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Durable Goods, Investment Shocks, and the Comovement Problem

Sticky-price models suggest that capital investment shocks are an important driver of business cycle fluctuations. Despite quantitative importance in explaining business cycles, a comovement problem emerges because the shocks generate intertemporal substitution effects away from consumption toward investment. This paper resolves the problem by extending the standard sticky-price model to a two-sector model with consumer durable services. When durable goods are used as investment in capital and consumer durables, positive capital investment shocks also generate intratemporal substitution effects away from consumer durable services toward nondurable consumption that dominates intertemporal effects. Consequently, consumption increases, and the comovement problem is resolved.

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RECENT RESEARCH SUGGESTS THAT AN IMPORTANT driver of business cycle fluctuations are not more traditional Hicks-neutral technology shocks (Galí 1999), but (equipment) capital investment-specific technology shocks (e.g., Greenwood, Hercowitz, and Krusell 2000, Christensen and Dib 2008, Justiniano and Primiceri 2008). Recently, using a one-sector model, Fisher (2006) estimated and found that capital investment shocks were the dominant source of business cycle fluctuations in the United States. In particular, Justiniano, Primiceri, and Tambalotti (2010) studied a one-sector, sticky-price model with a variety of real and nominal frictions such as wage rigidities, consumption habit formation, and capital utilization,

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along the lines of Christiano, Eichenbaum, and Evans (2005), and several shocks, as in Smets and Wouters (2007), including a shock to total factor productivity (or a neutral technology shock), as in Kydland and Prescott (1982) and Hansen (1985); a shock to the marginal efficiency of investment (MEI; or, for simplicity, an investment shock), as in Greenwood, Hercowitz, and Huffman (1988) and Greenwood, Hercowitz, and Krusell (1997); and a shock to desired wage markups (or, equivalently, a labor supply shock), as in Hall (1997). They found that over 50% of the fluctuations in output and hours, and over 80% of the fluctuations in investment were driven by capital investment shocks.

Even though capital investment shocks are of quantitative importance in explaining business cycle fluctuations, one difficulty remains in these models: consumption typically falls after a positive investment shock, which is at odds with the data that consumption and investment both increase in response to a positive capital investment shock.[1] A comovement problem emerges because a positive investment shock generates an intertemporal substitution effect away from current consumption and toward current investment and thus future consumption which dominates the income effect. As a result, these models do not result in comovements among macroeconomic aggregates in response to an investment shock, unlike observed business cycles in which output, consumption, investment, hours worked, and the real wage all rise and fall together. This lack of comovement is clearly problematic in viewing investment shocks as the dominant source of business cycle fluctuations. In this paper, we resolve the comovement problem by extending the standard neoclassical sticky-price model to a two-sector model with consumer durable services.

There is a growing volume of literature that studies consumer durable services. Mankiw (1985) stated the importance of understanding fluctuations in consumer durable services for understanding economic fluctuations in a paper that empirically estimated the link between interest rates and consumer durable services. Baxter (1996) formally established a theoretical model with two sectors that produce nondurable goods for consumption and durable goods for investment in consumer durable services and two types of capital. She investigated the effects of single shocks and sectoral shocks to Solow residuals on business cycles. Recently, there has been a growing literature led by Barsky, House, and Kimball (2003, 2007) that studied sticky-price models with two sectors that produced nondurable goods for consumption and durable goods for consumer durable services (e.g., Monacelli 2009, Carlstrom and Fuerst 2010, Bouakez, Cardia, and Ruge-Murcia 2011, Sudo 2012). This literature envisaged the effects of monetary policy shocks upon business cycles. Our study extends the strand of the research by incorporating consumer durable services in order to study the effects of capital investment-specific shocks on business cycle fluctuations.

Like Baxter (1996) and Barsky, House, and Kimball (2003, 2007), our model includes two sectors that produce nondurable goods and durable goods. Nondurable goods are used for consumption, and durable goods are used for investment in capital

1. Section 1 offers the evidence of comovement between consumption and investment in response to positive investment shocks.

and consumer durable services. The household obtains utility from consuming nondurable goods and consumer durable services. As in Barsky, House, and Kimball (2003, 2007), nondurable prices are stickier than durable prices.[2] Like Greenwood, Hercowitz, and Krusell (1997, 2000), there is a technical change specific to capital investment. If there were no consumer durable services, our two-sector sticky-price model would behave like a one-sector sticky-price model. In such a model, a positive capital investment-specific shock increases the efficiency of capital accumulation. An increase in the efficiency of capital investment creates an *intertemporal* substitution effect which dominates the income effect so that current nondurable consumption is substituted away toward investment and thus future consumption. Hence, there is the comovement problem. By contrast, because our two-sector model has consumer durable services, an additional effect is created. A positive capital investment-specific shock decreases the real price of capital (i.e., Tobin's Q), which raises the demand for capital investment. An increase in the demand for capital investment raises the price of durable goods relative to nondurables. This generates an *intratemporal* substitution effect away from consumer durable services and toward nondurable consumption that dominates the intertemporal substitution effect. As a result, nondurable consumption rises, and the comovement problem is resolved.

We note that if consumer durable services were introduced in a one-sector model, the comovement problem could not be resolved because there would not be an endogenous price of durables relative to nondurables. Indeed, Justiniano, Primiceri, and Tambalotti (2010, table 2) considered an extension of their baseline model to one with consumer durable services. In their extension, the household allocated income flows to nondurable consumption, capital investment, and consumer durable investment. Even though there were sticky prices of intermediates, there was only one final goods price. Without an endogenous price of durables relative to nondurables, there is no *intratemporal* substitution effect away from consumer durable services and toward nondurable consumption. As a consequence, the comovement problem is not resolved.

For related literature studying capital investment shocks, Guerrieri, Henderson, and Kim (2014) is the closest model to ours in that it is a two-sector model. These authors extended the one-sector model of Greenwood, Hercowitz, and Krusell (1997) to two sectors that produce machinery and nonmachinery goods, which are in turn used to assemble three types of final goods: equipment investment, structures investment, and nondurable consumption. They resolved the comovement problem by studying multifactor productivity (MFP) shocks to the machinery sector in place of shocks to the MEI. They found that the MFP shock increases consumption because of a weaker intertemporal substitution effect and a stronger wealth effect due to incomplete sectoral specialization in producing final goods, whereas the MEI shock temporarily decreases consumption substantially and creates the comovement problem. Unlike their paper, in our paper the MEI shock does not have the comovement problem, due

2. Bils and Klenow (2004) have documented that the price of durable goods changes more frequently than that of consumption goods.

to an intratemporal substitution effect which dominates the intertemporal substitution effect. In particular, nondurable consumption follows a hump shape in our model, which is consistent with the data, as opposed to changes in consumption with a *U* shape in response to the MFP shock in their model.

Moreover, our study complements three other papers that attempted to resolve the comovement problem using one-sector models with variable capital utilization. First, Khan and Tsoukalas (2011) studied a sticky price-wage model with the cost of capital utilization in terms of a higher depreciation rate of capital and with nonseparable preferences with a zero wealth effect on labor supply. By increasing the marginal productivity of labor, a higher utilization rate generated a substitution effect away from leisure and toward consumption, and resolved the comovement problem. Next, Eusepi and Preston (2009) also studied a model with the cost of capital utilization in terms of a higher depreciation rate of capital. They found that the heterogeneity in labor supply and consumption of employed and unemployed workers can generate comovement in response to investment shocks, since individual consumption was affected by the number of hours worked with the employed consuming more on average than the unemployed, and changes in the employment rate then affect aggregate consumption. Finally, Furlanetto and Seneca (2010) envisaged a model with the cost of capital utilization in terms of the maintenance cost of capital. They resolved the comovement problem by combining variable capacity utilization with nominal rigidities (in prices and wages) and nonseparable preferences with a zero wealth effect on labor supply. Unlike these papers, the mechanism in our paper is to consider consumer durable services so that there is an intratemporal substitution effect which dominates the intertemporal substitution effect.

