

The Timing of Purchases and Aggregate Fluctuations

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We study the cyclical effects of the timing of durable goods purchases in a general equilibrium model in which both durable and non-durable goods are consumed and the durable good is lumpy. At the microeconomic level, the timing of durable goods purchases supplies some insulation for non-durable consumption over the cycle. At the macroeconomic level, the timing decisions tend to amplify and propagate wealth and income shocks. Our model also allows for endogenous price determination. When the price of the durable changes due to inflexibility of workers between sectors, the effect of adverse shocks is even stronger and longer.

1. INTRODUCTION

Durable goods are usually purchased in discrete amounts at specific points in time. Therefore the decision to purchase actually consists of two decisions, one on the size of purchase and another on the timing of purchase. At the same time consumers also make a third decision: they decide on the size of the flow of non-durable consumption. In this paper, we construct a general equilibrium model in which we can analyse the macroeconomic implications of these three decisions. The model enables us to examine the different cyclical dynamics of durable and non-durable consumption and their reaction to various shocks. We find that the predictions of the model fit many empirical observations on durable and non-durable consumption.

Discrete purchases are notoriously difficult to model in general equilibrium. The key simplifying assumption in our analysis is that consumers purchase the durable once in their lives. We consider an economy populated by overlapping generations of infinitely lived consumers. Due to a non-convexity in tastes, or alternatively to the presence of transactions costs, consumers prefer not to purchase small amounts of the durable early in life. Rather, they wait, accumulate wealth, and make a discrete purchase at a later time. The modelling assumption most closely corresponds to the purchase of a large durable such as a home.

The analysis leads to several key results. At the individual level, it shows that the timing of the purchase of the durable good may play an important role in smoothing marginal utility over time. Changing the timing of purchase after a shock to wealth, income, or prices, enables the consumer to have only a small adjustment in non-durable consumption or in the size of durable. In one benchmark case, non-durable consumption and the size of purchase do not change at all in response to wealth shocks. In contrast, in a standard consumption model without frictions and a fixed relative price of durables, non-durable purchases and the stock of durables would both

tend to move proportionately in response to a shock. We call the smoothing effect of the timing of purchases the “insulation effect”.

At the aggregate level, the analysis shows how timing decisions can serve as a mechanism for both amplification and propagation of aggregate shocks. A decline in wealth causes individuals to delay their durable good purchases, which reduces demand dramatically for some time. This reduction of demand is temporary. Agents rebuild their wealth and demand for the durable returns to its pre-shock level. Our modelling assumptions allow us to analyse the effects on demand and prices of permanent and transitory shocks to income, as well as the effects of shocks to the interest rate.

Many of the novel implications of our model relative to the standard stock-adjustment model come from the differential effects that shocks have on agents from different age cohorts and also from the distinction between the number of agents who make purchases and the average size of the durable purchased. As an example of the former, wealth shocks have different effects than do income shocks. Shocks to financial wealth affect most those who are about to purchase the durable, since they have accumulated wealth for this purpose. Income shocks, on the other hand, affect these agents least, since they hold a comparatively large fraction of their wealth in financial assets. As an example of the latter, the model predicts that increases in interest rates, while causing agents to delay purchases, will also cause agents who do purchase the durable to make larger purchases.

The insulation effect highlighted in our model finds empirical support in the recent work of Browning and Crossley (1999) and Haj-Yehia (2003). Browning and Crossley argue that Canadian households use durables to insulate non-durable consumption from income shocks associated with unemployment, while Haj-Yehia finds that terrorist attacks in Israel have negatively affected durable consumption while having an insignificant effect on non-durable consumption. Haj-Yehia also finds that the effect on durable consumption has been temporary. Durable consumption has since returned to its prior level.

At a broader level, the insulation effect may help to explain the “excess sensitivity” puzzle in the consumption literature. Campbell and Deaton (1989) argue that non-durable consumption responds insufficiently to innovations in permanent income, which is precisely what one would expect if agents adjust the timing of durable purchases in response to wealth shocks.

An alternative approach to modelling discrete purchases is the (S, s) approach. (S, s) models also have a timing decision that is sensitive to wealth shocks, but we know of no analysis of the insulation effect in (S, s) models.¹ Few (S, s) models include non-durables, and those that do, such as Beaulieu (1993), Flavin (2001), and Martin (2003), consider single agent problems and focus on other issues such as the implications of complementarity or substitutability between durables and non-durables or the effect of durables on the intertemporal elasticity of substitution.

The aggregate dynamics of durables in our model are similar to the dynamics that would arise out of an (S, s) model. Our model, however, offers a broader and more comprehensive framework of analysis to these issues. (S, s) policies are difficult to aggregate because the entire distribution of desired demands becomes a dynamic variable.² The simplicity of our overlapping generations structure allows us to endogenize the price of durables and to consider a range of

1. Stacchetti and Stolyarov (2004) consider a setting in which durable goods purchases are infrequent because new, higher quality durables are introduced at discrete points in time. They find that in response to wealth shocks, some consumers insulate non-durable consumption, but other consumers insulate consumption of durables.

2. Many researchers in the area take shortcuts to analyse aggregates. Some authors, such as Bertola and Caballero (1990) and Caballero and Engel (1999), ignore non-durable consumption and forego equilibrium feedback altogether by treating the price of the durable as exogenous. Caballero (1993), Eberly (1994), Carroll and Dunn (1997), and Hassler (1998) also follow this strategy. De Gregorio, Guidotti and Vegh (1998) and Adda and Cooper (2000a) construct equilibrium models that effectively follow this strategy. The former assume that the domestic price is fixed on world markets, while the latter assume that marginal cost is constant.

shocks not normally considered in the (S, s) framework, such as temporary shocks to income and shocks to the interest rate. We are also able to prove general comparative static results rather than relying on simulations.

Adding non-durables and endogenous prices is much more than a mere extension of the theory. First, adding prices is empirically significant. Studies show that price is correlated with demand and that the timing of purchase is sensitive to price movements.³ Second, price movements are significant theoretically as well. Thomas (2002) has shown that it is possible for price movements to smooth out the lumpiness generated by (S, s) models. Our model shows instead that price fluctuations may exacerbate the effects of shocks by impacting the wealth of durable goods producers.

The few attempts at constructing equilibrium models of durable demand in the (S, s) literature are usually partial equilibrium models of a single market. Parker (1996) considers the response of a market to demographic shocks of a particular shape and solves his model numerically. Caplin and Leahy (1999) use an approximation to the distributional dynamics that reduces the dimensionality of the problem and enables a study of market dynamics.⁴

In order to gain some intuition for how our timing model operates, we begin in Section 2 by analysing the properties of the individual's decision for a given path of prices. We show that there is a range of wealth levels, at which the durable is purchased at a positive and finite time. In the benchmark case, where the relative price of the durable is constant over time, changes in wealth within this range affect only the timing of purchase and not the quantities of the durable and non-durable. Such perfect insulation does not hold in the more general case of variable price, but there is partial insulation nonetheless. Somewhat surprisingly, wealth shocks have ambiguous effects on non-durable consumption for more general price processes. We conclude this section by comparing our results with the more standard (S, s) framework of depreciation and multiple purchases of the durable good.

In Section 3, we place our consumers in a general equilibrium context. We begin with the standard assumption in the literature that prices are exogenous to durable demand. The relative price of durables and non-durables is fixed by the production technology and the interest rate is fixed by considering a small open economy that trades assets with the rest of the world. We examine the effects of a decline in financial wealth and in a decline in productivity, of one-time shocks and of occasional anticipated shocks. We also consider shocks to interest rates. All these shocks have a common effect: they reduce lifetime discounted wealth and thus cause a delay in purchase of the durable good. As a result, individuals who were going to purchase the durable postpone their purchases. Since price is exogenous, demand for the durable drops to zero. After some time individuals rebuild their wealth and durable good purchases resume. The model draws a distinction between permanent and temporary shocks, which in our case correspond to shocks that affect all future generations and shocks which affect only current cohorts. In the case of temporary shocks, we observe a bust followed by a boom, due to bunching of purchases in later periods. In the case of permanent shocks there is no bunching and no boom.⁵ A novel implication

3. Bils and Klenow (1998) show that durable goods prices tend to move procyclically relative to demand. Adda and Cooper (2000b) estimate a structural model of discrete purchases on U.S. and French automobile data. They find that in order to fit the data they must assume that price is positively correlated with the demand shock. They also find that the responses of consumers' purchases to price movements are more important than the changes in the distribution of holdings.

4. Although not applied to durable consumption yet, Dotsey, King and Wolman (1999) and Thomas (2002) represent an alternative approach to the problem. They consider settings in which all agents who act at the same time make the same choice. If the number of periods between actions is bounded, the distribution is represented as a finite dimensional vector and the model can be solved numerically.

5. Bar-Ilan and Blinder (1992), Caplin and Leahy (1999), Adda and Cooper (2000b), and Haj-Yehia (2003) find evidence of boom-bust cycles. (S, s) models generally consider only permanent shocks. As such they can generate cycles only through the dynamics of the distribution of holdings as in Bar-Ilan and Blinder (1992) or De Gregorio *et al.* (1998).

of the model is the relationship between the horizon of purchase and the propagation of shocks. In a timing model, shocks today propagate in part by affecting the timing of future decisions. If there is a long time before purchases there will be more propagation.

