A Model of Anticipated Consumption Tax Changes

(Preliminary. Under Frequent Updates)

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Abstract

This paper studies household responses to the anticipated changes in consumption tax. To do so, I construct a life-cycle heterogeneous-agent general equilibrium model with durables. The model features a wedge in durable transactions that reflects the actual tax system that households do not receive consumption tax when selling the durables.

First, the baseline model reproduces an empirically consistent dynamic pattern of tax elasticity, which witnesses the sharp spikes in the durable expenditure right before the tax hike and gradual convergence toward the new stationary state after the tax hike. To match the level of the tax elasticity, I find life-cycle is key. Second, the baseline model generates smaller stockpiling of durables than a model without the wedge.

I then use this model for both welfare analysis and two counter-factual experiments. The welfare analysis shows that the tax hike is progressive on the transition. The first counter-factual experiment where consumption tax is decreased finds that the effect of the tax decreases is not symmetric to the tax hike. The second counter-factual experiment which compares one-time tax hike with multiple-times tax hikes shows the latter tax hike scheme is welfare improving for almost all of households.

JEL code: C63, E62, E65.

Keywords: Durables, Anticipated Consumption Tax Change, Stockpiling, Tax Wedge, Life-cycle, Tax Elasticity.

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1. Introduction

Preannounced consumption tax hikes cause salient intertemporal substitution of household expenditures. Households increase expenditures before the tax hikes because the goods will be more expensive in the future. From a policy perspective, the effect of the preannounced future consumption tax hikes have been proposed as an aggregate demand stimulus policy tool, labeled unconventional fiscal policy.[1] The stimulative effects of change in the consumption taxes through the intertemporal substitution is similar to those of conventional monetary policy. This can be clearly confirmed with Euler equation from a simple growth model with the consumption tax below:

$$u'(c) = \beta(1+r')\frac{1+\tau^c}{1+(\tau^c)'}u'(c'), \tag{1}$$

where τ^c is the consumption tax. From the Euler equation, the effect of the change in the ratio of the consumption taxes $(1+\tau^c)/(1+(\tau^c)')$ is equivalent to a change in interest rate $1+r'$. This suggests that unconventional fiscal policy is, in theory, as important and powerful as *conventional* monetary policy. However, much less research focus on the consumption tax than monetary policy. The consumption tax policy can potentially become an important policy tool, particularly in the low interest rate environment.

Also, there exists a clear gap between empirical and macroeconomic structural studies on the intertemporal substitution effect due to the preannounced tax hike. The empirical studies show that the effect is prominent in long-lasting goods or durable goods (e.g. Cashin and Unayama (2016b), D'Acunto et al. (2016, 2018), Baker et al. (forthcoming), Baker et al. (2019), Nguyen et al. (2020)) whereas only a few macroeconomic structural studies on the consumption tax incorporate the durables into the analysis. This paper aims to fill this gap.

Motivated by them, this paper studies the effects of the anticipated future consumption tax changes on household expenditures using a life-cycle heterogeneous-agent general equilibrium model with consumer durables. A remarkable feature of my baseline model is a *tax wedge* to reflect the actual tax system that households pay the consumption tax when buying the durables, but do not receive the tax when selling it. This tax wedge is a variant of irreversibility constraint which has been used in investment literature. The tax wedge constraint plays central roles in predicting the household expenditure responses for the following two reasons.

First, the tax wedge helps account for the estimated dynamic pattern of the taxable spendings, reported in Baker et al. (forthcoming). As Figure 1 shows, Baker et al. (forthcoming) find that taxable spendings spike up right before the tax hike, plummet in the period of the tax hike and gradually recover to the new stationary states.[2] I show that the baseline model can reproduce

[1] The unconventional fiscal policy is, for example, proposed by Feldstein (2002) and Hall (2011), and extensively studied by Correia et al. (2013), Baker et al. (forthcoming) and Baker et al. (2019).

[2] More generally, stimulative policies to the durables witness this slow recovery. For instance, Mian and Sufi (2012) confirms that CARS program induces the fewer auto purchase for ten months after the expiration of the program.

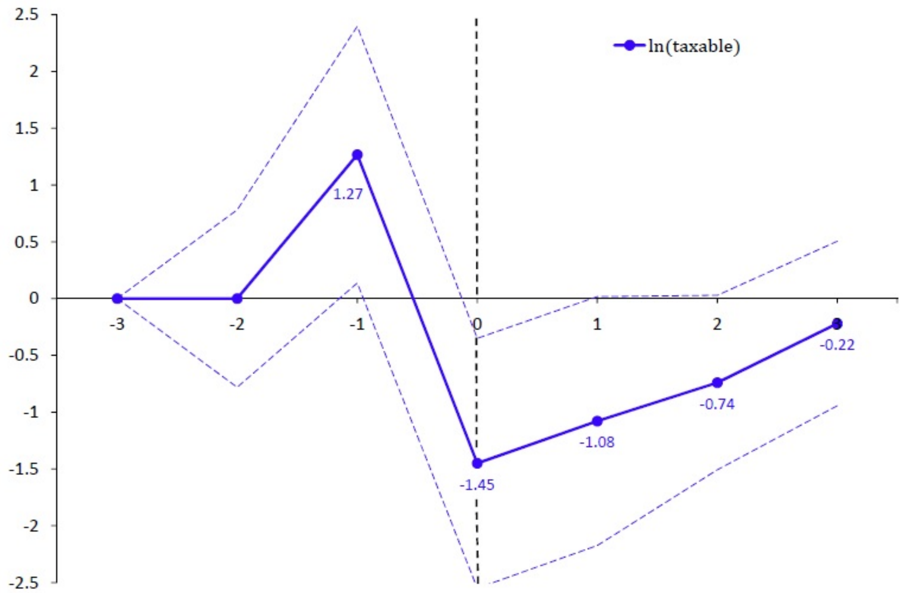


Figure 1: Dynamic Tax Elasticity of Taxable Spendings: from Baker et al. (forthcoming)

this dynamic response of taxable spendings. The households in my baseline model follow (S,s) rule for durable purchase and thus stays inaction after the stockpiling of the durable stocks. Consequently, the model-implied tax elasticity of taxable spendings from my baseline model is 1.87 one period before the tax hike, -1.44 in the period of the tax hike, -1.23 in the following period, falling into the confidence interval of Baker et al. (forthcoming) without targeting them in calibration. Furthermore, the baseline model also generates the tax elasticity of durable spendings of 10.6, which Baker et al. (2019) estimate $8.1 - 12.8$ depending on the data source.[3]

Second, the tax wedge helps predict theoretically correct stockpiling behavior. In other words, a model without the tax wedge overestimates stockpiling behavior. Without the tax wedge, the model allows the households to receive the consumption tax as revenue when they sell the durables. This unrealistic revenue generate unrealistic speculative stockpiling behavior. To demonstrate it, consider the following simple example. Suppose $\$10,000$ automobile and the tax hike from 5% to 10% will take place tomorrow. The household buys the auto today and pays $\$10,500$. When selling the auto with the tax rate of 10% next day, the household in the model without the tax wedge receives $\$11,000$. Thus, $\$11,000 - \$10,500 = \$500$ minus the depreciation is a monetary profit of speculation by taking advantage of the tax hike in the model without the tax wedge. Knowing this speculation opportunity, the households excessively stockpiles for the speculation motive but not for their own use. In this way, the model without the tax wedge overestimates the stockpiling behavior. This misspecification problem might affect the existing

[3] 8.1 is from Column (3) in Table 2 and 12.8 comes from Table 3. As they discuss timing issue of purchase and registration, I sum up to 9.05 and 3.70 in Column (1), and obtain the value of 12.8.

quantitative analysis. For instance, Cashin and Unayama (2016b) uses the model without the tax wedge to estimate the intertemporal elasticity of substitution (IES). To reconcile with observed large stockpiling behavior using the model, they conclude that IES is low. But, their result must be affected by the misspecification problem discussed above.

Next, incorporating life-cycle into the model is important to match magnitude of the tax elasticities as the life-cycle motives largely dampen the elasticity. Recently, Koby and Wolf (2020) and Winberry (2020) show that (S,s) investment models generate infinitely high interest rate elasticity of investment. This high interest rate elasticity also emerges in a model of durables with (S,s) rule as McKay and Wieland (2019) study. As shown using the Euler equation (1), the change in the interest rate has similar implication on the households expenditure as the change in the consumption tax and hence resolution of this puzzle is central problem this paper must address.[4] I found that incorporating the life-cycle structure makes the interest rate elasticity of the aggregate durable expenditure in the baseline model fit empirically reported values closely, without any additional frictions. This is because there is a mass of households who do not respond to interest rate in a life-cycle model. For instance, the young purchase durables regardless of interest rate as they have very high marginal utility of durables. In contrast, the old do not buy durables whatever the current interest rate is, since they will die soon. In this way, the life-cycle motive dampens the model-generated elasticity.

Heterogeneity also matters for welfare implication due to the consumption tax hike *over the transition* since the tax-induced inflation decreases the real value of preexisting wealth. Thus, while wealthy households incur the higher burden of the tax hike, the asset poor do not. This logic holds not only in the liquid asset but also in the durables. Thus, the presence of the durable widens the inequality of the welfare loss from the tax hike. These channels do not exist when focusing on the stationary environment only. While the studies on the stationary environment may have contributed to establishing a common sense that consumption tax is regressive, this paper finds that consumption tax hike is progressive on the transition.

Finally, I consider two counter-factual experiments. First, I consider anticipated tax decrease. This experiment is designed to deliver some insight on the VAT decrease policy actually implemented in Germany against the on-going pandemic crisis. Since the model is highly non-linear, the prediction of the tax decrease is asymmetric to the tax hike. Many of the households stop buying durables after the announcement. Second, I compare two tax hike scheme: a multi-times stepwise tax hikes scheme and a one-time tax hike scheme. The multiple stepwise tax hikes scheme causes stockpiling before the tax hike and the drop in the durable expenditure after the final tax hike. In reality, the economic slump is persistent and thus policy makers hope to avoid the drop in the durable expenditures in the midst of the recession. My result suggests that the policy makers can avoid the drop by keeping raising the tax rate. By doing so, the largest drop in the durable expenditure can be postponed to the period after the recession ends. Moreover, I find that multi-times tax hikes reduces the depth of the drop.

[4] The equivalence between fiscal and monetary policy is more formally discussed in Correia et al. (2008).

My focus is on Japan's consumption tax increase in 2014 because the Japanese consumption tax system had attractive features for the study of this paper. First, the consumption tax was a flat tax rate with few exceptions unlike EU countries where reduced taxes are common.[5] Thus, my model does not incorporate more than non-durable goods and durable goods, unlike Parodi (2018) and Parodi (2019), who study Italian consumption tax reform in a stationary environment. Second, the Japanese government prohibited the discount or sales in response to the consumption tax changes. Therefore, the consumption tax change is considered to be fully pass-through on prices that households faced. This price control allows us to assume this full pass-through of the tax change and ignore the change in price-setting patterns, which Karadi and Reiff (2019) extensively study.

The baseline model of this study is two asset models with a discrete choice. This class of the models is known to be computationally intensive. I extend the latest endogenous grid method (hereafter EGM), Nested EGM, which is developed by Druedahl (2020) and solve the entire analysis, including the transition of the general equilibrium with my laptop. A novel feature of Nested EGM is by nesting the timing of the household's problem, we can divide the multi-dimensional optimization over the asset and durable into two steps of uni-dimensional problems. The algorithm applies the off-the-shelf EGM to this uni-dimensional part and solves the dynamic optimization problem very fast.

1.1. Relation to Literature

To my best knowledge, this is the first paper to study the stockpiling behavior in response to the anticipated consumption tax changes with a general equilibrium model of consumer durables with the tax wedge. This paper aims to contribute to the three strands of literature mainly: unconventional fiscal policy, consumption tax reform, and lumpy durable literature.

This paper contributes to the theoretical and quantitative understanding of the unconventional fiscal policy. Correia et al. (2013) theoretically prove that unconventional fiscal policy resolves the limitation of traditional monetary policy in the zero lower bound using a representative agent New Keynesian model and show that it also achieves the efficient allocation. My model is an extension of Correia et al. (2013) with regard to the durables, the tax wedge, life-cycle, and heterogeneity. Once the durables are introduced into a model, responses to the preannounced consumption tax changes are significantly changed. Overall, my model aims to step forward the understanding of unconventional fiscal policy particularly in the durable and heterogeneity dimensions.

Baker et al. (forthcoming) also studies the unconventional fiscal policy both empirically and theoretically. They develop a consumer inventory model with shopping costs to account for the observed responses to the anticipated sales tax changes in the U.S. They focus on the U.S. sales tax system, i.e., local sales tax changes while I study changes in the nation-wide consumption tax

[5] Notable exceptions are rent, medical, tuition, and funeral fees. I exclude housing and education from my model. Therefore these exceptions are immune to my study.

rate. Therefore, I build an extended Bewley-Huggett-Aiyagari type model which is commonly used in the macroeconomic literature. Also, my model is able to reproduce the reported slow convergence to a new steady-state in Baker et al. (forthcoming).