The remainder of this paper is organized as follows. In Section 1, we present empirical evidence of comovement between consumption and investment in response to capital investment-specific shocks. In Section 2, we set up basic sticky-price models with and without consumer durable services. In Section 3, we calibrate the models and envisage the impulse responses to a positive capital investment-specific shock. Section 4 is the sensitivity analysis. Finally, concluding remarks are offered in Section 5.

1. INVESTMENT SHOCKS AND COMOVEMENT: EMPIRICAL EVIDENCE

This section estimates a vector autoregression (VAR) model and offers evidence showing that consumption and investment comove in response to investment shocks. Fisher (2006) has utilized a VAR model to estimate the impulse responses of the investment price, labor productivity, hours, and output to capital investment shocks. Here, we follow his approach to estimate the impulse responses of consumption, investment, and other variables to capital investment shocks.[3] We will find the

3. Different from Fisher (2006), our model does not involve a trend in the level of productivity. As a result, our model only assumes short-run recursive restrictions, without imposing long-run identifying restrictions.

evidence of comovement between consumption and investment in response to capital investment shocks. The evidence complements the findings provided by Fisher.

To this end, we formulate a 7-variable VAR representation for the U.S. economy written as

$$\mathbf{y}_t = \mathbf{\Gamma}\mathbf{y}_{t-1} + \mathbf{\Pi}\mathbf{u}_t, \tag{1}$$

where $\mathbf{u}_t$ is a vector of structural disturbances, and $\mathbf{\Gamma}$ and $\mathbf{\Pi}$ are matrices to be estimated.[4] The vector $\mathbf{y}_t$ consists of seven variables that include real gross domestic product (GDP), real consumption, real investment, hours, real wages, real consumer durable investment, and the level of investment-specific technology. Following Kydland and Prescott (1990) and Del Negro et al. (2007), consumption corresponds to personal consumption expenditures on nondurables and services, while investment is the sum of gross private domestic investment and personal consumption expenditures on durables. Hours are nonfarm business hours of all persons, wages are compensation of employees in wages and salary accruals, and consumer durable investment is personal consumption expenditures on durables. For the exogenous level of capital investment-specific technology,[5] we follow Fisher's (2006) method and use the inverse of the real price of capital to measure the level of investment-specific technology. Finally, to measure the real price of capital, we also follow Fisher's (2006) method, which is based on Gordon (1990) and Cummins and Violante (2002), and construct the (quality-adjusted) real price of equipment capital and software by dividing the equipment and software deflator by the consumption deflator. The source of the data is the Federal Reserve Economic Data, published by the Federal Reserve Bank of St. Louis, over the period 1947:Q1–2011:Q4.[6] The quarterly data are seasonally adjusted, deflated by the GDP deflators, and expressed in logarithms.

We use ordinary least squares to estimate this VAR model with an optimal lag length of two selected by the Akaike Information Criterion (AIC).[7] To recover the parameters in the structural VAR, we carry out a Cholesky decomposition of the residuals of the VAR. The ordering of the variables is real GDP, real consumption, real investment, hours, real wages, real consumer durable investment, and the level of investment-specific technology.[8] The ordering helps illustrate the stylized evidence of

4. Following Hamilton (1994), we impose restrictions on the matrix $\mathbf{\Pi}$ being lower triangular and the structural disturbances in $\mathbf{u}_t$ being serially uncorrelated and uncorrelated with each other.

5. Our model below includes the sector producing nondurable consumption and the sector producing investment goods for capital and consumer durables. However, there are no data for the technology level of capital investment goods. As a result, we follow Fisher's measure.

6. We employ 2011:Q4 as the end period because the data of the equipment and software deflator end in 2011:Q4. This series was discontinued afterward, and in the new NIPA data, equipment and software are classified as two separated series.

7. The optimal lag length selected by the Schwarz Information Criterion (SC) is one. We choose a longer optimal lag length of two quarters in order to capture more dynamics.

8. We follow the Cholesky decomposition of the VAR used by Christiano, Eichenbaum, and Evans (1997), Bernanke, Gertler, and Gilchrist (1999), Erceg and Levin (2006), Galí (2008), and Monacelli (2009), wherein these authors selected an ordering such that the impulse variable is placed in the last. That means the impulse variable does not affect the remaining variables contemporaneously but can

the comovement between consumption and investment in response to an investment-specific technology shock so as to motivate the purpose of our model in this paper.

We compute the impulse response functions (IRFs) to a one-standard-deviation innovation to the level of investment-specific technology. We also construct the approximate 95% confidence bands (two standard errors) for each IRF using 500 Monte Carlo repetitions. Figure 1 presents estimated IRFs of GDP, consumption, investment, and other variables with 95% confidence bands illustrated by dashed lines.

As is clear from the figure, a one-standard-deviation increase in the level of capital investment-specific technology causes a rise in all variables on impact. GDP, hours, and wages all increase. In particular, Panels B and C indicate that consumption and aggregate investment both increase on impact in response to investment-specific technology shocks. This offers the evidence that consumption and investment comove in response to investment shocks. Our results also show that consumer durable investment displays an opposite path to other variables in initial periods (cf. Panel F). Moreover, as we use the inverse of the real price of capital to measure the level of investment-specific technology, a rise in the level of investment-specific technology is associated with a fall in the real price of capital, and thus, a fall in Tobin's Q (cf. Panel G).

2. TWO-SECTOR STICKY-PRICE MODELS WITH AND WITHOUT CONSUMER DURABLE SERVICES

Two neoclassical sticky-price models are analyzed. One model includes consumer durable services and the other model does not. The model without consumer durable services is a special case of the model with consumer durable services.

The economy includes two final goods sectors: the nondurable goods and the durable goods sectors. The nondurable goods sector produces goods for nondurable consumption. The durable goods sector produces goods for two types of investment: investment in capital and investment in consumer durable services.[9] Each sector has a continuum of firms which produce and sell final goods at competitive prices and a continuum of businesses which produce and sell intermediates at monopolistic prices. The economy also consists of a continuum of households that supply labor elastically, consume, and offer capital. As the nondurable goods sector produces goods only for consumption, it is also referred to as the consumption goods sector. Similarly, the durable goods sector produces goods for investment and is also referred to as the investment goods sector. We use subscripts $j = C, I$ to denote the consumption goods and the investment goods sectors, respectively.

affect them with a lag. In our VAR, alternative orderings yield the robust results, as long as the level of investment-specific technology is not put in the first.

9. As in Baxter (1996), purchases of new consumer durables come from the sector producing investment goods. See also Kydland and Prescott (1990), Cooley and Prescott (1995), Christiano, Eichenbaum, and Evans (2005), and Del Negro et al. (2007).