In Section 4 we show the main virtue of our approach and endogenize the relative price of durables and non-durables. We examine how the economy reacts to a wealth shock when labour mobility between the two sectors is imperfect. If some workers in the durable sector cannot move to the non-durable sector when demand falls, supply becomes inelastic and the relative price of the durable must adjust to clear the market. This introduces a feedback into the economy. Durable producers lose not only from the initial shock but also from the decline in the price of the durable good. This leads them to delay their purchases of the durable good even further, which enhances the propagation mechanism. We prove that the size of the loss to the durable producers and the length of recession (defined as the return of the price of the durable to its pre-recession level) are increasing in the size of the shock, in the extent of the labour market rigidity, and in the age at which the durable is purchased in steady state.

2. THE TIMING OF PURCHASES AND THE INSULATION OF NON-DURABLE CONSUMPTION

Our aim is to develop a simple model in which we can investigate the timing of purchases. We consider a setting in which it is optimal to make a single discrete purchase of a durable good. We motivate this discrete purchase by assuming that there is a minimum size of the durable that provides utility. This assumption fits best our intuition for the housing market. No one likes to have a house of 5 square feet or without the necessary ingredients such as a kitchen and bathrooms. Our assumption makes utility convex near zero and makes small purchases unattractive to the consumer, who then must accumulate enough wealth to afford both the durable and the non-durable. Purchasing the durable earlier yields more pleasure from the durable good, but puts pressure on non-durable consumption.

While we motivate discrete purchases with an assumption on utility, anything that discourages small purchases will do. It might be the case that for technological reasons firms cannot produce the durable in small sizes. In the case of housing, the option to live at home with one's parents may dominate a small home or apartment. In Leahy and Zeira (2000), we show that transactions costs have exactly the same effect as a convexity in utility.

2.1. *The basic model*

Time is continuous and there is no uncertainty.⁶ An infinitely lived consumer derives utility from both the consumption of a durable good and a non-durable good. Utility is additively separable across time and between the two goods. The consumer discounts future utility at a rate ρ .

The durable comes in a variety of sizes and does not depreciate. Let $v(s)$ denote the flow of utility from a durable of size s . We assume that there is some minimum size of the durable that provides utility. Given some $\hat{s} > 0$, let $v(s) = 0$ for $0 \leq s \leq \hat{s}$. We also assume that $v(s)$ is increasing, differentiable, and concave for $s > \hat{s}$, with v continuous at \hat{s} and $\lim_{s \rightarrow \infty} v'(s) = 0$. The flow of utility from the non-durable is $u(c)$, where c is non-durable consumption. We assume that $u'(c) > 0$, $u''(c) < 0$, and that $\lim_{c \rightarrow 0} u'(c) = \infty$ and $\lim_{c \rightarrow \infty} u'(c) = 0$.

More often idiosyncratic shocks in these models eliminate cycles as in Caballero (1993). The approximation in Caplin and Leahy (1999) allows them to analyse bust-boom cycles that arise from temporary cost shocks.

6. We incorporate uncertainty into the model in Appendix A.

Let T denote the time at which the consumer purchases the durable good. To abstract from issues of resale, we assume that this purchase is irreversible. The consumer's utility U is therefore

$$U = \int_0^\infty e^{-\rho t} u(c_t) dt + \int_T^\infty e^{-\rho t} v(s) dt. \quad (2.1)$$

We assume that capital markets are perfect. The consumer begins life in period $t = 0$ with initial wealth W , which is the sum of financial wealth and human capital. We assume that the interest rate r is equal to the discount rate, $r = \rho$.⁷ Consumption smoothing therefore implies that c is constant and equal to the annuity value of wealth less the prospective cost of the durable. Letting P_t denote the unit price of the durable at date t and normalizing the price of the non-durable to one, we have

$$c = rW - e^{-rT} r s P_T. \quad (2.2)$$

The consumer therefore chooses the amount of non-durable consumption c and the time of the purchase of the durable T in order to maximize

$$U = \frac{1}{r} u(c) + \frac{1}{r} e^{-rT} v \left[\left(W - \frac{c}{r} \right) \frac{e^{rT}}{P_T} \right]. \quad (2.3)$$

The first-order conditions, when the solution is interior, follow immediately. Differentiating with respect to c , we have

$$v'(s) = u'(c) r P_T. \quad (2.4)$$

Differentiating with respect to T yields

$$\frac{v(s)}{s} = v'(s) \left[1 - \frac{\hat{P}_T}{r} \right] \quad (2.5)$$

where $\hat{P}_T = \dot{P}_T / P_T$. The positivity of v , v' , and s ensures that $\hat{P}_T < r$ at any point of purchase. Equations (2.2), (2.4), and (2.5) determine c , s , and T given initial wealth W and the path of prices. Next we examine how these decisions depend on these variables.

The fixed-price case. To gain intuition it is easiest to begin with the case in which the price of the durable is fixed at P and the optimal purchase time is interior, $0 < T < \infty$. With fixed prices, equation (2.5) determines the optimal purchase size s^* :

$$\frac{v(s^*)}{s^*} = v'(s^*). \quad (2.6)$$

Note that s^* is independent of both the price of the durable and wealth, and that s^* is the size that maximizes $v(s)/s$. Our assumptions on v imply that there exists a unique s^* .

Given s^* and the fixed price, equation (2.4) pins down the optimal level of non-durable consumption at a level c^* . Note that c^* is independent of W . Finally, given c^* , s^* , and W , the optimal time of purchase T^* is determined by (2.2).

This case provides a stark example of how the timing of the purchase of the durable can insulate non-durable consumption from shocks, and for this reason we refer to it as the "insulation effect". Changes in wealth affect T^* , but not c^* or s^* . The consumer always purchases the durable when wealth reaches a level of $\bar{W} \equiv c^*/r + s^*P$. Changes in initial wealth merely alter the date at which this level of wealth is reached.

7. The case where the interest rate might deviate from the subjective discount rate is discussed in Section 3.2. See also Leahy and Zeira (2000).

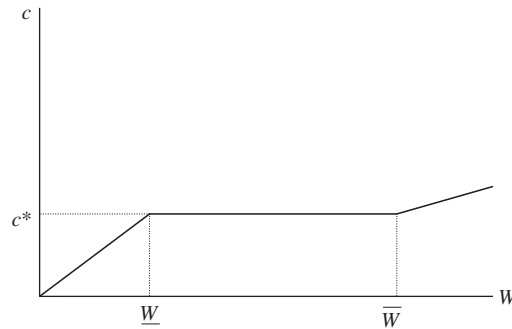


FIGURE 1

The optimal purchase time T^* depends negatively on initial wealth. As initial wealth increases towards \bar{W} , T^* approaches zero. If $W \geq \bar{W}$, the consumer purchases the durable immediately, and chooses non-durable consumption to maximize

$$u(c) + v \left[\left(W - \frac{c}{r} \right) / P \right].$$

For low levels of initial wealth, T^* is higher. As W approaches $\underline{W} \equiv c^*/r$, the purchase time approaches infinity. If $W \leq \underline{W}$, the consumer does not purchase the durable and all wealth goes to consumption of the non-durable: $c = rW$. Hence the insulation effect operates only when initial wealth is within (\underline{W}, \bar{W}) . Figure 1 illustrates the effect of wealth on the consumption of the non-durable for the case of $u(c) = \ln(c)$ and $v(s) = \max\{\ln(s), 0\}$.

The *complete* insulation of the consumption of non-durables is a very special result. It rests on three assumptions: the fixed price of the durable, the equality of the interest rate and the discount rate, and the time-additivity of preferences. The first of these ensures that changes in the timing of the purchase of the durable do not affect the marginal utility of consumption. The second ensures that the marginal utility of consumption is constant over time. The third is the source of linearity in the model. With these assumptions, adjustments in the date of purchase maintain a constant marginal utility of wealth, whereas increases in non-durable consumption or the size of the durable yield decreasing returns.

The fixed price of the durable is clearly the most stringent of the assumptions. We therefore analyse the effects of relaxing this assumption below.

Flexible price. We next consider a more general price process. We assume throughout that the price path is such that the second-order conditions for a maximum are satisfied, including $\hat{P} < r$. Equation (2.5) implies that the optimal size of the durable depends only on the rate of change in the price of the durable, and that this size is decreasing in the rate of change. We can therefore write the optimal size as $s = s(\hat{P}_T)$, where $s'(\cdot) < 0$. Substituting this relation into equation (2.4) yields

$$u'(c) = \frac{v'(s(\hat{P}_T))}{r P_T}, \quad (2.7)$$

which implicitly defines c as a function of T .

Consumption depends on the time of purchase through the budget constraint as well:

$$c = rW - e^{-rT} r P_T s(\hat{P}_T). \quad (2.8)$$

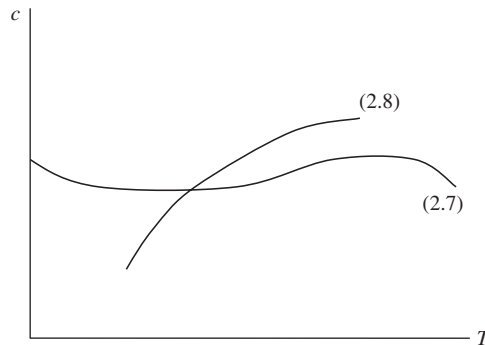


FIGURE 2

Figure 2 illustrates the two relationships between c and T described by equations (2.7) and (2.8). Their intersection determines the optimal level of consumption and the optimal time of purchase. The second-order conditions imply that (2.8) cuts (2.7) from below.

