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Technology and leisure: Macro economic Implications

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Abstract

While the impact of technology on production is widely researched, this study explores the economic implications of technology through the channel of enhancing leisure experience on the consumer side. We develop a theoretical model which allows for habit formation for a technology good purchased to enhance leisure activities. In contrast, for the normal consumption good, habits are irrelevant. A persistent fall in the relative price of the technology good and increased addiction to technology are shown to have significant macroeconomic consequences. For example, we show that these perturbations can drive the real interest rate below the rate of time preference and depress consumption growth of non technology goods. Modelling the framework with US data illustrates that model predictions of falling interest rates and consumption growth are consistent with the recent observations of declining technology's relative prices and increases in technology good purchases.

Keywords

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Technology and leisure: Macro economic implications

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Abstract

While the impact of technology on production is widely researched, this study explores the economic implications of technology through the channel of enhancing leisure experience on the consumer side. We develop a theoretical model which allows for habit formation for a technology good purchased to enhance leisure activities. In contrast, for the normal consumption good, habits are irrelevant. A persistent fall in the relative price of the technology good and increased addiction to technology are shown to have significant macroeconomic consequences. For example, we show that these perturbations can drive the real interest rate below the rate of time preference and depress consumption growth of non technology goods. Modelling the framework with US data illustrates that model predictions of falling interest rates and consumption growth are consistent with the recent observations of declining technology's relative prices and increases in technology good purchases.

1 Introduction

In order to model the consequences on interest rates and consumption growth of the rising fascination with the use of digital technology in leisure we introduce a habit formation model for technology-enhancing leisure purchases. This paper constructs a utility function for the consumer that separates normal consumption from the digital technology good used for leisure activities. The utility of the consumer depends on the level of the technology good purchased for leisure enhancement and on how these purchases compare to a habit stock. The impact of persistently falling technology prices and technology addiction[1] used to enhance leisure experience are examined. We find that our framework offers on explanation of observed interest rates and consumption growth over the past decades.

The remainder of the paper is organised as follows. In section 2, we introduce some stylised facts. In section 3, a simplified theoretical model is formulated. It involves a consumer who purchases a technology good to enhance leisure. The utility for the technology good involves habit formation.[2] Section 4 explores the steady state. Section 5 theoretically investigates the implications for interest rates and consumption growth of relative price change and technology addiction. Both of these perturbations drive the interest rate down below the rate of time preference. Section 6 studies the macroeconomic implications. The steady state equations of the model are applied to actual data. We find that the predictions from the framework contribute quantitatively to the observed experience. Section 7 provides concluding remarks.

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1. Ever since Stigler and Becker (1977) and Becker and Murphy (1988) there has been much economic literature on rational addiction. From a different perspective we define addiction in terms of habits. In this regard, this investigation differs from habit persistence literature and economic addiction literature. For instance, Carroll, Overland and Weil (1997) and Carroll, Overland and Weil (2000) investigated the impact of habit persistence on a normal consumption good. The papers restrict Θ, which indexes the importance of habits from between 0 and 1. Nonetheless, the conjecture in this paper is that addiction implies that a considerable amount of current technology is required to obtain a given utility. Consequently, the parameter should not be restricted to 1 and multiple times bigger.

2. The notion that an individual's utility depends on current consumption relative to a reference level is not new. See Constantinides (1990), Abel (1990), Carroll, Overland and Weil (1997), Carroll, Overland and Weil (2000), Deaton and Paxson (1992), Ferson and Constantinides (1991), Fuhrer (2000), Rayo and Becker (2007), and Atkin (2013) for interesting findings.

2 Stylised facts

2.1 Technology use in leisure activities

The time spent using a technology good[3] is significant. Lepp et al. (2015) found that 25 % of 454 US university students used their smartphone over 10 hours per day. Similarly, investigations by Junco and Cotten (2012) into the cell use of 1,649 college students found time spent per day is 118 minutes on the internet, 97 minutes on texting, 51 minutes talking, 49 minutes emailing and 41 minutes on Facebook.

Consequently, Psychologist Rosen (2012) in *'iDisorder: Understanding Our Obsession with Technology and Overcoming Its Hold on Us (2012)'* compares society's fascination with technology to the *habit of a drug addict.* Roberts, Pullig and Manolis (2015) suggest that there are similarities to substance and behavioural addictions with cell phone use including loss of control. The authors examine the relationship between personality traits and 'cell phone addiction' finding that impulsiveness is strongly associated with cell phone addiction. One important observation is that technology used to enhance leisure is almost exclusively where habits or addiction is forming. Deursen et al. (2015) found that those who use smartphones for leisure purposes develop smartphone habits faster. Lepp et al. (2013) found 88% of students used their phone primarily for leisure experience rather than for school. Despite the number of psychologists highlighting society's growing fascination with digital technology, there are limited economic studies that investigate the implications. An exception is Hurst (2016) who is one of the few economists who is investigating the implications of technology on leisure, primarily on labour supply.[4]

The annual percentage change in leisure technology consumed by the household is represented in Figure 1. This is the percentage change in the VAPIM chain-type quantity index devised by Federal Reserve Bank of St. Louis (2016c). Upward movements in the line indicate an increasing annual growth rate of consumed leisure technology. The data in Figure 1 consists of waves of technological innovation. Demand for personal computers

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3. What we mean by a technology good is digital technology such as smartphones, video games and DVD players. These are mainly used to magnify leisure experience.