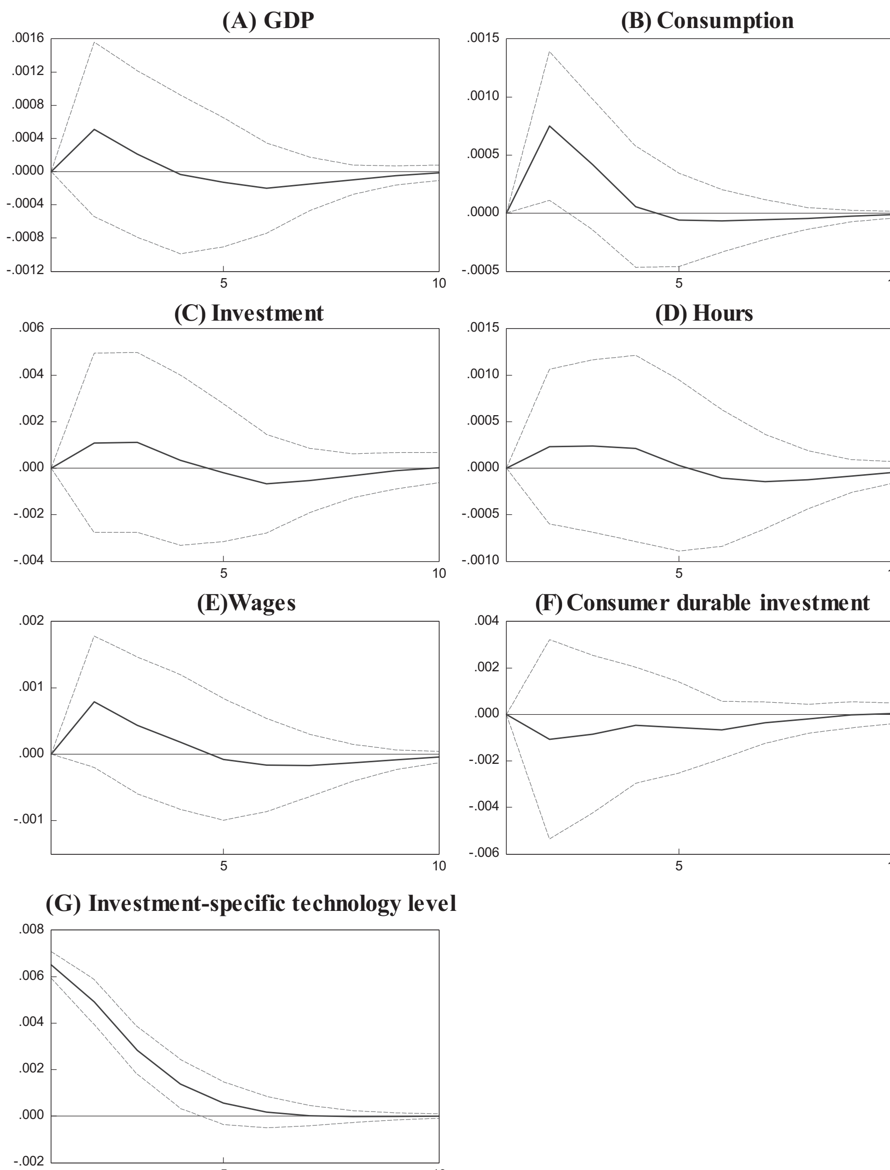

FIG. 1. Empirical Impulse Responses to a Positive Investment Shock.

NOTES: The horizontal axis is quarters; the vertical axis is percentage. The dashed lines indicate approximate 95% confidence bands.

2.1 Final Goods Producers

In each sector, there is a continuum of *final goods* producers of a unit mass. The representative producer in sector $j = C, I$, produces Y_j by combining a continuum of intermediates $Y_{jt}(z)$, $z \in [0, 1]$, according to the following technology:

$$Y_{jt} = \left[\int_0^1 (Y_{jt}(z))^{(\varepsilon_j - 1)/\varepsilon_j} dz \right]^{\varepsilon_j/(\varepsilon_j - 1)}, \quad j = C, I, \tag{2a}$$

where $\varepsilon_j > 1$ is the elasticity of substitution between intermediates. Nondurable goods Y_C are used for consumption. Durable goods Y_I are used for both capital investment I_K and consumer durable investment I_D which form the stock of capital and the stock of consumer durables, respectively. Final goods markets are competitive. The laws of motion for capital and consumer durable services will be specified in the household's problem below.

Maximization of profits in sector j gives the demand for the intermediate z in sector j:

$$Y_{jt}(z) = \left(\frac{P_{jt}(z)}{P_{jt}} \right)^{-\varepsilon_j} Y_{jt}, z \in [0, 1], \quad j = C, I, \tag{2b}$$

where P_{Ct} is the price of consumption (or nondurable) goods, P_{It} is the price of investment (or durable) goods, and $P_{jt}(z)$ is the price of the intermediate z in sector j.

A zero profit of final goods gives the following price of final goods in sector j:

$$P_{jt} = \left[\int_0^1 (P_{jt}(z))^{1-\varepsilon_j} dz \right]^{1/(1-\varepsilon_j)}, \quad j = C, I. \tag{2c}$$

2.2 Intermediate Goods Producers

In each sector, there is a continuum of *intermediate producers* of a unit mass indexed by $z \in [0, 1]$. The representative producer rents capital and hires labor to produce intermediates according to the following technology:

$$Y_{jt}(z) = A_j K_{jt}(z)^{\alpha_j} L_{jt}(z)^{1-\alpha_j}, \quad j = C, I, \tag{3a}$$

where $K_{jt}(z)$ is capital and $L_{jt}(z)$ is labor employed by a producer z in sector j. The parameter $\alpha_j \in (0, 1)$ is the capital share in sector j, and $A_j > 0$ is a productivity coefficient in sector j.

A producer z in sector j sells intermediates to final goods producers in sector j at a monopolistic price. In setting a price $P_{jt}(z)$, we follow Rotemberg (1982) and assume that an intermediate producer z faces the following adjustment cost:

$$\Theta(P_{jt}(z)) = \frac{\vartheta_j}{2} \left(\frac{P_{jt}(z)}{P_{jt-1}(z)} - 1 \right)^2 P_{jt} Y_{jt}, \quad j = C, I, \tag{3b}$$

where ϑ_j measures the degree of nominal rigidities in sector j.[10]

In each period, the firm z decides how much labor to hire, how much capital to rent, and what prices to set. Managers of the firm maximize the value to the owners which is the present discounted value of all current and future expected cash flows.

$$E_0 \sum_{t=0}^{\infty} \frac{\beta^t \Lambda_t}{\Lambda_0} [P_{jt}(z) Y_{jt}(z) - W_t L_{jt}(z) - R_t K_{jt}(z) - \Theta(P_{jt}(z))], \quad j = C, I, \tag{4}$$

where W_t is the nominal wage and R_t is the nominal capital rental, with their lower cases denoting the real wage and the real capital rental in terms of consumption goods, respectively (i.e., $w_t \equiv W_t/P_{Ct}$ and $r_t \equiv R_t/P_{Ct}$). In (4), E_t is conditional expectations in any given period t, and $(\beta^t \Lambda_t/\Lambda_0)$ is the stochastic discount factor, with $\beta \in (0, 1)$ and Λ_t being, respectively, the discount factor and the period-t marginal utility of real income of the representative household that owns the firm. As will be clear below, the period-t stochastic discount factor is equal to the owner's marginal rate of substitution between period t and period 0.

Given the technology (3a), managers choose $\{L_{jt}(z), K_{jt}(z), P_{jt}(z)\}_{t=0}^{\infty}$ to maximize the cash flows in (4) subject to the demand for the intermediate z in (2b). Let $\lambda_{jt}(z)$ denote the current-valued Lagrange multiplier of the demand for the intermediate z in (2b), $j = C, I$. Moreover, denote $MP_{jt}{}^{L}(z)$ and $MP_{jt}{}^{K}(z)$ as the period-t marginal product of labor and capital for the intermediate firm z in sector j, respectively. The first-order conditions for $L_{jt}(z)$, $K_{jt}(z)$, and $P_{jt}(z)$ are

$$w_t = \lambda_{jt}(z) \frac{P_{jt}(z)}{P_{Ct}} MP_{jt}^{L}(z), \tag{5a}$$

$$r_t = \lambda_{jt}(z) \frac{P_{jt}(z)}{P_{Ct}} MP_{jt}^{K}(z), \tag{5b}$$

$$\begin{aligned} &\left\{ [1 - (1 - \lambda_{jt}(z))\varepsilon_j] \left(\frac{P_{jt}(z)}{P_{jt}} \right)^{-\varepsilon_j} - \vartheta_j (\pi_{jt}(z) - 1) \frac{P_{jt}}{P_{jt-1}(z)} \right. \\ &\left. + \lambda_{jt}(z) \left[\frac{Y_{jt}(z)}{Y_{jt}} - \left(\frac{P_{jt}(z)}{P_{jt}} \right)^{-\varepsilon_j} \right] \right\} Y_{jt} \\ &+ E_t \left[\frac{\beta \Lambda_{t+1}}{\Lambda_t} \vartheta_j (\pi_{jt+1}(z) - 1) \frac{\pi_{jt+1}(z)}{\pi_{Ct+1}} \frac{P_{jt+1}}{P_{jt}(z)} Y_{jt+1} \right] = 0, \end{aligned} \tag{5c}$$

where $\pi_{jt}(z) \equiv P_{jt}(z)/P_{jt\text{-}1}(z)$ is the gross inflation of the intermediate z in sector j.

10. An alternative method of price adjustment is random price durations based on Calvo (1983). According to Rotemberg (1987), Roberts (1995), and Galí (2008), these two methods generate the same inflation dynamics.

