods are produced under perfect competition or by monopolists. Outside of steady state however,

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the relative price set by monopolists diverges from the perfect competition price ratio (see (9) and (10)). As will be shown in Section 5.2, this gives two distinct transition paths of consumption towards a steady-state equilibrium.

5   Transition

With habit formation, consumption need not always be in steady state. When consumption lies above or below the habit, the habit will change over time, affecting future demand and possibly prices. Starting in a steady state, any shock to production costs, either through a shock to the unit labor requirement δ_i, or a permanent change in taxes τ_i, will cause consumption to deviate from the habit.

Consider for instance a permanent increase in the cost of energy. This cost shock could be due to the introduction of an economy-wide carbon tax, a shutdown of coal or nuclear power plants, or import restrictions on oil or gas implemented for geopolitical reasons. Also developments un-related to a particular country's policies, such as increased global energy demand, or the depletion of oil and gas reserves will likely confront consumers with higher prices for energy. Such a perma-nent increase in energy cost, and correspondingly steady-state prices for energy-intensive goods, induces consumption to shift away from these goods. With slow habit adjustment, consumption of energy-intensive goods will then fall short of the habit and the consumption may require time to fully adjust to the lower-energy bundle. A qualitatively similar pattern will be observed in other applications. E.g. related to the examples discussed in the introduction, the introduction of a 'fat tax' will induce a substitution away from fatty foods, and effective water conservation policies will require substantial adjustment in water consumption and habits.

This section evaluates the transition paths of consumption, prices and habits towards their re-spective steady states. In Section 5.1, I provide a general characterization of the paths of con-sumption, prices and habits as the economy converges to the steady state. In Section 5.2, I use this characterization to evaluate changes in consumption in response to a permanent change in unit production costs. Section 6.2 evaluates the optimal path, and solves for the policy required to implement it.

5.1   General characterization

To approximate the path of consumption and prices I loglinearize the system around its steady state. Let a tilde denote a log-deviation from the steady-state, such that $\tilde{z}(t) \equiv dz(t)/z^* \approx (z(t) - z^*)/z^*$ and thus $\tilde{z}_i^R = \tilde{z}_i - \tilde{z}_b$ for some variable z. The loglinearized the demand equation (7) then reads

$$\tilde{c}_i^R(t) = -\eta \tilde{p}_i^R(t) + \theta \tilde{h}_i^R(t). \tag{20}$$

From (5), $\tilde{h}_i^R(t)$ evolves according to

$$\dot{\tilde{h}}_i^R(t) = -\xi \lambda \tilde{h}_i^R(t), \tag{21}$$

where I define the following linear relationship between $\tilde{c}_i^R(t)$ and $\tilde{h}_i^R(t)$:[13]

$$\lambda \equiv 1 - \tilde{c}_i^R(t)/\tilde{h}_i^R(t). \tag{22}$$

Then (20)-(22) give the following solutions for the evolution of relative consumption, prices and habits:

$$\tilde{c}_i^R(t) = [1 - \lambda] \tilde{h}_i^R(t); \tag{23}$$

$$\tilde{p}^R(t) = \left[\frac{\theta - 1 + \lambda}{\eta} \right] \tilde{h}_i^R(t); \tag{24}$$

$$\tilde{h}_i^R(t) = \tilde{h}_i^R(0)e^{-\xi \lambda t}. \tag{25}$$

From (6) I then solve for the evolution of good-specific consumption:

$$\tilde{c}_i(t) = \tilde{c}_i^R(t) - \frac{\int_0^1 \delta_i c_i^{R*} \tilde{c}_i^R(t)di}{\int_0^1 \delta_i c_i^{R*}di} \tag{26}$$

The variable $\tilde{h}_i^R(0)$ represents the initial deviation of relative habits from the steady state. Whenever this ratio of good i to b habits lies above the steady-state ratio, $\tilde{h}_i^R(0) > 0$, while $\tilde{h}_i^R(0) < 0$ if the opposite applies.[14] Then for a given value of $\tilde{h}_i^R(0)$, the paths of consumption and prices are fully determined by the familiar parameters θ, η and ξ, and λ, the convergence factor. This convergence factor can be interpreted in two ways. First, λ, multiplied by the habit adjustment speed ξ, is the rate at which habits converge to the new steady state. The larger λ, the more rapid convergence. Second, λ determines the choice of consumption c_i for a given level of our state variable, the (relative) habit. The larger the convergence factor λ, the closer good i consumption will

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[13]For ease of exposition, I implicitly assume λ is constant and strictly positive. In Sections 5.2 and 6.2 I use loglinearized pricing rules to determine λ and find that λ is indeed constant and positive.

[14]Note that $\tilde{h}_i^R(0) = 0$ does not neccesarily imply all h_i are in steady state. For instance, suppose that we start in a steady state, and all goods i are hit by the same proportional shock to δ_i. This affects the steady-state levels of the c_i. Steady-state *relative* consumption and habits however are unaffected (see (15) and (16)). Hence, $\tilde{h}^R(0) = 0$ and consumption c_i will immediately jump to the new steady state, while habits h_i slowly adjust.

be to its steady state for a given steady-state deviation of habits. Of course, the two interpretations are interrelated. Current consumption affects future habits, which in turn adjust more rapidly the further is consumption from the habit. Hence, one should expect convergence to be fast if c_i^R is close to the steady state for a given h_i^R. Both the former, fast convergence, and the latter, $\tilde{c}_i^R$ close to zero, are indeed the case if λ is high. In the next two sections, I solve for the convergence factor under perfect competition and monopolistic supply respectively.[15]

5.2 Transition under constant taxes

To determine the transition path under constant taxes, I use the general solution for the out-of-steady-state behavior of consumption, prices and habits as presented in the previous subsection. In this solution, the convergence factor λ was left undetermined. In this subsection, I solve for this convergence factor under perfect competition and monopolistic supply. To maximize profits, monopolists choose a time-varying markup on marginal cost. From (10), this markup depends not only on the elasticity of substitution across goods, but also on good-specific consumption, habits and future price changes. As a consequence, prices set by monopolists and perfectly competitive firms diverge, and so will consumption choices under these alternative market structures. For now, I assume taxes are constant and exogenous. Section 6.2 assesses the first-best transition path, and determines the good-specific taxes and that implement this path. For ease of exposition I explain results in the context of a sudden and permanent increase in relative unit production cost $\delta_i^R \tau_i^R$. Starting in a steady-state, such a shock triggers a transition of consumption from good i to the base good b. In line with the examples discussed before, this good i may represent an energy-intensive good, or unhealthy food.

5.2.1 Perfect competition

Under perfect competition, prices adjust one-for-one with marginal costs (see (9)), which gives

$$\tilde{p}_i^R = \tilde{\tau}_i^R. \tag{27}$$

With constant taxes $\tilde{\tau}_i^R = \dot{\tilde{\tau}}_i^R = 0$. This implies $\dot{\tilde{p}}_i^R = 0$ at all times. From (24) I can thus determine the value for the convergence term λ^{pc}:

Lemma 1 $\lambda^{pc} = 1 - \theta$

Proof In text. □

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[15]The paper focuses on gradual transitions, e.g. in response to a shock to production costs. Equation (23) can however also be interpreted in the context of a consumption or production quota. If the quota is binding, consumption immediately jumps to the steady state: $\tilde{c}_i^R(t) = 0$ for all t. This gives $\lambda = \lambda^{qt} = 1$.

Then, from (23) and (25), I can conclude the following regarding the path of (relative) consumption and habits. An increase in relative marginal cost for good i causes good i consumption to fall relative to good b. In response to the drop in c_i^R, the relative habit falls. This induces a further decrease in relative consumption until the economy has converged to its new steady state. The transition to the steady state will be faster the faster is habit adjustment, i.e. higher is ξ. Also, a low habit persistence (low θ) implies that both the initial drop in consumption is larger, and the economy transitions more rapidly to the new steady state.

5.2.2 Monopolists

Under monopolistic supply, the current price is a complex function of future consumption, prices and habits. The linearization of the monopolist's pricing rule as expressed by (10) and (11) around the post-tax steady state gives[16]

$$\tilde{p}_i^R = \tilde{\tau}_i^R - \frac{\xi\theta}{\rho(\eta-1)+\xi(\eta-1+\theta)}\left[\tilde{c}_i^R - \tilde{h}_i^R\right] + \frac{\eta-1}{\rho(\eta-1)+\xi(\eta-1+\theta)}\dot{\tilde{p}}_i^R - \frac{1}{\rho+\xi}\dot{\tilde{\tau}}_i^R. \quad (28)$$

Then for $\tilde{\tau}_i^R = \dot{\tilde{\tau}}_i^R = 0$, the following can be established regarding λ^{mc}:[17]

Lemma 2 If $\theta > 0$, then $\lambda^{mc} \in \left(\lambda^{pc}, 1+\theta(\eta-1)^{-1}\right)$. If $\theta = 0$, then $\lambda^{mc} = 1$.
Proof See Appendix A.2.1 □

Lemma 2a If $\theta > 0$, then $\frac{d\lambda^{mc}}{d\rho} < 0$, $\frac{d\lambda^{mc}}{d\xi} > 0$, and $\frac{d\lambda^{mc}}{d\eta} < 0$. For any θ, $\frac{d\lambda^{mc}}{d\theta} > 0$ iff $\eta-1 < (1-2\theta)\xi/(\rho+\xi)$. Finally, $\lambda^{mc} > 1$ iff $\theta > 0$ and $\eta-1 < (1-\theta)\xi/(\rho+\xi)$.
Proof See Appendix A.2.2 □

Whenever habits cause persistence at the level of specific goods ($\theta > 0$) convergence is faster if goods are produced by monopolists instead of perfectly competitive firms. This is due to the fact that it is optimal for producers to increase relative prices in <u>excess</u> of the marginal cost increase. When the marginal cost shock hits, the producer of a i-good realizes that future demand for i falls below the current habit. This reduces the return to investment in the habit. In response, the producer increases the markup, and thus increase prices by more than the increase in unit production costs. For a good-b producer, the exact opposite story holds: it anticipates an increase in (relative) demand, which increases the return to investment in the habit. A good-b producer thus chooses a lower markup than its good-i competitor. As consumption converges to the new steady state, the relative price will fall toward the long run relative price, which is equal to the ratio of marginal costs.

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[16]Detailed derivations can again be found in Appendix A.1.
[17]The closed-form solution for λ^{mc} can be found in Appendix A.3.1.

As initially, relative prices increase by more than the increase in relative marginal costs, the drop in relative consumption under monopolistic supply is greater than the one under perfect competition. In fact, the shift in prices may be so large that c_i^R undershoots the long run equilibrium. One can show this is the case if $\theta > 0$ and $\eta - 1 < (1-\theta)\xi/(\rho+\xi)$. This latter condition is more likely satisfied if goods are weak substitutes (η is low), habits are weak yet change rapidly (low θ and high ξ) and time preference is weak (low ρ). The intuition is subtle, and relates to the sensitivity of prices to good-specific habits, compared to the sensitivity of consumption to these habits, taking prices as given. Suppose that habits are above the steady state. Then from (11), this causes a large drop in the shadow value of the habit, κ_{h_i}, if habits affect future demand rapidly (high ξ), future returns are discounted little (low ρ), the elasticity of demand, η, is low and demand is sensitive to the habit (high θ). This drop in κ_{h_i} increases the monopolist's price p_i, which reduces c_i. The high θ however also implies consumption responds strongly to the above steady-state habit. This outweighs the effect of θ through prices; with a high θ, c_i^R is less likely to undershoot the long run equilibrium if $\tilde{h}_i^R(0) > 0$. More generally, and consistent with the intuition above, whenever $\theta > 0$, λ^{mc} is increasing in ξ, and decreasing in ρ and η. The effect of a change in θ on λ^{mc} is ambiguous and depends on parameter values.[18]

6   Optimal consumption and implementation

A change in relative prices always induces the consumer to reconsider its consumption choices and, over time, shift to a new consumption bundle. The consumer however is not perfectly rational. She is subject to projection bias and thereby does not internalize the effect of current consumption on future preferences through habit formation. Consumption choices are thus likely suboptimal; from a welfare perspective, the consumer may adjust her consumption choices too slowly, or too rapidly. In this section, I determine optimal consumption and prices, both in the steady state and along the transition towards the steady state. Optimal consumption choices are defined as the paths of consumption, $[c_i(v)]_{i\in[0,1],v=t}^{v=\infty}$, that maximize the present value of instantaneous utilities (1), subject to (2)-(4), taking into account the endogenous formation of habits (5), and labor market equilibrium (6). I then assess how policy can be used to implement this first-best consumption allocation. More specifically, I solve for the (path of) good i taxes or subsidies that induce op-

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[18]Lemmas 2 and 2a can be considered a generalization of a result presented in Ravn et al. (2010). This result states that monopolistic producers may increase markups following a temporary positive marginal cost shock. An increase is more likely the more persistent the shock, and for the limiting case where the shock is fully persistent, producers always increase markups. Ravn et al. (2010) arrive at this result in a discrete-time framework where $h_{it} = c_{it-1}$. Lemma 2 generalizes this result to a continuous time setup with slow habit adjustment and a permanent shock. Lemma 2a then points at the novel result that consumption may undershoot its long-run equilibrium.

timal consumption choices.[19] As established in the previous section, the transition path without intervention depends on the underlying market structure. In line with this result, the tax path that implements optimal consumption choices under perfect competition differs from the one when goods are produced by monopolists.