An increase in W leaves (2.7) unaffected, but shifts (2.8) upwards. It follows that an increase in W leads to a reduction in the time of purchase. This reduction in T provides some insulation to non-durable consumption. In a standard model of a consumer who costlessly adjusts the stock of a durable, an increase in wealth always increases consumption of both durables and non-durables. Here the effects of an increase in W on consumption and the optimal purchase size are ambiguous and depend on the properties of the price path through (2.7).⁸

While the stark result of complete insulation is special it serves three purposes. First, the lesson is general. In response to changes in their environment, agents will alter the timing of their durable goods purchases and this will provide some insulation for non-durable consumption. Second, given that the response of non-durable consumption to a change in wealth is ambiguous, it serves as a benchmark case. Third, the stark result simplifies consumer behaviour and provides a first step in developing aggregate models with discrete purchases. It is to this task that we turn in Section 3.

2.2. Depreciation

To this point we have assumed that consumers purchase durables only once in their lifetime. We now show that the general features of the model survive when we add depreciation. We assume that the value of the durable to the consumer at purchase is v and that it depreciates at a constant rate δ .⁹ The consumer has to decide at what time to discard the old durable and buy a new one.

8. The effect on s depends on what happens to \hat{P}_T . We can solve for the effect of a change in wealth on non-durable consumption:

$$\frac{dc}{dW} = \frac{ru'(c)\dot{P} - v''(s)\frac{ds}{dT}}{-rPu''(c)} \frac{dT}{dW}$$

Given that c was independent of W in the fixed-price case, it is not surprising that in the general case the effect of a change in wealth on the level of consumption is ambiguous. We see from (2.7) that the sign tends to be negative if the price is increasing or decelerating and positive if the price is decreasing or accelerating.

9. The assumption that the size of the durable is fixed is not necessary and only simplifies the presentation. Adding variable size of durable does not change the results of the analysis.

Formally the consumer has to maximize discounted utility:

$$\int_0^{\infty} u(c_t)e^{-rt} dt + v \sum_{n=1}^{\infty} e^{-rS_n} \int_0^{S_{n+1}-S_n} e^{-(r+\delta)t} dt$$

where S_n is the timing of the n -th purchase, and we have assumed that the consumer has no durable prior to time 0.

The budget constraint is

$$W = \int_0^{\infty} c_t e^{-rt} dt + P \sum_{n=1}^{\infty} e^{-rS_n}. \quad (2.9)$$

Given that the interest rate is equal to the discount rate, the consumer has a fixed level of non-durable consumption c . Let c^{**} be defined by $u'(c^{**}) = \frac{v}{P(r+\delta)}$. It is easy to show that for wealth $W < c^{**}/r$, the consumer never purchases the durable. For wealth $W \in (c^{**}/r, c^{**}/r + P)$ the consumer purchases the durable only once. The timing of this purchase is determined in a manner similar to the previous sections and the behaviour of the model is also similar. In particular, consumption of the non-durable is equal to c^{**} and independent of the level of wealth.

If $W > c^{**}/r + P$, the consumer makes multiple purchases, and consumption adjusts to the level of wealth. Let $T_n = S_{n+1} - S_n$ denote the length of time that the n -th purchase is held. After some manipulation, the first-order condition for all $n > 1$ is

$$u'(c) = \frac{v}{rP} \left[\frac{r}{r+\delta} + \frac{\delta}{r+\delta} e^{-(r+\delta)T_n} - e^{-\delta T_{n-1}} \right].$$

This equation defines a positive relationship between T_{n-1} and T_n , which is increasing and has a slope greater than 1. It is easy to see that the optimal solution is reached at the saddle point, $T_n = T$ for all n . Otherwise T_n can either diverge to infinity or go to zero in a finite number of steps. In the second case, the first-order conditions are violated, and in the first case utility is much lower as the durable is held for too long. Hence, the first-order conditions become

$$u'(c) = \frac{v}{rP} \left[\frac{r}{r+\delta} + \frac{\delta}{r+\delta} e^{-(r+\delta)T} - e^{-\delta T} \right]. \quad (2.10)$$

At this point it is easy to show that utility is strictly decreasing in the date of initial purchase, and hence $S_1 = 0$.

The optimal choice of c and T is determined by equation (2.10) and the budget constraint (2.9). Figure 3 graphs these two equations. Equation (2.9) describes a positive relationship between c and T with c approaching $r(W - P)$ as T approaches infinity. Equation (2.10) describes a decreasing relationship with c approaching c^{**} as T approaches infinity. T is finite as long as $rW > c^{**} + rP$.

As wealth W increases, the curve (2.9) shifts upward, while the curve (2.10) is unchanged. Therefore T decreases, namely the durable is purchased earlier, and consumption of non-durable c increases. Figure 3 shows that the degree by which durables insulate non-durables depends on the amount of time between purchases. If the time between purchases is high, then both curves in Figure 3 are very flat and the durable provides a lot of insulation for the non-durable. If the time between purchases is short, there is not much of a margin to adjust durable purchases and there is little insulation. Hence, in case of depreciation consumers purchase the durable many times during their life and not once, but other than that their economic behaviour is the same as in the benchmark model. A decline in wealth delays purchases of the durable, and changes in the timing of durable purchase still insulate non-durable consumption to a large extent.

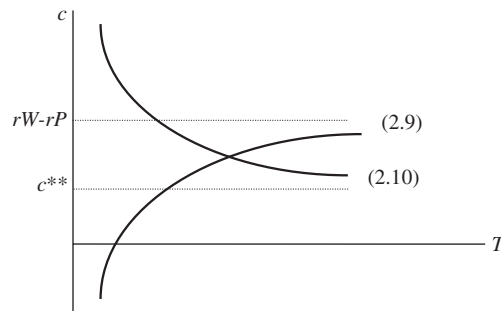


FIGURE 3

3. AGGREGATE SHOCKS WITH FIXED PRICES

Consider a small open economy with a continuum of infinitely lived agents who are identical except for their date of birth and hence differ in the wealth that they have accumulated during their lifetime. Each of these agents solves a problem similar to that of Section 2.1. Individuals begin life with zero financial wealth and earn income throughout their lives. Agents are self-employed and can choose to produce either a unit flow of the non-durable or a flow D of the durable.

We assume that the labour market is flexible. Workers are free to switch sectors, so that in equilibrium the returns to working in each sector must be equal. This mobility between sectors also fixes the price of the durable:

$$P = 1/D.$$

We assume that the non-durable good is tradable, whereas the durable is non-traded. This makes most sense if we think of the durable as something like housing. Asset trade with the rest of the world pins down the interest rate at r equal to the discount rate.

Let N_t denote the size of the cohort born at date t . Agents live forever and the population grows at a rate g . We assume that the economy began at $t = -\infty$ and is initially in its non-stochastic steady state. We view the overlapping generations structure as reflecting the flow of agents into the market, and the age of purchase as reflecting the time horizon over which agents contemplate purchases.

3.1. The steady state

Let $W(b, t)$ represent the wealth at time t of an agent born at date b . Wealth at birth is equal to the present value of labour income:

$$W(b, b) = \int_b^\infty e^{-r(t-b)} dt = 1/r.$$

We assume that $1/r$ is in the range that yields an interior solution for the age at which the durable is purchased. We therefore adopt the results of the fixed-price case of Section 2.1 directly. Equation (2.6) determines the optimal size of the durable purchase, s^* , and, given s^* , equation (2.4) determines the optimal level of consumption of the non-durable, c^* . The age at which the agent purchases the durable, T^* , follows from the budget constraint (2.2):

$$e^{-rT^*} = \frac{1 - c^*}{rPs^*}. \tag{3.1}$$

It will be useful for what follows to calculate the individual's financial wealth at age x , F_x . If $x < T^*$, this is simply

$$F_x = \frac{1 - c^*}{r} (e^{rx} - 1).$$

At age T^* the agent purchases the durable and financial wealth falls to $-(1 - c^*)/r$, where it remains forever.

In steady state, individuals born at date b purchase the durable at date $b + T^*$. As the population grows at rate g , purchases of the durable good grow at rate g as well.

The current account may be either positive or negative in steady state. The young accumulate wealth as they wait to purchase the durable. Upon purchasing the durable agents go into debt. Integrating over the population and using (3.1) to eliminate T^* shows that the stock of foreign assets in period t is equal to

$$A_t = N_t(1 - c^*) \left[\frac{\frac{P_{S^*}}{1 - c^*} \left(\frac{1 - c^*}{r P_{S^*}} \right)^{\frac{g}{r}} - \frac{1}{g}}{(r - g)} \right]. \quad (3.2)$$

The stock of foreign assets grows with N_t if foreign assets are positive, in which case the current account is in surplus.¹⁰

In the next three subsections, we study three shocks: a wealth shock, a productivity shock, and a shock to interest rates.

3.2. A wealth shock

Suppose that at date $t = 0$ a shock hits the economy that unexpectedly erodes all financial assets so that agents are left with a fraction λ of their accumulated wealth. This may be due to a stock market crash or a decline in bond prices. For simplicity, we assume that the shock affects only those with accumulated assets. Those with debts do not see their debts reduced. The reason for considering a wealth shock is that it represents the purest form of demand shock for durables. Many other shocks affect durable demand through their effect on wealth.¹¹ In this section we consider the effect of a one-time shock. Appendix A considers recurrent shocks.