4. His others investigating leisure time include Aguiar et al. (2017); Beraja, Hurst and Ospina (2016); Attanasio, Hurst and Pistaferri (2012); Aguiar, Hurst and Karabarbounis (2013) which may be of interest.

was booming in the 1990s. After a slow start for the initial release of the Apple II (1977), by 1993, 4 million Apple IIs were sold. There was another technology shift specifically in the electronic entertainment and video market in the late 1990s. DVDs were launched in 1996 (Seifert, Leleux and Tucci 2008), which was followed by the first DVD players in 1999. Huge uptake in DVD followed. Further, the mobile phone market was strong. Nonetheless, the increase in leisure technology growth in 2001 could be due to a shift in the audio market. Apple was the engine for the transformation of mp3 technology. The iPod was officially released in October 2001 and growth soared, to 42 million sold in 2004 and, by April 2007, 100 million. Leisure technology growth fell drastically in the lead up to the Great Recession of 2008 and 2009.

Figure 1: Percentage change in the quantity of technology in leisure activities
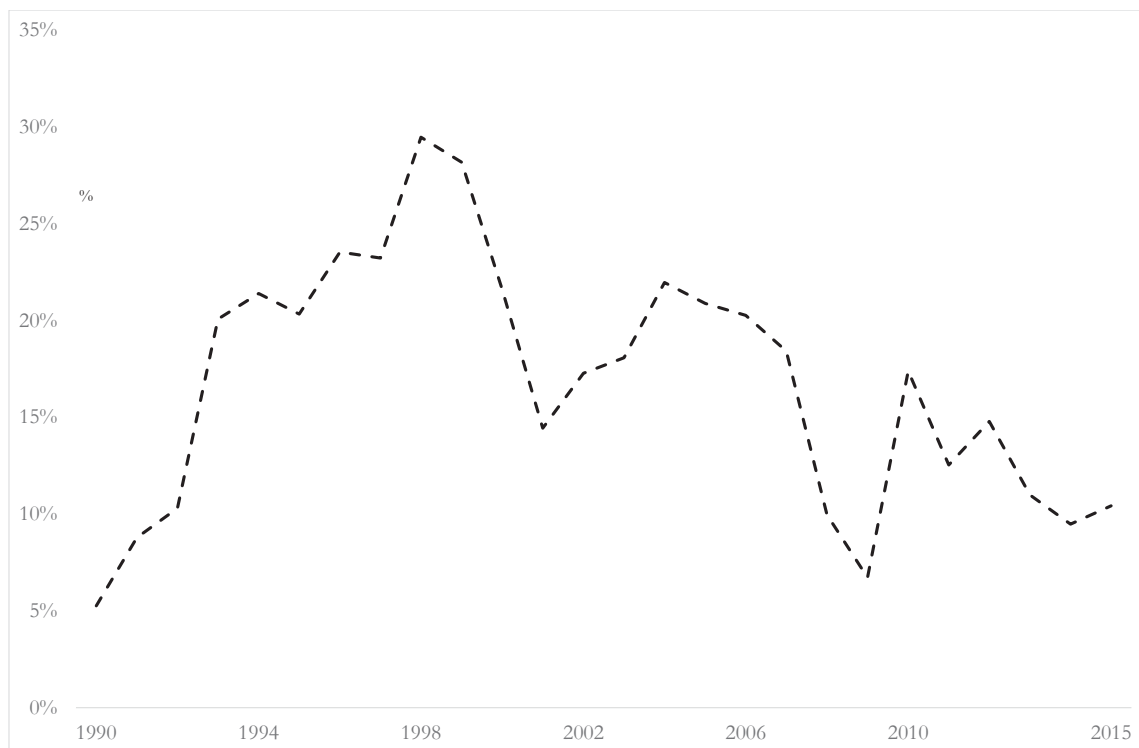
Note: The figure provides the percentage change in the chain-type quantity index for VAPIM.
Source: Federal Reserve Bank of St. Louis (2016c).

2.2 Percentage change in the relative price of technology

With the goal of creating a price series for technology used in leisure we use data on price indices from the Federal Reserve Bank of St. Louis (United States). For leisure technology, we use video, audio, photographic, and information processing equipment and media (VAPIM) purchased for recreational uses by the consumer. To accurately represent the change in the relative price we construct our index based on the indices between technology in leisure activities and normal consumption. Specifically, our index is the ratio between the chain-type price index for VAPIM (Federal Reserve Bank of St. Louis 2016a) to the chain-type price index for total consumption (Federal Reserve Bank of St. Louis 2016b). The relative price of leisure technology is represented by $p_R(t)$. In the model below the annual percentage change in the relative price index is:

$$\left[\frac{p_R(t+1) - p_R(t)}{p_R(t)} \right] \tag{1}$$

This is plotted in Figure 2. The relative price of technology has been constantly decreasing, mostly ranging between -10 % and -15 % per year. Jor-

Figure 2: Percentage change in the relative price of technology in leisure activities

Note: $p_R(t)$ represents the ratio between the chain-type price indices for VAPIM and consumption.
Source: Federal Reserve Bank of St. Louis (2016a); Federal Reserve Bank of St. Louis (2016b).

genson (2001) and Jorgenson and Vu (2007)) were the first to link the general price decline of technology to the economic growth of the United States and the G7. In a recent study, Jorgenson, Ho and Samuels (2016) investigate sub-periods of growth in the United States including 1973-1995, 1995-2000 (technology boom), 2000-2005 (post dot-com crash) and 2005-2010. Jorgenson,

Ho and Samuels (2016) show that price declines in technology throughout all the time periods. For instance, relative to the GDP deflator, computers and equipment price growth was -15.9 percent (1973-1995), -26.3 percent (1995-2000), -17.6 percent (2000-2005) and -15.7 percent (2005-2010). Nonetheless in 1995, Jorgenson (2005) points out that the microprocessor price decline jumped to over ninety percent per year, which sparked IT prices to plummet. This had a domino effect on the prices of aircraft, automobiles and a multitude of other sectors that all use this technology. The study shows that even in the Great Recession, innovation was still substantial. Byrne, Oliner and Sichel (2015) show post-Great Recession technology prices are still declining. They develop a hedonic index and show that the price of microprocessors declined by an average of forty-three percent per year from 2008 to 2013.