As the previous section, this section abstracts from the source of the increase in relative production cost $\delta_i^R \tau_i^R$, which sets in motion a transition to a new steady state. In Appendix B I extend the model to account for the presence of a (positive or negative) externality due to the production or consumption of one or multiple goods (e.g. an environmental externality). In this case the correction of such an externality affects the production costs of a subset of firms. I show that all results concerning the model dynamics carry through.[20]

The welfare function reads

$$W(t) = \int_t^\infty e^{-\rho(v-t)} U(v) dv, \tag{29}$$

and is maximized subject to (1)-(6). I solve the Hamiltonian and use consumer demand (7) to arrive at the following rule for optimal prices:[21]

$$p_i(t) = \delta_i \breve{\mu}_L(t) - \xi \breve{\mu}_{h_i}(t), \tag{30}$$

with

$$\breve{\mu}_{h_i}(t) = \int_t^\infty e^{-(\breve{r}+\xi)(v-t)} \frac{c_i(v)}{h_i(v)} p_i(v) \left[\frac{\theta}{\eta-1} - \left[\gamma + \frac{\theta}{\eta-1} \right] \left(\frac{h_i(v)}{H(v)} \right)^{\frac{\eta-1}{\eta}} \left(\frac{c_i(v)}{C(v)} \right)^{-\frac{\eta-1}{\eta}} \right] dv, \tag{31}$$

where μ_L is the shadow value of labor and μ_{h_i} the shadow value of the habit to the consumer in terms of C, and $\breve{r} = \rho - \left[\frac{d}{dt} \left(\frac{dU(t)}{dC(t)} \right) / \frac{dU(t)}{dC(t)} \right]$. The optimal price for c_i equals its marginal production cost, minus the marginal value of c_i due to habit formation. This value is equal to the direct effect of an increase in c_i on the future habit, ξ, multiplied by the shadow value of the habit, $\breve{\mu}_{h_i}$. The shadow value of the habit captures the effect of an increase in h_i on future welfare and can be

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[19]I focus on the use of taxes and subsidies to implement the first-best allocation. As the model features no uncertainty, any allocation implemented by a given path of taxes/subsidies can also be implemented by (time-varying) quota. Referring to Dalton and Ghosal (2011), this implies I take an (in)direct paternalistic approach to policy intervention where I implicitly assume the policymaker has full information regarding preferences and their evolution over time. I thus do not consider a soft-libertarian approach, where policy would take the form of teaching the consumer to internalize the endogenous habit formation process herself.

[20]More specifically, any optimal policy intervention can be decomposed into two elements: 1) state-independent (Pigovian) taxes that correct for the production externality. 2) state-dependent taxes that manage the rate at which consumption substitutes away from c_i, as discussed in the main part of this paper. See Appendix B for more details.

[21]See Appendix A.1 for detailed derivations.

separated into two components. First, for $\theta > 0$, an increase in the good-specific habit increases the consumption weight w_i, which increases the benefit from c_i. Simultaneously however, through H, an increase in h_i reduces the weight of all other goods. The net effect is positive only if c_i/C is large compared to h_i/H. Then, an increase in the consumption weight of good i positively affects aggregate consumption C. Put differently, an increase in h_i has positive value if it brings the 'pattern' of habits (h_i/H) more in line with the 'pattern' of consumption (c_i/C).

The second component is captures the welfare effect of the aggregate habit benchmark and is negative whenever $\gamma > 0$. Any increase in the good-specific habit h_i increases the aggregate habit H. This rise in the consumption benchmark in turn reduces utility for a given level of effective consumption C.

6.1   Steady state

In steady state, consumption equals habits, both at the good-specific and the aggregate level. This in turn implies prices are constant. From (31), the steady-state shadow value of the habit is

$$\breve{\mu}_{h_i}^* = -\gamma \frac{1}{\rho + \xi} p_i^*, \tag{32}$$

which, with (30), gives the following solution for the optimal steady state good i price:

$$p_i^* = \delta_i \breve{\mu}_L^* \left[\frac{\rho + \xi}{\rho + \xi (1 - \gamma)} \right]. \tag{33}$$

Whenever $\gamma > 0$, the shadow value of the habit is negative in steady state. Whereas good-specific persistence is not associated with any steady-state welfare effects, the aggregate habit causes a negative long-run effect on utility which the consumer does not internalize. The larger is γ, the greater is this negative externality on the future self (i.e. negative internality), which translates into a higher steady-state markup. More rapid adjustment of consumption to the habit implies the externality occurs sooner. Like a lower time preference, this increases the present value of the internality and thereby the optimal steady-state markup.

I can then establish the following:

Proposition 1 In steady state, laissez-faire consumption choices are optimal. Any uniform tax implements this optimum.

Proof By (33), the optimal relative price in steady state satisfies $p_i^{R*} = \delta_i^R$. This is equal to (16) with $\tau_i^{R*} = 1$. Under laissez faire, $\tau_i = 1$ for all i, so $\tau_i^{R*} = 1$. $\square$

As habits and market power affect demand and supply of all goods to an equal extent, they do not distort the steady-state allocation of consumption across goods. Hence, habits do not provide

a rationale for taxing or subsidizing one good more aggressively than another in the long run. As pointed out before, in the absence of savings and with inelastic labor supply, consumption decisions are fully determined by relative prices. As a consequence, any tax that is uniform across goods, including zero taxes, implements this first-best allocation.[22]

As will be demonstrated in the next subsection, this result only holds in the steady state. Along the transition towards the steady state, taxes and subsidies may be required to implement optimal consumption choices.

6.2 Transition

To determine the optimal path of consumption, prices and habits as consumption transitions away from good i, I adopt the same approach as in Section 5.2, where I solved for the convergence factor λ under perfect competition and monopolistic supply. With (23) and (24), this convergence factor pins down the paths of consumption and prices outside the steady state. To find the λ for the optimal path, λ^{opt}, I first linearize (30) and (31) to find

$$\tilde{p}_i^R = -\frac{1}{\eta} \frac{\xi (\theta - \gamma)}{\rho + \xi (1 - \gamma)} \left[\tilde{c}_i^R - \tilde{h}_i^R \right] + \frac{1}{\rho + \xi (1 - \gamma)} \dot{\tilde{p}}_i^R. \tag{34}$$

I can then establish the following regarding λ^{opt}:[23]

Lemma 3 If $\gamma \neq \theta$, then $\lambda^{opt} \in \left(\min \{ 1 - \gamma, \lambda^{pc} \}, \max \{ 1 - \gamma, \lambda^{pc} \} \right)$ while if $\gamma = \theta$, then $\lambda^{opt} = \lambda^{pc} = 1 - \theta$. Next, $\lambda^{opt} < \lambda^{mc}$ if $\max \{ \gamma, \theta \} > 0$, while $\lambda^{opt} = \lambda^{mc} = 1$ if $\gamma = \theta = 0$.
Proof See Appendix A.2.3 □

Lemma 3a For any γ and θ, $\frac{d\lambda^{opt}}{d\gamma} < 0$, $\frac{d\lambda^{opt}}{d\theta} < 0$, and $\frac{d\lambda^{opt}}{d\eta} = 0$. $\frac{d\lambda^{opt}}{d\rho} > 0$ and $\frac{d\lambda^{opt}}{d\xi} < 0$ if $\gamma > \theta$, while $\frac{d\lambda^{opt}}{d\rho} < 0$ and $\frac{d\lambda^{opt}}{d\xi} > 0$ in case $\gamma < \theta$, and $\frac{d\lambda^{opt}}{d\rho} = \frac{d\lambda^{opt}}{d\xi} = 0$ if $\gamma = \theta$.
Proof See Appendix A.2.4 □

From which follows

Proposition 2 Suppose goods are produced under perfect competition. If $\gamma > (<) \theta$, the laissez-faire transition to the steady state is suboptimally fast (slow). The optimal adjustment path can then be implemented by introducing a positive and declining subsidy (tax) on good i whenever

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[22]If we would extend the model to include endogenous labor supply such as in Cremer et al. (2010), or allow the consumer to transfer consumption across time, as in Carroll et al. (2000), price and tax level changes would affect consumption levels. Now, due to noninternalized habits, the steady-state consumption level is likely inefficient. In such a case, from (12), (14) and (33), a steady-state habit tax equal to $T^* = \frac{\rho + \xi}{\rho + \xi(1-\gamma)}$ and $T^* = \frac{1}{\eta} \frac{(\rho + \xi)(\eta - 1) + \xi \theta}{\rho + \xi(1-\gamma)}$ under perfect competition and monopolistic supply respectively implements the first-best steady-state consumption (note I implicitly assume the equilibrium wage is equal to μ_L). Note that results for consumption, price and tax *ratios* are independent of the *levels* of these variables, and thus independent of assumptions regarding labor supply and savings.
[23]The closed-form solution for λ^{opt} can be found in Appendix A.3.1.

$\tilde{h}_i^R(0) > 0$ and a positive and declining tax (subsidy) on good i if $\tilde{h}_i^R(0) < 0$. If $\gamma = \theta$, the laissez-faire transition to the steady state is optimal, and any constant subsidy (tax) implements this path.

Proof See Appendix A.2.5 ☐

If we take the transition where consumers face a flat price schedule with $\tilde{p}_i^R = p_i^{R*}$ as a benchmark, it is optimal to speed up the transition from good i to b if the good-specific habit parameter θ is larger than the aggregate habit parameter γ, whereas the opposite holds if $\gamma > \theta$. This result can be explained as follows. The consumer does not internalize the effect of current consumption on future habits. These habits however do affect future utility through the consumption weights w_i and the aggregate habit H. Whether a slower or faster shift in consumption from i to b is welfare-improving then depends on whether a slower or faster shift in habits increases future utility through w_i and H.

Starting with the effect through w_i, I find that a faster transition is welfare-improving. This can be seen as follows. An increase in $\tilde{p}_i^R$ induces the consumer to shift consumption away from good i and towards good b. This shift causes a larger increase (smaller drop) in future effective consumption C the higher is the weight of good b relative to good i. Hence, future effective consumption C increases if the weight of good b, relative to good i, rises. This can be achieved by building habit in good b, and divesting habit in i, which is in turn requires consumption to more rapidly shift away from good i and towards good b. To summarize, building b habit is beneficial if b consumption is rising, and conversely, a relatively high i habit is costly if good i consumption is falling. Hence, welfare is increased if consumers more rapidly get rid of this i habit.

Second, good-specific habits negatively affect welfare as through H, they jointly act as a benchmark against which effective consumption is evaluated. The transition offers an opportunity to manage, i.e. reduce, this benchmark H. It turns out this argues in favor of a slow transition away from good i consumption. Although not immediate, the result is intuitive. At each point in time, the consumer chooses i and b consumption such that it maximizes effective consumption C. Following an increase in the relative price for good i, consumption shifts away from this good, as postponing, or slowing down this shift, would reduce effective consumption C. A slow transition however also has an advantage, as 'too high' consumption of the now relatively expensive good pulls down the reference habit H.[24]

If $\theta = 0$, the consumption weights w_i are independent of habits and hence habits do not cause good-specific consumption persistence. This implies the first effect is absent, and only the second

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[24]As an extreme example, think of the following. Suppose consumption consists of apples and oranges. Then a strong increase in the price of apples initiates a shift towards oranges in the consumption bundle. Suppose the consumer is stubborn, and initially sticks to an apple-intensive diet. Since apples are very expensive, the consumer can afford only a few and is very hungry. The next period, the consumer decides to spend less on apples such that he can buy many oranges. As the consumer was used to starving in the previous period (H dropped a lot), the increase in orange consumption and elimination of hunger constitutes a large welfare gain.

effect, arguing in favor of a slower transition, is relevant. Similarly, if $\gamma = 0$, the benchmark H does not affect utility for given C, and habits only affect future utility through w_i. More generally, which of the two mechanisms dominates depends on whether habits are stronger at the good-specific or at the aggregate level. This can be evaluated by a simple condition comparing the deep habit strength, θ, to the aggregate habit strength, γ, as described in Proposition 2.

Finally λ^{opt}, and hence the optimal adjustment rate, falls in θ and γ. The effect of a change in ρ or ξ depends on whether λ^{opt} is larger or smaller than λ^{pc}. If $\lambda^{opt} > \lambda^{pc}$, λ^{opt} is decreasing in ρ and increasing in ξ.[25] If $\lambda^{opt} < \lambda^{pc}$ effects are opposite, and λ^{opt} is independent of η.

To implement a slower (faster) transition, the relative price the consumer faces should be below (above) the long run p_i^R. Let $\tilde{\tau}_i^{R,\lambda}(t)$ be the value of $\tilde{\tau}_i^R(t)$ required to implement a given λ. Then using (24) and (27), I find that under perfect competition:

$$\tilde{\tau}_i^{R,\lambda}(t) = \frac{\theta - 1 + \lambda}{\eta} \tilde{h}_i^R(t). \tag{35}$$

As described in Section 5.2, along the transition, strategic behavior by the monopolist increases the relative price p_i^R in excess of the increase in relative marginal costs. As a consequence, compared to the benchmark with $p_i^R = p_i^{R*}$, the shift in consumption from good i to b is already faster to begin with. One would thus expect that a subsidy on i, which slows down the transition, is more likely required to implement the optimal transition in the presence of market power. This is indeed the case:

Proposition 3 Suppose goods are produced by monopolists. If $\max\{\gamma, \theta\} > 0$, the laissez-faire transition to the steady state is suboptimally fast. The optimal adjustment path can then be implemented by introducing a positive and declining subsidy on good i whenever $\tilde{h}_i^R(0) > 0$ and a positive and declining tax on good i if $\tilde{h}_i^R(0) < 0$. If $\gamma = \theta = 0$, the laissez-faire transition to the steady state is optimal, and any constant subsidy (tax) implements this path.
Proof See Appendix A.2.6 □

With habit formation (i.e. either γ or $\theta > 0$), the monopolist always implements a transition that is too rapid from a welfare perspective. First, the monopolist does not take into account the benefits of a slow transition in bringing down the aggregate habit H. Yet even if $\gamma = 0$, i.e. even if the benchmark habit plays no role in determining utility from consumption C, a welfare-maximizing policy slows down the shift in consumption from i to b implemented by the monopolist. This is because of the following. We know that along the transition, there is a benefit to quickly 'rebalancing' the consumption weights w_i such that they become more in line with actual consumption. The monopolist recognizes this too; as demand for good i falls over time, investing in the habit

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[25]The rate at which consumption and habits adjust to the new steady state, $\xi\lambda^{opt}$, is always increasing in ξ. See Appendix A.3.2 for a proof.

becomes less valuable. As a response, the monopolist increases its markup to quickly divest habit and thus reduce the consumption weight. The monopolist however, does not take into account that this increases the consumption weight of all other goods, leading to a rapid rebalancing of the w_i. From a welfare-perspective, this rebalancing is too rapid. Hence, (partially) countering the monopolist's response to increase prices when habits are 'too high' increases welfare.