By imposing the symmetry conditions of $K_{jt}(z) = K_{jt}$, $L_{jt}(z) = L_{jt}$, $P_{jt}(z) = P_{jt}$, $Y_{jt}(z) = Y_{jt}$, and $\lambda_{jt}(z) = \lambda_{jt}$ for all z, (5a)–(5c) give, respectively,

$$\frac{w_t}{\lambda_{jt}} = \frac{P_{jt}}{P_{Ct}} MP_{jt}^{L}, \quad j = C, I, \tag{6a}$$

$$\frac{r_t}{\lambda_{jt}} = \frac{P_{jt}}{P_{Ct}} MP_{jt}^{K}, \quad j = C, I, \tag{6b}$$

$$\frac{1}{\lambda_{jt}} = \frac{\varepsilon_j}{\varepsilon_j - \Omega_{jt}}, \quad j = C, I, \tag{6c}$$

where $\Omega_{jt} \equiv 1 - \vartheta_j(\pi_{jt} - 1)\pi_{jt} + E_t[\frac{\beta\Lambda_{t+1}}{\Lambda_t}\vartheta_j(\pi_{jt+1} - 1)\frac{(\pi_{jt+1})^2}{\pi_{Ct+1}}\frac{Y_{jt+1}}{Y_{jt}}],\ j = C, I.$

The multiplier λ_{jt} stands for the real marginal cost of intermediates in sector j in period t, and its inverse in (6c) is the markup over the marginal cost. Thus, in (6a), the demand for labor is determined by the markup over the real wage equal to the real marginal product of labor. Similarly, in (6b), the demand for capital is determined by the markup over the real rental equal to the real marginal product of capital.

Data indicate that durable prices are more flexible than nondurable prices (cf. Bils and Klenow 2004). To simplify the analysis, our baseline analysis will focus on the case wherein durable prices are flexible and nondurable prices are sticky. For robustness, we will also carry out analyses of the case where durable prices are sticky but less so than nondurable prices. Note that a flexible durable price gives $\vartheta_I = 0$, and thus $\Omega_{It} = 1$ for all t. In this case, the markup $1/\lambda_{It} = \varepsilon_I/(\varepsilon_I\text{-}1)$ is constant for all t. Moreover, in a steady state, $\pi_{jt} = \pi_{jt+1} = 1$ for $j = C, I$, so $\Omega_{jt} = \Omega_{jt+1} = 1$. Then, the markup is $1/\lambda_j = \varepsilon_j/(\varepsilon_j$ - 1) in a steady state for $j = C, I$.

2.3 Households

Households obtain utility from nondurable consumption and consumer durable services and encounter disutility from working. Following Baxter (1996) and Barsky, House, and Kimball (2003, 2007), we define an index of consumption X as a function of consumption and consumer durable services given as follows:

$$X_t \equiv [(1-\mu)^{\frac{1}{\eta}}(C_t)^{1-\frac{1}{\eta}} + \mu^{\frac{1}{\eta}}(D_t)^{1-\frac{1}{\eta}}]^{\frac{\eta}{\eta-1}}, \tag{7a}$$

where C_t is consumption and D_t is the stock of consumer durables which offers services to the household in period t. The parameter $\mu > 0$ is the share of consumer durable services, and $\eta \geq 0$ is the elasticity of substitution between consumption and consumer durable services.

The household's expected lifetime utility is

$$E_0\left\{\sum_{t=0}^{\infty}(\beta)^t\left(\log X_t - \nu\frac{(L_t)^{1+\phi}}{1+\phi}\right)\right\}, \tag{7b}$$

where L_t is the hours of work. The parameter $\nu > 0$ is the coefficient associated with the disutility of work, and $\phi > 0$ is the inverse of the Frisch labor supply elasticity.

The instantaneous utility in (7b) is separable with the logarithmic form for the index of consumption. The utility function is consistent with the balanced growth path (cf. King and Rebelo 1999).

In each period t, the representative household faces the following budget constraint:

$$C_t + p_t(I_{Kt} + I_{Dt}) + b_t = i_{t-1}\frac{b_{t-1}}{\pi_{Ct}} + r_t K_t + w_t L_t + \frac{T_t}{P_{Ct}} + \frac{F_t}{P_{Ct}}, \tag{8}$$

where $p_t \equiv P_{It}/P_{Ct}$ is the relative price of durables. K_t is capital holding at the beginning of period t, and $B_{t\text{-}1}$ is nominal bond holdings at the end of period $t - 1$, with $b_{t\text{-}1} \equiv B_{t\text{-}1}/P_{Ct\text{-}1}$ being its real value. $i_{t\text{-}1}$ is the gross nominal interest rate on a bond holding between $t - 1$ and t. T_t is nominal lump-sum transfers, and F_t is nominal profits remitted from firms (i.e., dividends) in t. Thus, in each period t, with real income flows from returns to bonds and capital, wages, lump-sum transfers, and dividends, the household chooses consumption, labor supply, capital investment, consumer durable investment, and bond holdings.

The stock of consumer durables can be produced from investment goods on a one-to-one basis net of adjustment costs. The stock of consumer durables evolves according to

$$D_t - (1 - \delta_D)D_{t-1} = \left[1 - \Phi_D\left(\frac{I_{Dt}}{I_{Dt-1}}\right)\right] I_{Dt}, \tag{9a}$$

where $0 < \delta_D < 1$ is the depreciation rate of the stock of consumer durables and the function $\Phi_D(.)$ is the fraction of adjustment costs of investment in consumer durables.

The story for capital investment is different. The accumulation equation for the stock of capital is expressed as

$$K_{t+1} - (1 - \delta_K)K_t = \xi_t\left[1 - \Phi_K\left(\frac{I_{Kt}}{I_{Kt-1}}\right)\right] I_{Kt}, \tag{9b}$$

where $0 < \delta_K < 1$ is the depreciation rate of capital and the function Φ_K is the fraction of adjustment costs in capital investment. Note that we follow Greenwood, Hercowitz, and Krusell (1997, 2000) and Justiniano, Primiceri, and Tambalotti (2010) and include a factor ξ_t in the accumulation of capital in (9b). The factor ξ_t represents the current state of the technology for forming capital. It is an exogenous variation in efficiency and determines the amount of capital in the next period that can be formed from one unit of investment goods in this period. Changes in ξ_t formalize the notion of capital investment-specific technological change.

Following Christiano, Eichenbaum, and Evans (2005) and Justiniano, Primiceri, and Tambalotti (2010), we assume that the function of the adjustment cost Φ_i takes the form $\Phi_i(\frac{I_{it}}{I_{it-1}}) = \frac{\varphi_i}{2}(\frac{I_{it}}{I_{it-1}} - 1)^2,\ \varphi_i \geq 0, i = D, K.$[11]

As in existing work on capital investment-specific technology shocks, we assume that ξ_t follows a first-order stochastic process:

$$\log \xi_t = \rho \log \xi_{t-1} + e_t, \tag{10}$$

11. The form gives $\Phi_i'(\frac{I_t}{I_{t-1}}) = \varphi_i(\frac{I_{it}}{I_{it-1}} - 1)$ and $\Phi_i'(\frac{I_{it+1}}{I_{it}}) = \varphi_i(\frac{I_{it+1}}{I_{it}} - 1)$.

where the innovation in relation to the capital investment shock e_t is assumed to be independent and identically distributed normally with mean 0 and variance σ^2.

Several remarks are in order. As is standard, capital investment is accumulated into the stock of capital in the next period in (9b), and thus capital investment is for use in production in the next period. On the other hand, in terms of value, we think of consumer durables as mainly from residential houses. When these consumer durables are purchased, they are ready for use as consumption services. Hence, in (9a) we follow the conventional wisdom in Barsky, House, and Kimball (2003, 2007), Monacelli (2009), and Sudo (2012) and posit that the flow of consumer durables forms the stock in the same period.