The simplicity of the fixed-price case is that the only effect of the shock is on the demand for durables. Agents' labour income is unaffected since labour is perfectly mobile across sectors and there are no impediments to trade with the rest of the world. When demand for the durable falls, agents have the option of producing non-durable goods and shipping them abroad. Non-durable demand is also unaffected. Those who do not own durables insulate their consumption of the non-durable by postponing their purchases of the durable. Those who own durables do not alter their consumption either, since they are indebted and the shock does not alter their debt. Note also that as bad as the shock to financial wealth can be, agents affected by the shock do not postpone purchases of the durable forever, since their lifetime income still exceeds $1/r$.

10. Both g and r have ambiguous effects on the current account. On the one hand, an increase in the growth rate means that there are more young people who tend to be savers. On the other hand, there are more very young who have saved very little. It is easy to show, however, that there exists a level g^* such that the current account is positive if and only if $g > g^*$. As for the interest rate, an increase in r tends to increase saving and reduce debt at each age, but also causes agents to purchase the durable at an earlier age.

11. Grossman and Laroque (1990) and Eberly (1994) consider individual decision problems with wealth shocks. The reform considered in De Gregorio *et al.* (1998) affects durable demand only through wealth. Other shocks considered in the literature include changes in scrapping costs (Adda and Cooper, 2000a), uncertainty (Carroll and Dunn (1997), Hassler (1998)), demographics (Parker, 1996), and supply shocks (Caplin and Leahy, 1999).

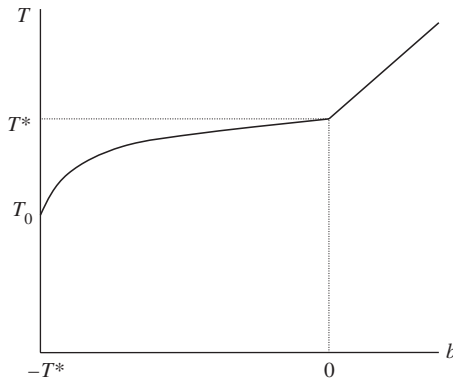


FIGURE 4

To solve for the effect of the shock on durable demand, consider an individual born at date $b \in (-T^*, 0)$. This agent is born prior to the shock and has not yet purchased a durable. Immediately after the shock, the agent has financial wealth in the amount of

$$\lambda \left(\frac{1 - c^*}{r} \right) (e^{-rb} - 1).$$

The agent will wait until total assets reach $\bar{W} = \frac{c^*}{r} + s^*P$ before purchasing the durable. Substituting financial and human capital into the budget constraint (2.2), we see that the agent waits until date $T(b)$, where

$$e^{-rT(b)} = e^{-rT^*} (1 - \lambda + \lambda e^{-rb}). \tag{3.3}$$

Figure 4 plots T as a function of b . $T'(b) > 0$ since older agents have more assets and purchase at an earlier date. $T(0) = T^*$ since an agent born at date zero has no wealth at the time of the shock and is therefore unaffected by it. Aggregate purchases of durables therefore return to trend after date T^* . Let T_0 denote the date at which the cohort that was about to purchase the durable at the time of the shock re-enters the market. $T_0 = T(-T^*)$ and is strictly greater than zero. This means that the people that were about to purchase the durable at the time of the shock, those of age T^* , delay their purchases for a discrete period of time. Purchases of the durable dry up during the period $(0, T_0)$. At dates $t \in (T_0, T^*)$ purchases are equal to $e^{gb(t)}b'(t)N_0$, where $b(t) = T^{-1}(t)$ is the inverse of T ; it maps $T(b)$ to b and gives the birth date of those who purchase at date T . Since T is monotonic, this inverse is well defined.

There are two effects on the number of agents purchasing the durable good once purchases resume after date T_0 . First, the cohort that delays until $t \in [T_0, T^*)$ is smaller than the cohort that would have purchased at this date in the absence of the shock. N_0 is the size of the cohort born at date zero, so $e^{gb(t)}N_0$ is the size of the cohort that purchases at date t . This is less than $e^{g(t-T^*)}N_0$, which is the size of the cohort that would have purchased at date t in the absence of a shock. Second, older agents lose more wealth and therefore delay longer. This leads to a bunching of purchases that tends to make the number of purchases greater than they would have been in the absence of the shock. The term $b'(t) = 1/[1 - (1 - \lambda)e^{r(t-T^*)}]$ reflects this bunching. These two forces are ambiguous near T_0 , but the second force becomes progressively more important and dominates by date T^* .

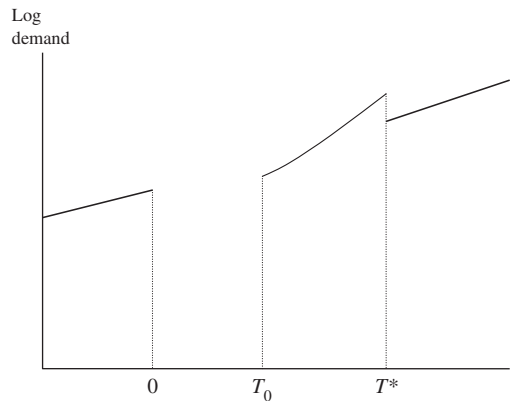


FIGURE 5

Figure 5 shows the log of the demand for the durable following the shock. The model predicts a slump in durables purchases followed by a boom and a return to trend. This pattern occurs because the shock only affects cohorts between 0 and T^* . These cohorts delay purchases in order to rebuild their assets. Although they delay, they still purchase the durable before the cohorts born after the shock. This causes the initial steep fall in demand, the bunching of demand near date T^* , and the return to trend after date T^* . This bust–boom cycle is therefore due to the demographic structure of the model and the differential impact of the wealth shock on different generations. In the standard model of a representative agent holding a stock of the durable, there would be a bust but no boom.

We can also describe the evolution of the current account and the trade balance in response to the wealth shock. Consumption of non-durables is not affected by the shock. Production of non-durables, however, rises because agents who had been producing the durable switch to producing non-durables for export. The trade balance rises immediately after the shock, falls below trend as date T^* approaches and returns to trend. The evolution of the current account is slightly more complex due to changes in interest payments, but given the fact that agents are rebuilding their wealth in the wake of the shock, we know that it must turn positive.

The age at which agents purchase the durable in the absence of a shock has a strong effect on the way in which the shock is propagated. Consider a slight modification of the model. Suppose that agents produce a flow y of the non-durable or a flow yD of the durable. So long as we have an interior solution for the time of purchase, equations (2.6) and (2.4) still determine s^* or c^* independently of y , while y affects T^* through equation (2.2). A little algebra shows that equation (3.3) still holds when $y \neq 1$. Note that this equation implies that $dT(b)/dT^* = 1$. We can now see how a change in y alters the response of demand to the shock. A reduction in y leads to an increase in T^* which has a one to one effect on $T(b)$. The entire steep segment in Figure 5 shifts to the right. The response plays itself out over a longer period of time. The period of low demand, in particular, becomes longer.

3.3. Temporary and permanent shocks to labour productivity

Productivity shocks will allow us to examine the effect of persistence. Consider a common shock to productivity in both sectors at date zero. Income which has been constant at 1 for a long time falls to λ where $\lambda \in (0, 1)$. Thereafter income returns to 1 at a rate $\alpha \geq 0$. Hence α is an inverse

measure of the persistence of the shock. At date t income is equal to

$$y_t = (\lambda - 1)e^{-\alpha t} + 1.$$

The shock causes the human capital component of wealth to fall by $(1 - \lambda)/(r + \alpha)$ at date zero for all individuals alive at date zero and by $(1 - \lambda)e^{-\alpha b}/(r + \alpha)$ at birth for all individuals born at date $b > 0$. We assume that the decline in productivity is not so large that agents forego purchasing the durable. We also maintain the assumption of full mobility of labour between the sectors.

Since the shock does not affect c^* or s^* , again we can use the budget constraint to relate the time of purchase and wealth at date zero. Substituting for wealth in (2.2) and rewriting the equation in terms of the age of the agent who purchases at T , namely $x = T - b$, yields

$$e^{-rx} = e^{-rT^*} - \frac{1 - \lambda}{(r + \alpha)s^*P} e^{rb}$$

where $-T^* \leq b \leq 0$. It follows that the shock hits the young hardest and that they delay more. This is the opposite of what we saw in the case of the wealth shock. The reason is that the young have accumulated less financial wealth at the time of the shock. For those born after the shock, $b > 0$, the age of purchase is given by

$$e^{-rx} = e^{-rT^*} - \frac{1 - \lambda}{(r + \alpha)s^*P} e^{-\alpha b}.$$

Note that the later agents are born the smaller the lost income and the shorter the delay in purchasing the durable.

The implications for durable consumption are governed by two effects. Among those who are alive at the time of the shock, older agents have accumulated more assets and therefore delay less. Among those who are born after the shock, those born later lose less income and therefore delay less. Since the shock is mean reverting, the delay in purchases eventually disappears. The evolution of the demand for durables follows from this purchase behaviour. Initially, demand falls to zero as all agents delay. After purchases begin, there is initially a period of weak demand. When $\alpha > 0$, this is followed by a period of above average demand as the economy returns to trend. Again we have a bust–boom cycle. The bust results from the initial delay. The boom results from the temporary nature of the shock: the pent-up demand must eventually hit the market. The more persistent the shock the *slower* the return of demand to trend. When $\alpha = 0$, the economy does not return to the initial trend. In this case, the shock is permanent; there is a bust but no boom.