Baker et al. (2019) emprically estimate the tax elasticity of the auto purchase in the U.S. D'Acunto et al. (2016, 2018) also study the effects of anticipated consumption tax and show that the readiness of the durable purchase increased before the consumption tax hike in Germany and Poland. To sum up, these empirical papers on consumption tax changes emphasized the roles of durable goods. This paper builds a bridge between these empirical findings and macroeconomic theory by introducing consumer durable goods into the theoretical model.

The second strand of the literature that I aim to contribute to is on consumption tax reforms.[6] Among them, Altig et al. (2001) and Nishiyama and Smetters (2005) studies a transition over the replacement of a realistic progressive income tax system with a flat consumption tax system, using a life-cycle model. They study on the intergenerational and heterogeneous welfare costs of the introduction of the consumption tax. My paper revisits their analysis with a model of the durables.

My baseline model is the most similar to Parodi (2018, 2019) from the structural modeling perspective. Parodi (2018) constructs a rich partial equilibrium life-cycle heterogeneous agent model with durable goods and the tax wedge to study the value-added tax system reform in Italy that changes from the current consumption tax system with reduced tax rates to a uniform tax rate. Parodi (2019) also uses a similar environment to study the optimal consumption tax rates for the Italian economy in the presence of reduced tax rates in a stationary environment. My paper differs from Parodi (2018, 2019) in that my focus is on the dynamic responses of the households to the anticipated tax change. I will argue that effects from the tax-induced inflation which cause heterogeneous welfare implication over the dynamics only, and therefore the analysis on the stationary environment misses important welfare consequence. Thus, my work complements her work by adding this dynamic perspective.

The third related literature is on the lumpy durable adjustments. There are a number of papers that contributed to this literature.[7] Among them, Berger and Vavra (2015) is a recent and particularly influential paper in the literature. They show that the response of the durable expenditure is more sluggish in recessions. Berger and Vavra (2015) also shows that this responsiveness is robust to the assumption of whether partial equilibrium or general equilibrium. My study applies the lumpiness to the responses to the anticipated consumption tax changes. Also, Fernández-Villaverde and Krueger (2007, 2011) and Yang (2009) study both empirically and theoretically the life-cycle profile of the durable expenditure. I find that life-cycle structure can dampen the interest rate elasticity of aggregate durable expenditure in a model and help match the observed elasticities.

[6] Krusell et al. (1997), Ventura (1999), Erosa and Ventura (2002), Correia (2010), Kitao (2011), Nakajima and Takahashi (2017a), Laczó and Rossi (2019) and Motta and Rossi (2019).

[7] For instance, Lam (1989, 1991), Grossman and Laroque (1990), Caballero (1990, 1993), Eberly (1994), Leahy and Zeira (2005), Luengo-Prado (2006), Favilukis et al. (2017), Guerrieri and Lorenzoni (2017), Gavazza and Lanteri (2018).

Finally, my paper relates to the conventional monetary policy because a permanent consumption tax hike can be viewed as lowering the real interest rate in a single period from the household perspective, as shown above using the simple Euler equation. This equivalence between the fiscal and monetary policy is formally established in Correia et al. (2008). My baseline model breaks the equivalence between monetary and fiscal policy in two respects. First, unlike the zero lower bound, the consumption tax rate does not have the upper bound as discussed in Correia et al. (2013). Therefore, the stimulus policy with the consumption tax will not be constrained and be effective even when conventional monetary policy is constrained. Second, the consumption tax system is a natural source of the irreversibility constraint. Thus, the change in the tax has asymmetric effects depending on whether tax is increased or decreased. This asymmetricity of the effects may not always exist or is not strong in monetary policy.[8]

Many Heterogeneous Agent New Keynesian (HANK) models recently feature roles of durable, housing, or illiquid asset. For instance, McKay and Wieland (2019) and Zorzi (2020) study transmission mechanisms of monetary policy with a model of lumpy durable adjustments. As discussed in the introduction using Euler equation and shown in Correia et al. (2008), the consumption tax policy is profoundly related to the monetary policy.

Doepke and Schneider (2006), Sterk and Tenreyro (2018), Auclert (2019) and Doepke et al. (2018) argue that inflation has a redistribution effect between the asset rich and the asset poor. Nishiyama and Smetters (2005) analyze the heterogeneous welfare cost of the tax-induced inflation on the consumption tax context. I follow and revisit those insights with a model of the durables.

1.2. Layout

In what follows, I explain Japanese consumption tax system briefly in the next section. The section 3 explains the baseline model and the section 4 discuss the computational solution. The section 5 is about parametrization. The section 6 illustrates the basic result in a stationary equilibrium. From section 7, I discuss the results of the consumption tax change. The section 7 discuss the long-run effects of the consumption tax change. The section 8 focuses on the dynamic responses to the anticipated consumption changes, assuming the partial equilibrium. The section 9 solves the general equilibrium dynamics and confirms that equilibrium assumption does not affect the result.

2. Japanese Consumption Tax System

This paper mainly studies a change in the consumption tax rate in2014 in Japan when tax rate was raised from 5% to 8%. Cashin and Unayama (2016b,a) document features of the Japanese

[8]For instance, Berger et al. (2018) discuss the asymmetric effects of monetary policy through the refinance channel of monetary policy.

consumption tax in detail. This section closely follows their exposition. First, unlike the value-added tax (hereafter, VAT) in many other countries, the Japanese consumption tax had a uniform flat rate across regions and goods with few exempted items until 2019 October. This feature simplifies our discussion because we do neither need to model reduced taxable goods nor consider possible substitution effects of relative tax rate difference due to reduced tax system. A notable example of tax-exempted expenditures is rent for housing. While housing is a huge and important component in household consumption, this paper focuses on a narrow definition of the durables which exclude housing. Thus, our definition of durables typically consists of auto, furniture, office supply owned by households. Second, the consumption tax in Japan is designed to be fully borne by households in Japan. Before the announcement of the consumption tax hike, the government announced that it prohibits price changes due to the tax hike. Thus, the Japanese tax hike is considered not to affect firms' price-setting behavior and I assume full pass-through.

Also, a key friction in my modeling is the tax wedge. This friction reflects the actual consumption tax system. That is, when households as individuals but not business sell the goods, the transaction is not subject to the consumption tax. For instance, when a household sell an auto to a dealer, the consumption tax is not applicable to this transaction. The consumption tax is applicable only when the seller is business. This tax system naturally justifies the introduction of price differential into the model.

Next section formulates this price differential in a baseline model.

3. Baseline Model

3.1. Households

Time is discrete. Let $t = 0, 1, \ldots$ be time and j be age. Households live for finite periods J. They start working as soon as they are born and works inelastically until period $J^R - 1 < J$. After the retirement age J^R, they receive social security ss. Households have no bequest motives and are born with neither asset a nor durables d. There exists bequest in the form of the durable despite the deterministic lifetime and no bequest motive because the households may own the durables in the last period of the life. The sum of the durables that deceased households own equals the total bequest, that is $D_J = B$. This total bequest B is equally distributed to all the alive households at the end of every period. Let b denote the bequest each household receives. For notational simplicity, I omit time and age subscript if not necessary.

The households supply labor inelastically. In beginning of every period, the working households draw an idiosyncratic labor productivity from a Markov process $\pi(e'|e)$ and receive a labor earning $w\kappa_j e$. $\{\kappa_j\}_{j=1}^{J^R-1}$ is a deterministic age-dependent component of the labor earnings. This κ_j is introduced to account for the hump-shaped labor earnings. An initial productivity e_0 at the age of 0 is assumed to be drawn from the ergodic distribution of the Markov process. For notational simplicity, let $y_j(e)$ denote the labor earnings and social security. That is,

$$y_j(e) = \begin{cases} w\kappa_j e & \text{if } j < J^R \\ ss & \text{if } j \geq J^R. \end{cases}$$

Also, the households receive an interest income $(1 + r_t)a_{-1}$, and spend the sum of labor and interest income and the bequest on either non-durables $c \geq 0$, the durables $d \geq 0$ or save in liquid asset a. The durables depreciate at the rate of δ^d. When purchasing the non-durables and durables, the households face same consumption tax rate τ^c. The common consumption tax rate is assumed because the consumption tax rate is uniform across goods in Japan during sample period I study.[9] Let x^d be the purchase of the durables. The households cannot borrow, i.e. $a \geq 0$ is imposed.

Furthermore, the households are subject to a friction for the durable adjustments. The households face the tax wedge due to the consumption tax. Let $q \in [0, 1]$ be an exogenous resale adjustment friction of the durables. If $q < 1$, this is the classical irreversibility constraint. Then, the tax wedge takes a form of the following:

$$I(d, d_{-1}) = \begin{cases} (1 + \tau^c)x^d & \text{if } x^d \geq 0 \\ qx^d & \text{if } x^d < 0. \end{cases}$$
$$\text{where } x^d = d - (1 - \delta^d)d_{-1}$$

Therefore the households in the baseline model face different consumer price between buying and selling the durables. It is important to notice that the tax wedge is necessary even when $q = 1$ for the model with the durables and the consumption tax. When referring to a model without the tax wedge, I assume $q = (1 + \tau^c)$ in which no irreversibility is introduced.

To sum up, the households face the budget constraint below,

$$(1 + \tau^c)c + a + I(d, d_{-1}) = (1 + r)a_{-1} + y_j(e) + b \tag{2}$$

The household state space is (j, a_{-1}, d_{-1}, e). Let $\mu_j(a_{-1}, d_{-1}, e)$ be the distribution of the households at the age of j. Note that without the tax wedge (i.e. setting $q = 1 + \tau^c$), the households receive the consumption tax $\tau^c x^d$ when selling the durables ($x^d < 0$).[10] We will discuss the importance of this misspecification later in detail in section 8.2.

[9] As of 2019 October, Government of Japan introduced a reduced tax system.

[10] That is, suppose $q = 1 + \tau^c$. Then, when $x^d < 0$, the budget constraint implies that $(1 + \tau^c)c + a = (1 + r)a_{-1} + y_j \underbrace{-(1 + \tau^c)x^d}_{>0}$.

The households' dynamic optimization problem can be written as

$$v_j(a_{-1}, d_{-1}, e) = \max_{(a,c,d)\geq 0} u(c,d) + \beta \sum_{e'} v_{j+1}(a,d,e')\pi(e'|e) \tag{3}$$
$$\text{s.t. (2).}$$

where $v_{J+1}(a,d,e') = 0$ for all (a,d,e').

Alternatively, it seems to be more intuitive to rewrite the optimization problem explicitly with discrete choices in the following way. The households choose either upward adjusting the durables (i.e. buy the durables), inaction, or downward adjusting the durables (i.e. sell the durables),

$$v_j(a_{-1}, d_{-1}, e) = \max\{v_j^{up}(a_{-1}, d_{-1}, e), v_j^{inact}(a_{-1}, d_{-1}, e), v_j^{down}(a_{-1}, d_{-1}, e)\}.$$

Each choice-conditional problem is solved separately in the following manner.

When upward adjusting the durables, the households solve

$$\begin{aligned} v_j^{up}(a_{-1}, d_{-1}, e) = \max_{(a,c,d)\geq 0} \; & u(c,d) + \beta \mathbb{E}[v_{j+1}(a,d,e')|e] \\ \text{s.t. } & (1+\tau^c)[c + x^d] + a \\ & \quad = (1+r)a_{-1} + y_j(e) + b \\ & \quad x^d > 0. \end{aligned}$$

Notice that $x^d > 0$ is explicitly imposed.

When inaction, the households solve

$$\begin{aligned} v_j^{inact}(a_{-1}, d_{-1}, e) = \max_{(a,c)\geq 0} \; & u(c, (1-\delta^d)d_{-1}) + \beta \mathbb{E}[v_{j+1}(a, (1-\delta^d)d_{-1}, e')|e] \\ \text{s.t. } & (1+\tau^c)c + a \\ & \quad = (1+r)a_{-1} + y_j(e) + b. \end{aligned}$$

The households who choose inaction simply carry the depreciated durable $(1-\delta)d_{-1}$ to the next period. Thus, this optimization is essentially one-dimensional as in a standard incomplete market model. This becomes key in computation. This inaction problems allows us to apply the EGM technique for this choice-specific Bellman equation with special treatment for the kinky value functions due to discrete choices. The Nested EGM heavily takes advantage of this structure and I will discuss the detail in appendix 11.1.

Finally when downward adjusting the durables, the households solve

$$\begin{aligned} v_j^{down}(a_{-1}, d_{-1}, e) = \max_{(a,c,d)\geq 0} \ & u(c,d) + \beta \mathbb{E}[v_{j+1}(a,d,e')|e] \\ \text{s.t. } & (1+\tau^c)c + qx^d + a \\ & \quad = (1+r)a_{-1} + y_j(e) + b \\ & x^d < 0. \end{aligned}$$

Again, notice that $x^d < 0$ is imposed.

It is worth noting that households are not allowed to trade durables between households but trade durables with competitive dealers. I will discuss this dealers when defining the equilibrium in subsection 3.4.