Second, we posit that only capital investment encounters investment shocks, because when both investments are subject to investment shocks, the intratemporal substitution effect is so weak that it cannot dominate the intertemporal substitution effect. Then, the comovement problem cannot be resolved. Our formulation is based on the following reasons. First, in Greenwood, Hercowitz, and Krusell (1997, 2000), there are two types of capital that are accumulated from investment that is produced in the same sector, but only equipment capital confronts investment-specific technology shocks while structures capital is not affected by investment-specific technology shocks. Second, and more importantly, existing studies, such as Chung, Kiley, and Laforte (2010), argue that there are two categories of durables, and they differ in the way that they are affected by investment-specific shocks. The first category of durables includes personal computers and home appliances. It is likely that production of these goods receives a favorable impact from a positive investment technology shock. The second category of durables includes residential investment. Existing studies agree that productivity of residential investment is not affected by investment-specific technology shocks. Besides, in terms of value, the majority of consumer durables are residential houses. Thus, we can think of consumer durables in our paper as residential houses, and their productivity is not affected by investment-specific technology shocks.

Moreover, viewing consumer durables as residential housing, our formulation is the same as Barsky, House, and Kimball (2003), whose model includes two sectors: a durable goods sector and a nondurable goods sector. In Barsky, House, and Kimball (2003, section 6), their specification allows for the durable to function as productive capital or consumer durables, the former of which is treated as a fixed factor of production. Thus, our two-sector model is similar to that of Barsky, House, and Kimball, except that our model allows for capital accumulation and investment-specific technology shocks, and their model does not.[12]

12. The purpose of Barsky, House, and Kimball (2003, 2007) is to study the business-cycle effect of a monetary shock, not an investment shock. In particular, these authors found a comovement problem because, in response to monetary tightening, nondurable consumption decreases but durable consumption increases. Monacelli (2009) allowed for friction in lending between households in the model of Barsky, House, and Kimball and resolved the comovement problem only when durable prices have some degrees of stickiness. The comovement puzzle is not settled when durable prices are flexible. By adding capital into Monacelli's model, Chen and Liao (2014) resolved the comovement problem when durable prices are flexible.

Furthermore, although like Barsky, House, and Kimball (2003), investment in both capital and consumer durables comes from the same sector and thus has the same price of goods p_{It}, capital investment is subject to an investment-specific technology progress at rate ξ_t, and consumer durable investment is not. As a result, the price of capital investment relative to the price of consumer durable investment is not unity but is $1/\xi_t$, which is Tobin's Q. When the investment-specific shock follows the first-order stochastic process as in (10), their relative price also follows a stochastic process.

The representative household's problem is to maximize the expected lifetime utility (7b) subject to (8), (9a), and (9b). Let Λ_t, ζ_t, and q_t be the current-valued Lagrange multipliers of the budget constraint (8), the accumulation of consumer durables (9a), and the capital accumulation equation (9b), respectively. Moreover, we denote U_{Ct}, U_{Dt}, and U_{Lt}, respectively, as the marginal utility of consumption, consumer durable services, and hours worked in t. The first-order conditions for C_t, L_t, b_t, I_{Kt}, I_{Dt}, K_{t+1}, and D_t are

$$U_{Ct} = \Lambda_t, \tag{11a}$$

$$\frac{-U_{Lt}}{U_{Ct}} = w_t, \tag{11b}$$

$$U_{Ct} = \beta E_t \left(U_{Ct+1} \frac{i_t}{\pi_{Ct+1}} \right), \tag{11c}$$

$$\begin{aligned} p_t U_{Ct} = {} & p_t q_t \xi_t \left[1 - \Phi_K \left(\frac{I_{Kt}}{I_{Kt-1}} \right) - \frac{I_{Kt}}{I_{Kt-1}} \Phi'_K \left(\frac{I_{Kt}}{I_{Kt-1}} \right) \right] \\ & + \beta E_t \left[p_{t+1} q_{t+1} \xi_{t+1} \left(\frac{I_{Kt+1}}{I_{Kt}} \right)^2 \Phi'_K \left(\frac{I_{Kt+1}}{I_{Kt}} \right) \right], \end{aligned} \tag{11d}$$

$$\begin{aligned} p_t U_{Ct} = {} & p_t \zeta_t \left[1 - \Phi_D \left(\frac{I_{Dt}}{I_{Dt-1}} \right) - \frac{I_{Dt}}{I_{Dt-1}} \Phi'_D \left(\frac{I_{Dt}}{I_{Dt-1}} \right) \right] \\ & + \beta E_t \left[p_{t+1} \zeta_{t+1} \left(\frac{I_{Dt+1}}{I_{Dt}} \right)^2 \Phi'_D \left(\frac{I_{Dt+1}}{I_{Dt}} \right) \right], \end{aligned} \tag{11e}$$

$$p_t q_t = \beta E_t \left[r_{t+1} U_{Ct+1} + p_{t+1} q_{t+1} (1 - \delta_K) \right], \tag{11f}$$

$$p_t \zeta_t = U_{Dt} + \beta E_t \left[p_{t+1} \zeta_{t+1} (1 - \delta_D) \right], \tag{11g}$$

along with the transversality conditions $\lim_{t\to\infty}(\beta)^t \Lambda_t b_t = 0$, $\lim_{t\to\infty}(\beta)^t q_t K_{t+1} = 0$, and $\lim_{t\to\infty}(\beta)^t \zeta_t D_t = 0$. Thus, Λ_t is the marginal utility of the household. Using (11a), the firm's stochastic discount factor $(\beta^t \Lambda_t / \Lambda_0)$ in (4) is equal to $(\beta^t U_{Ct}/U_{C0})$, which is the intertemporal marginal rate of substitution between period t and period 0.

In these conditions, (11a) and (11b) are standard, and (11c) is the consumption-Euler equation, which equates the marginal utility of consumption in this period to the discounted expected marginal utility of shifting one unit of consumption to the next period. In condition (11d), q_t is the shadow value of installed physical capital. Like Justiniano, Primiceri, and Tambalotti (2010), Tobin's Q is q_t/Λ_t, the relative marginal value of installed capital with respect to consumption, which is the real price of capital stock. This condition equates the foregone value of capital investment, which is the marginal utility of consumption, to the marginal value of capital investment. The marginal value of capital investment includes the shadow value, net of adjustment costs, of installed physical capital in this period (the first term) and the enhanced shadow value of capital due to lowering adjustment costs in the next period (the second term). In the case without adjustment costs of capital investment (i.e., $\Phi_K = 0$ and $\Phi'_K = 0$), the condition reduces to $q_t/\Lambda_t = 1/\xi_t$, which indicates that, in optimum, Tobin's Q is equal to a reciprocal of capital investment shocks. It follows that positive capital investment shocks reduce the real price of capital, which in turn raises the demand for capital investment.

Similar to (11d), condition (11e) equates the marginal utility of consumption to the marginal value of consumer durable investment. The stock of consumer durables also has a Tobin's Q-like concept, which is the shadow value of consumer durable services in terms of consumption, ζ_t/Λ_t. In the case without adjustment costs of consumer durable investment (i.e., $\Phi_D = 0$ and $\Phi'_D = 0$), the condition reduces to $\zeta_t/\Lambda_t = 1$, which indicates that, in optimum, the marginal value of consumer durable services is equal to the marginal utility of consumption.

Condition (11f) determines the demand for capital in the next period. The marginal cost of capital is this period's effective relative price of durables evaluated by the shadow value of installed physical capital. The marginal benefit is the expected discounted sum of the next period's real rental (in terms of consumption) and next period's effective relative price of undepreciated capital evaluated by the shadow value of installed capital.

Finally, (11g) determines the demand for consumer durable services in this period. The marginal cost is this period's effective relative price of durables evaluated by the shadow value of consumer durable services. The marginal benefit is the sum of this period's marginal utility of consumer durable services and the expected discounted next period's effective relative price of undepreciated consumer durables evaluated by the shadow value of consumer durable services. Through (11g), variations in the relative price of durables are expected to affect the demand for nondurable consumption as analyzed in the next section.