3.4. A shock to interest rates

Central banks often use the interest rate to affect economic activity. Next we examine how a change in the interest rate affects the demand for durables and non-durables. The economy begins in steady state with an interest rate equal to the discount rate ρ . At time zero, the interest rate rises above ρ and gradually returns to ρ along the path r_t .

In order to analyse the demands for the two goods consider an individual in time 0, who was born at date $b < 0$, and has accumulated financial savings equal to F_{-b} . This individual chooses the time of purchase T to maximize intertemporal utility (2.1) subject to the budget constraint

$$F_{-b} + \int_0^\infty e^{-\int_0^t r_\tau d\tau} dt = \int_0^\infty e^{-\int_0^t r_\tau d\tau} c_t dt + P s e^{-\int_0^T r_\tau d\tau}.$$

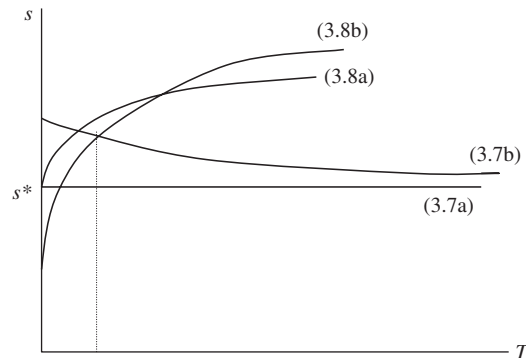


FIGURE 6

The three first-order conditions to the consumer's optimization problem are

$$u'(c_t) = u'(c_0)e^{\int_0^t (\rho - r_\tau) d\tau} \quad (3.4)$$

$$v'(s) = \rho P u'(c_0) e^{\int_0^T (\rho - r_\tau) d\tau} \quad (3.5)$$

and

$$v(s) = r_T P s u'(c_0) e^{\int_0^T (\rho - r_\tau) d\tau}. \quad (3.6)$$

As long as the optimal allocation is interior, it is determined by these three first-order conditions and the budget constraint.

Since the interest rate is above the subjective discount rate, equation (3.4) implies that consumption rises over time. Equations (3.5) and (3.6) imply

$$\frac{v(s)}{s v'(s)} = \frac{r_T}{\rho}. \quad (3.7)$$

Hence the optimal size of durable is above s^* , which is the optimal size of durable when $r = \rho$. Equation (3.7) determines one relationship between the timing of purchase and size of purchase: as T rises, r_T falls to ρ and s falls to s^* .

Another relationship may be derived from the first-order conditions and the budget constraint. To simplify the analysis, consider the case in which utility from the non-durable is logarithmic: $u(c) = \ln c$. In this case, equations (3.4), (3.5) and the budget constraint imply

$$W(b, 0) e^{\int_0^T (r_\tau - \rho) d\tau} - P s e^{-\rho T} - \frac{P}{v'(s)} = 0 \quad (3.8)$$

where $W(b, 0)$ is the present value of financial wealth and human capital at time zero of an agent born at date b .

Equation (3.8) describes a positive relationship between s and T , whereas (3.7) describes a negative relationship between them. The intersection of these two relationships determines the size and the timing of purchase.

In order to gain a better understanding of the effect of the rise in interest rates, Figure 6 illustrates equations (3.7) and (3.8) under both the fixed initial interest rate and the temporary rise in interest rates. The curves (3.7a) and (3.8a) describe the situation before the shock, while curves (3.7b) and (3.8b) describe it after the shock at time 0. The curves are drawn for an individual who was going to purchase the durable just before the shock occurred.

We can now use Figure 6 to analyse the effect of this transitory increase in interest rates. Since the shock raises interest rates, curve (3.7b) lies everywhere above curve (3.7a). The effect of the shock on (3.8) depends on its effect on $W(b, 0)e^{\int_0^T (r_\tau - \rho)d\tau}$. On the one hand, the rise in interest rates reduces the present value of income, this reduces $W(b, 0)$ and shifts the curve down. On the other hand, the rise in interest rates raises $e^{\int_0^T (r_\tau - \rho)d\tau}$ and shifts the curve up. Since the latter effect is negligible for small T , we know that for small T the curve shifts down. Whether or not it shifts down for large T depends on the parameters of the model.

We are now in a position to discuss the response of the economy to the rise in interest rates. For agents who were preparing to purchase the durable when the shock hits, curve (3.7a) intersects curve (3.8a) at $T = 0$ and $s = s^*$ as in Figure 6. The rise in (3.7) and the fall in (3.8) for small T imply that these agents delay their purchases, but eventually purchase larger durables. Subsequent generations also purchase larger durables. Whether or not they delay their purchases depends on the relative balance of income and substitution effects. In the end, since the shock is temporary we get a bust–boom cycle similar to the previous section.

The increase in the size of purchase in response to an increase in the interest rate is a novel feature of this timing model. A consumer who continually adjusts his stock of durables will set marginal utility equal to the user cost. Increases in the interest rate reduce holdings of the durable. Our consumer always balances the loss from delaying $\rho v(s)$ against the gain from delaying, which with fixed prices is $r_t s v'(s)$. As r rises, the loss and gain balance at a higher s . The consumer delays and purchases a larger durable.

We can use this analysis to discuss the reaction of the monetary authority to a sudden shock to financial wealth. Such a shock would cause agents to delay their durable goods purchases. A quick reduction of the interest rate, however, can counteract the delay by increasing the current value of future incomes and reversing the delay.

4. AGGREGATE SHOCKS WITH FLEXIBLE PRICES

In this section we depart from the fixed-price case, by introducing a friction to labour mobility across sectors. This friction serves two purposes. First, it prevents supply from falling to zero, so that the price of the durable must fall to equate supply and demand. Second, it introduces an interesting source of feedback into the analysis. Thus far the only effect of the shock from the individual's perspective was the direct effect on the individual's wealth or income. One agent's actions had no effect on others. That was specific to the fixed-price case. In general, the decline in the demand for the durable good will further reduce the income of durable goods producers if they cannot costlessly shift into non-durable goods production. They see their income fall for two reasons: the direct effect of the shock and the indirect effect through the demand for their output.

We introduce the friction in a simple manner. We assume that a fraction γ of the agents who produce durable goods cannot switch jobs. It may be the case that durable goods industries require human capital that is more specific to the industry and less general to other occupations, or simply that it is more difficult for suppliers to alter their plans than for consumers to alter the timing of durable consumption. Non-durable producers can costlessly switch to production of durables at any time.¹² We assume that prior to the shock producers of the durable and non-durable are evenly distributed across age cohorts. New entrants can choose what to produce.

12. In Section 4.3, we examine the case of two-sided frictions.

As before we assume that financial wealth F falls to λF at date zero.¹³ For simplicity we focus on the timing of purchases and fix the size of the durable to 1.¹⁴

The recession can be divided into two phases. In the first phase the price of the durable P_t is less than the steady-state price. Only agents who are constrained to produce the durable will willingly choose to do so during this phase. Supply is fixed by the number of agents attached to durable goods production. At some date \tilde{T} the price of the durable returns to its steady-state level, and the second phase begins. After this date, the price of the durable is fixed at its steady-state level, so that agents are indifferent as to which good they produce, and supply adjusts to meet demand. Since the second phase is essentially the same as the case that we studied in Section 3, we concentrate on the first phase in what follows.

4.1. Equilibrium

Individuals. We begin with the consumption decision of a non-durable good producer. Let $W_n(b, 0)$ denote total wealth (financial and human) in period zero of an individual who is born at date b where $-T^* \leq b \leq 0$ and who produces non-durables. Recall that T^* is the age at which agents purchase the durable in steady state and c^* is consumption in steady state.

After the crash, this individual's total wealth, financial and human, is equal to

$$W_n(b, 0) = \lambda \frac{1 - c^*}{r} (e^{-rb} - 1) + \frac{1}{r}.$$

Note that these workers do not lose income, only wealth.

Let t denote the date of purchase of the durable by a non-durable producer born at b_n . Total utility in period 0 is

$$\frac{u(rW_n(b_n, 0) - re^{-rt}P_t)}{r} + \frac{v}{r}e^{-rt},$$

and maximization with respect to t yields

$$u'(rW_n(b_n, 0) - re^{-rt}P_t)(rP_t - \dot{P}_t) = v. \quad (4.1)$$

This is the same first-order condition as we had before in the flexible-price case in Section 2 except that size is fixed. Recall from Section 2 that increases in wealth reduce the date of purchase t . The older non-durable producers therefore purchase first.

The solution to the durable goods producers' problem is similar except that wealth falls by the additional amount Δ which reflects the decline in their income due to the decline in the price of the durable. Let $W_d(b, 0)$ denote the wealth at date zero (after the shock) of a producer of durables born at date b where $-T^* \leq b \leq 0$. Then $W_d(b, 0) = W_n(b, 0) - \Delta$. The first-order condition for the optimal purchase time for a durable producer born at date b_d is

$$u'(rW_d(b_d, 0) - re^{-rt}P_t)(rP_t - \dot{P}_t) = v. \quad (4.2)$$

It is convenient to solve for the birth date as a function of the time of purchase. Let the function $b_n(t)$ denote the birth date of those non-durable goods producers who purchase at date t ,

13. We again consider a decline in wealth. An increase in wealth would be analysed in a similar manner. A positive wealth shock leads to a stock increase in demand for the durable. Since production is a flow, the price must rise to discourage buyers. There is also a feedback effect as agents who produce the valuable durable good see their income in terms of non-durables rise.