3.2. The Goverment

The government collect consumption tax as a revenue and use it to finance total pension $SS = \sum_{j\geq J^R} ss\mathrm{d}\mu_j$ and government expenditure G.

$$G + SS = \tau^c(C + X_+^d) \tag{4}$$

where $X_+^d = \sum_j \int_{x^d>0} x^d \mathrm{d}\mu_j$ is positive aggregate expenditure on the durables because consumption tax is paid only when the expenditure is positive.

In my model, additional tax revenue from the tax hike is spent on the government expenditure G. The government expenditure G is not used anywhere and wasteful. An alternative modeling of the use of the tax revenue is to transfer it to the households or mix of the government expenditure and the transfer. I choose the government expenditure as a benchmark for three reasons. First, I want to isolate the effect of anticipated consumption tax hike from effects of the transfer. It is well known that Hand-to-Mouth (including wealthy Hand-to-Mouth) households strongly react to the lump-sum transfer in two asset models as Kaplan and Violante (2014) point out. Therefore, the lump-sum transfer potentially boosts the stockpiling behavior in response to anticipated consumption tax change in a non-trivial way. This makes interpretation of the household responses complicated and we cannot identify whether the heterogeneous response is due to the tax hike or the transfer. Also, if the government transfers the revenue to the households, the model would generate stronger stockpiling responses. In other words, my result can be seen as lower bound in this respect. Second, this modeling is intended to reflect the fact that the additional tax revenue is mostly for the sustainability of the Japanese Government Debt and used for the repayment of the debt. While the accumulated government debt is unmodeled, the government expenditure can be interpreted as expenditures on such a unmodeled factor.[11] Third, this modeling is computationally easy. Given the OLG structure with two assets and discrete choices,

[11]Other unmodeled objects include frequent natural disasters (e.g. typhoons, earthquakes) and spending on the on-going pandemic crisis.

burden of the computation, especially for the dynamics, is non-negligible.

3.3. The Firm

The firm side is standard. I assume a representative competitive firm which owns Cobb-Douglas technology for the final output. This firm follows

$$\begin{aligned} r + \delta &= \alpha K^{\alpha-1} N^{1-\alpha} \\ w &= (1-\alpha) K^{\alpha} N^{-\alpha}. \end{aligned} \tag{5}$$

where K and N are aggregate capital and labor respectively. This output is used for the non-durable and the durable consumption, the capital investment and the government expenditure.

3.4. A Recursive Competitive Equilibrium

A recursive competitive equilibrium of this model consists of a pair of functions,

$$\left(\{v_j, g_j^d, g_j^a\}_j, \{\mu_j\}, C, D, K, N, w, r\right)$$

that solves the households and the firm optimization problems and clear markets for asset, labor and output. That is, the equilibrium satisfies

(i) v_j solves age j household problem (3) given prices (w, r). g_j^d and g_j^a are policy functions for the durables and the assets respectively.

(ii) Firm solves the static optimization (5).

(iii) The government observes its budget constraint (4).

(iv) The distribution $\{\mu_j\}$ follows

$$\mu_{j+1}(\mathbf{s}, e') = \int_{\{(a_{-1}, d_{-1}, e) | \left(g_j^d(a_{-1}, d_{-1}, e), g_j^a(a_{-1}, d_{-1}, e)\right) \in \mathbf{s}\}} \pi(e'|e) \mathrm{d}\mu_j(a_{-1}, d_{-1}, e)$$

(v) The labor market clears:

$$N = \sum_{j=1}^{J^R-1} \int e\kappa_j \mathrm{d}\mu_j.$$

(vi) The asset market clears:

$$K = \sum_{j=1}^{J} \int a \mathrm{d}\mu_j.$$

(vii) The good market clears:

$$C + \sum_{j=1}^{J} \int \mathbb{Q}_{x^d<0}(g_j^d - (1-\delta^d)d_{-1})\mathrm{d}\mu_j + G + K' = K^\alpha N^{1-\alpha} + (1-\delta)K.$$

where $\mathbb{Q}_{x^d<0}$ is an indicator function for the irreversibility constraint. That is, $\mathbb{Q}_{x^d<0}$ takes q when $x^d < 0$ and 1 otherwise.

The equilibrium assumption above involves an implicit assumption on the secondary market of the durables. In reality, a direct trade between households of the durable is a way to avoid the consumption tax.[12] Here I do not allow such direct trades.

Instead, I assume that all the transactions of the durables are managed by the competitive dealers. That is, when the households sell the durables, they receive q per unit of the durables from the dealer. Similarly, when the households buy the durables from the dealers, they pay 1 per unit to the dealers and τ^c per unit to the government. The dealers consume premium $1-q$ for repairment of the used durables, and sell it to the goods market as new durables. Thus, the used and new durables are perfect substitute and thus I do not distinguish them in the household optimization problem.

4. Computation

Solving this class of the models is computationally demanding in the presence of the discrete choices and a multidimensional optimization. The discrete choices cause non-concave regions on the both unconditional and choice-specific value functions and therefore derivative based optimization methods become less accurate or unstable. Researchers may need to worry the local optima. Moreover, the multidimensionality in the optimization often suffers the curse of the dimensionality. When solving perfect foresight dynamics with a simulation period of T, we must solve $J+T-1$ generations' dynamic optimization problems. Hence, efficient solution method for the dynamic programming is necessary.

Druedahl (2020) develops a novel algorithm to solve this class of models with multidimensional optimization problem with the discrete choices. I applied his Nested EGM to the model with the tax wedge and show that this algorithm gives a well-behaved solution to the richer model than the benchmark model he used for exposition. While details of the algorithm are explained in the appendix 11.1, this section briefly overviews ideas of Nested EGM.

The critical insight of the Nest EGM is nesting a model to reduce a dimension of choice-conditional optimization problems, introducing the additional timing structure within a period. That is, the Nest EGM views both upward and downward adjusting problem as sequential. The households are assumed to, first, decide how much durables they buy, and then decide how much

[12] For example, when we buy furniture from a friend or a relative, this direct trade between individuals may take place without paying the consumption tax.

non-durables. Importantly, this nesting timing assumption allows us to use the consumption function derived by the inaction problem for the both adjusting problems to reduce a dimension of the optimization problems. Thanks to this dimension reduction technique, the resulting optimization problems for both adjusting become one dimensional. These maximization problems are solved with standard VFI.[13]

Since the dimension of the optimization for the inaction problem is essentially one in computation, we can use EGM with upper envelope algorithm, developed by Druedahl and Jørgensen (2017) and Iskhakov et al. (2017). We extend these techniques for the model with the tax wedge or the partial irreversibility constraint.[14]

I use this algorithm for solving both the stationary equilibrium and the perfect foresight equilibrium path.

5. Parameterization

This section discusses the parametrization of the models. The model frequency is annual. consumption tax rate τ^c is set 0.05 and 0.08 in the baseline which were actual consumption tax rates in Japan until 2014 April and since then until 2019 October.

The Cobb-Douglas utility function is commonly assumed in the durable literature, following Ogaki and Reinhart (1998). However, as Fernández-Villaverde and Krueger (2011) find, the Cobb-Douglas utility specification in a simple life-cycle model with the durables does not reproduce empirically observed hump-shape in durable expenditure. Thus, I adopt non-homothetic utility function blow as with Parodi (2019),

$$u(c,d) = \frac{\left(c^{\theta}(d+\epsilon_d)^{1-\theta}\right)^{1-\sigma}}{1-\sigma}$$

where $\epsilon_d > 0$ and ϵ_d is not close to 0. This Stone-Geary functional form implies that durable stock is *luxury*, consistent to the finding in Pakoš (2011). Typically, since households in a life-cycle model get rich in middle-age in terms of both asset and earnings, middle-age households increase the durable purchase. In this manner, this utility functional form helps reproduce the hump-shaped durable expenditure. I pin down θ and ϵ_d to simultaneously match the ratio between initial level and peak of average durable expenditure, and aggregate non-durable and durable share. Then, I set $\sigma = 2.0$ and $\beta = 0.977$ which are standard values in the literature.[15]

Next, there is no official data for the durable depreciation in Japan. Thus, I take a depreciation

[13] Due to the discrete choice and a kinky value function, this optimization problem may have many local maxima. I use Rowan's Subplex algorithm (a local optimization method) provided by `NLopt` toolbox on very finely-spaced subintervals and find a local maximum in the subintervals. And then I take the maximum from these local maxima in practice.

[14] Also, I solved a model with fixed-cost and quadratic adjustment cost with this solution method.

[15] High discount factor β is common in Japanese economy literature, for example, Hayashi and Prescott (2002) and Yamada (2012).

rate of each durable goods (e.g. furniture, appliances, auto) from Fraumeni (1997), and compute the weight average of the depreciation rates using the share of the expenditure from National Survey of Family Income and Expenditure.

The resale adjustment cost q in the tax wedge is set to be 1.0. I discuss the alternative value case in the appendix. The choice of q affects the wealth formation in the stationary equilibrium because the durables play a role as an insurance if q is high. Hence, the higher the q is, the more households save in durables in the stationary equilibrium. But, I confirm that the stockpiling behavior over the transition is almost irrelevant to choice of q.

As for the calibration of idiosyncratic shocks, I assume the simplest AR(1) labor productivity process.

$$\ln e' = \rho \ln e + \epsilon'.$$

I follow a calibration strategy of Nakajima and Takahashi (2017b) for the parameters of the idiosyncratic shocks. There is no suitable panel data for the estimation of the earnings in Japan. Thus, they set persistence ρ of the shock to be standard value of 0.9 a priori.[16] Then, the age-dependent components $\{\kappa_j\}_j$ is set so that labor earnings in the model match observed hump-shape in average labor earning reported in Yamada (2012). I make it annual by interpolating with the cubic spline.Lise et al. (2014) combines four major data in Japan to estimate volatility of shocks: Basic Survey on Wage Structure (BSWS), the Family Income and Expenditure Survey (FIES), the National Survey of Family Income and Expenditure (NSFIE), and the Japanese Panel Surveyof Consumers (JPSC). To be consistent with Lise et al. (2014), the earnings dispersion conditional on $\{\kappa_j\}$ is generated by idiosyncratic shocks and then I set $\sigma_\epsilon = 0.2072$. Finally I use the Rouwenhorst (1995) method to discretize this AR(1) process with 13 grid points. The social security is set at $ss = 0.64$ following the report of the OECD (2017), which includes voluntary components.

6. Stationary Equilibrium

Figure 2 is a durable expenditure function $x^d = g_j^d(a_{-1}, d_{-1}, e) - (1-\delta^d)d_{-1}$. Due to the partial irreversibility constraint, the durable expenditure function exhibits high nonlinearity. The durable expenditure function consists of three regions: upward adjustment, inaction, and downward adjustment. Movement across different regions means the extensive margin.

Next, I assume the population of each generation is $10,000$ in the model economy so that total population is large enough ($J \times 10,000 = 550,000$) and run the stochastic simulation. Figure 3 shows the average of non-durable, durable stock asset, and positive durable expenditure profiles over the lifetime. The asset profile is much taller than other two profiles and thus scaled down

[16]For example, Floden and Lindé (2001) finds 0.914 for the U.S. Alonso-Ortiz and Rogerson (2010) report 0.94 for the US.

Table 1: Parameters in the Baseline Model

parameters	values	description
β	0.977	discount factor
σ	2.0	risk aversion
δ	0.1	annual depreciation rate of the capital
δ^d	0.15	annual depreciation rate of the durables
ϵ_d	1.47	Stone-Geary preference parameter
θ	0.77	utility share of the non-durables
ss	0.64	social security
q	1.0	resale adjustment friction
ρ	0.9	persistence of the idiosyncratic shocks
σ_ϵ	0.2072	std of the idiosyncratic shocks

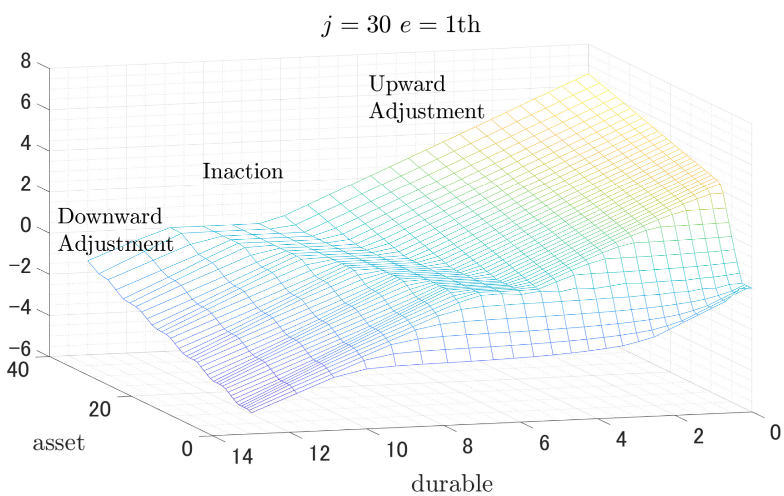


Figure 2: Durable Expenditure Function $x^d = g_j^d(a_{-1}, d_{-1}, e) - (1-\delta^d)d_{-1}$. when age of 55 ($j = 30$), 1st idiosyncratic shock.