2.4 Equilibrium

In equilibrium, the consumption goods and the investment goods markets clear:

$$Y_{Ct} - \frac{\vartheta_C}{2}(\pi_{Ct} - 1)^2 Y_{Ct} = C_t, \tag{12a}$$

$$Y_{It} - \frac{\vartheta_I}{2}(\pi_{It} - 1)^2 Y_{It} = I_{Kt} + I_{Dt}. \tag{12b}$$

We abstract from redistribution via the fiscal policy, and hence $T_t = 0$. Moreover, the capital, the labor, and the bond markets all clear:

$$K_t = K_{Ct} + K_{It}, \tag{13a}$$

$$L_t = L_{Ct} + L_{It}, \tag{13b}$$

$$b_t = 0. \tag{13c}$$

The model is closed by a monetary policy rule. As we do not analyze the effects of monetary shocks, the simplest rule is used:

$$\frac{i_t}{i} = \left(\frac{\pi_t}{\pi}\right)^{\chi}, \quad \chi > 1, \tag{14}$$

where $\pi_t \equiv (\pi_{Ct})^{1-\mu}(\pi_{It})^{\mu}$ is a composite inflation index with the weight for non-durable goods inflation being the share of nondurable consumption in the index of consumption, and i and π are steady-state values. We assume that χ is sufficiently large in order to ensure equilibrium determinacy.

2.5 The Model without Consumer Durable Services

The model without consumer durable services is a special case of the two-sector model above when there are no consumer durable services. In the model without consumer durable services, the utility function in (7b) is reduced to $\log C_t - \nu(L_t)^{1+\phi}/(1 + \phi)$. Moreover, (9a), (11e), and (11g) are not equilibrium conditions. As equilibrium conditions (8) and (12b) involve consumer durable investment, they are also modified.

Even with two sectors, because of no consumer durable services, as will be seen below, a positive capital investment-specific shock leads to an increase in investment and a decrease in consumption, thus the comovement problem, as in Justiniano, Primiceri, and Tambalotti (2010).

3. COMPARISONS OF BOTH MODELS

In this section, we study the effects of positive investment-specific technology shocks on the impulse responses of aggregate macro- and other relevant variables.

3.1 Calibration

The time frequency is quarterly. The households' discount factor β is pinned down by the steady-state real rate of return i. We choose a real rate of return per annum of 4%. This implies a quarterly discount factor of $\beta = 0.99$.

For production, the total factor productivities in the consumption goods and investment goods sectors are normalized to unity, so $A_C = A_I = 1$. We follow Acemoglu and Guerrieri (2008) and set the capital shares of the investment goods and the consumption goods sectors equal to $\alpha_I = 0.27$ and $\alpha_C = 0.47$, respectively, to match the average capital shares in their respective sectors between 1987 and 2005. The elasticity of substitution between intermediates is set so that the desired markup is 20% in both sectors, which gives $\varepsilon_C = \varepsilon_I = 6$. We follow Hansen (1985) and set the quarterly depreciation rate of capital equal to $\delta_K = 0.025$, which implies a 10% annual depreciation rate. Moreover, following Carlstrom and Fuerst (2010) and Sudo (2012), we assume that the quarterly depreciation rate for consumer durable services equals $\delta_D = 0.025$.[13]

As to the coefficient of adjustment costs, the existing literature sets a zero adjustment cost for the accumulation in consumer durable investment (e.g., Iacoviello 2005, Barsky, House, and Kimball 2007, Monacelli 2009). We follow this convention and set $\varphi_D = 0$. We set the coefficient of adjustment costs in capital investment to be $\varphi_K = 0.5\%$. This value is somewhat smaller than the value used by Greenwood, Hercowitz, and Krusell (2000) and Guerrieri, Henderson, and Kim (2014). These authors studied investment shocks in models wherein the intertemporal substitution effect dominates the income effect, which causes the comovement problem. When they use a large fraction of adjustment costs in capital investment, the intertemporal substitution effect is weakened and smaller than the income effect, so the comovement problem is resolved. By contrast, capital adjustment costs do not play such an important role in our model because, by introducing consumer durable services, there is a sufficiently large intratemporal substitution effect that dominates the intertemporal substitution effect. In order to highlight the role of consumer durable services in resolving the comovement problem, we choose a small fraction of adjustment costs in capital investment.

For the preference, by using the consumption-leisure trade-off condition in (11b), we set the parameter value of leisure in preference at $\nu = 5.573$ to target hours of work in the steady state at $L = 1/3$. As for the elasticity of substitution between nondurable consumption and consumer durable services, we follow Barsky, House, and Kimball (2007) and set $\eta = 1$, implying a Cobb–Douglas form for the consumption index. In addition, like Barsky, House, and Kimball, we set the inverse of the Frisch labor supply elasticity at $\phi = 1$, which is within the range of values used in the existing literature. We will perform robustness analysis for different values of η and ϕ in Section 4. We choose the share of consumer durable services in the consumption index equal to $\mu = 0.2$ in order to match the 20% share of spending on consumer durables in total private spending in the United States.

13. Our results are robust within a wide range of $\delta_K \in [0.015, 0.055]$ and $\delta_D \in [0.010, 0.037]$.

As for the degree of price-stickiness, we set $\vartheta_I = 0$ so that durable prices are flexible, as shown in Bils and Klenow (2004), among others. Justiniano, Primiceri, and Tambalotti (2010) estimated the price-stickiness of consumption goods at over six quarters (the probability of not resetting prices being 0.84), and Khan and Tsoukalas (2011) estimated the price-stickiness of consumption goods at over four quarters (the probability of not resetting prices being 0.77). We target the stickiness of nondurable prices at five quarters, which lies within the range of these estimates. This pins down $\vartheta_C = 96.154$.[14] As for the monetary policy rule, we set the coefficient of the inflation in the policy rule at $\chi = 1.5$, which is a standard value in the literature regarding Taylor rules.

Finally, the autocorrelation of the capital investment shock and the standard deviation of errors to the capital investment shock are set to be $\rho = 0.72$ and $\sigma = 0.0603$, respectively, which are within the range of the estimated values in the literature, such as Smets and Wouters (2007), Justiniano, Primiceri, and Tambalotti (2010), and Khan and Tsoukalas (2011).

Parameter values in the baseline parameterization are summarized in Table 1. In the table, we also list parameter values used in the model without consumer durable services wherein all parameter values are the same as those for the model with consumer durable services except for $\mu = 0$ and a different calibrated value of ν.

3.2 Effects of a Positive Investment Shock

We carry out a positive capital investment shock in the same way as in Justiniano, Primiceri, and Tambalotti (2010). Specifically, the innovation in relation to the capital investment shock e_t is increased by one standard deviation in the stochastic process with the initial value of the capital investment shock ξ_t normalized at unity. The results of the impulse responses are illustrated in Figure 2. An increase in e_t raises the marginal efficiency of capital investment. As a result of a positive shock to the marginal efficiency of capital investment, Tobin's Q, and thus the real price of capital, goes down (cf. Panel J), which raises the demand for investment goods on impact (cf. Panel C). Since durable prices are more flexible than nondurable prices, the relative price of durables, and thus the relative price of investment, increases (cf. Panel G). A higher durable price increases inflation, which in turn raises the nominal interest rate (cf. Panels H and I). Moreover, a positive investment shock produces a drop in the price markup in sticky-price models, as is evident from the fact that the real marginal cost of intermediates in the consumption sector increases (cf. Panel F).

We remark that a positive shock to the marginal efficiency of capital investment decreases the real price of capital and thus Tobin's Q. The price of capital is often seen as a good proxy for the stock market value. A positive shock to the marginal

14. To obtain the value of ϑ_C, we use the log-linearization of the optimal pricing condition in (6c) to yield the slope of the Phillips curve equal to $(\varepsilon_C - 1)/\vartheta_C$. Then, we equate the slope to the slope of the New Keynesian Phillips curve in the standard Calvo–Yun model, which is $(1 - \theta_C)(1 - \beta\theta_C)/\theta_C$, where θ_C is the probability of not resetting prices for consumption goods. Thus, we obtain $\vartheta_C = (\varepsilon_C - 1)\theta_C/[(1 - \theta_C)(1 - \beta\theta_C)]$. See the Appendix for details. By setting the stickiness of nondurable prices at five quarters so $1 - \theta_C = 1/5$, with $\varepsilon_C = 6$ and $\beta = 0.99$, we obtain $\vartheta_C = 96.154$.