I can again solve for $\tilde{\tau}_i^{R,\lambda}(t)$, now under monopolistic supply. Equations (24) and (28) give

$$
\tilde{\tau}_i^{R,\lambda}(t) = \frac{1}{\eta} \left[\frac{(\theta - 1)\left[(\rho + \xi) + \xi \frac{\theta}{\eta - 1}\right] + \lambda(\rho + \xi\lambda)}{(\rho + \xi) + \xi \frac{\theta}{\eta - 1}} \right] \frac{\rho + \xi}{\rho + \xi(1 + \lambda)} \tilde{h}_i^R(t), \qquad (36)
$$

where by definition, the bracketed term is zero for $\lambda = \lambda^{mc}$, and negative for $\lambda < \lambda^{mc}$.

7 Application

To illustrate the adjustment path of consumption and assess the potential quantitative implications of habit formation I evaluate the effects of an unanticipated 10 percent increase in the production cost of a subset of goods. Though insights apply more generally, for the sake of exposition, I interpret this cost shock in the context of food taxes, where the subset of goods are 'unhealthy foods', and the cost increase may resemble the introduction of a 10 percent charge on the saturated fat and sugars.[26,27] This charge may be fully passed through to consumers, or producers may act strategically and adjust markups in response to the levy. In either case, due to habits in consumption, demand for fatty and sugary foods will not instantly jump to the new steady state with a lower consumption of unhealthy foods. I compute the paths of consumption and prices as the economy converges to its new steady state. I compare the paths under perfect competition and monopolistic supply to the first-best consumption path. Temporary subsidies will be required to implement the optimal consumption path. These subsidies can be interpreted as temporary discounts on the permanent charge, or simply a slow phase-in of the charge. Finally, I compute the welfare gain of implementing an optimal path instead of the alternative adjustment paths.

To obtain numerical results I discretize the model. Further details about the discrete-time model setup can be found in Appendix C.

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[26]Thus, I do not aim to perform a detailed policy simulation such as Allais et al. (2010). Given the stylized nature of the framework, the results should be primarily viewed as an indication of the quantitative significance of the habit internality

[27]**[order of magnitude ref]** To ensure a clear distinction between the 'habit' tax (or subsidy) and the 'fat and sugar' tax, I will refer to the latter as a charge.

7.1 Parameter choices

The parameter values are determined as follows. Across the US and Europe, spending on food and nonalcoholic beverages accounts for about 12 percent of household spending (Eurostat, 2016; BLS, 2017). Of this 12 percent, about a third can be classified as 'unhealthy' (Mytton et al., 2007). Based on this, I set n, which I define as the share of goods subject to the charge, equal to 0.04. I separate the gross tax τ_i into two parts, the constant charge τ_{iC}, and the (potentially) time-varying 'habit tax' τ_{iH}, such that $\tau_i = \tau_{iC}\tau_{iH}$. Initial τ_{iC} and τ_{iH} are equal to 1 for all goods. Then, as of time $t = 0$, unhealthy food will be subject to an additional charge, such that for producers of goods $i \in [0, n]$, τ_{iC} increases to 1.1.

In the framework, the elasticity of substitution directly determines the short run price elasticity of demand (see (7)). Empirical estimates for the latter for specific consumer goods, including food categories, typically deliver low values, often below 1, suggesting complementarity (see for instance Andreyeva et al., 2010; Zhen et al., 2011; Green et al., 2013). Macro-level calibrations require values above 4 to match observed markups (Ravn et al 2006; 2010). For the main part of the numerical exercise I take a middle ground and set $\eta = 2$; I perform sensitivity analysis for $\eta = 0.4$ and $\eta = 1.2$.[28]

The habit parameters θ and γ are major determinants of the rate at which consumption transitions take place, and the policy required to maximize welfare along a transition. Several approaches can be used to infer the appropriate values for these parameters.

For θ, I consider empirical research on good-specific consumption persistence, and research that estimates both the short- and long run price elasticities of demand. Under the former approach, estimates for θ range from zero to 0.72, with a central value of about 0.3 (Carrasco et al., 2005; Zhen et al., 2011; Bronnenberg et al., 2012; Verhelst and Van den Poel, 2014). With the exception of Bronnenberg et al. (2012), these estimates use (a measure of) previous month or quarter consumption expenditure as a benchmark. The appropriate benchmark is however not immediate, and if habits are persistent, these estimates may either under- or over-estimate the 'real' θ. Bronnenberg et al. (2012) instead use geographic variation in brand preferences to elicit the causal effect of past experiences on future preferences. They find that 60 percent of the gap in brand preferences can be attributed to supply-side factors, while endogenous and persistent brand preferences explain 40 percent of the geographic variation in brand market shares. One can show this corresponds to $\theta = 0.4$.[29]

An alternative estimation procedure for θ does not face the 'benchmarking' problem either. This approach is based on short- and long-run price elasticities of demand. From Section 4.1, I

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[28]Since the analysis for the monopolist requires $\eta > 1$, I will only explore the perfect competition and first-best equilibria for $\eta = 0.4$.

[29]Details available on request.

know these are equal to $\varepsilon_p^{SR} = \eta$ and $\varepsilon_p^{LR} = \eta/(1-\theta)$ respectively. Then $\theta = 1 - \varepsilon_p^{SR}/\varepsilon_p^{LR}$. Espey et al. (1997) conduct a meta analysis of price elasticities for residential water consumption. Based on their median estimates for short and long run elasticities, I find a θ equal to 0.41. Scott (2015) presents an overview of estimates of the elasticity of gasoline demand. The central value for θ based on these estimates is 0.6. Baltagi et al. (2000) estimate cigarette demand and also arrive at a value of 0.6.[30] Demand persistence for gasoline and cigarettes however likely overestimates the persistence of a 'representative' good: cigarettes are highly addictive and short-run gasoline demand is to a large extent determined by the vehicle a consumer owns. For this reason, I consider the estimate of 0.6 to be an upper bound for the appropriate θ and set $\theta = 0.4$. I perform sensitivity analysis for $\theta = 0.2$ and $\theta = 0.6$,

For γ, I consider estimates based on empirical evidence related to the Easterlin paradox and hedonic adaptation, aggregate consumption persistence and calibrations. High values for γ (close to 1) are required to explain the Easterlin paradox (Easterlin, 1974; Easterlin et al., 2010). Although evidence for happiness, or hedonic, adaptation is robust, the strong form of the Easterlin paradox, where long-run happiness is unaffected income changes, is heavily contested (Clark, 1999; Oswald and Powdthavee, 2008; Stevenson and Wolfers, 2008; Easterlin et al., 2010). With incomplete adaptation, the value of γ is not easily determined, as reported happiness scores cannot be directly translated to utility units.

In my framework, to focus on consumption shifts across sectors, I abstract from saving and capital accumulation. If intertemporal consumption tradeoffs are take into account, the aggregate habit parameter γ plays an additional role in determining the degree of aggregate consumption persistence.[31] Empirically estimating this persistence, Ravina (2005) and Alvarez-Cuadrado et al. (2012) find that a 1 percent increase in past aggregate consumption increases current consumption by 0.3 to 0.5 percent.[32] The corresponding estimate for γ then depends on the σ chosen. For $\sigma = 2$, γ lies in between 0.6 and 1, and higher γ are found for lower σ.[33]

Finally, I turn to calibrations. In a model that allows for saving, Abel (1990) requires values for γ close to 1 to explain the equity premium puzzle. Fuhrer (2000) introduces habits in a monetary policy model and estimates γ to fit the data. He arrives at a value of 0.8 to 0.9. Overall, evidence seems to suggest higher values for γ than θ. I follow Fuhrer (2000), and set $\gamma = 0.8$, and perform

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[30]Baltagi et al. (2000) compare a large number of models. I use the estimate of the model they consider best-performing.

[31]See for instance Carroll et al. (2000), Fuhrer (2000), Diaz et al. (2003) and Alvarez-Cuadrado et al. (2004). See also footnote 22.

[32]Dynan (2000) and Guariglia and Rossi (2002) estimate consumption persistence based on aggregate food consumption. As food is still a broad aggregate, I cannot readily reinterpret their estimates as estimates of θ or γ. They both find no or negative consumption persistence. However, their estimates, as well as those by Ravina (2005) and Alvarez-Cuadrado et al. (2012), suffer from the same 'benchmarking' problem discussed before.

[33]For $\sigma = 1$, aggregate consumption demand is independent of the habit. For $\sigma < 1$, $\gamma < 0$ is required to generate aggregate persistence.

sensitivity analysis for $\gamma = 0.4$ and $\gamma = 0.6$.

Less empirical guidance exists regarding the speed of habit adjustment, ξ. Ravn et al. (2012) and Bronnenberg et al. (2012) find habits to adjust very slowly over time; on an annual basis ξ is equal to 0.05 and 0.025 respectively. This slow adjustment is in line with Logan and Rhode (2010) and Atkin (2013), who find that prices (more than) 10 years in the past can partly explain current patterns of food consumption. Carroll et al. (2000) adopt an annual value of 0.2 while Constantinides (1990) requires values as high as 0.6 to explain the equity premium puzzle. Finally, much of the literature takes habits as equal to past-year consumption. I take a 50 percent annual adjustment. As I estimate the model on a monthly basis ($dt = 1$ month), this gives $\xi = 0.06$. In the sensitivity analysis I consider $\xi = 0.03$ and $\xi = 0.12$. Finally, I set the monthly discount rate $\rho = 0.0035$,[34] the elasticity of marginal utility $\sigma = 1.5$, unit labor requirement $\delta_i = 1$ for all i, and total labor supply $L = 1$. With initial marginal production cost δ_i equal to 1 for all i, this gives initial steady state consumption, habits and prices equal to 1 for all goods. An overview of all baseline parameter values can be found in Table 1.

Table 1: Parameter values

Parameter	Baseline values	Description
n	0.04	Share of goods subject to the charge
δ_i	1	Unit labor requirement
η	2	Elasticity of substitution
θ	0.4	Deep habit strength
γ	0.8	Aggregate habit strength
ξ	0.06	Habit adjustment speed (monthly)
ρ	0.0035	Rate of time preference (monthly)
σ	1.5	Elasticity of marginal utility
L	1	Labor supply

7.2 Results

Figure 1 shows the response of unhealthy food consumption and prices relative to 'non-unhealthy food' consumption following the introduction of the permanent charge on saturated fats and sugar at time 0. The dashed and dotted curves depict the response when goods are produced competitively or by monopolists respectively, without any additional policy intervention. The solid curves depict the optimal paths.

Under perfect competition, consumers face a one-off increase in prices (see Figure 1b). In response to this price increase, consumers instantly reduce relative consumption by 17 percent.[35]

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[34]This corresponds to an annual discount rate of about 4 percent.

[35]Figure 1a depicts relative consumption paths. As the price change only affects 4 percent of goods, demand for

An additional 10 percent reduction is achieved as habits fall over time and consumption follows this drop in habit. As expected, the shift away from unhealthy foods is faster under monopolists: at $t = 0$ consumption immediately drops by 24 percent. Following this drop, also habits quickly adjust. The rapid consumption response is the consequence of strategic behavior; monopolists increase prices for unhealthy foods relative to other goods by an additional 5 percent (see Figure 1b).

Along the transition to the new steady state, neither of the two paths described above are optimal. From Proposition 3 we know that the monopolist always implements a transition that is suboptimally fast. For our parameter values we have $\gamma > \theta$. Proposition 2 then informs us that also under perfect competition, the shift away from unhealthy food consumption under perfect competition is faster than optimal. Figure 1a confirms this: c_i^R is higher along the optimal path (solid curve) than along the paths where the transition is not specifically managed (dashed and dotted curves). In the optimum, time 0 unhealthy food consumption falls by only 11 percent. Consumption continues to drop afterwards, yet it takes more than 10 years until the full transition is accomplished. To ensure consumers select these first-best consumption levels, the relative price for unhealthy food should increase by only 5.9 percent initially, and then slowly rise to its long run level of 1.1.