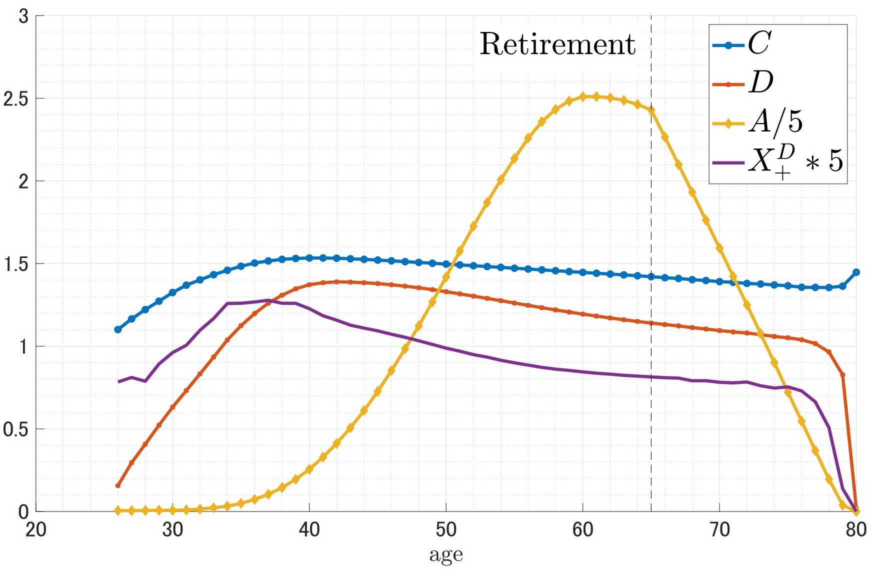


Figure 3: Average Life-cycle Profiles: the Non-Durables, the Durables Stock and Asset
Average life-cycle obtained from stochastic simulation. Each generation consists of 10, 000 households.

while the durable expenditure profile is scaled up. Due to the extensive margin the individual profiles show some spikes over the life-cycle but the spikes in individual level are canceled out in aggregation. Therefore, the Figure 3 looks smooth despite the presence of the discrete choice.

The Figure 3 shows that the average of the households increase the non-durable c and durable consumptions d. The growth of the durable consumption d is more persistent than non-durables c because of the Stone-Geary utility function. Since the middle-age households become richer in both earnings and assets, they buy more luxurious durables. Due to this effect, the baseline model replicates the hump-shaped positive durable expenditure x^d profile. After the age of 40, the average of both consumptions continue declining steadily toward the near end of life. At the end of the life, the dying households substitute the durables with the non-durables and increase the non-durable consumption but decrease durables expenditure. The average households start accumulating the liquid asset a around the age of 35. In their middle-age, the liquid assets a sharply rise and hit a peak before the retirement age. After the retirement the households decumulate the assets since social security is less than the average of the labor earnings,.

These life-cycle profiles turn out to be important for short-run responses to the anticipated consumption tax hike. I will show that while the young do not exhibit the strong stockpiling of the durables in response to the anticipated hike, all the other generation hoard the durable well. I will discuss this again later in the subsection 8.2.4.

Also, it is worth reporting the wealth distribution in my baseline model and from the observation. The wealth distribution I refer to is reported by Kitao and Yamada (2019). They use the

	1st	2nd	3rd	4th	5th	top10%	top1%
Data (2014)	0.3%	3.7%	9.8%	21.3%	64.9%	45%	10.2%
Baseline	0.1%	2.4%	12.6%	27.3%	57.6%	35.8%	5.7%

Table 2: Wealth Share owned by each quintile

Data (2014) is the figure reported in Kitao and Yamada (2019). The 1st quintile means the bottom of the distribution.

National Survey of Family Income and Expenditure (NSFIE). The NSFIE is a cross-sectional date which has a very large sample size with $55,000$ to $60,000$ households in each survey year without top-coding. The survey is collected every five year since 1959. This paper compares with data in 2014 because it is the latest one in Kitao and Yamada (2019). In particular, I compare wealth share from their report with the asset share in my model economy for three reasons. First, their definition of the household wealth is the sum of financial assets and thus does not include either real assets or durables. Second, they also exclude debt associated with purchases of real estate. In my model economy, the borrowing is strictly prohibited, and therefore the net assets coincide with wealth. Third, they report the share of the wealth but not that of net wealth.

Table 2 is the wealth share both in the model and the NSFIE. Overall, the distribution generated from the baseline model matches the observed wealth distribution well. It is noteworthy that Japanese wealth share is much less concentrated than that of the U.S. Since common difficulty is to reproduce the fat right tail of the wealth distribution, our model also misses right tail of the distribution.[17] Also note that my baseline model does not incorporate adjustment frictions typically used to match the wealth distribution such as heterogeneous discount factor or idiosyncratic shocks to the return. Overall, the baseline model matches the wealth share.

7. Long-Run Effects of the Consumption Tax Change

This section studies influences of the consumption tax hike on life-cycle consumption profiles and distribution in the long-run. Specifically, I will compare two stationary equilibria under the two consumption tax rate, 5% and 8%. 5% consumption tax rate was the Japanese consumption tax rate until 2014 March, and 8% was between 2014 April and 2019 September.

7.1. Intergenerational Effects

In figure 4, solid lines are the profiles with the consumption tax rate of 5% and dashed lines are the profiles with $\tau^c = 8\%$. The figure demonstrates both the non-durable and durable consumptions profile are shifted downward almost in parallel. These observations imply that burdens of

[17]For the survey of the wealth distribution literature, for example, see De Nardi and Fella (2017) and Benhabib and Bisin (2018).

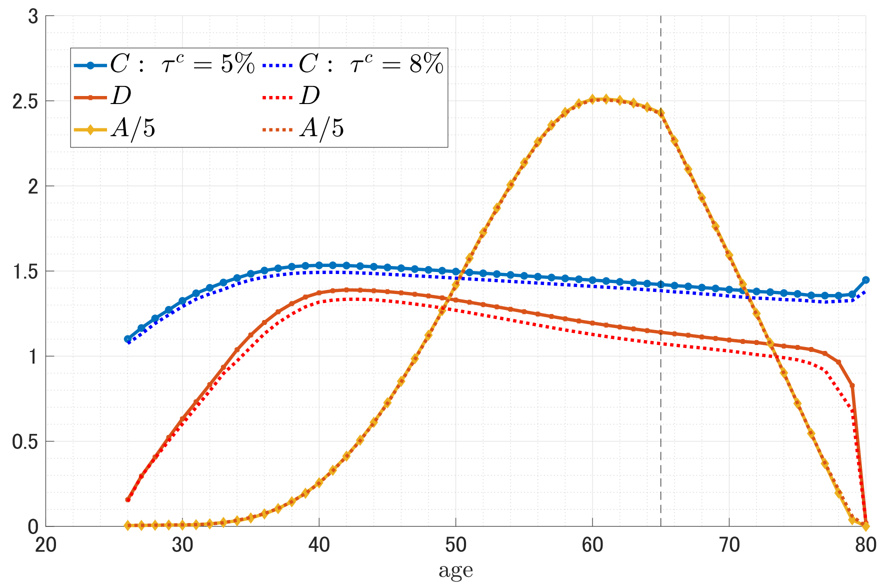


Figure 4: Life-cycle Consumptions Profile in response to Consumption Tax Hike. Solid lines are when $\tau^c = 5\%$ and dotted lines are when $\tau^c = 8\%$.

the consumption tax on the consumptions are borne by all the generations fairly equally in the long-run. Also, as known in the literature, consumption tax change in the long-run do not affect asset accumulation in my baseline model as well. This is because the intertemporal relative price remains constant in the stationary equilibrium.

7.2. Cross-sectional Effects

Next, I am interested in the cross-sectional effects in this model. In the literature, it has been controversial whether or not fundamental tax reform which replaces current complex income tax with a flat consumption tax induces exacerbate inequality.[18] Regarding the tax reform, there are two policy changes: (i) an increase in consumption tax rate and (ii) elimination of the income tax. This section focuses on the former effect with a model of the durables.

Figure 5 shows distributional changes of consumptions against the consumption tax hike in the long-run. A left panel shows the changes in the non-durable distribution and a right panel shows that in the durable distribution. Both distributions see the larger impacts in the right than left, and thus result in being more right-skewed. This is because the poor and have stronger incentive to maintain the level of consumptions than the rich. The resulting right-skewness has a potential policy implication that the consumption tax affects the rich more than the poor in the long-run. In fact, standard deviation of non-durables and durables decrease by 2.81% and

[18] For instance, Ventura (1999) and Altig et al. (2001) argue the tax reform causes further inequality in earning and wealth and the poor lose with the flat tax, whereas Correia (2010) argue opposite.

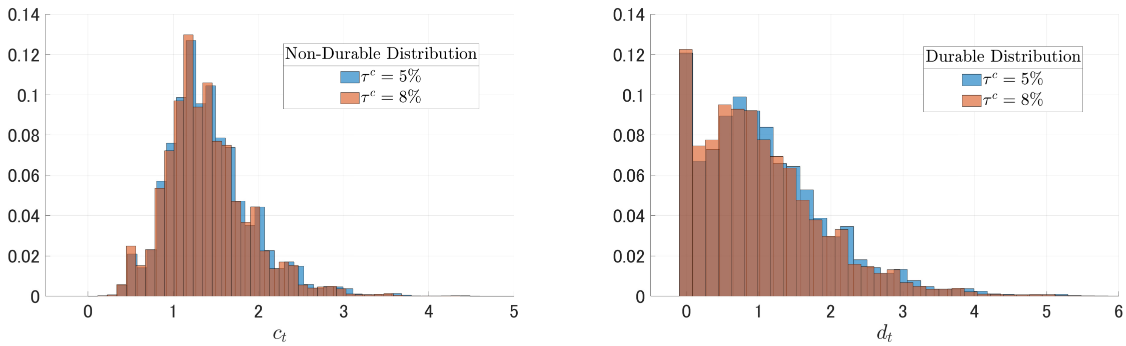


Figure 5: Changes in the Stationary Distributions in response to the Consumption Tax Hike: Left Non-Durable, Right Durble.

2.71% respectively, implying that the increase in the consumption tax decreases the consumption inequality. Regarding the change in asset distribution, there was no change and thus I do not display it here.

8. Short-Run Impacts: Partial Equilibrium

The focus of this paper is on the study of stockpiling behavior in response to the anticipated consumption tax change. The analysis of the stockpiling in response to the anticipated consumption tax changes is implemented by solving the perfect foresight path. First, I test whether the baseline model can replicate *dynamic pattern of empirical tax elasticities*.

I assume the partial equilibrium for the perfect foresight path in this section. That is, the economy faces constant prices (r, w) over the sample periods. These prices (r, w) are taken from the prices at the initial stationary. This assumption significantly reduces the computational burden. I show the results from the general equilibrium in the next section.

8.1. Tax Elasticities

8.1.1. Taxable Spendings

Figure 6 compares the elasticity of taxable spendings $(X_+^D + C)$ from the baseline model and the empirical result reported in Baker et al. (forthcoming). I assume that tax hike is announced before the $t = 1$ and implemented $t = 4$ in the model.[19] Since their data frequency is monthly and

[19] As will be clear in the next subsection, the announcement of the tax hike has a negative income effect. But we do not see the effects in the Baker et al. (forthcoming) result because local governments had different lags between announcement and implementation of the tax change in their sample. In this way, empirical result mutes the negative income effects. By assuming the announcement before $t = 1$, I also mute the negative income effect in the simulation period shown.

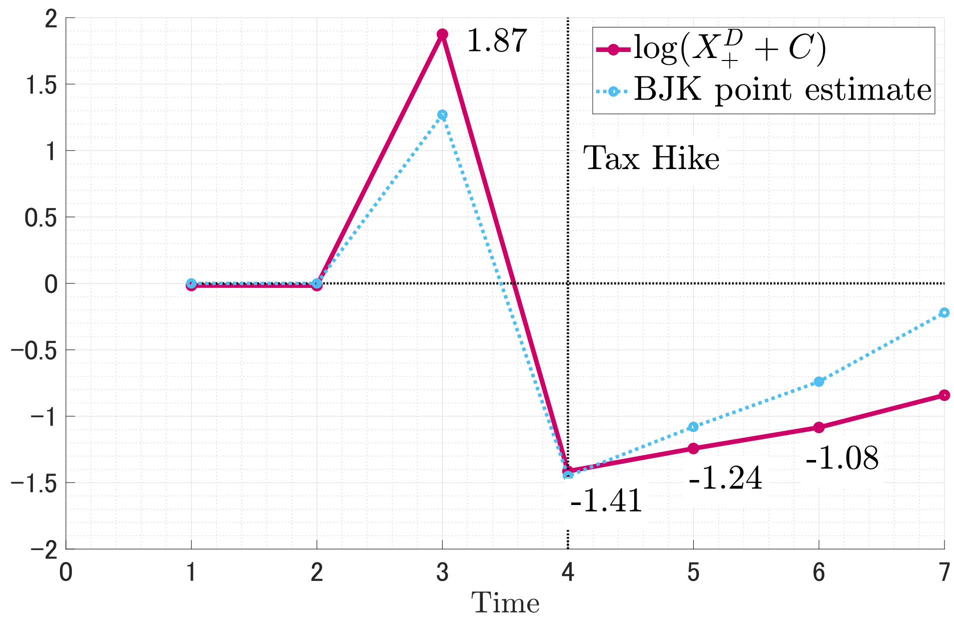


Figure 6: Tax Elasticity of Taxable Spendings ($X_+^D + C$)

BJK refers to the point estimate in Figure 1 also from Baker et al. (forthcoming)

my model frequency is annual, I do back-of-envelope calculation for the frequency adjustment.[20] Figure 6 shows that the baseline model replicates both dynamic pattern of tax elasticity and levels of these values.