3   Model

We investigate a closed economy with an infinitely lived representative household. $R(t)$ is the instantaneous flow of technology goods (e.g., ipads, Apple watches) for the representative household at time t. The economy is in discrete time with time in this period and the next period denoted by (t) and $(t+1)$. $h(t)$ is the stock of habits of the consumer for its purchases of the technology good. The household uses the technology good to enhance leisure experience (l). σ is the coefficient of relative risk aversion and ρ the rate of time preference. For simplicity, the household does not supply labour and does not derive any income from work. This simplicity does not change the results themselves.[5] The household provides capital to firms to produce the consumption and the technology goods. The household maximises a discounted infinite discrete stream of utility:

$$Max \sum_{s=0}^{\infty} \left\{ \rho^s \left[\frac{C(t)^{1-\sigma}}{1-\sigma} + \frac{\left(l(t)R(t)/h(t)^{\Theta}\right)^{1-\sigma}}{1-\sigma} \right] \right\} \tag{2}$$

$\sigma > 1$
$0 \leq l(t) \leq 1$
$\Theta \geq 0$

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5. The explicit trade-off between consumption and leisure was initially included, but this adds complications without changing the analysis in this paper. See Kavuri (2017) with labour employment.

We assume that the evolution of the habit stock of technology is taken as exogenous to the household (i.e., the household cannot influence the evolution of habits based on decisions). The habit stock of technology is a weighted average of past technology with ψ being the relative weight of technology at different times. $\psi > 0$, with larger values implying greater importance of the recent past. Θ indexes the importance of habits:[6]

$$h(t+1) = h(t) + \psi(R(t) - h(t)) \tag{3}$$

There are two goods produced in the economy: the consumption good (C) and the technology good (R). Assume the following production functions for technology and the consumption good is:[7]

$$Y_R(t) = A_R(t)K_R(t) \tag{4}$$
$$Y_C(t) = A_C(t)K_C(t) \tag{5}$$

The household provides capital to the firms. Consequently, the following is the evolution of savings for the household:

$$\Delta K(t+1) = r(t)K(t) - \delta K(t) - p_R(t)R(t) - C(t) \tag{6}$$

The price of the technology good relative to the consumption good is $p_R(t)$. If the price of the consumption good is normalised to 1, then decreases in $p_R(t)$ would mean the price of technology is decreasing compared to the price of the consumption good. Capital depreciates at δ.

To optimise this dynamic discrete time problem, the constrained form of the Lagrangian is adopted. The choice variables are technology $(R(t))$ and consumption $(C(t))$. Neither leisure $(l(t))$ nor habits $(h(t))$ are choice variables. The problem is solved for each period given the respective constraints. (7) and (8) are obtained by reformulating the first order conditions:

$$\rho \left[\frac{C(t)}{C(t+1)} \right]^{-\sigma} = [r(t+1)K(t+1) + (1-\delta)] \tag{7}$$

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6. Θ represents the importance to utility of current technology good purchases relative to habits. When $\Theta = 0$, the household cares only about the absolute level of the technology good. Its habits become irrelevant. As Θ increases to compensate for its habits, more of the leisure technology good is required to obtain a given amount of utility.

7. An AK model is used for simplicity. The only two differences in the analysis between the standard neoclassical growth model is firstly the steady state level of consumption relative to consumption-sector capital. The second difference is the steady state level of technology consumption to technology-sector capital.

$$\rho \left[\frac{(l(t)R(t)/h(t)^{\Theta})}{(l(t+1)R(t+1)/h(t+1)^{\Theta})} \right]^{-\sigma} \left[\frac{l(t)}{l(t+1)} \right] \left[\frac{h(t+1)}{h(t)} \right]^{\Theta} \left[\frac{p_R(t+1)}{p_R(t)} \right] =$$
$$[r(t+1)(t+1) + (1-\delta)] \tag{8}$$

$$\frac{K(t+1)}{K(t)} = 1 + r(t) - \frac{p_R(t)R(t)}{K(t)} - \frac{C(t)}{K(t)} \tag{9}$$

$$\frac{h(t+1)}{h(t)} = 1 + \psi \left(\frac{R(t)}{h(t)} - 1 \right) \tag{10}$$

4 Steady state

The next task is to explore the steady state of the model. Following Mulligan and Sala-i-Martin (1992), we transform the equations into variables that are constant in the steady state.[8] We define the steady state for the technology sector when R, h and K_R grow at the same rate.[9] For their consumption-based habit model Carroll, Overland and Weil (2000) also defined steady state in a similar fashion. The ratio of the technology good and leisure per habits ($\frac{Rl}{h}$) and technology-sector capital per habits ($\frac{K_R}{h}$) are constant in the steady state. Mulligan and Sala-i-Martin (1992) point out that in most sectors the consumption good to consumption-sector capital is a constant ratio. As the consumption sector does not have habits, this is applicable here. The steady state for the consumption sector is defined when $\frac{C}{K_C}$ is a constant ratio. This implies that the following holds:

$$g_R = g_h \tag{11}$$
$$g_{K_R} = g_h \tag{12}$$
$$g_C = g_{K_C}, \tag{13}$$

where:
$$\left[\frac{R(t+1)-R(t)}{R(t)} \right] = g_R, \quad \left[\frac{K_R(t+1)-K_R(t)}{K_R(t)} \right] = g_{K_R}$$
$$\left[\frac{C(t+1)-C(t)}{C(t)} \right] = g_C, \quad \left[\frac{K_C(t+1)-K_C(t)}{K_C(t)} \right] = g_{K_C}.$$

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8. As we are investigating the steady state, t for time is dropped.

9. More accurately, the technology good and leisure combined should grow at the rate of habits. Nonetheless, growth of leisure is zero in the steady state.