Figure 1: Transition away from unhealthy food consumption
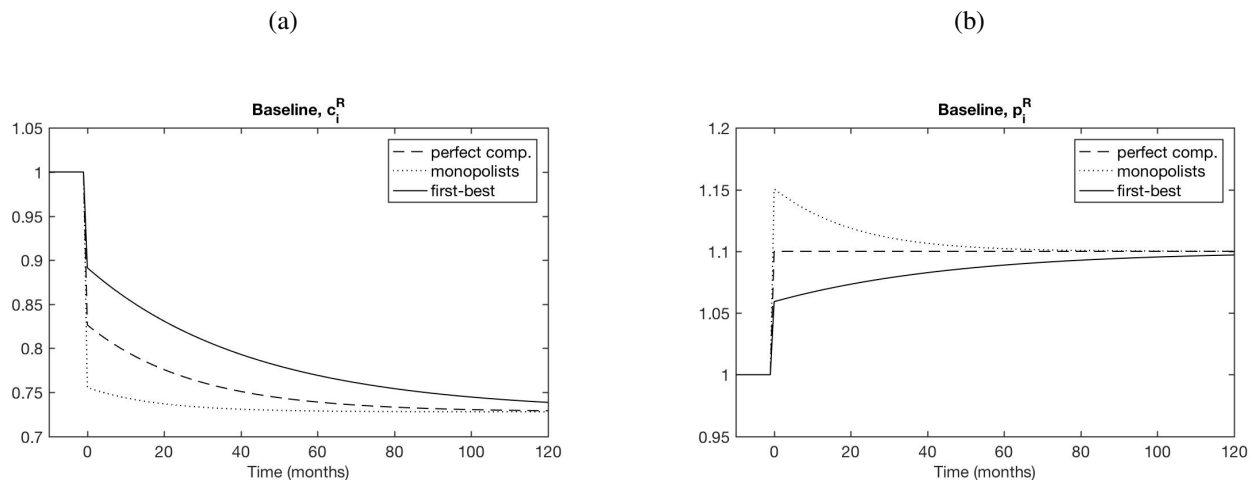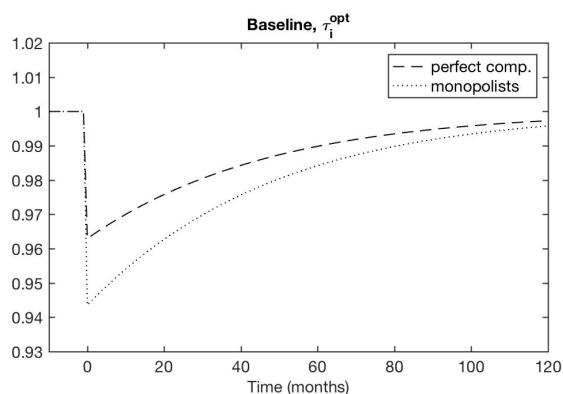
(a)

(b)

The curves depict responses to the unanticipated introduction of the 10 percent charge at $t = 0$, where I assume the economy is in steady state for all $t < 0$. Responses are shown for a good $i \in [0, n]$ relative to any good $b \in (n, 1]$.

To implement the a price path according to the solid line in Figure 1b we require a temporary

all other goods increases by less than 1 percent at any point during the transition. The difference between changes in absolute unhealthy food consumption, and consumption of unhealthy food relative to non-unhealthy food goods is thus small, and I use the two concepts interchangeably.

subsidy to unhealthy food (i.e. discount to the food charge). Under perfect competition, this would amount to a subsidy of about 3.4 percent (gross tax of 0.966, see Figure 2). This is about a third of the total 10 percent charge. A larger transitory subsidy is required if goods are produced by monopolists, who initially increase prices in excess of the charge. Now, an initial subsidy of 5.6 percent, which falls to 4.6 percent after 1 year and 1.6 percent after 5 years implements the optimal adjustment path.

Figure 2

The curves depict the path of taxes required to implement the first-best adjustment path, in response to the unantici-pated introduction of the 10 percent charge at $t = 0$, where I assume the economy is in steady state for all $t < 0$. Taxes are shown for a good $i \in [0, n]$ relative to any good $b \in (n, 1]$.

The above-mentioned subsidies have a large impact on prices and consumption choices as the economy reduces its unhealthy food consumption. This raises the question of whether this policy also generates sizable welfare gains. For this purpose, I compute the consumption-equivalent welfare loss due to the transition.[36] Here I take into account that the charge may be implemented as a welfare-improving policy to begin with, and may thus not only set in motion a transition to a new steady state, but also move the economy away from a *distorted* steady state.[37] To separate these two effects, I compute two losses, one which solely captures the loss due to the transition, and one which, in addition, captures the benefit from correcting a previously uncorrected externality. Results are presented in Table 2.[38]

From Figure 1a I know that consumption adjustment is relatively slow along the optimal path, and fast under monopolistic supply. Hence, I expect welfare to be highest (losses to be lowest) in

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[36]More formally, let $W_X(C_X)$ be welfare under consumption path X and $W^*(C^*)$ welfare if the economy is in steady-state. Then the (steady-state) consumption-equivalent welfare loss is β_X, with β_X implicitly determined by $W_X(C_X) = W^*((1 - \beta_X)C^*)$.

[37]This can for instance be motivated by the existence of publicly-paid healthcare systems, which cause consumers to not carry the full burden of dietary choices.

[38]See Appendix C.1 for more details.

the first-best transition, followed by the transition under perfect competition and monopolists. This is confirmed by Table 2. Table 2 reports the consumption-equivalent welfare loss of the transition for four cases; the three cases considered in the paper, and the case where all c_i are set to their respective steady-state immediately ('no transition', bottom row).[39] Reported losses are small, about 0.008%; as the 10% long-run price shock only affects a share $n = 0.04$ of goods this is not surprising. Optimally managing the transition reduces welfare losses by 0.0056% to 0.0012%; this is 1.4%-6.9% of the loss under first-best. This reduction in welfare losses is very similar when I take into account benefits from correcting for the production externality.

Table 2: Consumption-equivalent loss of transition

Case	Loss excluding 'externality benefit'	Loss including 'externality benefit'
First-best	0.0811%	-0.0067%
Perfect competition	0.0823%	-0.0055%
Monopolists	0.0851%	-0.0027%
No transition	0.0867%	-0.0014%

Rule of thumb policy   Even though the first-best adjustment path minimizes welfare losses, the other two paths have a clear advantage in terms of implementation. Under the perfect competition and monopolists path, policy takes the form of a one-off increase in the 'unhealthy-food' charge, absent any further intervention. Of these two paths, the perfect competition path, where consumers face a flat price schedule, performs best. In this paragraph, I consider two 'rule of thumb' policies which aim to reduce welfare losses compared to this perfect competition path, yet are more straightforward to implement than the optimal path. The first rule of thumb policy targets consumption; it is a 'unhealthy food' quota, that is lowered each year. In the first year, it imposes a 11 percent drop in c_i^R. Then, each year, for four consecutive years, the c_i^R is lowered by an equal amount, such that after 4 years, it reaches its steady state.[40] The second rule of thumb policy targets prices. It sets a relative price of 'unhealthy food' equal to 1.06 in the first year, and increases this price by 0.01 point each year for four years thereafter. Figure 3 presents the paths of c_i^R and p_i^R under both rules of thumb, and in the first-best transition. As is clear from Figure 3a, both rules implement a shift that is somewhat slower than first-best initially, yet reaches the steady state sooner. Under the consumption rule, (implicit) prices overshoot the long run equilibrium for a

[39]Note that even though consumption immediately jumps to its long run level, habits still require time to adjust.

[40]The 4 year period is chosen as follows. For the parameter values in Table 1, $\lambda^{opt} = 0.3656$ (see Appendix A.3.1). The adjustment speed, $\xi * \lambda$ is then about 2.2 percent a month. A rough approximation of the total adjustment period in turn gives $1/0.022 = 45.5$ months$\approx$4 years. The 11 percent initial drop in c_i^R is set close to the initial drop in the optimal path (10.87%). The approach to determine the rule of thumb price path is equivalent, with the initial 6% price increase set close to the initial increase in first-best (5.92%).

substantial period of time. The simple policy rules do not always improve upon the allocation with the flat price schedule (Table 2, second column). Under the consumption rule, the consumption-equivalent loss of the transition is 0.0824%, i.e. it performs better than the monopolist (and no transition) path, but is just shy of beating the perfect competition case. The price rule performs better, here I find a loss of 0.0818%.[41]

Figure 3: Transition under rules of thumb

(a)

(b)
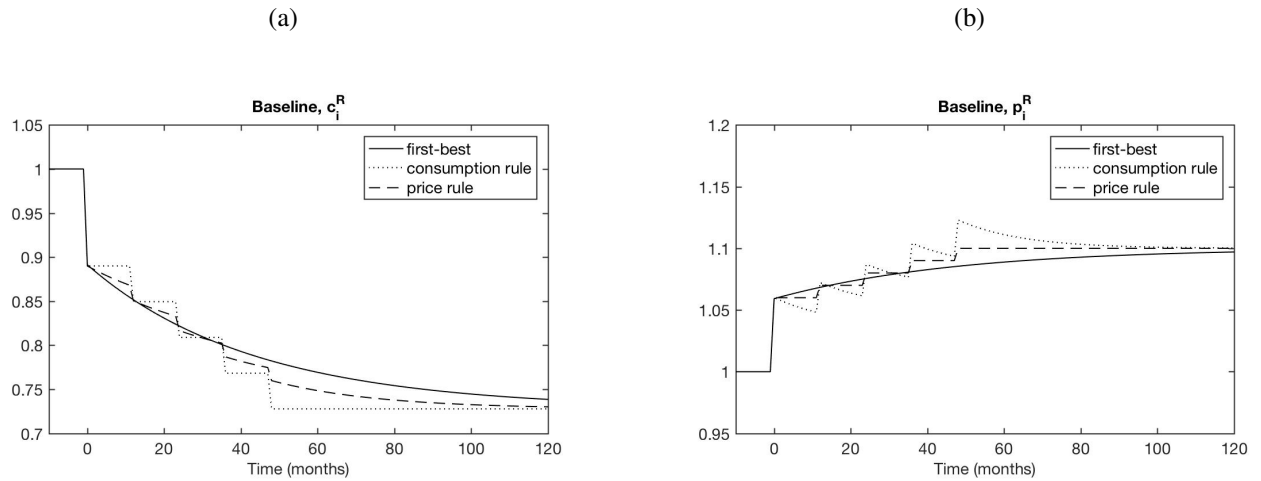
Curves depict policy rules where policy is introduced at $t = 0$. I assume the economy is in steady state for all $t < 0$. Paths are shown for a good $i \in [0, n]$ relative to any good $b \in (n, 1]$.

Sensitivity   Results for alternative parameter values are presented in Figures D.1-D.3 in Appendix D. The effects of a change in the value of a particular parameter are fully in line with the results presented in Sections 4-6 and Lemmas 1-3. A lower short run price elasticity of demand, η, reduces the short- and long-run consumption responses in response to the charge. Interestingly, for $\eta = 1.2$, consumption undershoots its long run equilibrium if goods are produced by monopolists. This is in line with Lemma 2a, which states that $\lambda^{mc} > 1$ if $\theta > 0$ and $\eta - 1 < (1 - \theta)\xi/(\rho + \xi)$.[42] The long run price elasticity is also determined by θ, with higher values for θ implying larger long-run consumption adjustment in response to the charge. A lower θ (good-specific demand less dependent of habits) and higher ξ (faster habit adjustment) clearly increase the rate at which the economy transitions to the steady-state. Proposition 3 stated that in the log-linearized model, the perfection competition transition equals first-best when $\gamma = \theta$. I consider this case when I set

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[41]When I take into account the benefit from correcting the externality, as in the rightmost column of Table 2, I find values of -0.0060% and -0.0066% respectively. Now, the consumption rule does improve welfare compared to the perfect competition path.

[42]For the parameter values in Table 1, $(1 - \theta)\xi/(\rho + \xi) = 0.57$. Thus, this condition is satisfied whenever $\eta < 1.57$.

$\gamma = 0.4$ (Figures D.1-D.3, third row, left column), and find that also here, the approximation is very accurate; the respective c_i^R deviate by less than 0.003.

The result that habit formation might call for substantial discounts on the initial charge is not very sensitive to parameter choices. With the exception of the last case discussed above, implied short-run discounts on the charge range from 20 to 60 percent. In addition, within the range I consider, the variation in $\tau_i^{opt}(0)$ is almost fully driven by variation in the two habit parameters, θ and γ.

Accuracy of the linear approximation   As a final exercise, I compare the numerical results to the linear approximation of the consumption path in (23). I find that this approximation is accurate. For the parameter values in Table 1 we have $\lambda^{pc} = 0.6$, $\lambda^{mc} = 0.91$ and $\lambda^{opt} = 0.37$ and $\tilde{h}_i^R(0) = 0.37$. Then, from (23), time 0 unhealthy-food relative to non-unhealthy-food consumption should equal $0.84, 0.75$, and 0.90 under perfect competition, monopolists and the optimal path respectively. Comparing these values to the results discussed above I find that the approximation is off by at most 0.01 points. The linear approximation is accurate too regarding the adjustment speed. For the change in c_i^R that remains after the initial drop, the approximation predicts a half life of 19, 13 and 32 months for perfect competition, monopolists and the optimal path respectively.[43] Comparing these half-lives to those in Figure 1a reveals a bias of at most one month.

8   Conclusion

This paper studies consumption choices when consumption is subject to good-specific habit formation. I develop a stylized representative-consumer model where I explicitly distinguish between two roles of habits. First, good-specific habits cause the allocation of consumption across goods to be persistent; shift within the consumption bundle are slow. Second, these habits jointly determine the benchmark against which consumption is evaluated; the higher habits, the higher the 'standard of living' the consumer is accustomed to and the lower is welfare for a given level of consumption. I consider the case where the consumer does not internalize the fact that current consumption affects future habits (projection bias) and characterize the equilibrium consumption choices and prices when goods are produced under perfect competition or by forward-looking monopolists.