First, the baseline model replicates the dynamic pattern of the empirical elasticity. Key dynamic patters of the empirical tax elasticity are two fold. First, the empirical tax elasticity spikes up only in period 3 but not in period 1 and 2. Second, the empirical elasticity plummets in period 4 and slowly recover to the new stationary equilibrium level. The baseline model exactly replicates dynamic pattern.

Second, the baseline model is roughly consistent to the reported point estimate and all the values of the model-implied elasticity falls within empirical 95% confidence interval. It is notewothy that these moments in the model are not targeted in calibration. The model sees some discrepancies in the elasticity. A potential reason for this discrepancy is compositions in sample. Since Baker et al. (forthcoming) uses Nielsen which mainly collects data on groceries and sundries, their sample set do not contain many of typical consumer durables such as autos, appliances, furniture etc. Thus, the share of the durables in their sample must be smaller than aggregate level share, which dampens the elasticity. Since my model is calibrated to the macroeconomic level data, it is natural that my model predicts higher elasticity than the result in Baker et al. (forthcoming).

[20]First, I increase the tax rate by 12% in the annual model that corresponds to 1% increase in a monthly basis. I compute the elasticity $\epsilon_{X_+^D+C}|_{12\%}$ of 12% tax hike and then obtain $\epsilon_{X_+^D+C}|_{1\%} = \epsilon_{X_+^D+C}|_{12\%}/12$.

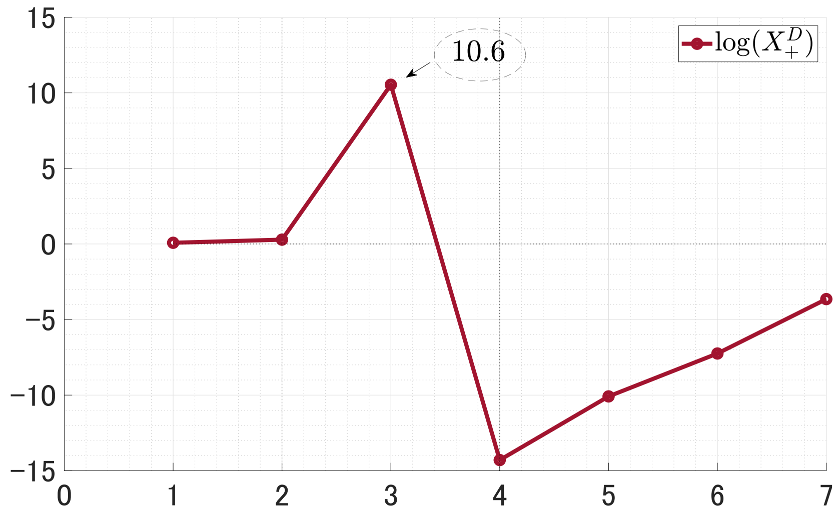


Figure 7: Tax Elasticity of Durable Expenditure (X_+^D) from the baseline model.

Overall, my model replicates the dynamic pattern of the empirical tax elasticity. This is the strong evidence that the baseline model is correctly specified for the consumption tax change.

8.1.2. Durable Expenditure

Next, I compare the tax elasticity of the aggregate durable expenditure with the result from Baker et al. (2019). They estimate the tax elasticity of the auto sales and obtain the value of $8.1 - 12.8$ one month before the tax hike.[21]

Figure 7 shows the elasticity of the aggregate durable expenditure from the baseline model. I did same back-of-envelope calculation as the previous subsection 8.1.1. I find the elasticity one period before the tax hike from the baseline model is 10.6, which again is consistent to the empirical finding in Baker et al. (2019).

8.2. Baseline Experiment: 5% $\rightarrow$ 8%

We then turn to the baseline experiment that mimics Japanese consumption tax in 2014 in which consumption tax rate was raised from 5% to 8%. At the same time, this section examines how the tax wedge help account for the dynamic pattern of the empirical tax elasticity discussed in the previous subsection 8.1.1. To investigate the roles of frictions, I compare the baseline model with a model without the tax wedge, where $q = (1 + \tau^c)$.

In the following experiments, the economy is assumed to be in the stationary equilibrium in the first period, the government announces in the beginning of the second period that the

[21] 8.1 is from Column (3) in Table 2 and 12.8 comes from Table 3. As they discuss timing issue of purchase and registration, I sum up to 9.05 and 3.70 in Column (1), and obtain the value of 12.8.

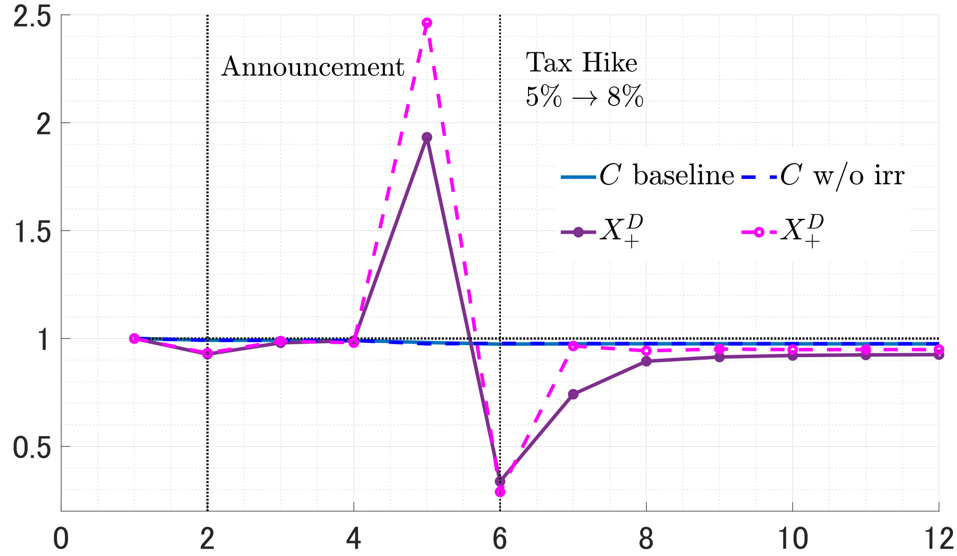


Figure 8: Consumption Tax Hike 5% → 8%

The economy start at stationary equilibrium at $t = 1$. In beginning of $t = 2$, the government announces that it will increase the tax in $t = 6$. Solid lines depict baseline result and dashed lines show results of a model without irreversibility constraint. The values are normalized by the initial stationary equilibrium values.

consumption tax is increased in the sixth period, and the households fully understand this announcement.

Figure 8 shows the result of the experiment in which consumption tax is raised from 5% to 8%. All the variables are normalized by the initial stationary equilibrium values (e.g. non-durable consumption in the figure in period t is C_t/C_1). The solid lines depict dynamics of one with the partial irreversibility (baseline) and dashed line show that in the model without the tax wedge, that is when $q = 1 + \tau^c$. Regarding the dynamics of the durable expenditure, I report $X^D_+ \equiv \sum_j \int_{x^d>0} x^d \mathrm{d}\mu_j$.

In the Figure 8, the non-durables stay almost constant in both models. Also, the both models predict a large durable purchase right before the tax hike $t = 5$ and a large drop in the durable expenditure in common in the period of the tax hike, implying that the stockpiling is due to short-run intertemporal substitution. The two models, however, exhibit distinct predictions in speed of the recovery after the tax hike and the magnitude of stockpiling in durable expenditure X^D_+ in fifth period.

8.2.1. Slow Recovery

Looking at the durable expenditure X^D_+ after the tax hike, it can be confirmed the baseline model exhibits gradual recovery. This is because of (S,s) nature resulted from the tax wedge,

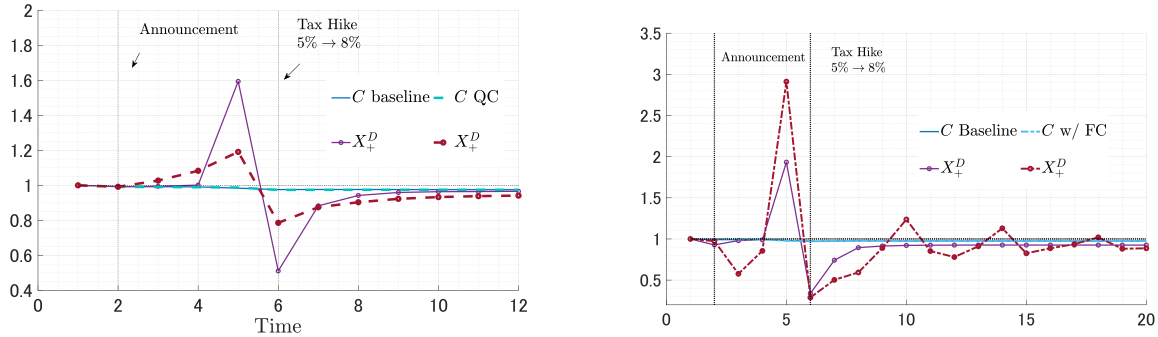


Figure 9: Left: Comparison with the Quadratic adjustment cost model. Right: Comparison with Fixed Cost model.

The functional form of the quadratic adjustment cost is $QC(d, d_{-1}) = \frac{QC}{2}[d - (1-\delta^d)d_{-1}]^2$, and that of the fixed cost is $F(d, d_{-1}) = \mathbb{1}_{x^d \neq 0} F^d (1-\delta^d)d_{-1}$.

which works the way the irreversibility constraint functions. That is, once households accumulate enough amounts of durable stocks before the tax hike, the they do not adjust the durables for some periods afterwards. This keeps the households to wait inactively until the stockpiled durables depreciate enough. The fact that the partial irreversibility constraint increases the persistence of aggregate expenditure is known in the literature (e.g. Lam (1989)). A new finding here is that higher persistence comes from the slow convergence only after the tax change (or shock) but not before it. That is, persistence is asymmetric before and after the tax change. As discussed, this asymmetric persistence is key observed pattern in empirical tax elasticity of taxable spendings.

Readers may wonder if other investment frictions, for instance fixed-cost and quadratic adjustment cost, works in the same way. This concern is critical because if a model with other fictions behaves in the same manner, the researcher cannot identify the model correctly. To resolve the concern, I construct a model that added to the baseline model (i) quadratic adjustment cost, $QC(d, d_{-1}) = \frac{QC}{2}[d - (1-\delta^d)d_{-1}]^2$ or (ii) fixed-cost,

$$F(d, d_{-1}) = \begin{cases} F^d(1-\delta^d)d_{-1} & \text{if } d \neq (1-\delta^d)d_{-1} \\ 0 & \text{otherwise} \end{cases}$$

which follows Berger and Vavra (2015). QC and F^d are fixed parameters that governs degree of adjustment cost respectively.[22]

Figure 9 shows the results from two models. The left panel compares the baseline model and the model embedded with the quadratic adjustment costs. The quadratic adjustment cost model exhibits slow recovery in the aggregate positive durable expenditure X_+^D but gradual stockpiling in third and forth period which is inconsistent to Baker et al. (forthcoming) for aforementioned

[22] $QC = 0.09$ taken from Cashin (2017) and $F^d = 0.05$ taken from Berger and Vavra (2015).

reason.

The right panel of Figure 9 shows the results from the fixed-costs model. This model also generates slow recovery but the aggregate durable expenditure X^D_+ dips in third and forth period which is also counter-factual. In addition, the fixed-cost model exhibits overshooting in tenth, fourteenth and eighteenth periods due to negative persistence that fixed-cost generates.

With these properties in the quadratic adjustment and fixed-cost, it seems that the tax wedge (or the irreversibility constraint) is the best investment frictions for the study of the consumption tax change.