TABLE 1

Parameter Setting (Frequency: Quarterly)

Description	Parameter	Model with consumer durables	Model without consumer durables
TFP in the consumption and investment sectors	A_C, A_I	1	1
Elasticity of sub. between nondurables and durables	η	1	1
Elasticity of sub. between intermediates	$\varepsilon_C, \varepsilon_I$	6	6
Share of durable services	μ	0.2	0
Inverse elasticity of labor supply	ϕ	1	1
Hours of work	L	1/3	1/3
Discount factor	β	0.99	0.99
Autocorrelation of the capital investment shock	ρ	0.72	0.72
Standard deviation of error to the investment shock	σ	0.0603	0.0603
Coefficient of inflation rates in Taylor rule	χ	1.5	1.5
Capital share in the investment sector	α_I	0.27	0.27
Capital share in the consumption sector	α_C	0.47	0.47
Depreciation rate of capital	δ_K	0.025	0.025
Depreciation rate of consumer durable services	δ_D	0.025	–
Coefficient of adjustment costs in capital investment	φ_K	0.005	0.005
Coefficient of adjustment costs in consumer durable investment	φ_D	0	–
Parameter of labor in utility	ν	5.573	5.794
Coefficient of price adjustment in investment sector	ϑ_I	0	0
Coefficient of price adjustment in consumption sector	ϑ_C	96.154	96.154

efficiency of capital investment delivers at the same time an output boom and a stock market bust, as discussed in Christiano, Motto, and Rostagno (2014).

By contrast, because we have an endogenous price of durables relative to nondurables, a positive shock to the marginal efficiency of capital investment increases the relative price of durables (i.e., the relative price of investment). A procyclical relative price of investment is consistent with the data. Although a branch of research indicated a countercyclical relative price of investment prior to the mid-1980s or 1990s (e.g., Fisher, 2006), recent evidence indicates no robust evidence that this relative price is countercyclical. For example, using three definitions of aggregate investment and two measures of the price of consumption, Beaudry, Moura, and Portier (2015) found that the price of investment relative to consumption was procyclical over the post-1983 period and almost always significantly so for all the measures. When considering a longer sample, it was rarely countercyclical and never significantly so. They showed that their result held for the other G7 countries.

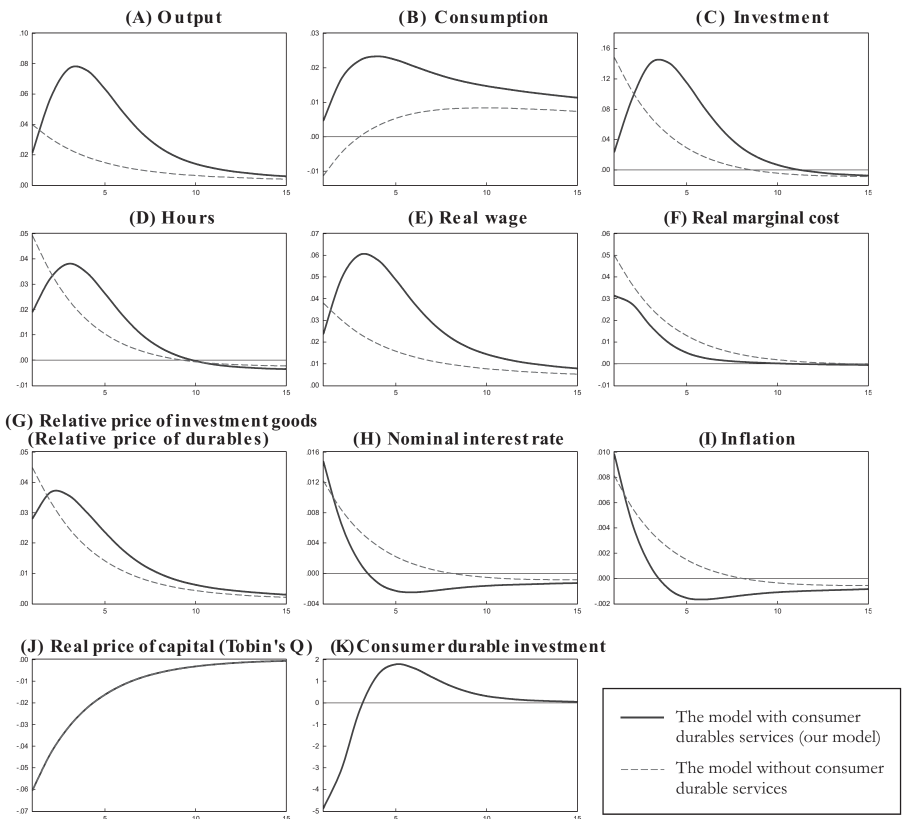

FIG. 2. Impulse Responses to a Positive Investment Shock.

NOTE: The horizontal axis is quarters; the vertical axis is percentage deviations from a steady state.

The model without consumer durable services. To see the impulse responses of other variables, we begin by envisaging the effects in the model without consumer durable services. The results are delineated by the dashed red lines in Figure 2.

An increase in the marginal efficiency of capital investment generates an *intertemporal* substitution effect away from nondurable consumption and toward investment, and thus future consumption. Hence, nondurable consumption falls (cf. the dashed red line in Panel B). The higher return on currently available resources would, at the same time, operate to persuade individuals to postpone leisure. Consequently, there is an expansion in hours of work and, thus, output (cf. the dashed red lines in Panels D and A). Moreover, the real wage rises since the increase in the real marginal cost dominates the decrease in the marginal product of labor (cf. the dashed red line in Panel E). Therefore, all other real variables increase except for consumption. The model thus fails to generate the comovement between investment and consumption.

The model with consumer durable services. Now, we analyze the impulse responses of other variables in the model with consumer durable services. The results are illustrated by solid blue lines in Figure 2.

Consumer durable services are now a substitute for nondurable consumption. Thus, there is another substitution effect. A higher relative price of durables generates an *intratemporal* substitution effect away from consumer durable services and toward nondurable consumption. As the intratemporal substitution effect dominates the intertemporal substitution effect, nondurable consumption goes up (cf. the solid blue line in Panel B). As a result, nondurable consumption comoves with output, investment, hours of work, and real wages (cf. the solid blue lines in Panels A–E).

It should be noted that, in response to a positive capital investment shock, the model with consumer durable services amplifies the impulse responses of real variables with hump-shaped patterns (cf. the solid blue lines in Panels A–E), but the impulse responses of real variables in the model without consumer durable services do not have hump-shaped patterns (cf. the dashed red lines in Panels A–E). As remarked by King and Rebelo (1999), the results emerge because consumer durable investment has larger amplitudes of percentage fluctuations, similar to capital investment.

Furthermore, even though the consumer durable investment does not increase on impact, we have found that the consumer durable investment comoves with other real variables from $t + 1$ onward, because shocks to the marginal efficiency of capital investment in t influence the production of durables in $t + 1$, which increases consumer durable investment (cf. Panel K). As a result, the simulated correlation between consumption and consumer durable investment is still positive but low, about 0.16.

We remark that in the figure, the maximal change of a decrease in consumer durable investment in Panel K is close to 4.8 on impact and is large as compared to the change of an increase in output in Panel A, which is near 0.1, that is, 10%. Nevertheless, such a large change in consumer durable investments is commonly seen in the literature on consumer durables. In the model that studied the response to a permanent 1% increase in the money supply by Barsky, House, and Kimball (2007), when nondurable prices are sticky at four quarters and durable prices are flexible as is in our model, the change of a decrease in consumer durable investment is more than 11, which magnitude is much larger than the change in output which is around 0.01. In an extension made by Monacelli (2009) later, the author introduced two types of agents, namely, savers and borrowers, and found that, in response to a 25-basis-point increase in the innovation of the interest rate policy shock, the change of a decrease in consumer durable investment is around 6, which is much larger than the change in consumption, which is close to 0.1.[15]

Finally, we must report that the simulated correlation between output and consumption in our model is 0.81. The simulated correlation matches well with the correlation

15. These numbers are taken from figure 1 in Barsky, House, and Kimball (2007) and figure 4 in Monacelli (2009).

of 0.76 in the United States over the postwar period of 1947:Q1–2016:Q2. However, in the model without consumer durable services, the simulated correlation between output and consumption is only 0.14, which fails to match the data.[16]

3.3 *Why Does the Model with Consumer Durable Services Resolve the Comovement Problem?*

This subsection explains the underlying reasons why, in an otherwise standard two-sector sticky-price model with more flexible durable prices, adding consumer durable services resolves the comovement problem. At the center of the analysis is the fact that in a two-sector model with consumer durable services, the demand for consumer durable services changes the household's expenditure behavior.