I find that the steady-state allocation of consumption across goods is independent of market power. As all goods are to an equal extent subject to habit formation, projection bias does not distort the steady-state consumption allocation. The transition toward the steady state may however be suboptimal. Whenever goods are produced by monopolists, strategic pricing speeds up shifts within the consumption bundle, and cause those to be suboptimally fast. In this case, the optimal

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[43]For the approximation, the half life T is computed by solving $e^{-\xi \lambda T} = 0.5$.

transition can be implemented by tax that slows down the transition to the steady state. In the absence of market power, the consumer adjusts its consumption bundle suboptimally fast if the second, 'welfare', role of habits is particularly strong. If instead the persistence effect of habits dominates, a tax policy that speeds up the transition is preferred.

While the model and its discussion are stylized, its applications are numerous. In the upcoming decades, some major shifts will likely occur in our consumption patterns. Increased water shortages in many regions in the world necessitate consumers to reduce water use. Resource scarcity and concerns about climate change will call for a reduction in energy use, especially if the cost of renewable energy remains high, and in many countries, taxes on fatty or sugary foods to induce consumers to adopt a healthier diet are currently on the table. Such (policy-induced) shifts in our consumption bundles will not happen from one day to another, with habit formation being one reason for such slow transitions. In all these instances, a relevant question is whether there is a role for policy in managing the rate at which such change occurs. For instance, in the context of fat taxes, it is optimal to force consumers to quickly get rid of unhealthy dietary habits by introducing hefty initial rates? Or is it perhaps preferred to allow consumers to slowly adjust their demand for fatty foods, by implementing a tax that starts low and increases over time?

In a numerical exercise I apply the model to answer the latter question. More specifically, I consider the introduction of a 10 percent charge on a subset of good ('unhealthy food'), which induces a transition away from these goods. This application reveals that the theoretical effects are also quantitatively meaningful. I find that the transition under perfect competition and monopolistic supply is substantially faster than the first-best transition; the first-best path calls for a lower immediate reductions in 'unhealthy food' consumption, and allows the remaining reduction to slowly materialize over time. To implement this path, the policymaker can offers consumers an initial discount of as much as 60 percent of the long-run charge. The optimal path requires careful management of consumption and/or prices. I evaluate two rule of thumb policies that are easier to implement and have the potential to bring welfare closer to first-best compared to the one-off charge.

In the above examples the shift in the consumption bundle is policy-induced to begin with. The same questions and insights however apply if the cause of the shift is external. Consider for example the common call for policy action when gasoline prices increase due to shifts on world oil markets. Also shifts in food prices, caused by misharvests or increased openness to trade, are often followed by appeals for government intervention such as (temporary) subsidies or tax breaks.[44] The framework and numerical results in this paper provide support for such measures; with habit formation and projection bias, a policy that allows people to partly postpone adjustment

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[44]The latter example relates to the work by Atkin (2013), who documents that habits reduce the nutritional gains from trade in India, as consumers continue to favor foods that were relatively inexpensive in the past.

in consumption is welfare-improving.

Acknowledgments

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A   Derivations and proofs

A.1   Detailed derivations

A.1.1   Equations (10), (11) and (28)

The good i monopolist maximizes $V_i(t) = \int_t^\infty e^{-\int_t^v r(x)dx} c_i(v) \left[p_i(v) - \delta_i \tau_i(v) \right] dv$, by choosing the path of supply, $[c_i(v)]_{v=t}^{v=\infty}$, taking into account demand, (7), and the process of good-specific habit formation, (5). The producer takes as given the price index P and aggregate habit H. Hence it solves the following Hamiltonian:

$$\mathcal{H} = c_i \left[p_i - \delta_i p_L \tau_i \right] + \kappa_{p_i} \left[c_i^{-\frac{1}{\eta}} \left(\frac{h_i}{H} \right)^{\frac{\theta}{\eta}} C^{\frac{1}{\eta}} - p_i \right] + \kappa_{h_i} \left[\xi \left(c_i - h_i \right) \right], \qquad (A.1)$$

where κ_{p_i} is the shadow value of inverse demand p_i and κ_{h_i} is the shadow value of habits h_i and I have already substituted (3) in (2). This gives the following FOC:

$$
\begin{aligned}
[c_i] \quad & p_i - \delta_i p_L \tau_i - \kappa_{p_i} \frac{1}{\eta} \frac{p_i}{c_i} + \xi \kappa_{h_i} = 0 && \text{(A.2)}\\
[p_i] \quad & c_i - \kappa_{p_i} = 0 \\
[h_i] \quad & \frac{\theta}{\eta} \kappa_{p_i} \frac{p_i}{h_i} - \xi \kappa_{h_i} = r \kappa_{h_i} - \dot{\kappa}_{h_i}
\end{aligned}
$$

Then I substitute $\kappa_{p_i} = c_i$ (see FOC with respect to p_i) in the FOCs for c_i and h_i. This gives (10) and (11). Next, I take the time derivative of (10):

$$
\dot{\kappa}_{h_i} = -\frac{1}{\xi} \left[\frac{\eta - 1}{\eta} \dot{p}_i - \delta_i p_L \tau_i \left[\frac{\dot{p}_L}{p_L} + \frac{\dot{\tau}_i}{\tau_i} \right] \right], \tag{A.3}
$$

which with the FOCs for h_i gives

$$
\kappa_{h_i} = \frac{1}{r + \xi} \left[p_i \frac{\eta - 1}{\eta} \left[\frac{\theta}{\eta - 1} \frac{c_i}{h_i} - \frac{1}{\xi} \frac{\dot{p}_i}{p_i} \right] + \frac{1}{\xi} \delta_i p_L \tau_i \left[\frac{\dot{p}_L}{p_L} + \frac{\dot{\tau}_i}{\tau_i} \right] \right]. \tag{A.4}
$$

I then substitute this result in (10) to find the following solution for p_i:

$$
p_i = \delta_i p_L \tau_i \frac{\eta}{\eta - 1} \left[\frac{1 - \frac{1}{r + \xi} \left[\frac{\dot{p}_L}{p_L} + \frac{\dot{\tau}_i}{\tau_i} \right]}{1 + \frac{1}{\eta - 1} \frac{\xi}{r + \xi} \theta \frac{c_i}{h_i} - \frac{1}{r + \xi} \frac{\dot{p}_i}{p_i}} \right]. \tag{A.5}
$$

This equation is in turn used to obtain the steady-state price, (14), and loglinearized to arrive at (28).

A.1.2 Equations (30), (31) and (34)

To maximize (29) subject to (1)-(6) by choosing $[c_i(v)]_{i \in [0,1], v=t}^{v=\infty}$ I write the following Hamiltonian:

$$
\begin{aligned}
\mathscr{H} = {} & \frac{(CH^{-\gamma})^{1-\sigma}}{1 - \sigma} + \mu_C \left[\left[\int_0^1 \left(\frac{h_i}{H} \right)^{\frac{\theta}{\eta} \frac{\eta - 1}{\eta}} c_i^{\frac{\eta - 1}{\eta}} di \right]^{\frac{\eta}{\eta - 1}} - C \right] + \mu_H \left[\left[\int_0^1 h_i^{\frac{\eta - 1 + \theta}{\eta}} di \right]^{\frac{\eta}{\eta - 1 + \theta}} - H \right] \\
& + \mu_L \left[L - \int_0^1 \delta_i c_i di \right] + \mu_{h_i} [\xi (c_i - h_i)], \tag{A.6}
\end{aligned}
$$

where μ_C, μ_H and μ_L are the shadow values of effective consumption, aggregate habit and labor respectively, μ_{h_i} is the shadow value of the good-specific habit, and (2) and (4) have been slightly

rewritten by substituting in (3). This gives the following FOC:

$$[C] \qquad (CH^{-\gamma})^{1-\sigma}\tfrac{1}{C} - \mu_C = 0 \tag{A.7}$$

$$[H] \qquad -\gamma(CH^{-\gamma})^{1-\sigma}\tfrac{1}{H} - \mu_C\tfrac{\theta}{\eta-1}\tfrac{C}{H} - \mu_H = 0$$

$$[c_i] \qquad \mu_C C^{\frac{1}{\eta}}\left(\tfrac{h_i}{H}\right)^{\frac{\theta}{\eta}} c_i^{-\frac{\eta-1}{\eta}}\tfrac{1}{c_i} - \delta_i\mu_L + \xi\mu_{h_i} = 0$$

$$[h_i] \quad \mu_C\tfrac{\theta}{\eta-1}\left(\tfrac{c_i}{C}\right)^{-\frac{1}{\eta}}\left(\tfrac{h_i}{H}\right)^{\frac{\theta}{\eta}}\tfrac{c_i}{h_i} + \mu_H\left(\tfrac{h_i}{H}\right)^{-\frac{1-\theta}{\eta}} - \xi\mu_{h_i} = \rho\mu_{h_i} - \dot{\mu}_{h_i}$$

Next define $\breve{\mu}_L \equiv \mu_L/\mu_C$ and $\breve{\mu}_{h_i} \equiv \mu_{h_i}/\mu_C$, such that $\dot{\breve{\mu}}_{h_i} = \breve{\mu}_{h_i}\left[\tfrac{\dot{\mu}_{h_i}}{\mu_{h_i}} - \tfrac{\dot{\mu}_C}{\mu_C}\right]$, and rewrite (7) to

$$p_i = \left(\tfrac{c_i}{C}\right)^{-\frac{1}{\eta}}\left(\tfrac{h_i}{H}\right)^{\frac{\theta}{\eta}}. \tag{A.8}$$

With the FOC for c_i this gives (30). Then to arrive at (31), I first substitute $\mu_C = (CH^{-\gamma})^{1-\sigma}C^{-1}$ in the FOC for H. This gives $\mu_H = -\mu_C\tfrac{C}{H}\left[\gamma + \tfrac{\theta}{\eta-1}\right]$. I then substitute these results for μ_C and μ_H and (A.8) in the FOC for h_i to find

$$\breve{\mu}_{h_i} = \frac{1}{\breve{r}+\xi}\left[\dot{\breve{\mu}}_{h_i} + \frac{c_i}{h_i}p_i\left[\frac{\theta}{\eta-1} - \left[\gamma + \frac{\theta}{\eta-1}\right]\left(\frac{h_i}{H}\right)^{\frac{\eta-1}{\eta}}\left(\frac{c_i}{C}\right)^{-\frac{\eta-1}{\eta}}\right]\right] \tag{A.9}$$

where $\breve{r} = \rho - \dot{\mu}_C/\mu_C$ and which gives (31). Next, I take the time derivative of (30):

$$\dot{\breve{\mu}}_{h_i} = -\frac{1}{\xi}\left[\dot{p}_i - \delta_i\dot{\breve{\mu}}_L\right], \tag{A.10}$$

and substitute this in (A.9) which gives

$$\breve{\mu}_{h_i} = \frac{1}{\breve{r}+\xi}\left[p_i\left[\frac{c_i}{h_i}\left[\frac{\theta}{\eta-1} - \left[\gamma + \frac{\theta}{\eta-1}\right]\left(\frac{h_i}{H}\right)^{\frac{\eta-1}{\eta}}\left(\frac{c_i}{C}\right)^{-\frac{\eta-1}{\eta}}\right] - \frac{1}{\xi}\frac{\dot{p}_i}{p_i}\right] + \frac{1}{\xi}\delta_i\dot{\breve{\mu}}_L\right]. \tag{A.11}$$

I then substitute this result in (10) to find the following solution for the optimal price:

$$p_i = \delta_i\breve{\mu}_L\left[\frac{1 - \frac{\xi}{\breve{r}+\xi}\frac{\dot{\breve{\mu}}_L}{\breve{\mu}_L}}{1 + \frac{\xi}{\breve{r}+\xi}\frac{c_i}{h_i}\left[\frac{\theta}{\eta-1} - \left[\gamma + \frac{\theta}{\eta-1}\right]\left(\frac{h_i}{H}\right)^{\frac{\eta-1}{\eta}}\left(\frac{c_i}{C}\right)^{-\frac{\eta-1}{\eta}}\right] - \frac{\xi}{\breve{r}+\xi}\frac{\dot{p}_i}{p_i}}\right], \tag{A.12}$$

which can in turn be loglinearized to find (34).

A.2 Proofs

A.2.1 Proof to Lemma 2

First I take the time derivative of the loglinearized consumer demand function (20):

$$\dot{\tilde{c}}_i^R = -\eta \dot{\tilde{p}}_i^R + \theta \dot{\tilde{h}}_i^R. \tag{A.13}$$

Next, loglinearizing (5) allows me to write

$$\dot{\tilde{h}}_i^R = \xi \left[\tilde{c}_i^R - \tilde{h}_i^R \right]. \tag{A.14}$$

Then using (20), (A.13) and (A.14) in (28) and observing that under constant taxes, $\tilde{\tau}_i^R = \dot{\tilde{\tau}}_i^R = 0$, I find the following formula for change in $\tilde{c}_i^R$ as a function of $\tilde{c}_i^R$ and h_i^R:

$$\dot{\tilde{c}}_i^R = (\rho + \xi)\tilde{c}_i^R - \frac{\theta}{\eta - 1}\left[(\rho + \xi)(\eta - 1) + \xi(\theta - 1) \right]\tilde{h}_i^R. \tag{A.15}$$

This gives the following system of dynamic equations:

$$
\begin{bmatrix} \dot{\tilde{h}}_i^R \\ \dot{\tilde{c}}_i^R \end{bmatrix} = \begin{bmatrix} -\xi & \xi \\ -\frac{\theta}{\eta-1}\left[(\rho+\xi)(\eta-1)+\xi(\theta-1) \right] & \rho+\xi \end{bmatrix} \begin{bmatrix} \tilde{h}_i^R \\ \tilde{c}_i^R \end{bmatrix}. \tag{A.16}
$$

From (23) and (25), $\dot{\tilde{h}}_i^R = -\xi\lambda\tilde{h}_i^R$ and $\dot{\tilde{c}}_i^R = -\xi\lambda\tilde{c}_i^R$, so

$$
0 = \begin{bmatrix} -\xi(1-\lambda) & \xi \\ -\frac{\theta}{\eta-1}\left[(\rho+\xi)(\eta-1)+\xi(\theta-1) \right] & \rho+\xi(1+\lambda) \end{bmatrix} \begin{bmatrix} \tilde{h}_i^R \\ \tilde{c}_i^R \end{bmatrix}. \tag{A.17}
$$

This gives

$$R^{mc}(\lambda) = (\theta - 1)\left[(\rho+\xi) + \xi\frac{\theta}{\eta-1} \right] + \lambda[\rho+\xi\lambda], \tag{A.18}$$

with λ^{mc} implicitly determined by $R^{mc}(\lambda^{mc}) = 0$.