8.2.2. Overprediction

The baseline model predicts lower stockpiling in the $t = 5$. Alternatively a model without the tax wedge generates larger stockpiling. It is due to the unrealistic revenue from the tax system in the model without the wedge. If ignoring the tax wedge, the budget constraint is simply

$$(1 + \tau^c)[c + x^d] + a = (1 + r)a_{-1} + y_j(e) + b$$

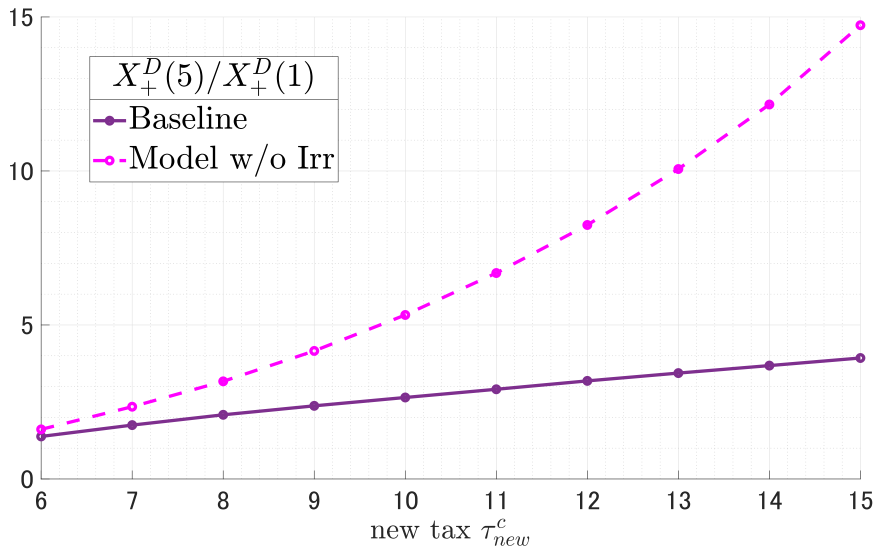
regardless of sign of x^d. Therefore, if the household sells durables (i.e. $x^d < 0$), the household receive $\tau^c x^d$ as a revenue on top of x^d. This becomes more problematic on the dynamics. To demonstrate the problem, consider a simple example. Suppose $\tau^c_{\text{today}} = 5\%$ today and $\tau^c_{\text{tomorrow}} = 8\%$ tomorrow. Importantly, the households in a model without the tax wedge can make an unrealistic revenue by doing the following speculation. That is, if the households buy the durable today and sell it tomorrow, they will make a profit due to tax differential $\tau^c_{\text{tomorrow}} - \tau^c_{\text{today}} = 3\%$. This revenue from the tax differential partly offsets the cost of holding the durables i.e., the depreciation and the cost of large utility fluctuation due to the stockpiling. In this way, the unrealistic revenue induces the speculative stockpiling in the model without the tax wedge.

Notice that this problem is more critical as (i) the tax differential becomes large, (ii) the depreciation rate is low or (iii) the utility cost of fluctuation is low. For instance, if a researcher construct a monthly model, she would set δ^d very low. This implies that choice of frequency of the model and coverage of the durable goods critically matter. Or, if the researcher introduces very long-lasting goods (e.g., housing) into a model, very low δ^d is also set.[23] Then, the cost of holding of durable in a model decreases and therefore the aforementioned speculation problem becomes more critical. My model frequency is annual and the model does not include housing so far. That is, the potential problem due to misspecification is more critical and I view my result as a lower bound of the problem.

Cashin and Unayama (2016b) and Cashin (2017) estimate intertemporal elasticity of substitution $1/\sigma$ using a representative household model with durables but without the tax wedge. If true data generation process is my baseline model, their models overpredict the stockpiling behavior due to the misspecification. This overprediction must lead to a bias in their estimation results. For instance, Cashin and Unayama (2016b) should have the lower IES than true value due to the

[23]The purchase of houses is subject to consumption tax in Japan.

Figure 10: Stockpiling over $\tau^c_{\text{next}} = 6, 7, \ldots, 15\%$.



$\tau^c_{\text{old}} = 5\%$ here. τ^c_{new} is the new tax rate after $t = 6$ and changed $\tau^c_{\text{new}} = 6, 7, \ldots, 15\%$.

misspecification.

8.2.3. *Stockpiling with Different Magnitude of the Tax Hike*

The previous subsection discussed the speculative stockpiling largely depends on the degree of the tax hike. This subsection quantitatively study how much the stockpiling behavior can be biased due to the misspecification problem with different scale of the tax hike.

Before demonstrate it, let be clear about how this section examines the speculation. As discussed in previous sections, the stockpiling in the benchmark model takes place (i) in the form of durables only (ii) only one period before the tax hike. Thus, the Figure 10 reports $X^D_+(5)/X^D_+(1)$ for different new tax rates $\tau^c_{\text{new}} = 6, 7, \ldots, 15\%$. The Figure 10 reports results of both baseline model and the model without the tax wedge.

In the Figure 10, two models generate clearly distinct predictions. On the one hand, the baseline model predicts relatively moderate and almost linearly increasing stockpiling in the new tax rate. On the other hand, the model without the tax wedge shows far large and non-linearly increasing stockpiling. Note that since the scale is $X^D_+(5)/X^D_+(1)$, 2 in the y-axis, for instance, means double but not 2 % increase. This large difference cannot be ignored for the analysis of tax hike.

This analysis suggests an application of this work to future fiscal problem in Japan. Government of Japan is advised by IMF to increase consumption tax rate to 20% in the end (See Georgieva (2019)). Also, macroeconomic research (e.g. Braun and Joines (2015) and Hansen and İmrohoroğlu (2016)) suggest the need of further consumption tax increase to around 30%. Thus,

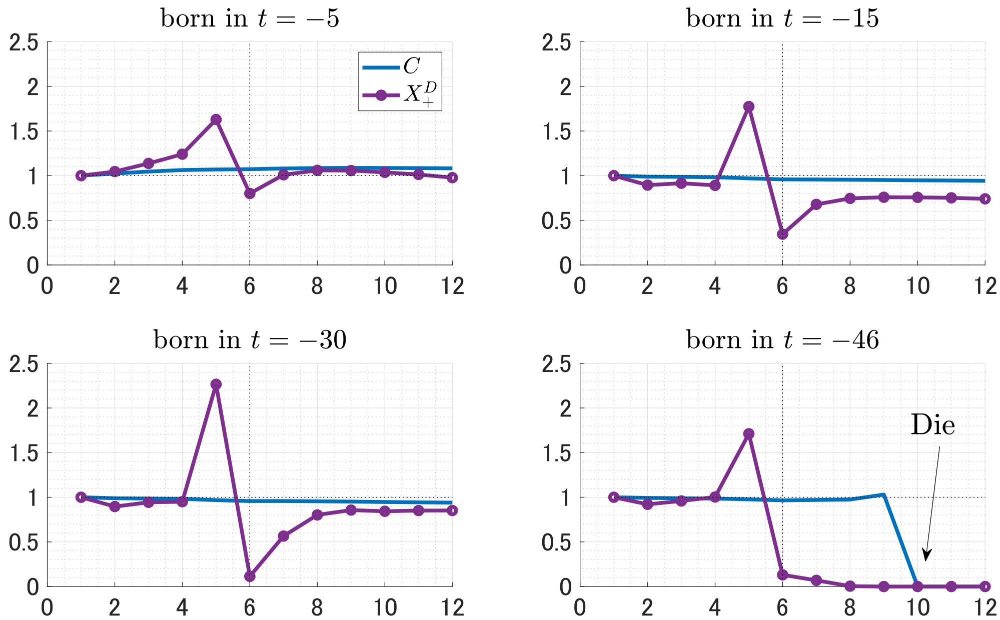


Figure 11: Age-Dependent Responses to the Consumption Tax Hike 5% $\rightarrow$ 8%

it is not unrealistic that Government of Japan need to implement large scale consumption tax hike at some point. To the credibly assess the large scale consumption tax hike, I argue the model with the tax wedge is necessary.

8.2.4. Age-Dependency

There are, in theory, several age-dependent effects in this dynamics. First, as shown in Figure 3, different generations have different amount of assets. Cash-on-Hands are essential for the stockpiling and thus the life-cycle asset profile determines the degree of stockpiling for each generation. Second, different generations have different degree of needs of the durables. For instance, most of the young need the durables immediately because they do not own them and thus have the high marginal utility of the durables. The middle-age and old have weaker motive in this respect. Third, different generations pay the higher consumption tax rate for different duration of periods. That is, the young live longer under the new tax rate than the old and thus they pay the the high tax rate longer. This, in turn, implies the young incurs the heavier burden of the tax hike.

Figure 11 shows four generations consumption spending responses. A top-left panel in Figure11 illustrates the response of those who are born in $t = -5$ (i.e. age of $11 + 25 = 36$ in $t = 5$). This generation of households show relatively weak response to the anticipated consumption tax hike. There are two reasons for this. First, the young have high marginal utility of the durables soon and purchased large amount of durables not only in $t = 5$ but also $t = 1, 2, 3, 4$. That is, the denominator of the variable shown $X^D_+(t)/X^D_+(1)$is large. Second, this generation of the households do not own liquid assets a much, which prevent them from stockpiling large amount of the durables. As a result, this generation of households do not show the strong stockpiling in the panel. Next, a top-right panel is expenditure responses of those who are born $t = -15$ (i.e. who are age of $21 + 25 = 46$ at $t = 5$). This generations of households illustrate strong stockpiling behavior for two reasons. First, since the average of this generation of households are asset-wealthy, they afford the durable more freely than the young. Second, this households already accumulated enough durable stocks and thus did not have strong needs for the durables in period $t = 1$ unlike the young generation. Therefore, this households stock up the large amount of durables for the short-term intertemporal substitution motive in $t = 5$. A bottom-left figure shows another middle-age generation who are born in $t = -30$ (i.e. who are age of $36 + 25 = 61$ at $t = 5$). The responses of this middle-age generation in $t = 5$ is stronger than those of who are born in $t = -15$ (top right). This is because they are very rich in asset and thus buy the luxurious durables more than those who are born in $t = -15$. Finally, a bottom-right figure demonstrates how the old (who are age of $51 + 25 = 76$ in $t = 5$) react to the tax hike. Because of the high durable depreciation rate, this old households still stockpile the durables to a certain degree.

Overall, Figure 11 confirms that stockpiling behavior is highly age-dependent and most of the aggregate stockpiling behavior is explained by the middle-age generations.

8.2.5. *Welfare Analysis*

Next, I analyze welfare changes over the transition with consumption equivalent variation (CEV, hereinafter). The welfare evaluation over the transition is of the first order interest in this paper. The tax-induced inflation effect, for instance, only appears over the dynamics.

Figure 12 shows the welfare changes of two generations, age of 30 at $t = 1$ and age of 45 at $t = 1$, along asset dimension and idiosyncratic shock over the transition. Overall, all the households in the Figure 12 incur the welfare costs, simply because the policy change we consider here is tax hike with no transfer. What this paper is interested in here is which households loose more.

First, lines in both left and right panels of the Figure 12 show that asset poor households lose less. This is because the tax-induced inflation effect. Asset wealthy households see large decline in their assets value, and thus reduces the consumption more than the asset poor. In other words, the consumption tax hike is a policy tool to tax preexisting wealth. Also, both of the panels confirms that highly productive households lose more as well. This is negative income effect. That is, given the high persistence of labor productivity, the highly productive households lose the future potent high wage. This results in the larger decline in the consumption of high earners. These analysis does not support regressivity of the consumption tax burden, which many of popular discussions argue.

Second,I find that young households potentially lose more by comparing two panels in 12. That is, the young households in the left panel see more than 2.7% decline in the CEV while the middle-age households in the right panel see less than 2.7%. This is because the young live longer

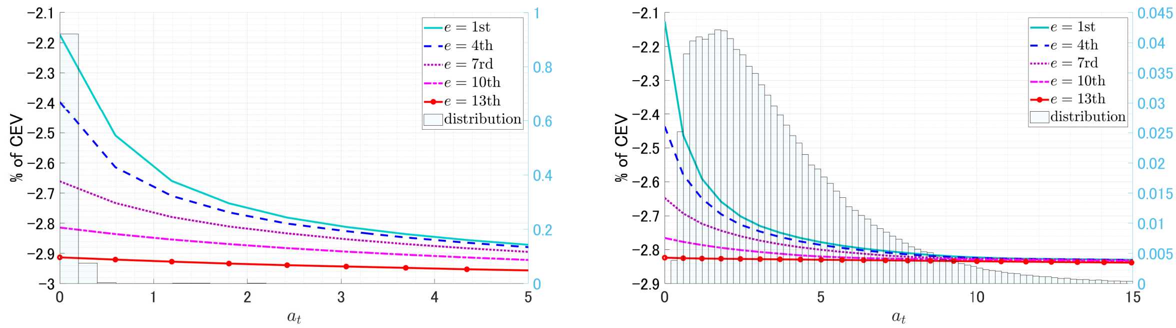


Figure 12: Welfare Changes by Consumption Equivalent Variation

in the remaining life and thus see a larger decline in the present value of labor earnings.

Third, these lines only shows the decline in the welfare given state spaces (a, d, e, j), but does not reflect the distribution. Thus, I overlay the distribution on the both of panels. The distributions clearly show that there is no asset wealthy young households in the model thus only a few young households loose -2.8% in CEV while many of middle-age households accumulate the asset and thus face -2.8% decline in CEV.

Overall, welfare analysis shows burden of the consumption tax is highly heterogeneous, and asset wealthy and highly productive young households incur the largest burden of the consumption tax hike.

8.3. Consumption Tax Decrease: Asymmetricity

This section examines a counter-factual experiment in which the tax is decreased. The result of this analysis can be insightful for the recent policies implemented in Germany and U.K in 2020 in order to combat the on-going pandemic crisis. As the model features the high non-linearity, this section confirms that the tax decrease is highly asymmetric to the tax hike.

Figure 13 shows the results of when consumption tax is decreased from 8% to 5%. For the comparison, I also depict the result when tax is raised from 5% to 8%. The tax decreases have different effects. As the households know the future tax decreases, they gradually decreases X^D_+ to postpone the purchase by letting the durable stock depreciate. Then, they recover the stock of durables once the tax is decreased in period $t = 6$.