We take equations (7) to (10) and derive the following system applicable to the steady state. See Appendix for the full derivation.

$$g_R + \frac{\pi_R}{\sigma - \Theta\sigma + \Theta} = \frac{r_{ss} - \rho}{\sigma - \Theta\sigma + \Theta} \tag{14}$$

$$g_C = \frac{r_{ss} - \rho}{\sigma} \tag{15}$$

$$\pi_R = \lambda_R \tag{16}$$

Where λ_R is a constant growth/decline of technology relative to consumption and r_{ss} is the interest rate in the steady state.[10] The equations imply that the following holds:

$$(\sigma - \Theta\sigma + \Theta)g_R + \lambda_R = \sigma g_C \tag{17}$$

Equation (17) shows that there is no unique equilibrium. Nonetheless, we define a benchmark steady state below. In addition, we recognise that r_{ss} may be described as a yield on capital.

4.1 Equilibrium

The growth rates for this benchmark steady state are as follows:

$$\pi_R = 0 \tag{18}$$

$$g_R = 0 \tag{19}$$

$$g_C = 0 \tag{20}$$

$$r_{ss} - \rho = 0, \tag{21}$$

5 Implications of perturbations

This section investigates two different exogenous perturbations. One is the impact of a sustained decline in the relative price of technology. The other is a sustained period of addiction. A relative price decline may occur from a technology shift. Addiction may result from an impulse to purchase a cutting-edge technology good. Equation (17) highlights the dynamics of movements of the steady states under the temporary perturbations. As suggested, there

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10. $r_{ss} = r(t+1) = r(t)$.

is no one unique equilibrium. However, as a theoretical exploration, we investigate each perturbation in isolation.[11]

5.1 Perturbation one: Relative price decline

Proposition 1 *(Relative price proposition): Other things being equal, a persistent decline in the price of technology to consumption will lead to the interest rate falling below the rate of time preference.*

Proof
A sustained, decreasing relative price of technology to consumption $\pi_R = \Lambda_R < 0$. The economy is sent into a dynamic adjustment path. With this perturbation equations of the model shows that the following will apply:

$$g_R = 0 \tag{22}$$
$$\pi_R = \Lambda_R < 0 \tag{23}$$
$$g_C = \frac{\Lambda_R}{\sigma} < 0 \tag{24}$$
$$r_{ss} - \rho = \Lambda_R, \tag{25}$$

As Λ_R is negative, the last condition implies that $r_{ss} < \rho$.

Consumption growth is falling and interest rates will fall persistently.[12]

QED

5.2 Perturbation two: Addiction

To focus solely on technology addiction, consider the economy back at the benchmark growth rates with $r_{ss} = \rho$. We now state the second proposition of this paper.

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11. Notice that unless there are some adjustments during the perturbations in A_R, A_C or markups. steady state conditions on the production side will not apply.

12. As can be seen in equation (25), $\pi_R = r_{SS} - \rho$. This does not hold generally. Nonetheless, this is a theoretical analysis. Furthermore, in the empirical section, we allow for positive growth in technology and do not apply this condition.

Proposition 2 *(Addiction proposition): Other things being equal, technological addiction in leisure will cause the interest rate to fall below the rate of time preference.*

Proof

This paper defines technology addiction as:

$$\frac{\sigma}{\sigma - 1} < \Theta \tag{26}$$

Notice, with addiction, the parameter $(\sigma - \Theta\sigma + \Theta)$ is negative. To understand the impact, recall the relationship between g_R and r_{ss}:

$$(\sigma - \Theta\sigma + \Theta)g_R + \pi_R = r_{ss} - \rho \tag{27}$$

As $\pi_R = 0$, addiction will send consumption of non technology goods into decline. [13] Further, as can be seen in the equation above, it will drive interest rates below ρ.[14]

$$\pi_R = 0 \tag{28}$$

$$g_R = \bar{g}_R > 0 \tag{29}$$

$$g_C = \frac{(\sigma - \Theta\sigma + \Theta)\bar{g}_R}{\sigma} \tag{30}$$

$$r_{ss} - \rho = (\sigma - \Theta\sigma + \Theta)\bar{g}_R \tag{31}$$

QED

This model provides some interesting insights. Economies have been characterised by consumption growth falling, technology booming with plummeting interest rates. With addiction, more and more of an activity, product, drug, etc., is required for recreational benefit. Consequently, growth of a non technology consumption is negative. This leads to depressed interest rates. The economy finds itself at this new state with consumption declining every year, interest rates depressed but with technology good growth.[15]

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13. We can express g_C in terms of g_R. With positive g_R addiction implies $g_C < 0$. Although g_R can be negative, here we investigate the theoretical impact of positive growth for our addiction case study. In the empirical section, as we are using real data we allow for negative growth in technology.

14. Note that $r(t) > \bar{g}_R$

15. We do not disagree that time spent on leisure technology can increase. More complexity can be introduced into our framework.

6 Macroeconomic implications

The previous section demonstrated the impact of technology in leisure on the macroeconomy in theory. One key result is that the two perturbations would drive the interest rate below the rate of time preference. This section explores the macroeconomic implications generated through our model. First, to motivate this analysis, consider some stylised facts of the present economic environment.

Stylised facts

1. Low interest rate environment: There has been a period of persistently low real and nominal interest rates for OECD countries especially since 2000 (see Figure 3).

2. Low consumption growth: The decline started around 15-20 years ago for the vast majority of OECD economies. However, post-Great Recession, the trend has accelerated. Petev, Pistaferri and Saporta (2012) argues that out of all the recent US recessions consumption remains below the pre-recession levels for a longer period. Figure 3 presents household consumption growth and real interest rates.[16] over the last 30 years. As can be seen, both have been on a downward trend. Nonetheless, since the Great Recession, a new equilibrium appears to be emerging with depressed rates and low consumption growth.