As $\theta < 1$, I know $R^{mc}(0) < 0$. Then as $dR^{mc}/d\lambda > 0$ for $\lambda > 0$ know there exists a solution $\lambda^{opt} > 0$. Next $R^{mc}(\lambda^{pc}) = -\lambda^{pc}\xi\theta\eta(\eta-1)^{-1}$, which is strictly negative for $\theta > 0$ and equal to zero if $\theta = 0$. Hence, I can conclude that if $\theta = 0$, $\lambda^{mc} = \lambda^{pc} = 1$, while if $\theta > 0$, $\lambda^{mc} > \lambda^{pc}$. Then for $\lambda' = 1 + \frac{\theta}{\eta-1}$, $R^{mc}(\lambda') = \theta\frac{\eta}{\eta-1}\left[(\rho+\xi) + \xi\frac{\theta}{\eta-1} \right] > 0$, so $\lambda^{mc} < 1 + \frac{\theta}{\eta-1}$ whenever $\theta > 0$. □

A.2.2 Proof to Lemma 2a

The effect of a change in the individual parameters on λ^{mc} can be determined by taking a total differential of (A.18) and evaluating it at $\lambda = \lambda^{mc}$. I first consider the case with $\theta > 0$.

Then $\frac{d\lambda^{mc}}{d\rho} = -\frac{dR^{mc}/d\rho}{dR^{mc}/d\lambda}\Big|_{\lambda=\lambda^{mc}}$, with $dR^{mc}/d\rho = (\theta-1)+\lambda$. As has been established in Section A.2.1, $dR^{mc}/d\lambda > 0$ and $\lambda^{mc} > 1-\theta$, so $d\lambda^{mc}/d\rho < 0$. Next, $\frac{d\lambda^{mc}}{d\xi} = -\frac{dR^{mc}/d\xi}{dR^{mc}/d\lambda}\Big|_{\lambda=\lambda^{mc}}$, where $dR^{mc}/d\xi = (\theta-1)\left(1+\frac{\theta}{\eta-1}\right)+\lambda^2$ which is ambiguous at first sight. Note however that by using (A.18) one can rewrite $dR^{mc}/d\xi = \frac{1}{\xi}(R^{mc} - \rho(dR^{mc}/d\rho))$. At $\lambda = \lambda^{mc}$, $R^{mc} = 0$ and $dR^{mc}/d\rho > 0$, so $dR^{mc}/d\xi > 0$ and $d\lambda^{mc}/d\xi < 0$. Next, $\frac{d\lambda^{mc}}{d\eta} = -\frac{dR^{mc}/d\eta}{dR^{mc}/d\lambda}\Big|_{\lambda=\lambda^{mc}}$, with $dR^{mc}/d\eta = -(\theta-1)\xi\frac{\theta}{(\eta-1)^2} > 0$, which gives $d\lambda^{mc}/d\eta < 0$. In addition, $\frac{d\lambda^{mc}}{d\theta} = -\frac{dR^{mc}/d\theta}{dR^{mc}/d\lambda}\Big|_{\lambda=\lambda^{mc}}$, with $dR^{mc}/d\theta = \rho + \frac{\xi}{\eta-1}[\eta+2(\theta-1)]$. Rewriting this equation reveals that $dR^{mc}/d\theta < 0$, and thus $d\lambda^{mc}/d\theta > 0$, iff $(\eta-1) < (1-2\theta)\xi/(\rho+\xi)$. Inspection of $dR^{mc}/d\theta$ reveals this latter result continues to apply if $\theta = 0$.

Lastly, $\lambda^{mc} > 1$ if $R^{mc}(1) = (\theta-1)\left[(\rho+\xi)+\xi\frac{\theta}{\eta-1}\right]+[\rho+\xi] < 0$. This inequality can be rewritten as $\theta(\eta-1) < \theta(1-\theta)\xi/(\rho+\xi)$. $\qquad\square$

A.2.3 Proof to Lemma 3

The optimal path of consumption can be found by combining (30), with (20), (A.13) and (A.14):

$$\dot{\tilde{c}}_i^R = (\rho+\xi)\tilde{c}^R - [\theta(\rho+\xi)+\xi\gamma(1-\theta)]\tilde{h}_i^R. \tag{A.19}$$

Then together with the time derivative of (20) I find the following system of dynamic equations

$$\begin{bmatrix} \dot{\tilde{h}}_i^R \\ \dot{\tilde{c}}_i^R \end{bmatrix} = \begin{bmatrix} -\xi & \xi \\ -[\theta(\rho+\xi)+\xi\gamma(1-\theta)] & \rho+\xi \end{bmatrix} \begin{bmatrix} \tilde{h}_i^R \\ \tilde{c}_i^R \end{bmatrix}. \tag{A.20}$$

From (23) and (25) I have $\dot{\tilde{h}}_i^R = -\xi\lambda\tilde{h}_i^R$ and $\dot{\tilde{c}}_i^R = -\xi\lambda\tilde{c}_i^R$, so

$$0 = \begin{bmatrix} -\xi(1-\lambda) & \xi \\ -[\theta(\rho+\xi)+\xi\gamma(1-\theta)] & \rho+\xi(1+\lambda) \end{bmatrix} \begin{bmatrix} \tilde{h}_i^R \\ \tilde{c}_i^R \end{bmatrix}. \tag{A.21}$$

This gives

$$R^{opt}(\lambda) = (\theta-1)[\rho+\xi(1-\gamma)]+\lambda(\rho+\xi\lambda), \tag{A.22}$$

with λ^{opt} implicitly determined by $R^{opt}(\lambda^{opt}) = 0$.

As $\theta < 1$, I know $R^{opt}(0) < 0$. Then as $dR^{opt}/d\lambda > 0$ for $\lambda > 0$, I know there exists a solution $\lambda^{opt} > 0$. Next, I can show that $R^{opt}(1-\gamma) = (\theta-\gamma)[\rho+\xi(1-\gamma)]$ while $R^{opt}(\lambda^{pc}) = (\theta-\gamma)(\theta-1)\xi$. Then if $\gamma = \theta$, we have $\lambda^{opt} = 1-\theta = \lambda^{pc}$. If $\gamma < \theta$, we must have $\lambda^{opt} \in (1-\theta, 1-\gamma)$ while if $\gamma > \theta$, $\lambda^{opt} \in (1-\gamma, 1-\theta)$. Finally, $R^{opt}(\lambda^{mc}) = -(\theta-1)\xi\left[\gamma+\frac{\theta}{\eta-1}\right]$ which is strictly positive if γ and/or θ are strictly positive, and equal to zero if $\gamma = \theta = 0$. Hence,

I can conclude that $\lambda^{opt} < \lambda^{mc}$ if $\max\{\gamma,\theta\} > 0$, while $\lambda^{opt} = \lambda^{mc} = 1$ if $\gamma = \theta = 0$. $\qquad\square$

A.2.4 Proof to Lemma 3a

The effect of a change in the individual parameters on λ^{opt} can be determined by taking a total differential of (A.22) and evaluating it at $\lambda = \lambda^{opt}$. Then $\frac{d\lambda^{opt}}{d\gamma} = -\frac{dR^{opt}/d\gamma}{dR^{opt}/d\lambda}\Big|_{\lambda=\lambda^{opt}}$, with $dR^{opt}/d\gamma = \xi(1-\theta) > 0$. As has been established in Section A.2.3, $dR^{opt}/d\lambda > 0$, so $d\lambda^{opt}/d\gamma < 0$. Next $\frac{d\lambda^{opt}}{d\theta} = -\frac{dR^{opt}/d\theta}{dR^{opt}/d\lambda}\Big|_{\lambda=\lambda^{opt}}$, where $dR^{opt}/d\theta = \rho + \xi(1-\gamma) > 0$ so $d\lambda^{opt}/d\theta < 0$. Similarly, $\frac{d\lambda^{opt}}{d\rho} = -\frac{dR^{opt}/d\rho}{dR^{opt}/d\lambda}\Big|_{\lambda=\lambda^{opt}}$, with $dR^{opt}/d\rho = \lambda - (1-\theta)$. Then if $\gamma > \theta$, $\lambda^{opt} < 1-\theta$ and $d\lambda^{opt}/d\rho > 0$, if $\gamma < \theta$, $\lambda^{opt} > 1-\theta$ and $d\lambda^{opt}/d\rho < 0$, and if $\gamma = \theta$, $\lambda^{opt} = 1-\theta$, which gives $d\lambda^{opt}/d\rho = 0$. I know $\frac{d\lambda^{opt}}{d\xi} = -\frac{dR^{opt}/d\xi}{dR^{opt}/d\lambda}\Big|_{\lambda=\lambda^{opt}}$, where $dR^{opt}/d\xi = \lambda^2 - (1-\theta)(1-\gamma)$. By (A.22), I can rewrite the latter as $dR^{opt}/d\xi = (R^{opt} - \rho(dR^{opt}/d\rho))/\xi$. At $\lambda = \lambda^{opt}$, R^{opt} is equal to zero, which implies $d\lambda^{opt}/d\xi$ is of opposite sign as $d\lambda^{opt}/d\rho$. Finally, as η does not appear in (A.22), $d\lambda^{opt}/d\eta = 0$. $\qquad\square$

A.2.5 Proof to Proposition 2

First, the optimal adjustment to the steady state is equal to $\xi\lambda^{opt}$, while $\xi\lambda^{pc}$ is the adjustment rate to the steady state under constant taxes (including laissez-faire). From Lemma 3, it then directly follows that if $\gamma > (<)\theta$, $\xi\lambda^{opt} < (>)\xi\lambda^{pc}$. Next, define $\tilde{\tau}_i^{R,\lambda}(t)$ as the $\tilde{\tau}_i^R(t)$ that implements a given λ. Then, under perfect competition, by (24) and (27), $\tilde{\tau}_i^{R,\lambda}(t) = [(\theta - 1 + \lambda)/\eta]\tilde{h}_i^R(t)$ with $\tilde{h}_i^R(t) = \tilde{h}_i^R(0)e^{-\xi\lambda t}$. The term within square brackets is increasing in λ, and, by definition, equal to zero for $\lambda = \lambda^{pc}$. Thus, for $\lambda = \lambda^{opt}$, $\tilde{\tau}_i^{R,\lambda}(t)$ is positive (negative) and falling over time whenever $\lambda^{opt} > \lambda^{pc}$ and $\tilde{h}_i^R(0) > (<)0$. By Lemma 3 $\lambda^{opt} > \lambda^{pc}$ whenever $\gamma < \theta$. Similarly, for $\lambda = \lambda^{opt}$, $\tilde{\tau}_i^{R,\lambda}(t) < (>)0$ and rising (falling) over time if $\gamma > \theta$ and $\tilde{h}_i^R(0) > (<)0$ while $\tilde{\tau}_i^{R,\lambda}(t) = 0$ for all t if $\gamma = \theta$. $\qquad\square$

A.2.6 Proof to Proposition 3

First, the optimal adjustment to the steady state is equal to $\xi\lambda^{opt}$, while $\xi\lambda^{mc}$ is the adjustment rate to the steady state under constant taxes (including laissez-faire). From Lemma 3, it then directly follows that if $\max\{\gamma,\theta\} > 0$, $\xi\lambda^{opt} < \xi\lambda^{mc}$. Next, define $\tilde{\tau}_i^{R,\lambda}(t)$ as the $\tilde{\tau}_i^R(t)$ that implements a given λ. Then, under monopolists, by (24) and (28), $\tilde{\tau}_i^{R,\lambda}(t) = \frac{1}{\eta}\left[\frac{(\theta-1)\left[(\rho+\xi)+\xi\frac{\theta}{\eta-1}\right]+\lambda(\rho+\xi\lambda)}{(\rho+\xi)+\xi\frac{\theta}{\eta-1}}\right]\frac{\rho+\xi}{\rho+\xi(1+\lambda)}\tilde{h}_i^R(t)$, with $\tilde{h}_i^R(t) = \tilde{h}_i^R(0)e^{-\xi\lambda t}$. The term within square brackets is increasing in λ, and, by definition, equal to zero for $\lambda = \lambda^{mc}$. By Lemma 3, if $\max\{\gamma,\theta\} > (=)0$, $\lambda^{opt} < (=)\lambda^{mc}$ and the bracketed term is negative (zero) for $\lambda = \lambda^{opt}$. As $t \to \infty$, $\tilde{h}_i^R(t)$ converges to zero, and so will $\tilde{\tau}_i^{R,\lambda}(t)$ for $\lambda = \lambda^{opt}$. $\qquad\square$

A.3 Additional results

A.3.1 Closed-form solutions for λ^{mc} and λ^{opt}

From (A.18) and $R^{mc}(\lambda^{mc}) = 0$ I find the following closed-form solution for λ^{mc}:

$$\lambda^{mc} = \frac{\sqrt{\rho^2 - 4\xi(\theta-1)\left[(\rho+\xi)+\xi\frac{\theta}{\eta-1}\right]} - \rho}{2\xi}. \tag{A.23}$$

Similarly I find the following closed-form solution for λ^{opt} using (A.22) and $R^{opt}(\lambda^{opt}) = 0$:

$$\lambda^{opt} = \frac{\sqrt{\rho^2 - 4\xi(\theta-1)\left[\rho + \xi(1-\gamma)\right]} - \rho}{2\xi}. \tag{A.24}$$

A.3.2 Proof to $d(\xi\lambda^{opt})/d\xi > 0$

The effect of a change in ξ on the adjustment speed $\xi\lambda^{opt}$ is equal to $d(\xi\lambda^{opt})/d\xi = \lambda^{opt} + \xi(d\lambda^{opt}/d\xi)$. From Appendix (A.2.3) I know $\frac{d\lambda^{opt}}{d\xi} = -\frac{(\lambda^{opt})^2 - (1-\theta)(1-\gamma)}{\rho + 2\xi\lambda^{opt}}$. This allows me to rewrite $d(\xi\lambda^{opt})/d\xi$ as $\frac{d(\xi\lambda^{opt})}{d\xi} = \frac{\lambda^{opt}[\rho + \xi\lambda^{opt}] + \xi(1-\theta)(1-\gamma)}{\rho + 2\xi\lambda^{opt}}$, and conclude $d(\xi\lambda^{opt})/d\xi > 0$.