Since the tax change induces the short-run intertemporal substitution regardless of whether tax is increased or decreased, both of the tax change seem to cause an increase in the durable expenditure. But, while the tax hike brings the expenditure forward, the tax decrease put it off. Also, the scale of durable expenditure is large when tax is raised even though this case results in the reduction in the real valued future income.

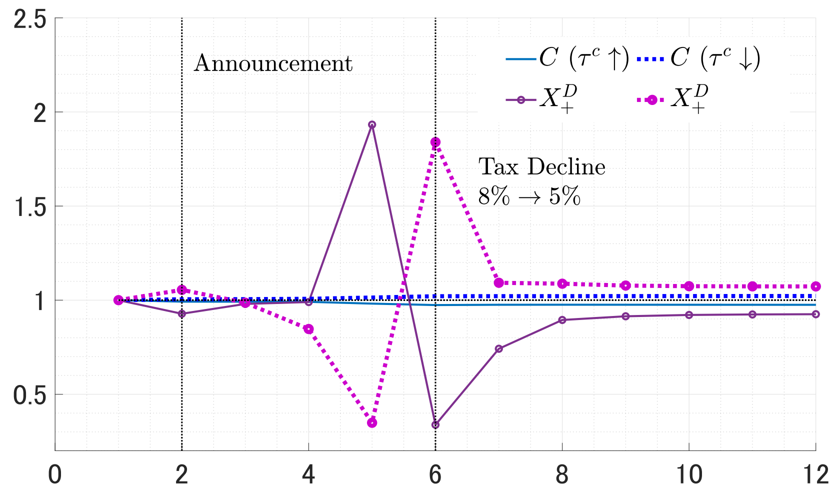


Figure 13: The Tax Hike vs Decrease 8% $\rightarrow$ 5%.

8.4. One-Time vs Two-Times

Many of the economic downturn are persistent. When considering the tax hike as the aggregate demand stimulus policy in the recessions as Feldstein (2002) and Hall (2011) proposed, the natural concern is whether the policy simply induces the short-run intertemporal shifting of the households expenditures. If the consumption tax hike induces the short-run intertemporal demand shifting only, the economy may see the plummet of the households expenditure in the midst of the recovery from the crises. Thus, a natural question is how to design the policy so that it causes longer intertemporal shifting.[24]

To answer the question, this section compares two experiments: an experiment with one time tax hike and the other with two tax hikes. The idea borrows from the original proponent of the unconventional fiscal policy, Feldstein (2002). If the government keeps increasing the tax successively, the households do not stop purchasing the durable right after the first tax hike.

Figure 14 simulates the both experiments. In the one time hike case, the government increases the tax to 8% in $t = 6$. The effects of the tax hike is similar to previous section. When the government increases two times, I assume it first increases to 6.5% in $t = 6$, and then 6.5% to 8% in $t = 7$.

Figure 14 illustrates the effects of two tax hikes. The stockpiling behavior in the two times hikes case is a bit weaker than one time. However, importantly, the drop in the durable expenditure after the tax hike gets (i) moderate and (ii) is postponed to the future. This result imply that if the government keep increasing the tax hike until the end of the recession, it can postpone the timing of the drop in the households expenditure.

[24] Also, Government of Japan increased consumption tax rate with two steps: from 5% to 8% in 2014 and 8% to 10% in 2019. This Japanese experience is one motivation for this experiment.

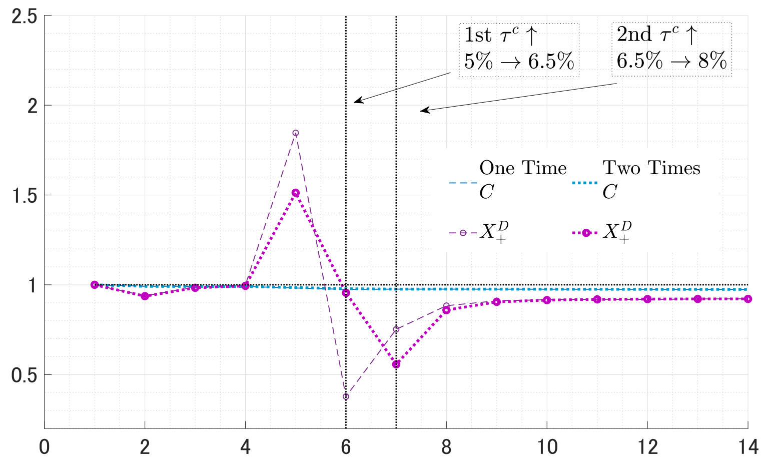


Figure 14: One Time Hike vs Two Times Hikes.

In one time case: the government raises the tax rate 5% to 8% in $t = 6$. In two times case: the government raises it 5% $\to$ 6.5% in $t = 6$ and 6.5% $\to$ 8% in $t = 7$.

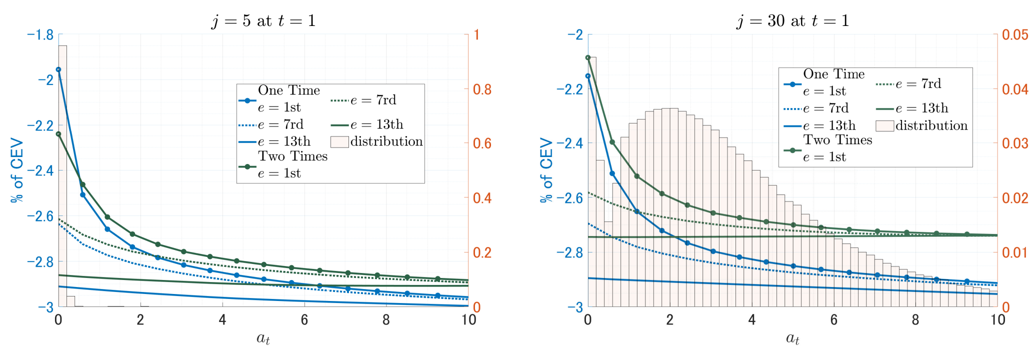


Figure 15: Welfare Costs of One Time Hike vs Two Times Hikes.

In one time case: the government raises the tax rate 5% to 8% in $t = 6$. In two times case: the government raises it 5% $\to$ 6.5% in $t = 6$ and 6.5% $\to$ 8% in $t = 7$.

Also, welfare analysis in Figure 15 indicates the two-times tax hike scheme is welfare improving for almost all of the households except young borrowing constrained households. The welfare gains comes from the fact that the households change the durable stock less in the two-times tax hike case. Thus, they do not incur the utility costs of violation of the consumption smoothing due to the large stockpiling behavior.

9. Short-Run: General Equilibrium

My baseline tax hike experiment is to raise the tax by 3% and this experiment is arguably a macroeconomic-scale tax policy change. Therefore, it seems natural to consider how macroeconomic variables including prices respond to the policy change while I have discussed the consequences of the anticipated changes in the consumption tax with the partial equilibrium. This section finally shows the result from the general equilibrium and compare the two. Interestingly, it turns out that the equilibrium assumption does not alter the results. This section discuss why two equilibrium assumptions predict the very similar consequence.

Figure 16 compares the dynamics of partial and general equilibrium. Overall, the dynamics of the two look very similar. There are two main reasons that the general equilibrium does not change the result: two asset structure and low interest elasticity of the aggregate durable expenditure.

First, a key reason is that households have two sources of savings, as explored in Berger and Vavra (2015). That is, if the agents have only one asset as in Khan and Thomas (2008), the good market clearing condition $Y = C + I_k$ implies that a change in I_k propagates a change in C. At the same time, C is governed by the household smoothing motive in the equilibrium. Thus strong households consumption smoothing motive smooths the investment I_k through the good market clearing condition or large price adjustment. By contrast, if the households have two assets, a lumpiness in one type of assets may not be smoothed by the consumption smoothing motive much because households now have an additional measure to smooth consumption. In this way, two asset models weaken the irrelevance result.

The second reason is a very low interest rate elasticity of the aggregate durable expenditure in my baseline model. This implies that the movement in the interest rate does not change the aggregate durable expenditure. This further means that endogenizing interest rate does not alter the model's prediction of the aggregate durable expenditure. In other words, whether partial equilibrium or general equilibrium does not matter. In my benchmark case, the elasticity is as low as 0.59. On the contrary, many of fixed-cost models generate the elasticity of $50 - 1,075$.[25] Empirical literature on the durables shows it is between $1.1 - 5.0$ (Baker et al. (2019), Mian and Sufi (2012)).

Successful matching is crucial not only for the equilibrium concept but also for the tax change

[25] see Koby and Wolf (2020) and Winberry (2020) for the lumpy investment, and McKay and Wieland (2019) for the lumpy durables.

experiment because the tax change has a profound connection with the change in the interest rate as Euler equation (1) shows. The discussion on the Euler equation does not necessarily depend on the completeness of the market because the focus is only on the right hand of the equation. Also, even if adding the durables into the model, the right hand of the Euler equation holds roughly same as long as preference is either additive separable or Cobb-Douglas. Thus, the tax change has a very similar implication to the interest rate in my baseline model as well. As a result, replicating the low elasticity in line with the empirical studies is key for the main focus of this study.

The baseline model produces the very low interest elasticity for three reasons: irreversibility constraint, high durable depreciation rate, and life-cycle. I will discuss them in detail.

First, it is known that the irreversibility constraint does not cause large spikes at the durable expenditure, but the fixed-cost does. Thus, the discrete choice due to the irreversibility constraint induces only a small movement in response to the changes in the interest rate. Compared to the irreversibility constraint model, the fixed-cost model tends to generate the large interest elasticity. This is because if the households in the fixed cost model decide to adjust their durables, they must have done much enough to be worth paying fixed-cost.[26]

Second, since I do not include housing in my analysis, the depreciation of the durables is higher than the value typically used in the literature. As House (2014) discusses, the higher the depreciation is, the lower the interest sensitivity is. This is because, if the depreciation is high, the households make a durable spending for a short-term use. Thus, the durable expenditure is frequent and small-scale. This, in turn, reduces the sensitivity of the durable expenditure to the interest rate.

Finally and most importantly, it turns out that life-cycle motives dampens the interest rate elasticity. This is because there is a mass of households who adjusts durables regardless of the change in interest rate, which reduces the interest sensitivity of the durable expenditure in a model. For instance, the young buy the durables because of the infinitely high marginal utility while the old do not buy the durable because they will die soon. In this way, the model implied interest elasticity of the aggregate durable expenditure is dramatically lowered.

10. Concluding Remarks

This paper is, to my best knowledge, a first paper that studies the stockpiling of in response to the anticipated future consumption tax changes using a life-cycle incomplete market general equilibrium model of durables with the partial irreversibility constraint. The model performance is confirmed with relatively successful matching of the wealth distribution and the interest rate

[26] Lumpy investment literature evolved with fixed-cost models because fixed-cost model can generate large investment spikes but the irreversibility cost cannot. But in a life-cycle model, the young have an incentive to make a large expenditure. Thus, I predict that life-cycle with irreversibility constraint does not necessarily contradict with the observed frequency of the large investment spikes.

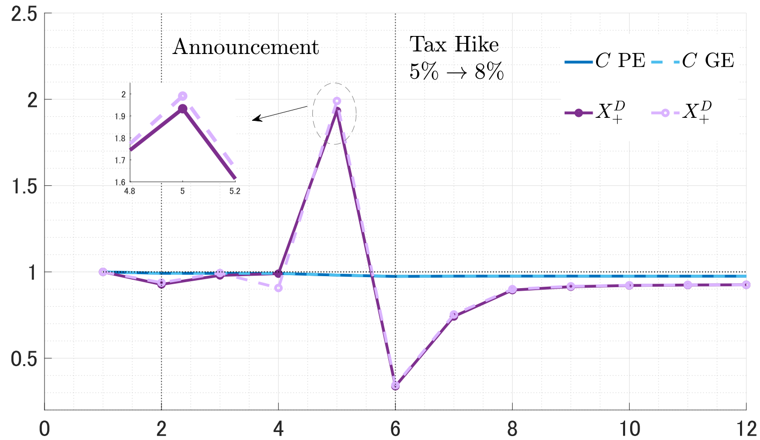


Figure 16: Partial Equilibrium and General Equilibrium

elasticity of the aggregate durable expenditure. Using this model, I unravel the critical importance of the partial irreversibility constraint for the analysis of the accurate stockpiling behavior. My findings are as follows. First, if a researcher misses the irreversibility constraint, the model would significantly overpredict the stockpiling behavior. Second, the model successfully reproduces the slow recovery in the aggregate durable expenditure after the tax hike which empirical studies on the durable stimulus policy showed. Third, the tax decrease influences the households expenditure responses asymmetrically.

Also, I find that heterogeneity and life-cycle matters for the welfare consequences. Since the tax-induced inflation decreases the real values of the preexisting assets, durables and the earnings, the richer households loses more from the consumption tax hike. In other words, the consumption tax hike on the transition is progressive. In particular, these effects works for the young strongly. Thus, it is, if any, the wealthy young that incurs the costs of the tax hike the most.