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16. We use World Bank's data for household consumption growth for the United States, Euro Area and Japan. We use World Bank's data for Japan's real interest rate and the real interest rate for the United States. The OECD interest rate estimations are used for the Euro Area. The World Bank's real interest estimations tend to be lower and have more fluctuations than the OECD calculations.

Figure 3: Decline of consumption growth and real interest rates
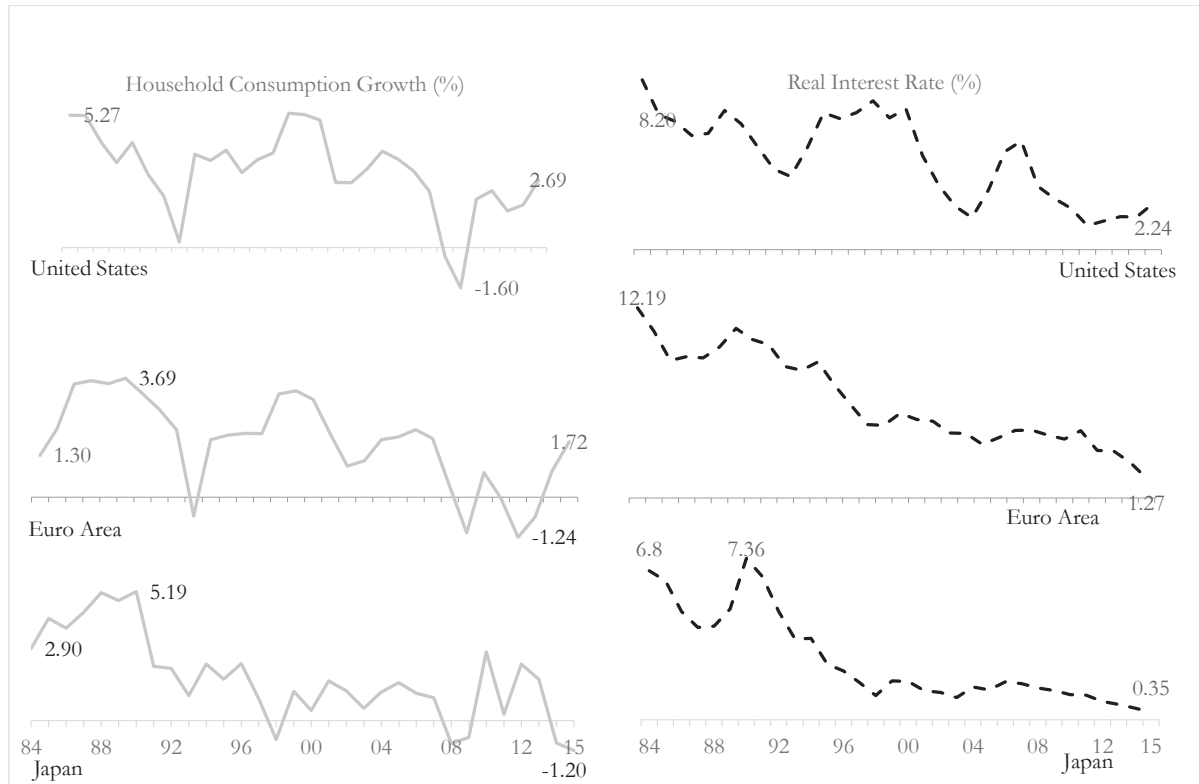
A rising number of papers highlight various reasons for the low interest rates and lack of consumption growth, including demand-side secular stagnation (Summers 2015), supply side secular stagnation (Gordon 2015), overhanging debt (Rogoff and Reinhart 2010) and a liquidity trap (Bernanke 2016) In conjunction with these studies, we offer an additional explanation related to the increasing use of technology in leisure and the large fall in the

relative price of this technology.[17]

We now use plausible parameters in the theoretical model to generate paths of interest rates and real consumption growth given observed perturbations to the model.

6.1 Interest rates

Interest rates are computed using US data from 1990 to 2015 to investigate the dynamics associated with a moving steady state. This ignores the transitional adjustment between steady states.

$$(\sigma - \Theta\sigma + \Theta) \left[\frac{R(t+1) - R(t)}{R(t)} \right] + \left[\frac{p_R(t+1) - p_R(t)}{p_R(t)} \right] = r(t+1) - \rho \quad (32)$$

For Figure 4, 5, 6 and 7 and 8 we use 1.5 % (Evans and Sezer 2004) for ρ and 1.3 for σ (coefficient of relative risk aversion) (Zhuang et al. 2007). A 5-year moving average is provided to smooth the variability. In the figures, the black dash line is the computed interest rate. The grey solid line is the actual annual interest rate (World Bank 2016b). The consumers do not have addictions. However, Θ is relatively high at 1.5.[18] Figure 4 and 5 shows the dynamics over the last 25 years. Figure 4 is calculated using the raw data. In figure 5 the data is smoothed using a 5-year moving average.

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17. Bosworth (2014) makes a valid point that it makes little sense to forecast interest rates within a closed-economy framework as markets are integrated globally. Nonetheless, we hope that the framework provides some useful insights.