B Extension: habit formation and production externalities

In this appendix I show how the model can be adapted to explicitly account for the presence of an externality due to the production of one or multiple goods.[45] Optimally correcting the externality will require introducing a Pigovian tax (or subsidy), which in turn induces consumption to shift away from highly-taxed goods. I can then show that the optimal policy can be decomposed into two types of taxes; a time-independent externality tax τ^E that corrects the production externality, and a 'habit' tax τ_i^H that satisfies Propositions 1-3 and, as before, optimally manages the speed at which consumption moves toward the new steady-state.

Suppose that the production of a good i has an external effect on overall labor productivity, such that (6) is replaced by

$$L\left(1 - \int_0^1 \Delta_i c_i di\right) = \int_0^1 \delta_i c_i di. \tag{B.1}$$

Here, Δ_i denotes the size of the external effect due to good i. If Δ_i is positive, the production of good i imposes a negative externality; the externality is positive if $\Delta_i < 0$ and absent if $\Delta_i = 0$. To ensure consumption remains bounded, I require $\delta_i + \Delta_i L > 0$ for all i.

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[45] As I consider a closed economy, production is equal to consumption, and the production externality can be reinterpreted as a consumption externality. To avoid any confusion with the consumption/habit internality, I will discuss the results in the context of a production externality only.

Suppose that initially, no policy is in place to correct the externality. Then, equations (7)-(16) continue to apply, while (17) and (18) are replaced by

$$c_i^* = c_i^{R*} \left[\int_0^1 (\delta_i + \Delta_i L) c_i^{R*} di \right]^{-1} L, \tag{B.2}$$

and

$$C^* = \left[\int_0^1 \left(c_i^{R*} \right)^{\frac{\eta-1+\theta}{\eta}} di \right]^{\frac{\eta-1+\theta}{\eta}} \left[\int_0^1 (\delta_i + \Delta_i L) c_i^{R*} di \right]^{-1} L, \tag{B.3}$$

respectively. The presence of a negative externality ($\Delta_i > 0$) reduces overall labor productivity, and thereby steady-state consumption c_i^* for all goods i. Conversely, positive externalities ($\Delta_i < 0$), increase steady state c_i^* and C^*. Equation (19) also continues to apply, now with (B.3) as the expression for steady-state effective consumption. Concerning the transition to the steady state, one can show that equations (20)-(25) remain unchanged, which implies Lemmas 1, 2 and 2a still apply, while (26) is adjusted to

$$\tilde{c}_i(t) = \tilde{c}_i^R(t) - \frac{\int_0^1 (\delta_i + \Delta_i L) c_i^{R*} \tilde{c}_i^R(t) di}{\int_0^1 (\delta_i + \Delta_i L) c_i^{R*} di}. \tag{B.4}$$

When the production of certain goods imposes an externality on aggregate labor productivity, consumption patterns may not be first-best, even in steady-state. To determine the first-best consumption allocation, I again maximize (29), now subject to (1)-(5) and (B.1). This gives the following rule for optimal prices:

$$p_i(t) = \breve{\mu}_L(t) [\delta_i + \Delta_i L] - \xi \breve{\mu}_{h_i}(t), \tag{B.5}$$

where $\breve{\mu}_{h_i}$ is still specified as in the main text (equation (31)). This in turn allows me to solve for the optimal steady-state good i price:

$$p_i^* = \breve{\mu}_L^* [\delta_i + \Delta_i L] \frac{\rho + \xi}{\rho + \xi (1 - \gamma)}. \tag{B.6}$$

In can then prove the following proposition, which replaces Proposition 1:[46]

Proposition B1 In steady state, laissez-faire consumption choices are optimal if only if $\Delta_i / \delta_i = \Delta_j / \delta_j$ for all $i, j \in [0, 1]$. A relative tax that satisfies $\tau_i^{R*} = \frac{1 + (\Delta_i/\delta_i)L}{1 + (\Delta_b/\delta_b)L}$ implements optimal steady-state consumption.

Proof By (B.6), the optimal relative price in steady state satisfies $p_i^{R*} = \frac{\delta_i + \Delta_i L}{\delta_b + \Delta_b L}$. This is equal to (16) iff $\tau_i^{R*} = \frac{1 + (\Delta_i/\delta_i)L}{1 + (\Delta_b/\delta_b)L}$. Under laissez faire, $\tau_i = 1$ for all i, so $\tau_i^{R*} = 1$. Then the laissez-faire τ_i^{R*}

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[46]In fact, Proposition 1 can be considered a special case of Proposition B1.

is equal to the first-best τ_i^{R*} iff $\Delta_i/\delta_i = \Delta_j/\delta_j$ for all $i, j \in [0, 1]$. $\qquad\square$

To determine the optimal path of consumption, prices and habits as consumption transitions away from good i, I solve for $\lambda^{E,opt}$, the λ for the optimal path in the presence of the production externality. This $\lambda^{E,opt}$ can then be used in (35) and (36) to determine the value of $\tilde{\tau}_i^R(t)$ required to implement the optimal transition path under perfect competition and monopolistic supply, respectively. I find that the optimal rate of adjustment is independent of the production externality:

Lemma B1 $\lambda^{E,opt} = \lambda^{opt}$

Proof Loglinearizing (B.5) around the steady state gives (34). (20)-(25) still, so $\lambda^{E,opt} = \lambda^{opt}$. $\quad\square$

The result that $\lambda^{E,opt} = \lambda^{opt}$ implies that Propositions 2 and 3 continue to apply, and the $\tilde{\tau}_i^R$ required to implement the optimal consumption path under perfect competition and monopolistic supply are still characterized by (35) and (36) with $\lambda = \lambda^{opt}$, respectively. Put differently, even though the production externality affects the tax that implements optimal steady-state consumption, it does not affect the optimal adjustment path to the steady state and thus the path of taxes, $\tilde{\tau}_i^R$, required to implement it. Hence, the optimal corrective tax can be separated into two parts. The first part corrects for the external effect on labor productivity. This tax is time-independent. The second part corrects for habit formation, and changes as the economy moves to its steady-state.

Starting in a steady state with no taxes, the introduction of an optimal corrective tax then sets in motion a process where consumption shifts away from goods with a relatively high Δ_i. In this context, the optimal $\tilde{\tau}_i^R(t)$ can be interpreted as the discount (or premium) to the optimal long-run tax that ensure the economy moves toward the new steady-state consumption bundle at its optimal rate. For example, suppose we start in a steady state with no taxes and $\frac{1+(\Delta_i/\delta_i)L}{1+(\Delta_b/\delta_b)L} > 1$, such that the optimal steady-state relative tax is positive ($\tau_i^{R*} > 1$). Suppose also that for any $\tilde{h}_i^R(t) > 0$, the optimal $\tilde{\tau}_i^R(t)$ is negative. Then, the optimal tax policy would be to introduce a positive tax which rises over time to the long-run optimal rate τ_i^{R*}.

C Discrete-time setup

Instead of discretizing the pricing rules (10) and (30) (or (B.5)), I rederive them by solving the discrete-time model 'bottom up'. I solve the more general setup presented in Appendix B. By setting all $\Delta_i = 0$, all results can be directly compared to their counterparts in Sections 4 to 6. Note that in this setup, as discussed in Appendix B, all Lemmas, as well as Propositions 2 and 3, continue to apply and we can interpret the numerical results referring to these analytical results.

In discrete time, (1)-(4), (B.1) and (7)-(8) still apply. The equation of motion for habits is replaced by

$$h_{it+1} = \xi c_{it} + (1 - \xi) h_{it}, \tag{C.1}$$

where the use of time subscripts indicates we now deal with the discrete-time version of the model. Under perfect competition, $p_{it} = \delta_i p_{Lt} \tau_{it}$ still. The good i monopolist maximizes $\Pi_{it} = \sum_{v=t}^{V=\infty} \left[c_{iv} \left(p_{iv} - \delta_i p_{Lv} \tau_{iv} \right) \prod_{x=t+1}^{x=v} \frac{1}{1+r_x} \right]$, subject to (7) and (C.1) by choosing $[c_{iv}]_{v=t}^{V=\infty}$. This gives the following pricing rule:

$$p_{it} = \delta_i p_L \tau_{it} \frac{\eta}{\eta - 1} \left[\frac{1 - \frac{1-\xi}{r_{t+1}+\xi} \frac{p_{Lt+1}\tau_{it+1} - p_{Lt}\tau_{it}}{p_{Lt}\tau_{it}}}{1 + \frac{\xi}{r_{t+1}+\xi} \frac{\theta}{\eta-1} \frac{c_{it+1}}{h_{it+1}} \frac{p_{it+1}}{p_{it}} - \frac{1-\xi}{r_{t+1}+\xi} \frac{p_{it+1}-p_{it}}{p_{it}}} \right]. \qquad \text{(C.2)}$$

The interest rate r_{t+1} is determined by the consumption Euler equation: $\frac{dU_t/dC_t}{\mathbb{E}^{rc}[dU_{t+1}/dC_{t+1}]} = \frac{1+r_{t+1}}{1+\rho}$. As pointed out in footnote 11, further assumptions must be made regarding the representative consumer's anticipation of the change in H as the economy transitions to the steady state. For the numerical application, I have computed the transition for two cases; one where the consumers anticipate the change in H, and one where they do not. As results are virtually indistinguishable I only present the latter.[47]

The policymaker instead chooses the $[c_{iv}]_{i \in [0,1], v=t}^{V=\infty}$ that maximize $W_t = \sum_{v=t}^{V=\infty} (1+\rho)^{-(v-t)} U_v$, subject to (1)-(4), (B.1) and (C.1). This gives the optimal price for good i

$$p_{it} = \check{\delta}_i \check{\mu}_{Lt} \left[\frac{1 - \frac{1-\xi}{\check{r}_{t+1}+\xi} \left(\frac{\check{\mu}_{Lt+1} - \check{\mu}_{Lt}}{\check{\mu}_{Lt}} \right)}{1 + \frac{\xi}{\check{r}_{t+1}+\xi} \frac{p_{it+1}}{p_{it}} \frac{c_{it+1}}{h_{it+1}} \left[\frac{\theta}{\eta-1} - \left[\gamma + \frac{\theta}{\eta-1} \right] \left(\frac{c_{it+1}}{C_{t+1}} \right)^{-\frac{\eta-1}{\eta}} \left(\frac{h_{it+1}}{H_{t+1}} \right)^{\frac{\eta-1}{\eta}} \right] - \frac{1-\xi}{\check{r}_{t+1}+\xi} \left(\frac{p_{it+1}-p_{it}}{p_{it}} \right)} \right], \qquad \text{(C.3)}$$

where I define $\check{\delta}_i \equiv \delta_i + \Delta_i L$, and $\check{r}_{t+1}$ is now determined by the discrete-time Euler equation $\frac{dU_t/dC_t}{dU_{t+1}/dC_{t+1}} = \frac{1+\check{r}_{t+1}}{1+\rho}$. A comparison of (C.2) to (10), and (C.3) to (30), reveals two differences between the continuous and discrete-time pricing rules.

First, in continuous time, the denominator features the instantaneous ratio of good-specific consumption to habits, $c_i(t)/h_i(t)$, while in discrete time this is the $t+1$ ratio c_{it+1}/h_{it+1}, multiplied by the ratio of time $t+1$ to time t good-specific prices. Similarly, for the discrete-time optimal price (C.3), C and H are evaluated at time $t+1$, while in continuous time we have $C(t)$ and $H(t)$. This can be explained as follows. In continuous time, the habit adjustment occurs instantaneously. Hence to evaluate the value of the habit, instantaneous consumption, habits and prices are relevant. In discrete time, it is the next-period habit that adjusts, and thus next-period consumption, habit and prices are used to determine the value of investing in the habit. In both cases, the value of the habit is then evaluated relative to current prices.

Second, in the discrete-time pricing rules, the future change in taxes and prices are multiplied

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[47]This is not surprising. The shock I consider is one that is relatively small, and applies to a small share of goods. Hence, even if shifts in c_i^R are large, shifts in C and H, and hence r, are expected to be small.

by an additional $1 - \xi$. This is intuitive. In the discrete-time model, if $\xi = 1$, habits fully adjust from one period to another and the decision maker only needs to know the value of habits one period ahead. Hence, for $\xi = 1$, future changes in the value of the habit, captured by the change in prices (net of taxes), become irrelevant and drop out. In the continuous-time pricing rules, (10) and (30), this full adjustment from one *instant* to another occurs if $\xi \to \infty$. Here again, future price and tax changes drop out. Note that where any $\xi \geq 0$ can be rationalized in the continuous time model, in the discrete-time model only $\xi \in [0, 1]$ are sensical.