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11. Appendix A: Computation

11.1. Nested EGM Algorithm

This section explains algorithm of the Nested EGM used in the paper. The algorithm is originally developed by Druedahl (2020) and I extend it so as to incorporate the irreversibility constraint into the model. The critical advantage of this algorithm is the *nesting* assumption which reduces the dimensions of the maximization problem in choice-specific value functions. I start with the exposition of the nesting assumption. For simplicity, I focus on the solution of stationary equilibrium where prices (r, w) and the taxτ^c are fixed. Extending the algorithm to the dynamics is straightforward.

Also, adding fixed-cost to the model is no additional cost for the computation. Thus, I add the following form of fixed-cost here:

$$F(d, d_{-1}) = \begin{cases} F^d(1-\delta^d)d_{-1} & \text{if } d \neq (1-\delta^d)d_{-1} \\ 0 & \text{otherwise} \end{cases}$$

where F^d is a parameter. This is a common functional form in the lumpy durable literature (e.g., Berger and Vavra (2015), McKay and Wieland (2019)).

In order to apply the Nested EGM, we need to rewrite the model in the following way. The notation here from now on follows the old version of Druedahl (2020)[27]. Let m be a cash-on-hand, and which is defined as

$$\begin{aligned}
&m = (1+r)a_{-1} + y_j, \\
&\text{where } y_j = (1 - \mathbb{1}_{j<J^R}) w \kappa_j e + \mathbb{1}_{j<J^R} ss + b.
\end{aligned}$$

where a_{-1} is the asset stocks at the end of previous period and y_j is the either labor earning or the social security depending on the age plus received bequest.

In the beginning of every period, households own a set of $(m, \bar{d}, e)$ and compute

$$\begin{aligned}
m^{up} &= m + (1+\tau)(1-\delta^d)\bar{d} - F^d(1-\delta^d)\bar{d} \\
m^{down} &= m + q(1-\delta^d)\bar{d} - F^d(1-\delta^d)\bar{d}
\end{aligned}$$

where m^{up} and m^{down} are *choice-specific cash-on-hands* for up and $down$ respectively, and $\bar{d}$ is a stock of the durable at the beginning of the period.

Given these cash-on-hands (m, m^{up}, m^{down}), the households compute choice-specific value functions $(v^{inact}(\cdot), v^{up}(\cdot), v^{down}(\cdot))$in the midst of the period. Particularly, I assume that the inaction problem is solved first. This is the assumption *nesting* the timing within a period so that the households first decide how much non-durable consume, and then decide later how much durable.

$$\begin{aligned}
v_j^{inact}(m, \bar{d}, e) = \max_{a \geq 0} \ & u(c, (1-\delta^d)\bar{d}) + w_j(a, (1-\delta^d)\bar{d}, e) \\
\text{s.t. } & (1+\tau^c)c + a = m.
\end{aligned}$$

Given the choice of the non-durable consumption $c^{inact}(\cdot)$, the households choose intensive margin of the durable. When upward adjusting, the households use this consumption function and solve the problem below,

$$\begin{aligned}
v_j^{up}(m, \bar{d}, e) = \max_{d} \ & u(c, d) + w_j(a, d, e) \\
\text{s.t. } & (1+\tau^c)[c+d] + a = m^{up} \\
& c = c^{inact}(m^{up} - (1+\tau)d, d, e) \\
& d > (1-\delta)\bar{d}.
\end{aligned}$$

Notice that the dimension of the maximization is only one, thanks to the nesting assumption.

[27] The title of his old version was "A Fast Nested Endogenous Grid Method for Solving General Consumption-Saving Models."

This significantly reduces the computational burden and we are not bothered by the curse of the dimensionality to solve this optimization problem[28].

When downward adjusting,

$$
\begin{aligned}
v_j^{down}(m, \bar{d}, e) = \max_{d}\ & u(c, d) + w_j(a, d, e) \\
\text{s.t. } & (1+\tau^c)[c+d] + a = m^{down} \\
& c = c^{inat}(m^{down} - qd, d, e) \\
& d < (1-\delta)\bar{d}
\end{aligned}
$$

Also notice that these Bellman equation does not contain $v_{j+1}(\cdot)$. We used instead *post-decision value function* $w_t(\cdot)$ and its domain is different from value function $v_j(\cdot)$. The inclusion of post-decision value function allows pre-computation.

This post-decision value function is defined as

$$
\begin{aligned}
w_j(a, d, e) &= \beta \mathbb{E}[v_{j+1}(m', \bar{d}', e')|e] \\
m' &= (1+r)a + y_{j+1}.
\end{aligned}
$$

We are ready to explain the algorithm.

(i) **Grid spacing**: Space the grids for $a, \bar{d}, m, m^{up}, m^{down}$. In practice, we use the same grid for m^{up} and m^{down} but they are conceptually different[29].

(ii) **Last period problem**: Solve the last period problem.[30] That is, for any $(m, \bar{d}, e)$,

$$
\begin{aligned}
(1+\tau^c)c &= m \\
v_J(m, \bar{d}) &= u\left(\frac{m}{1+\tau^c}, \bar{d}\right).
\end{aligned}
$$

(iii) **Loop for age**: For any $j = J-1, \dots, 1$, repeat the below.

   (i) **Inaction Problem**:

      (i) **Pre-computation**:

[28] In practice, $w_j(\cdot)$ can be a very kinky function due to the discrete choices. Thus, I use many multi-starts and a local-maximization method for this problem.

[29] It is not computationally costly to use a large number of grid points for (a, m) because the inaction problem is solved fast. But an increase in the number of grid points for $\bar{d}$ is very costly.

[30] If solving an infinitely lived agent model, this computation can be also applicable if you set $v^0 = 0$.

(i) **Next Period Values**: For any $(e, a, \bar{d}')$, compute[31]

$$
\begin{aligned}
m' &= (1+r)a + y_{j+1} \\
(m^{up})' &= m' + (1+\tau^c)(1-\delta^d)\bar{d}' - F^d(1-\delta^d)\bar{d}' \\
(m^{down})' &= m' + q(1-\delta^d)\bar{d}' - F^d(1-\delta^d)\bar{d}'
\end{aligned}
$$

(ii) **Interpolations**: Evaluate the value functions on (e, a, d). That is, compute[32]

$$
\begin{aligned}
v_{j+1}^{inact}(e', a, \bar{d}') &= v_{j+1}^{inact}(e', m', \bar{d}'') \\
&\quad \text{where } \bar{d}'' = (1-\delta^d)\bar{d}' \\
v_{j+1}^{up}(e', a, \bar{d}') &= v_{j+1}^{up}(e', (m^{up})', \bar{d}') \\
v_{j+1}^{down}(e, a, \bar{d}') &= v_{j+1}^{down}(e', (m^{down})', \bar{d}')
\end{aligned}
$$

and then take a maximum of the discrete choice

$$
v_{j+1}(e', a, \bar{d}') = \max\{v_{j+1}^{inact}(\cdot), v_{j+1}^{up}(\cdot), v_{j+1}^{down}(\cdot)\}.
$$

and here store the unconditional *next-period* consumption function $c'(e, a, \bar{d}')$ and durable function $d'(e, a, \bar{d}')$.

(iii) **Post-Decision Value Function**: For (e, a, d),

$$
\begin{aligned}
w_j(e, a, \bar{d}') &= \beta \mathbb{E}[v_{j+1}(e', a, \bar{d}')|e] \\
q_j(e, a, \bar{d}') &= \beta(1+r)\mathbb{E}_j[\alpha(c')^{\alpha(1-\rho)-1}(d')^{(1-\alpha)(1-\rho)}].
\end{aligned}
$$

(ii) **EGM**: Apply EGM to the inaction problem. Here, notice $d = \bar{d}'$ is used due to the inaction.

$$
\begin{aligned}
c(e, a, \bar{d}') &= u^{-1}\left(\frac{q(e, a, \bar{d}')}{\alpha(\bar{d}')^{(1-\alpha)(1-\rho)}}\right)^{\frac{1}{\alpha(1-\rho)-1}} \\
m(e, a, \bar{d}') &= (1+\tau^c)c(e, a, \bar{d}') + a
\end{aligned}
$$

The $m(e, a, \bar{d}')$ is the *endogenous grid* for the cash-on-hand.

(iii) **Borrowing Constraint**: This part is standard. Denoting m as an exogenous grid

[31] Notice that $\bar{d}'$ is the durable stock at the beginning of next period, and d is the durable stock at the end of this period. Thus, $d = \bar{d}'$. Also, a is asset stocks at the end of the period.

[32] Regarding $\bar{d}''$, we need to count the depreciation here only for inaction because depreciation for *up* and *down* are already taken into account in m^{up} and m^{down}.

point, if $m(e,a,\bar{d}') \geq m$, then set

$$(1+\tau^c)c = m$$
$$v^{inact}(e,m,\bar{d}') = u\left(c,\bar{d}\right) + w(e,0,\bar{d}')$$

(iv) **Upper Envelop Algorithm (and Interpolations)**: Let ia be the ia-th grid point of grid a. Similarly, ie, im, id are defined as well. We can create the following function,

$$c^*(ie,ia,id,im) = c(ie,ia,id) + \frac{m(im) - m(ie,ia,id)}{m(ie,ia+1,id) - m(ie,ia+1,id)}(c(ie,ia+1,id) - c(ie,ia,id)),$$

where $m(im)$ is im-th exogenous grid point value. Subsequently define $a^* = m - (1+\tau^c)c^*(ie,ia,id,im)$, and then

$$w^*(ie,ia,id,im) = w(ie,ia,id) + \frac{a^* - a(ia)}{a(ia+1) - a(ia)}(w(ie,ia+1,id) - w(ie,ia,id)).$$

Finally, take the max over a as follows

$$v_j^{inact}(ie,im,id) = \max_{ia}\ u(c^*(ie,ia,id,im),d(id)) + w^*(ie,ia,id,im).$$

The obtained choice-specific value function $v_j^{inact}(\cdot)$ here is the globally maximizing choice-specific value function. Also, the consumption function for the inaction problem $c_j^{inact}(\cdot)$ is found here and will be used to solve up and down problems. Note that this procedure does not take so much time, because these maximization are taken only over the candidates that satisfies necessary conditions for maximization (i.e. the Euler equation with inequality and the budget constraint), but not over entire a.

(ii) **Upward Adjusting Problem**: Solve the upward adjusting problem with standard VFI.

$$\begin{aligned} v_j^{up}(e,m^{up},\bar{d}) = \max_{d}\ & u(c,d) + w_j(e,a,d) \\ \text{s.t. } & (1+\tau^c)[c+d] + a = m^{up} \\ & c = c^{inact}(e,m^{up} - (1+\tau)d,d) \\ & d > (1-\delta)\bar{d} \end{aligned}$$

From practical perspective, kinks in the value function are caused by the discrete choice and amplified through v_{j+1} over the iteration of age. Thus, w_j is supposed to be non-differentiable and have many local-maxima. To deal with this, we separate the grid d very finely, compute local maximum in the subinterval, and take the maximum of the local maxima.

(iii) **Downward Adjusting Problem**: Similarly, solve the downward adjusting problem with standard VFI.

$$
\begin{aligned}
v_j^{down}(e, m^{down}, \bar{d}) = \max_{d}\ & u(c,d) + w_j(e,a,d) \\
\text{s.t. } & (1+\tau^c)c + qd + a = m^{down} \\
& c = c^{inact}(e, m^{down} - qd, d) \\
& d < (1-\delta)\bar{d}
\end{aligned}
$$

Almost all of the codes are written in `C++` and they are called by `MATLAB` through `MEX` file. When solving upward and downward adjusting problem with value function iteration, I used `NLopt` Library for the optimization toolbox. I tried several optimization methods and reach a conclusion that Subplex algorithm is the best for this model in practice.

11.2. Perfect Foresight Path of The Life-cycle Model

Compared with solving the perfect foresight equilibrium path of an infinitely-lived agent model, it is by far more computationally costly to solve that of the life-cycle model. This is because each generation experiences tax change at a different age. For instance, suppose tax change is announced at $t = 1$ and implemented at $t = 5$. Then, a generation of households who are born at $t = 4$ experience the tax change at the age of $j = 2$. Those who are born at $t = 3$ experience it at $j = 3$. Subsequently, *all the different generations of households experience tax change at different ages*. That is, there are J generations at every period t.

This implies that all the generations Bellman equations must be solved for the dynamics. Let be $C_{j,t} \equiv \int c_{j,t}(a_{-1}, d_{-1}, e) \mathrm{d}\mu_j$ and as follows. Then the quantities for all the ages $(C_{j,t}, D_{j,t}, A_{j,t})_j$ are aggregated at every period, i.e.,

$$
C_t = \sum_{j=1}^{J} C_{j,t}, \quad D_t = \sum_{j=1}^{J} D_{j,t}, \quad A_t = \sum_{j=1}^{J} D_{j,t}.
$$

Notice that there are some generations who are born after the tax change and some who die before the tax change. Thus, I must solve the $T + J - 1$ Bellman equations conditional on (w, r) where T is the time horizon for the simulation.

My solution method to solve the perfect foresight follows Nishiyama and Smetters (2005) and Nishiyama and Smetters (2014), except that I use stochastic simulation for solving the distribution.