18. Addiction implies $\Theta > 4.33$.

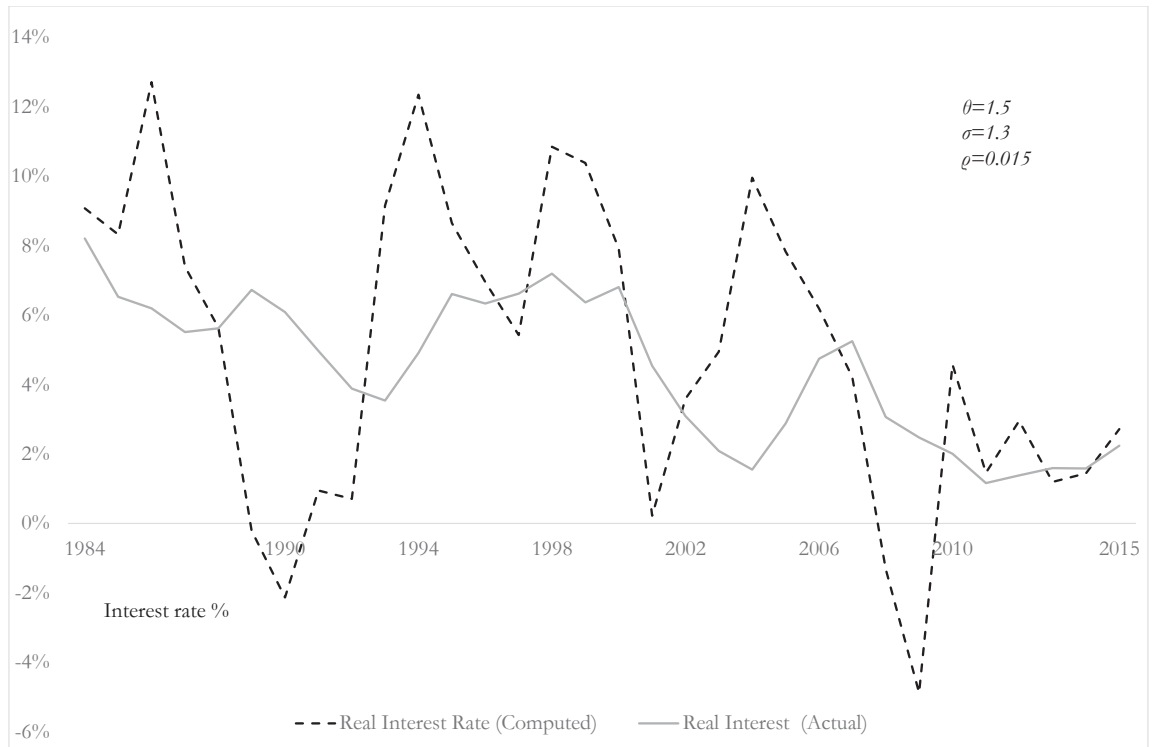Figure 4: Computed and actual annual interest rates

Figure 5: Computed and actual annual interest rates: 5-year moving average

Note: The predicted interest rate are calculated using data from Federal Reserve Bank of St. Louis. The observed annual interest rate is obtained from the World Bank.
Source: Federal Reserve Bank of St. Louis (2016a); Federal Reserve Bank of St. Louis (2016b); World Bank (2016b).

In Figure 6 we decompose the computed interest rate into ρ, the growth of leisure technology purchased and the change in the relative price of leisure technology. Intuitively, higher growth in leisure technology purchased leads to higher interest rates. Growth in leisure technology implies a production shift with businesses borrowing for future profit. The growth in production

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ensures higher real interest rates. As the relative price of technology falls consumers shift from consumption of goods to consumption of leisure, which drives down the real interest rate.

Figure 6: Decomposition
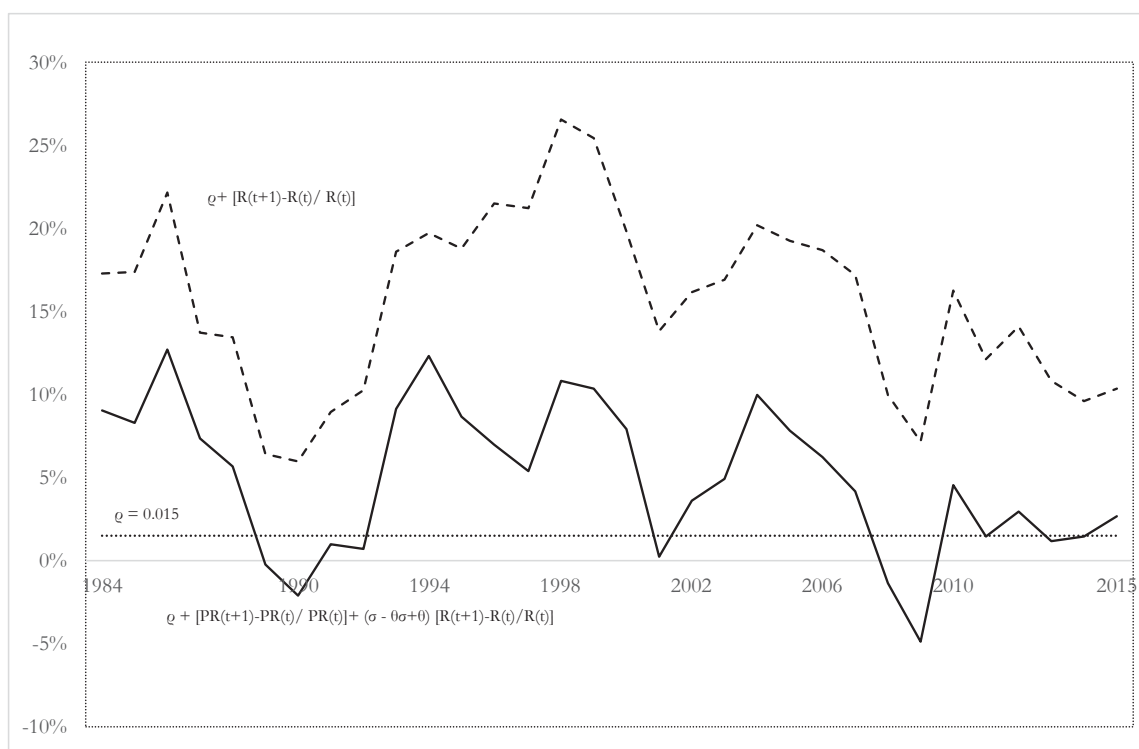
Note: Actual/raw data.