## C.1 Additional details for numerical results

I use the Dynare package version 4.4 to solve the model numerically.

I assume the charge optimally corrects for a production externality, as in Appendix B. Put differently, I assume that for 'unhealthy foods', $\Delta_i = 0.1$ while $\Delta_i = 0$ for all other goods (see Proposition B1 and (C.3)), and that in the initial steady-state relative consumption and habits equal unity. The difference between the welfare gains including and excluding the benefit from correcting the production externality comes from a difference in initial steady states. In the former case, I assume $\Delta_i = 0.1$ already prior to the implementation of policy, implying the initial steady state was distorted. In the latter, I consider an initial steady state that was undistorted: prior to $t = 0$, $\Delta_i = 0$ for all i. Here, the charge is implemented immediately in response to an increase in Δ_i to 0.1 for $i \in [0, n]$ at $t = 0$. Initial relative prices and consumption, as well as the new steady state are identical in both cases, yet due to the noninternalized production externality, initial consumption levels are lower in the former case.

All transition paths presented in this paper resemble the case where the initial steady state is distorted. To determine gains for the alternative case, I compute all transition paths again. Results for c_i^R, p_i^R and τ_i^{opt} are virtually indistinguishable.
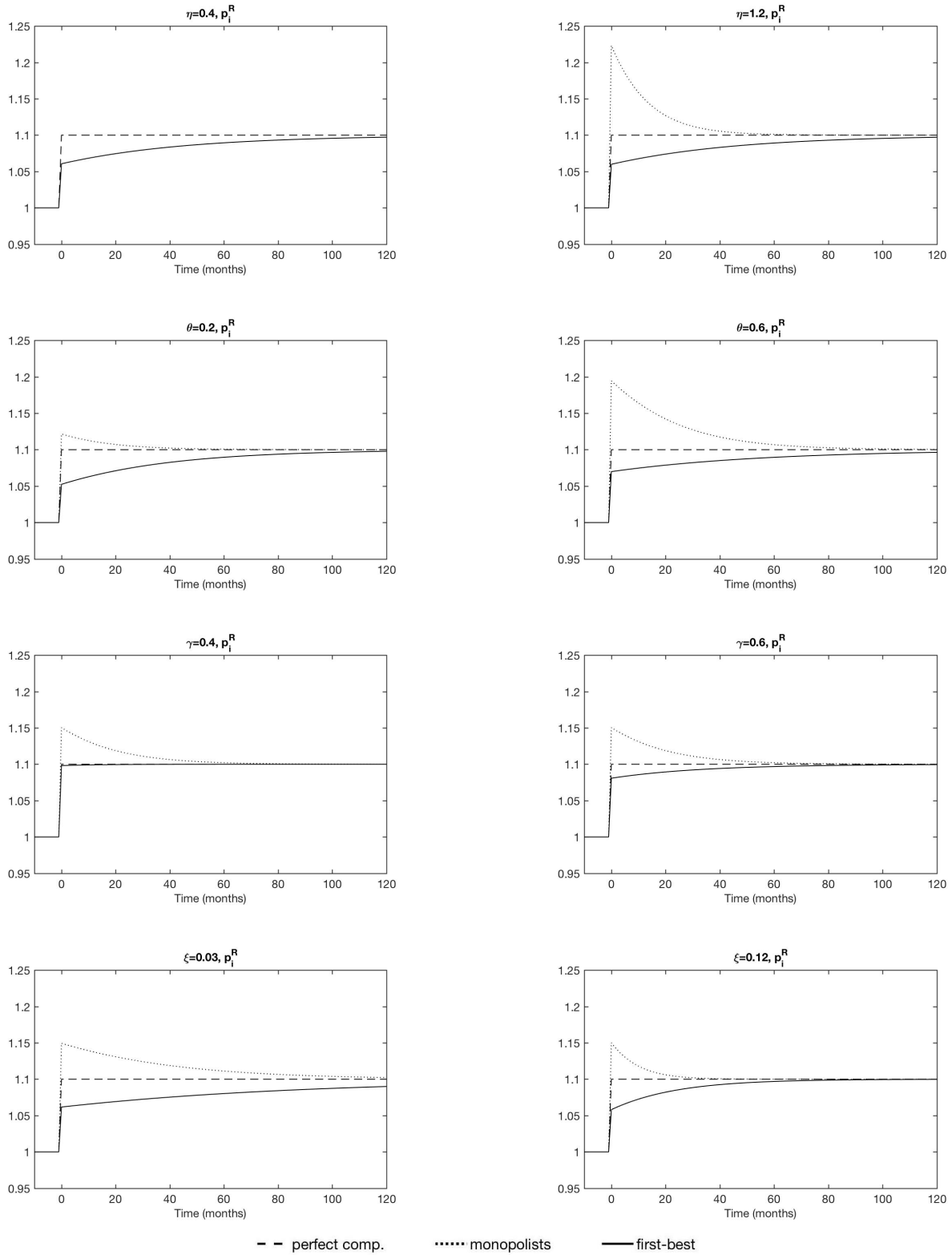
D   Additional figures
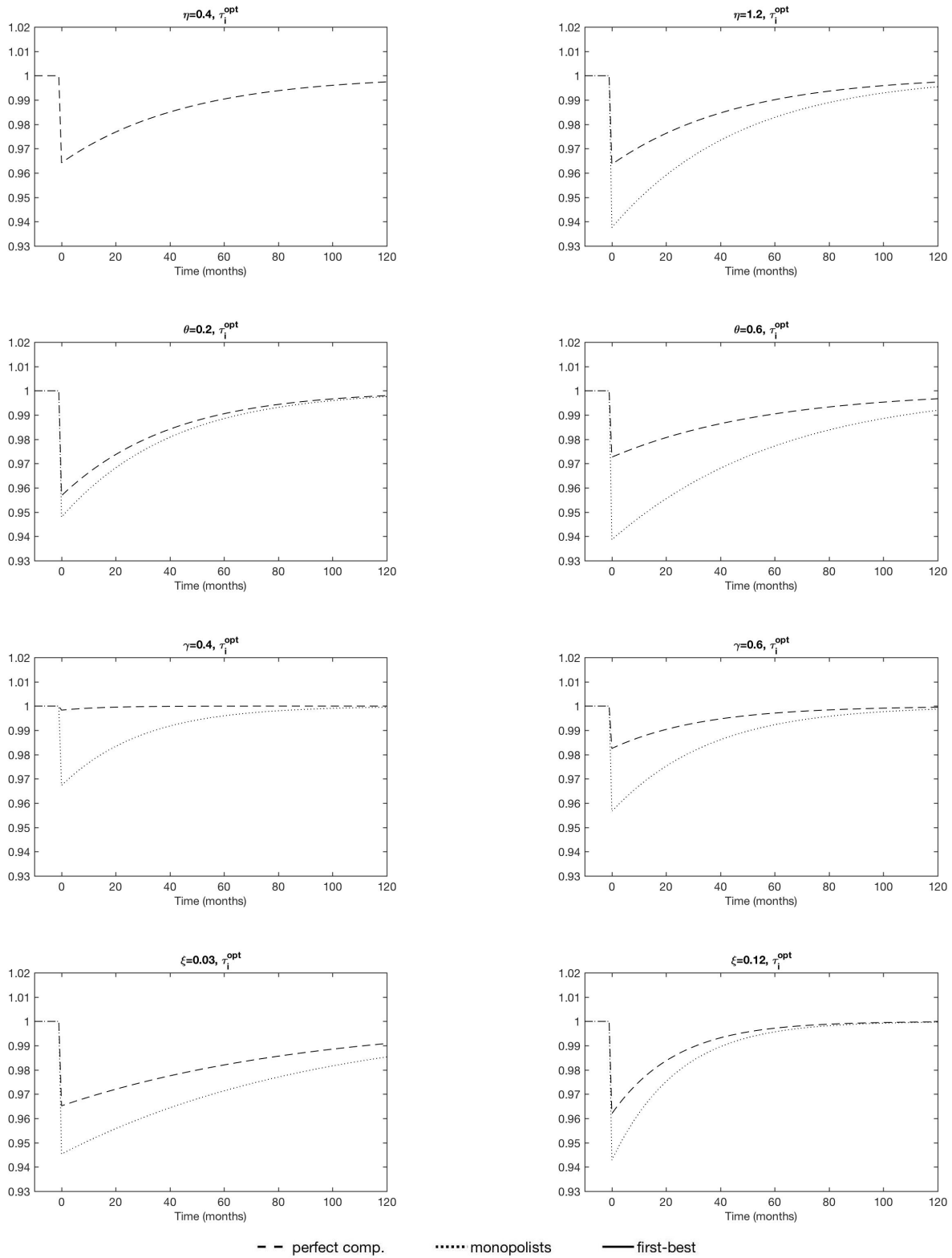
Figure D.1: Sensitivity analysis, c_i^R
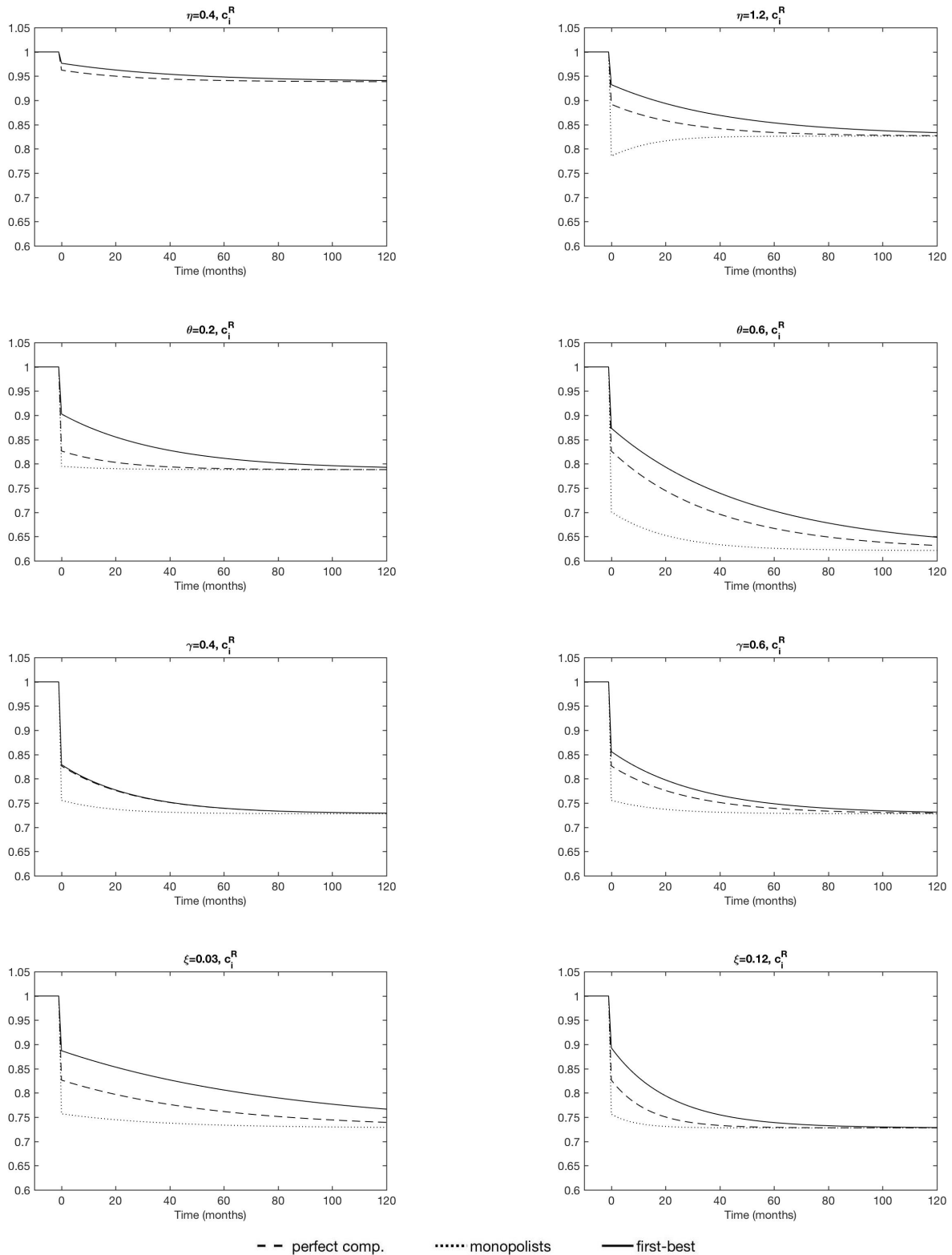
The curves depict responses to the unanticipated introduction of the 10 percent charge at $t = 0$, where I assume the economy is in steady state for all $t < 0$. Responses are shown for a good $i \in [0, n]$ relative to any good $b \in (n, 1]$.

Figure D.2: Sensitivity analysis, p_i^R

The curves depict responses to the unanticipated introduction of the 10 percent charge at $t = 0$, where I assume the economy is in steady state for all $t < 0$. Responses are shown for a good $i \in [0, n]$ relative to any good $b \in (n, 1]$.

Figure D.3: Sensitivity analysis, τ_i^{opt}

The curves depict responses to the unanticipated introduction of the 10 percent charge at $t = 0$, where I assume the economy is in steady state for all $t < 0$. Responses are shown for a good $i \in [0, n]$ relative to any good $b \in (n, 1]$.