14. In Appendix B, we show that the case of flexible size can be analysed in a similar manner and that flexibility tends to exacerbate all of the effects of recession: the price falls further, the losses to the producers of the durable are greater, and the recession lasts longer. Intuitively, the recession tends to reduce the size of purchases which further reduces demand. The price must fall further to compensate for the decline in demand. This increases the losses to producers and propagates the shock.

and let $b_d(t)$ denote the same for durable goods producers. These functions are defined implicitly by equations (4.1) and (4.2). It is easy to see that both functions are monotonically increasing. In addition, equations (4.1) and (4.2) imply a relationship between the birth dates of durable and non-durable goods producers that purchase at the same date. In particular, they both have the same wealth, $W_n(b_n(t), 0) = W_d(b_d(t), 0)$. Substituting the expressions for initial wealth and rearranging,

$$e^{-rb_d(t)} = e^{-rb_n(t)} + \frac{r\Delta}{\lambda(1-c^*)}. \tag{4.3}$$

An implication of this relationship is that the non-durable producers who buy at t are younger: $b_d(t) < b_n(t)$. Equation (4.3) allows us to write b_d as a function of $b_n(t)$ and Δ , namely, $b_d(b_n(t), \Delta)$. Note that $b_d(b_n(t), \Delta)$ is increasing in its first argument and decreasing in the second.

Equation (4.1) characterizes the price process during the first phase. To complete this description we need three pieces of information. We need to know the function $b_n(t)$ and the boundary condition on the price path. The boundary condition is the date \tilde{T} at which the price returns to its steady-state value. We also need to solve for Δ . We address these issues in turn.

Supply and demand. During the period prior to \tilde{T} supply is fixed at a fraction of the level that prevailed at the time of the shock. No newly born agents will choose to produce durables so long as their price is below steady state, and all durable producers that have the opportunity to switch will switch to producing non-durables. Only those that cannot switch will continue to produce durables.

Immediately prior to the shock, the economy is in steady state, and the supply of the durable good is equal to the steady-state demand, $N_0e^{-gT^*}$. After the shock supply falls to $\gamma N_0e^{-gT^*}$. Hence the supply of durables over the period 0 to t is

$$\int_0^t \gamma N_0e^{-gT^*} ds = t\gamma N_0e^{-gT^*}. \tag{4.4}$$

$b_n(t)$ must be such that demand is equal to this supply. We know that initially there is a period of time in which only non-durable goods producers who were born prior to the shock purchase the durable. As time passes durable goods producers can re-enter the market.¹⁵ Let T' be the date that durable goods producers begin purchasing, $b_d(T') = -T'$. Hence,

$$e^{-rb_d(T')} = e^{rT'} = \frac{rP}{(1-c^*)},$$

so that from equation (4.3) we get

$$e^{-rb_n(T')} = \frac{r}{(1-c^*)} \left(P - \frac{\Delta}{\lambda} \right),$$

or

$$b_n(T') = \frac{1}{r} \left[\log(1-c^*) - \log r - \log \left(P - \frac{\Delta}{\lambda} \right) \right]. \tag{4.5}$$

We denote the R.H.S. of this equation b' .

Consider first the period $[0, T']$ when only non-durable producers purchase. The fraction of each cohort that belongs to this group is equal to $n = 1 - \gamma g e^{-gT^*} P$. Recall that we assume the

15. For sufficiently large shocks it might be the case that durable goods producers re-enter after the price returns to steady state. We shall assume that γ is sufficiently small to avoid these scenarios. It is straightforward to amend the analysis to include these cases. See footnote 12.

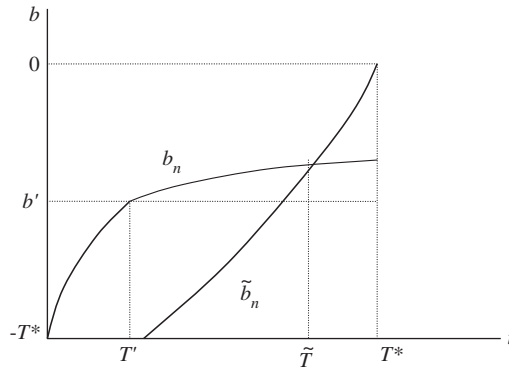


FIGURE 7

same fraction of each age cohort finds itself constrained. Hence demand over the period 0 to t is

$$\int_{-T^*}^{b_n(t)} n N_0 e^{gb} db = \frac{n}{g} N_0 (e^{g b_n(t)} - e^{-g T^*}).$$

Putting together supply and demand and solving for t yields

$$t = \frac{n}{\gamma g} (e^{g(b_n(t)+T^*)} - 1) = \left(\frac{1}{\gamma g} - e^{-g T^*} P \right) (e^{g(b_n(t)+T^*)} - 1), \tag{4.6}$$

where the second equality follows from the definition of n . This equation implicitly defines the function $b_n(t)$ over $[0, T']$.

We next define b_n for $t \geq T'$. Demand from 0 to t is equal to the sum of the demand of both durable and non-durable goods producers:

$$\int_{-T^*}^{b_n(t)} n N_0 e^{gb} db + \int_{-T^*}^{b_d(t)} (1 - n) N_0 e^{gb} db,$$

implying

$$\begin{aligned} t &= \frac{1}{\gamma g} [n e^{g(b_n(t)+T^*)} + (1 - n) e^{g(b_d(t)+T^*)} - 1] \\ &= \left(\frac{1}{\gamma g} - e^{-g T^*} P \right) e^{g(b_n(t)+T^*)} - \frac{1}{\gamma g} + e^{g b_d(b_n, \Delta)} P. \end{aligned} \tag{4.7}$$

Here the second equality follows from the definition of n . This equation implicitly defines the function $b_n(t)$ over $[T', \tilde{T}]$. Note that at T' , $b_d = -T^*$, so the b_n defined by (4.7) is equal to that defined by (4.6). For $t > T'$, $b_d > -T^*$, so the b_n defined by (4.7) is less than that defined by (4.6). The function b_n is illustrated in Figure 7. Recall that $b_n(T') = b'$.

The boundary condition. We now introduce the boundary condition that pins down the price process. At \tilde{T} the price has returned to its steady-state level, $P_{\tilde{T}} = P$. Therefore at \tilde{T} agents must be wealthy enough to want to purchase the durable at its steady-state price. Note that people who purchase at \tilde{T} and after consume the steady-state amount of the non-durable c^* . Consider a producer of non-durables who was born at b_n and purchases at date $t > \tilde{T}$. The budget constraint implies $r W_n(b_n, 0) - r e^{-rt} P = c^*$. Hence,

$$\lambda e^{-r b_n} + (1 - \lambda) = e^{-r(t-T^*)}. \tag{4.8}$$

This defines a relation between b_n and t , which we denote by $\tilde{b}_n(t)$. Note that $\tilde{b}_n(t)$ is increasing, convex and $\tilde{b}_n(T^*) = 0$.

The end of the recession, \tilde{T} , is determined by the intersection of $b_n(t)$ and $\tilde{b}_n(t)$, namely of equations (4.7) and (4.8). Figure 7 summarizes what we know about these functions.¹⁶ Given \tilde{T} , we can solve the differential equation (4.1) backwards for the price path P_t on $0 \leq t \leq \tilde{T}$.

The loss of the durable goods producers. Everything to this point was contingent on a given value for Δ . We pin down Δ by a fixed-point argument. Given a conjecture for Δ we get a price path, from which we can define the actual loss by

$$\psi(\Delta) = \int_0^{\tilde{T}} \frac{P - P_T}{P} e^{-rT} dT.$$

In equilibrium the conjectured and actual losses are the same:

$$\psi(\Delta) = \Delta.$$

A simple argument shows that an equilibrium exists. First, note that if Δ were zero, then the price would still have to fall in order to induce consumers to purchase the durable at date zero. Hence $\psi(0) > 0$. On the other hand, even if Δ is equal to infinity, the price of the durable cannot fall below zero so ψ is bounded from above by $1/r$. Combining these statements with the continuity of ψ shows that a fixed point exists.¹⁷

4.2. Discussion

In earlier sections of the paper, changes in wealth led agents to alter the timing of their purchases, causing large fluctuations in aggregate demand. In this section, the price adjusts to smooth demand for the durable. After the shock, supply falls to a fraction γ of its initial value and the price falls to equate supply and demand. Supply remains at this level until \tilde{T} , during which time agents rebuild their wealth. After falling on impact, the price rises and eventually returns to its pre-shock level at \tilde{T} . After \tilde{T} , the price remains constant at P . Agents continue to rebuild their wealth, and both demand and supply rise. Since only the timing of durable purchases are affected and not their total number, sales must at some time rise above trend and make up the ground that they lost during the recession. The wealth shock therefore leads to a bust–boom cycle as in the fixed-price case.

Given the fluctuations in the price of the durable, non-durables are not completely insulated from the shock. It is easy to see from (4.1) that the low and increasing price of the durable reduces non-durable demand among agents who purchase prior to \tilde{T} . By reducing agents' incentive to intertemporally substitute, the price fluctuation smooths durable demand at the expense of non-durable demand.

Note that price smooths demand only so long as it is below its steady-state value of P . It follows from (4.8) that non-durable producers who purchase after \tilde{T} purchase at the same date as in the fixed-price case. Durable producers who purchase after \tilde{T} purchase at a later date due to the additional loss that they face when prices adjust. Therefore, while the fall in price induces some agents to purchase earlier, it causes others to delay and prolongs the effects of the shock.

16. If the shock is large, b' will be large and may lie above the intersection of b_n and \tilde{b}_n . In this case the durable goods producers begin purchasing after the price has returned to steady state.