6.2 Consumption growth

We take a two-step approach to compute consumption growth. First, the computed interest rates from our model are obtained, After which, consumption growth is computed with the formula below. It has been suggested that computed rates from the Euler equation can be very different to the actual interest rate.[19]

$$\frac{r(t+1) - \rho}{\sigma} = \left[\frac{C(t+1) - C(t)}{C(t)} \right] \tag{33}$$

Using equation (33), we plot the calculated rate of consumption growth in Figure 7 and 8. Figure 7 is calculated using the actual data. Figure 8 is Figure 7 transformed using a 5-year moving average.

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19. Hansen and Singleton (1982) and Mulligan (2004) show that aggregate consumption Euler equations are very poor fits to the empirical data. Furthermore, Canzoneri, Cumby and Diba (2007) compute interest rates implied by the consumption Euler equations for various models with different consumer preferences and compare them with money market rates. They find that the correlations between these Euler equation rates and the Federal Funds rate are generally negative. The models include CRRA preferences (-0.37), Abel (1999) (-0.36), Campbell and Cochrane (1995) (-0.37) , Fuhrer (2000) (-0.07), Boldrin, Christiano and Fisher (2001), Edge (2002) and Christiano, Eichenbaum and Evans (2005) (-0.09).

Figure 7: Computed and actual consumption growth

Figure 8: Computed and actual consumption growth: 5-year moving average
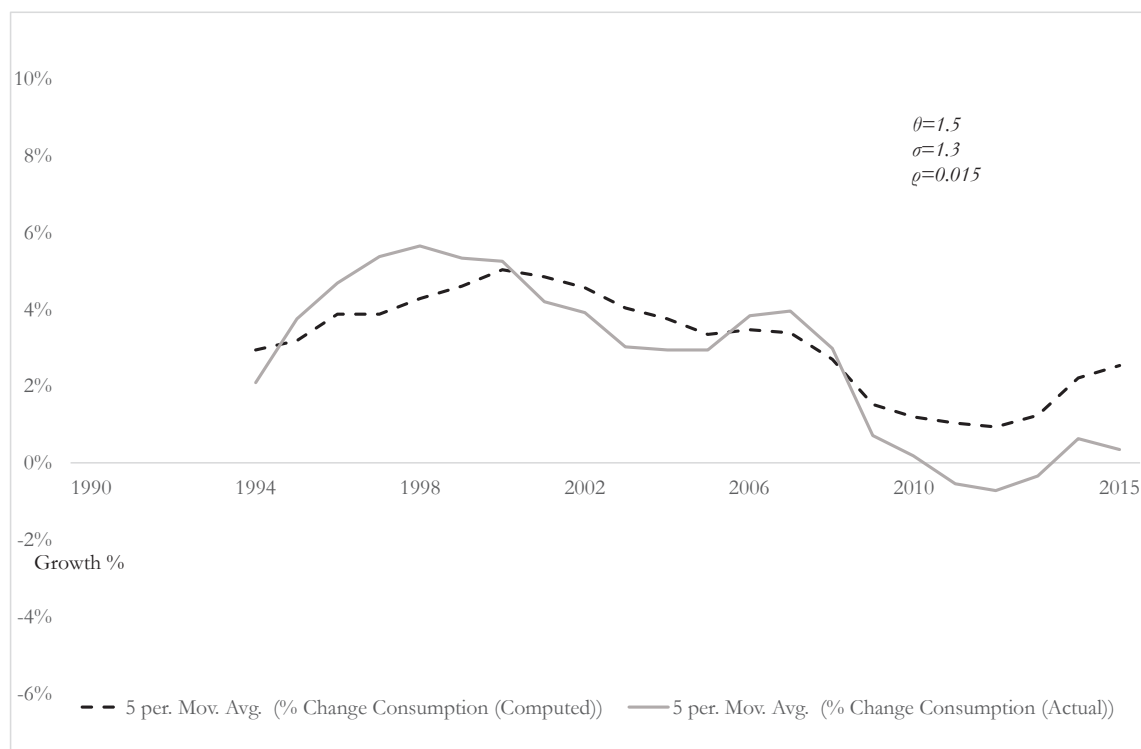
Note: The predicted and actual consumption growth are calculated using data from the Federal Reserve Bank of St. Louis.
Source: Federal Reserve Bank of St. Louis (2016a); Federal Reserve Bank of St. Louis (2016b); Federal Reserve Bank of St. Louis (2016c); Federal Reserve Bank of St. Louis (2016d).

The figures show that the shifting steady state caused by the decline in the price of technology used in leisure and technology addiction is consistent with trend changes in real interest rates and consumption observed in the past 20 years.

6.3   Concluding remarks

This paper has provided a theoretical framework to study the macroeconomic implications of a technology good purchased by the consumer to enhance leisure activities. Furthermore, we have made predictions based on United States data to determine how much the framework can contribute to our understanding of recent economic trends.

There is a number of explanations for the global decline in real interest rates and consumption growth. In this paper, we have proposed that technology enhanced leisure and addiction to technology may be a further explanation that warrants further investigation.

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7 Appendix

7.1 Technology: Sector R

Growth of $R(t)$

The steady state occurs for sector R when leisure and technology combined grow at the rate of habits growth. The following holds for the steady states

$$\frac{R(t+1)l(t+1)}{h(t+1)} - \frac{R(t)l(t)}{h(t)} = 0 \qquad (34)$$

Obviously:

$$\frac{l(t+1)}{l(t)} \frac{R(t+1)}{R(t)} = \frac{h(t+1)}{h(t)} \qquad (35)$$

We use equation (8) and obtain the steady state level change of $R(t)$ as below:

$$\rho \left[\frac{p_R(t+1)}{p_R(t)}\right] \left[\frac{R(t+1)}{R(t)}\right]^{\sigma-\Theta\sigma+\Theta} \left[\frac{l(t+1)}{l(t)}\right]^{\sigma-\Theta\sigma+\Theta-1} = [1+r(t+1)] \quad (36)$$