17. It is also the case that the slope of ψ is positive. As Δ rises, durable producers become less wealthy and hence less willing to buy. $b_d(t)$ falls and T' rises. This reduces demand and the price must fall in order to encourage non-durable producers to fill the gap. The fall in price increases ψ . This positive slope might suggest that the model may have multiple equilibria, but this is rather unlikely since ψ should be quite flat.

We next consider some of the comparative static properties of the model. The first proposition states that an increase in the friction in the labour market causes a greater fall in the price of the durable and hence greater losses for durable producers. It also increases the length of the recession, defined as \tilde{T} .

Proposition 1. *An increase in γ raises Δ and \tilde{T} and reduces P_t for $t \in [0, \tilde{T}]$.*

Proof. Fix Δ . An increase in γ leads to an increase in $b_n(t)$ for all $t \in (-T^*, 0]$. $\tilde{b}_n(t)$ is unaffected. It follows that \tilde{T} must increase. Call this new level \tilde{T}_1 . We now analyse how these changes affect Δ . The increase in $b_n(t)$ implies an increase in P_T for any given P_T by equation (4.1). Since the slope of the price path has increased and since it now reaches P at \tilde{T}_1 , the price path must be below the former one. Hence $\psi(\Delta)$ must rise. Hence the equilibrium Δ must rise. This causes $b_n(t)$ to increase even further, so that the recession ends at a date later than \tilde{T}_1 . This completes the proof. \parallel

An increase in γ leads to an increase in supply during the recession. The price of the durable must therefore fall further to encourage consumers to purchase the durable earlier. Both the number of durable producers and the loss per durable producer increase. This prolongs the recession.

The next proposition shows that a larger wealth shock also leads to greater losses and to a longer recession.

Proposition 2. *A decrease in λ raises Δ and \tilde{T} and reduces P_t for $t \in [0, \tilde{T}]$.*

Proof. Fix Δ . According to equation (4.3), the reduction in λ leads to a reduction in b_d given b_n and Δ . This decline in $b_d(b_n, \Delta)$ increases b_n and causes the b_n curve to shift upward due to (4.7). The reduction in λ causes the \tilde{b}_n curve to shift downward by (4.8). Together these imply that \tilde{T} must increase for any given Δ . A similar argument to that given in Proposition 1 implies that the increase in \tilde{T} is even greater if we allow Δ to change. This completes the proof. \parallel

Finally, we suppose that agents can produce a flow y of the non-durable and a flow yD of the durable and consider the effect of a reduction in y . Recall from the fixed-price analysis that this reduction causes an increase in T^* but has no effect on c^* . It is easy to see from (4.8) that the $\tilde{b}_n(t)$ curve shifts to the right. This is the same effect that we saw in the fixed-price case. The $\tilde{b}_n(t)$ curve describes the time needed to rebuild wealth to the level needed to make purchases in steady state. The increase in T^* prolongs this rebuilding process. The effect on (4.7) is complicated by demographic effects: on the one hand, the reduction in productivity y increases n , the proportion of durable goods producers in steady state, whereas the increase in T^* reduces n . The change in productivity is therefore altering the fraction of the population that is subject to the labour market friction. To neutralize these demographic effects, we adjust γ along with y in a way that maintains a constant n . We then have the following proposition:

Proposition 3. *Consider a reduction in y and a corresponding change in γ such that n remains fixed at some level \bar{n} . As a result T^* , \tilde{T} and Δ rise and P_t falls for $t \in [0, \tilde{T}]$.*

Proof. Fix Δ . Suppose $n = \bar{n}$. We have already seen that a reduction in y leads to an increase in T^* and leaves c^* unchanged. We can use (3.1) and (4.3) to rewrite (4.7) as

$$t = \frac{1}{\gamma g} \left[n e^{g(b_n(t)+T^*)} + (1-n) \left(e^{-r(b_n(t)+T^*)} + \frac{\Delta}{\lambda P} \right)^{-\frac{g}{r}} - 1 \right].$$

Given n and γ , this equation pins down $b_n(t) + T^*$ as a function of t . Recall that $n = 1 - \gamma e^{-rT^*} P/y$. It follows from the budget constraint $c^* = y - e^{-rT^*} rP$ that a reduction in y leads to a reduction in e^{-rT^*}/y . When y falls, γ must rise to maintain $n = \bar{n}$. A fall in y therefore causes $b_n(t) + T^*$ to rise for all t . From (4.8) we see that as T^* rises, $\tilde{b}_n(t) + T^*$ falls. Together these two facts imply that \tilde{T} must increase for any given Δ . The same argument as in 1 implies that the increase in \tilde{T} is even greater if we allow Δ to change. This completes the proof. \parallel

As in Section 3, an increase in the decision-making horizon prolongs the effect of the shock.

4.3. Two-sided labour market frictions

In this subsection, we assume not only that durable producers find it hard to change sectors, as was assumed in Sections 4.1 and 4.2, but that non-durable producers find it difficult as well. For simplicity, we assume that $\gamma = 1$, so that labour is completely immobile between sectors. New entrants, however, can still freely choose where to work. Initially, when the price of the durable falls, all new entrants will choose non-durable production. The bust–boom dynamics of the model imply, however, that at some future point in time demand for the durable will rise above trend. At this point, demand for the durable will exceed supply, and the price of the durable will also rise above trend. New entrants will therefore wish to be producing durable goods at this time. In fact, they will shift towards durable production sometime earlier, as soon as the present value of doing so dictates.

We solve for the model as above. Given a loss to durable goods producers Δ , we can calculate cumulative demand conditional on the date of birth of the non-durable goods producers. Then given a date z at which new entrants begin producing durables, we can find the date t at which cumulative supply equals demand. We then look for a fixed point in Δ and a date z such that the entrants' choice is optimal.

We simulate the model since the analytical solution of this two-variable fixed-point problem is somewhat cumbersome. We calibrate values of P , r , g , and c^* to match broad features of the U.S. housing market. In the model there are only two uses for income: non-durable consumption and durable consumption. We set c^* equal to the fraction of personal consumption expenditures not allocated to housing services. This was 85% in the year 2000. We set rP equal to the fraction of personal consumption expenditures on housing services divided by the home ownership rate, about 0.22 in 2000. We choose the discount rate $r = 5\%$ and the growth rate $g = 4\%$. Given these parameter choices, T^* is 7.66, v is 0.50, and the fraction of the population that own homes is 68%. We use a CRRA utility function with coefficient of relative risk aversion of 5.

We consider a shock that destroys 90% of financial wealth. This may seem large, but the only reason to save in this model is to purchase the durable and most of the durable purchase is financed by borrowing. Financial wealth is therefore quite small. This shock represents a 6% reduction in human and financial capital among those who were on the verge of purchasing the durable at the time of the shock. Initially, on impact, the price falls by 5%. It then rises gradually over the next 7.5 years, overshooting its long run level very slightly, before falling and returning to trend by year nine. This overshooting is sufficient to get new entrants to begin producing

durables in year $z = 6$. Until that time quantity remains fixed at $N_0 e^{-T^*}$. Quantity quickly rises to just over twice that level by the time the price returns to trend in year nine. A value of $\Delta = 0.1$ is sufficient to cause durable goods producers to delay their purchases half a year.

The price response is fairly small. In the fixed-price case, consumers wait until $T_0 = 6.7$ to purchase the durable. A 5% decline in price is enough to cause some agents to purchase at date zero. The high elasticity of the purchase time with respect to the price of the durable appears to be a general property of this timing model under reasonable parameterizations. A look at (4.1) shows that if P falls by ratio r then T will fall by more than one period. If the curvature of the utility function is low, then T will fall by much more.

5. CONCLUDING REMARKS

Consumers purchase durable goods infrequently. An important part of their purchase decision is therefore the timing of their purchase. This paper makes progress at embedding these decisions in a dynamic equilibrium setting. By placing the purchase decision in the context of a life-cycle model, we are able to analyse equilibrium interactions which have proved difficult for the literature on discrete purchases. The model illustrates the important role that purchase horizon plays in the propagation of shocks to demand.

We can think of several directions for future research. One is to use the model to study the interaction between durable goods markets and imperfect capital markets (see Chah, Ramey and Starr (1997) and Kruger and Fernandez-Villaverde (2002)). If borrowing is difficult or costly, consumers may need to save some wealth before they can purchase a durable. This will obviously delay purchases. If durables act as collateral, however, there may be some incentive to accelerate purchases. Another extension further develops the case of depreciation, which is discussed in Section 2, and extends it to an aggregate model. These and other extensions can deepen our understanding of the cyclical behaviour of durable and non-durable consumption and of business cycles in general.

APPENDIX A. RECURRENT SHOCKS

So far we have considered only one-time unanticipated shocks. The purpose of this appendix is to incorporate recurrent shocks into the model. Naturally, if the economy is hit by occasional shocks, they can no longer be completely unanticipated. We extend our analysis of wealth shocks and assume that there are periodic collapses, in which financial wealth F falls to a fraction λ of its initial level, and that these collapses are Poisson with an arrival rate equal to β .

Given that these shocks are anticipated, the expected rate of return is no longer equal to the interest rate r , but rather to $r - \beta(1 - \lambda)$. We therefore assume that the discount rate ρ is equal to $r - \beta(1 - \lambda)$. As before, we assume that there are no shocks to debt and that borrowers pay an interest rate equal to the expected return on assets, namely to ρ . All other aspects of the individual's problem are the same. We assume that the price of the durable is constant and that the wage rate is equal to 1.