With R the subject it follows:

$$\left[\frac{R(t+1)}{R(t)}\right]^{\sigma-\Theta\sigma+\Theta} = \left[\frac{1+r(t+1)}{\rho}\right] \left[\frac{l(t+1)}{l(t)}\right]^{-(\sigma-\Theta\sigma+\Theta-1)} \left[\frac{p_R(t+1)}{p_R(t)}\right]^{-1} \tag{37}$$

The growth of habits is substituted into the above formula to obtain:

$$\left[\frac{1+r(t+1)}{\rho}\right] \left[\frac{l(t+1)}{l(t)}\right]^{-(\sigma-\Theta\sigma+\Theta-1)} \left[\frac{p_R(t+1)}{p_R(t)}\right]^{-1} = \left(\left(\psi\frac{R(t)}{h(t)} - \psi + 1\right)\frac{l(t)}{l(t+1)}\right)^{\sigma-\Theta+\Theta} \tag{38}$$

The equation is reformulated. Natural logs are taken to obtain approximations.

$$\ln\left[\frac{p_R(t+1)}{p_R(t)}\right] \approx \frac{p_R(t+1) - p_R(t)}{p_R(t)} \qquad (39)$$

$$\ln\left[\frac{1+r(t+1)}{\rho}\right] \approx r(t+1) - \rho \qquad (40)$$

The steady state level of technology and leisure to habits is obtained as follows:

$$\frac{R(t)l(t)}{h(t)} = l(t)\left[\frac{1}{\psi}\left(\frac{r(t+1)-\rho}{\sigma-\Theta\sigma+\Theta} - \frac{1}{(\sigma-\Theta\sigma+\Theta)}\left[\frac{p_R(t+1)-p_R(t)}{p_R(t)}\right]\right)+1\right] \tag{41}$$

Note that in the steady state the following applies:

$$\left[\frac{l(t+1)-l(t)}{l(t)}\right] = 0 \tag{42}$$

Steady state growth of $K_R(t)$

The steady state growth rate of $K_R(t)$ requires the growth rate of capital to habits to go to zero. In order to make it simpler to determine the steady state growth of capital, assume that the purchase of the leisure technology good comes out of its capital stock. However, this assumption does not change the analysis in the paper.

$$\frac{K_R(t+1)}{K_R(t)} = 1 + r(t) - \frac{p_R(t)R(t)}{K_R(t)} \tag{43}$$

$$\frac{K_R(t+1)}{h(t+1)} - \frac{K_R(t)}{h(t)} = 0 \tag{44}$$

Multiply by 1 to obtain:

$$\frac{K_R(t+1)}{K_R(t)}\frac{K_R(t)}{h(t+1)} - \frac{K_R(t+1)}{h(t+1)}\frac{h(t+1)}{h(t)} = 0 \tag{45}$$

The evolution of capital $\Delta K_R(t+1)$ and the change of habits $\Delta h(t)$ is substituted in the above formula to obtain.

$$1 + r(t) - \frac{p_R(t)R(t)}{h(t)}\frac{h(t)}{K_R(t)} = 1 + \psi\left(\frac{R(t)}{h(t)} - 1\right) \tag{46}$$

The steady state level of technology to habits $\frac{R(t)}{h(t)}$ is substituted into (41) and the formula reworked. Natural logs are also taken to obtain approximations. The steady state level of capital to habits is the following:

$$\frac{K_R(t)}{h(t)} = \frac{p_R(t)}{\psi}\left[\frac{(r(t+1)-\rho)+\frac{\psi}{P_{R(t)}}(\sigma-\Theta\sigma+\Theta)-\pi_R}{r(t)(\sigma-\Theta\sigma+\Theta)-r(t+1)+\rho+\pi_R}\right] \tag{47}$$

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$$\pi_R = \left[\frac{p_R(t+1) - p_R(t)}{p_R(t)} \right] \tag{48}$$

As can be seen above, obviously $r(t)$ and $r(t+1)$ impacts the steady level of $K_R(t)$ to $h(t)$. However, more interestingly notice how heavily the growth rate of productive leisure and deflation of technology prices impacts the level.

7.2 Consumption: Sector C

Mulligan and Sala-i-Martin (1992) point out that in most sectors consumption per capital is a constant ratio in the steady state. This is also applicable for sector C. Assume like for the leisure technology sector, that the consumption good is consumed out of its capital stock.

$$\frac{K_C(t+1)}{K_C(t)} = 1 + r(t) - \frac{C(t)}{K_C(t)} \tag{49}$$

$$\frac{C(t+1)}{K_C(t+1)} - \frac{C(t)}{K_C(t)} = 0 \tag{50}$$

Recall the consumption-based Euler as follows:

$$\rho \left[\frac{C(t)}{C(t+1)} \right]^{-\sigma} = 1 + r(t+1) \tag{51}$$

We take a natural log of the Euler equation and equate it to the percentage change in the motion of capital:[20]

$$\frac{C(t)}{K_C(t)} = r(t) - \left[\frac{r(t+1) - \rho}{\sigma} \right] \tag{52}$$

7.3 Equilibrium

There is only one unique equilibrium steady state under the assumption that π_R is constant. With natural log the equations below apply:

$$r(t+1) - \rho = (\sigma - \Theta\sigma + \Theta) \left[\frac{R(t+1) - R(t)}{R(t)} \right] + \left[\frac{p_R(t+1) - p_R(t)}{p_R(t)} \right] \tag{53}$$

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20. For equation (49) we do not take a natural log, but instead subtract one from the left and right side.

$$r(t+1) - \rho = \sigma \left[\frac{C(t+1) - C(t)}{C(t)} \right] \tag{54}$$

As this is the stationary state, we assume that $r(t)^* = r(t+1)^*$. In that case steady state levels of technology to capital and consumption to capital simplify further. However, to avoid confusion, we use $r_{ss} = r(t+1)$ to represent the interest rate in the steady state.