For the individual, the state of the economy is characterized by the level of financial wealth F and whether or not they have purchased a durable. Let $V(F)$ represent the present value of utility under the optimal purchase policy for an agent who has yet to purchase the durable. The Bellman equation for this agent's problem is

$$\rho V(F) = \max\{\max_s u(\rho F + 1 - \rho P s) + v(s), \max_c u(c) + V'(F)[rF + 1 - c] + \beta[V(\lambda F) - V(F)]\}. \quad (\text{A.1})$$

Here the two terms in brackets reflect the two options available to the agent: purchase the durable and wait, respectively. When the agent purchases a durable of size s , an amount $F + \frac{1}{\rho} - P s$ is left over for non-durable consumption. When the agent waits, financial assets grow at rate $rF + 1 - c$ and financial shocks arrive at rate β .

We conjecture that the value function takes the form $V(F) = a + bF$. Substituting this solution into the first-order condition for consumption when waiting is optimal yields

$$u'(c) = V'(F) = b.$$

It follows that in the period prior to the purchase of the durable, consumption is constant at some level \bar{c} . Substituting the conjectured solution into (A.1), we arrive at the following relationship between the parameters:

$$\rho a = u(\bar{c}) + b(1 - \bar{c}). \quad (\text{A.2})$$

There are two boundary conditions. The first is a value-matching condition. At the level of financial wealth that the durable is purchased \bar{F} , the two options in (A.1) must offer the same utility. Hence $V(\bar{F})$ must equal the present value of utility from the durable and the non-durable:

$$\frac{1}{\rho} u(\rho \bar{F} + 1 - \rho P s) + \frac{v(s)}{\rho} = V(\bar{F}) = a + b \bar{F}. \quad (\text{A.3})$$

The second is a smooth pasting condition: V is differentiable at \bar{F} .¹⁸

$$u'(\rho \bar{F} + 1 - \rho P s) = V'(\bar{F}).$$

Since $V'(\bar{F}) = u'(\bar{c})$, this condition implies that marginal utility does not jump at the date of purchase, and therefore consumption is constant over the individual's lifetime.

Combining equations (A.2) and (A.3) and noting $\bar{c} = \rho \bar{F} + 1 - \rho P s$, we arrive at

$$\frac{v(s)}{\rho P s} = b = u'(\bar{c}).$$

This is the same first-order condition that we had in the certainty case.

Finally, solving for a and b , we find that the choice of s that maximizes V is given by

$$v(s)/s = v'(s).$$

This condition is the same as in the certainty case.

It follows that the optimal choices of consumption and the size of the durable are the same in this model with periodic shocks to wealth as they were in the benchmark model with certainty. In a sense, this is not surprising given the insulation effect. Shocks to wealth affect only the timing of purchases.¹⁹ Individuals accumulate wealth and purchase the durable only when their financial wealth reaches a level \bar{F} , where

$$\bar{F} = \frac{c^*}{\rho} + P s^* - \frac{1}{\rho}.$$

The aggregate dynamics of the model with uncertainty are similar to those of Section 3. Agents buy the durable when their wealth reaches a certain threshold. Shocks to financial assets shift agents away from this threshold. As a result agents delay their purchases of the durable as they rebuild their assets, and the aggregate demand for durables falls to zero for some time. The only difference is that the economy may occasionally be hit by a new shock before it has recovered from the last one. In this case, demand may remain low for a much longer period.

APPENDIX B. FLEXIBLE PRICES WITH FLEXIBLE SIZE

In this appendix, we show how to find the equilibrium when the size of the durable is flexible. We assume a general form for the utility from durable, $v(\cdot)$, as in Section 2 of the paper. We normalize the size of durable at the steady state to be 1, by assuming that $v'(1) = v(1)$.

The solution is similar to the fixed-size case discussed in Section 4. We first fix Δ and describe the equilibrium-price path. We then find the equilibrium Δ by the same fixed-point argument as in the paper. The only difference is that instead of a differential equation with one variable we have here a set of two differential equations with two variables, the price $P(t)$ and the birth time of non-durable producers, who purchase at $t: b_n(t)$. These equations are presented and solved next.

18. To see where this condition comes from, note that any policy "consume \bar{c} until financial wealth reaches \bar{F} " yields a value function V on $[0, \bar{F}]$ that has slope $b > 0$ and intersects the function $J(\bar{F}) = \max_s u(\rho \bar{F} + 1 - \rho P s) + v(s)$ at \bar{F} . Since J is increasing and concave, the choice of \bar{F} that maximizes V on $[0, \bar{F}]$ is the one in which $J'(\bar{F}) = b$.

19. We were careful to choose our shocks so that they maintained wealth in the interval (\underline{W}, \bar{W}) in order to take full advantage of the insulation result. If the shock had taken wealth outside of this range, insulation would not have been complete.

Optimal size

For each value of these two main variables, we determine the equilibrium size of durable by the first-order condition with respect to c :

$$\frac{v'(s)}{rP(t)} = u'(rW_n(b_n, 0) - re^{-rt} sP(t)). \quad (\text{B.1})$$

Note that the function W_n is the same as in Section 4 in the paper. We can now describe the differential equations for the two variables. The one for prices is derived from the first-order condition with respect to the timing of purchase:

$$P'(t) = \left[1 - \frac{v(s)}{sv'(s)} \right] rP(t), \quad (\text{B.2})$$

where s is defined by (B.1). The derivation of the differential equation with respect to b_n is more complex and involves the equalization of demand and supply for the durable at any period of time. Unlike in Section 4, which used accumulated supply and demand over periods of time, here we equate the flows of supply and demand momentarily. The supply for durable at any point in time is $\gamma g N_0 e^{-gT^*}$. The demand for durable as long as only non-durable producers buy at time t is $ng N_0 e^{-gb_n(t)} s b'_n(t)$, where s is given by (B.1). Hence we get that, for $t \in [0, T']$,

$$b'_n(t) = \frac{\gamma}{ns} e^{-g[b_n(t)+T^*]}. \quad (\text{B.3})$$

The time where durable producers enter as consumers of durables, T' , is determined by

$$b_n(T') = b',$$

where b' is the same as in Section 4. For $t > T'$, we get that b_d depends on b_n as in the paper. Hence,

$$b'_n(t) \left[ne^{gb_n(t)} + (1-n)e^{gb_d(t)} \frac{e^{-rb_n(t)}}{e^{-rb_n(t)} + \frac{r\Delta}{\lambda(1-c^*)}} \right] = \frac{\gamma}{s} e^{-gT^*}, \quad (\text{B.4})$$

where s again is determined by (B.1).

Boundary conditions

Equations (B.3), (B.2), and (B.4) must satisfy the following boundary conditions. First $b_n(0) = -T^*$. Second, at the end of the recession \tilde{T} , $P(\tilde{T}) = P$ and the time of birth on non-durable producers should satisfy

$$\lambda e^{-rb_n(\tilde{T})} + 1 - \lambda = e^{-r(\tilde{T}-T^*)}.$$

This last equation is the same as equation (4.8). As in the paper, it defines a relation between b_n and t , which we denote by $\tilde{b}_n(t)$. The intersection of $\tilde{b}_n(t)$ and $b_n(t)$ defines the end of the recession \tilde{T} .

The solution

Instead of supplying a full proof of the existence and uniqueness of the solution for this set of differential equations and its boundary conditions, we present the following way to construct the solution, which can also be helpful in analysing various changes. We begin with an arbitrary price immediately after the shock: $P(0)$. From this price and from the initial condition we can construct $P(t)$ and $b_n(t)$ by use of the differential equations. When $b_n(t)$ intersects with the $\tilde{b}_n(t)$ curve we check whether $P(\tilde{T})$ is above or below P . If it is above we lower $P(0)$ and if it is below we raise it. Clearly $P(0) = P$ is too high, and also $P(0) = 0$ is too low (it leads to a path of prices equal to zero, according to (B.2)). Hence, by continuity there is a right initial price in between.

Graphically the solution to the differential equations can be described in a diagram similar to that in Figure 7 in the paper. Note that the solution to the set of differential equations is derived for a given Δ . Finding the equilibrium Δ is done in a similar way as in the case of fixed size, which is described in Section 4.

Comparison of results with the fixed-size case

It is easy to see that the durables purchased during the recession are smaller than those purchased in the steady state. Since both price and consumption fall during the recession, equation (B.1) implies that s must fall. Given that s is less than one, it follows that $b_n(t)$ must be greater when size is flexible than when size is fixed. That can be seen from equations (B.3) and (B.4), and is clear intuitively: if people buy smaller durables, more people must buy for demand to equal the fixed supply. Hence the people who purchase must be born later. Figure 7 shows that an upward shift in the b_n curve implies a longer recession. Finally, combining (B.1) and (B.2) yields

$$\frac{v(s)}{s} = u'(rW_n(b_n, 0) - re^{-rt} P(t))(rP(t) - P'(t)).$$

This is the flexible-size version of equation (4.1). There are two differences. First, during a recession the fall in s lowers $v(s)/s$, while v in (4.1) was fixed. Second, b_n is greater when size is flexible, which implies that purchasers are less wealthy and have higher marginal utility. Both these differences imply that any given P is associated with a greater $P'(t)$. Hence the entire price path in the flexible-size case must lie below that in the fixed-size case. This implies greater losses to the producers of durables. In sum, size flexibility exacerbates all of the effects of recession.

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