First, we analyze the model without consumer durable services. By using (6a) and (11b), we obtain

$$\frac{-U_{Lt}}{U_{Ct}} = \nu L_t^{\phi} C_t = \lambda_{jt} \frac{P_{jt}}{P_{Ct}} MP_{jt}^{L}, \quad j = C, I. \tag{15}$$

With standard preferences and technology, the marginal rate of substitution between consumption and leisure ($\frac{-U_{Lt}}{U_{Ct}} = \nu L_t^{\phi} C_t$) is increasing in consumption and hours of work, while the marginal product of labor ${MP_{jt}}^L$ is decreasing in hours of work. For ease of exposition, we focus on a one-sector flexible-price model without consumer durables, so $\lambda_{jt} = \lambda_j$ is constant for all t and $P_{jt}/P_{Ct} = 1$ for $j = C, I$. As a result, a capital investment shock that increases hours of work on impact and, thus, decreases the marginal product of labor, would lower consumption in order to meet (15) in equilibrium. This is exactly what happens in response to a capital investment shock in the model without consumer durable services, as described above. A two-sector model with a consumption good sector and an investment good sector behaves like a one-sector model with goods used as consumption and investment described above. Their mechanisms are the same. As a result, consumption falls in response to a positive capital investment shock.

By contrast, in the two-sector model with consumer durables, there is an additional optimization condition, which is the household's shadow value of consumer durable services in period t given by (11g) with $\zeta_t = U_{Ct}$ when $\varphi_D = 0$ in (11e). In the optimum, this shadow value is equal to the marginal cost of investment in consumer durable services in terms of the marginal utility of consumption. If we denote $V_t \equiv p_t U_{Ct}$, the household's shadow value of consumer durable services in (11g) can be rewritten as

$$V_t = U_{Dt} + \beta(1 - \delta_D) E_t(V_{t+1}) = E_t \sum_{\tau=0}^{\infty} \beta^{\tau} (1 - \delta_D)^{\tau} U_{Dt+\tau}, \tag{16}$$

in which the second equality follows from the law of iterated expectations.

16. When durable prices are sticky at two quarters, the simulated correlation between output and consumption is still 0.78 in our model but only 0.05 in the model without consumer durable services.

The condition above has something to do with the observation that the shadow value of a long-lived durable is approximately unchanged in the wake of a shock (e.g., Barsky, House, and Kimball 2003, 2007, House and Shapiro 2008). This condition indicates that a household's shadow value of consumer durable services in this period is equal to the expected discounted sum of the marginal utility of undepreciated consumer durable services from period t onward. The household's shadow value of consumer durable services is quasi-constant, since variations in the flow of consumer durables in this period have little effect on the stock of consumer durables upon which the marginal utility of consumer durable services depends. With a quasi-constant shadow value of consumer durable services V_t, the relative price of durables p_t (i.e., the relative price of investment) and the marginal utility of consumption U_{Ct} in this period will move in opposite directions. A positive capital investment-specific shock decreases the real price of capital, which in turn leads to an increase in the demand for capital investment. The rise in the demand for capital investment then increases the relative price of durables. Thus, it is necessary to decrease the marginal utility of nondurable consumption, which is associated with an increase in expenditure on nondurable consumption. As a result, nondurable consumption rises, and the comovement problem is resolved.

4. SENSITIVITY ANALYSIS

In our calibration exercises, the baseline parameter values are well justified. To better understand whether or not our results are robust to variations in key parameter values used in the baseline, this section analyzes sensitivity analysis.

4.1 Price Stickiness in Investment Goods

So far, our result of comovement is obtained under the situation wherein durable prices are flexible. Our results still hold true if durable prices are sticky but are less sticky than nondurable prices.

To see this, we carry out analysis by increasing price stickiness in investment goods. Our baseline sets $\vartheta_I = 0$ so that the probability of resetting durable prices is $1 - \theta_I = 1$. If the value of ϑ_I is increased, the cost of durable price adjustments is higher. Then, durable prices are stickier than the baseline. With stickier durable prices, in response to a positive capital investment shock, fewer firms raise durable prices. The price of durables relative to the price of nondurables increases less than that in the baseline. Then, the intratemporal substitution effect is weaker, so consumption on impact increases by less.

Figure 3 illustrates the impulse responses when the probability of resetting durable prices $(1 - \theta_I)$ is decreased from 1 to 1/2 and then 2/5, which implies that the price of durables is reset less frequently at every 2 quarters and 2.5 quarters, respectively, with the corresponding parameter value of ϑ_I being increased from 0 to 9.90 and then 18.47, respectively. When durable prices are adjusted less frequently, the relative price of durables is increased by a smaller degree (cf. Panel G), and thus, the intratemporal

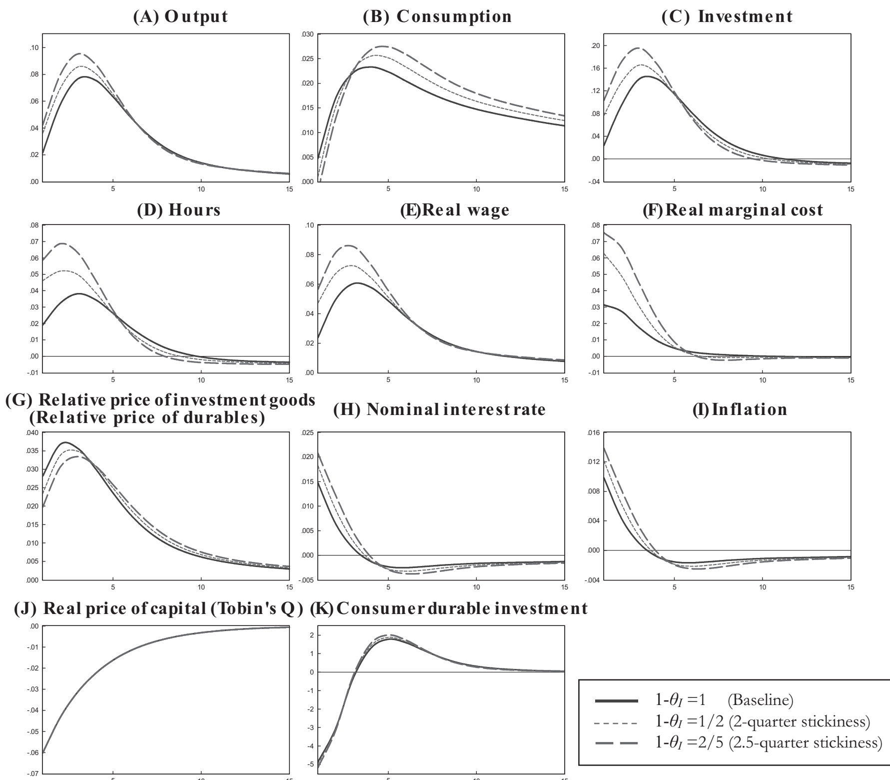

FIG. 3. Impulse Responses to a Positive Investment Shock in the Model with Sticky Durable Prices.

NOTE: The horizontal axis is quarters; the vertical axis is percentage deviations from a steady state.

substitution effect becomes weaker. Figure 3 suggests that our result of comovement is robust even when durable prices are sticky, as long as the frequency of durable price adjustment is lower than 2.5 quarters.

4.2 *Price Stickiness in Consumption Goods*

In our baseline, the nondurable price is reset every 5 quarters. Our results of comovement still hold true if nondurable prices are less sticky but are stickier than durable prices.

To see this, we carry out analysis by decreasing nondurable price stickiness. Our baseline sets $\vartheta_C = 96.15$ so that the probability of resetting nondurable prices is $1 - \theta_C = 1/5$. If the value of ϑ_C is decreased, the cost of nondurable price adjustments is lower. Then, the price of nondurable consumption is less sticky than the baseline. With less sticky nondurable prices, in response to a positive capital investment shock,

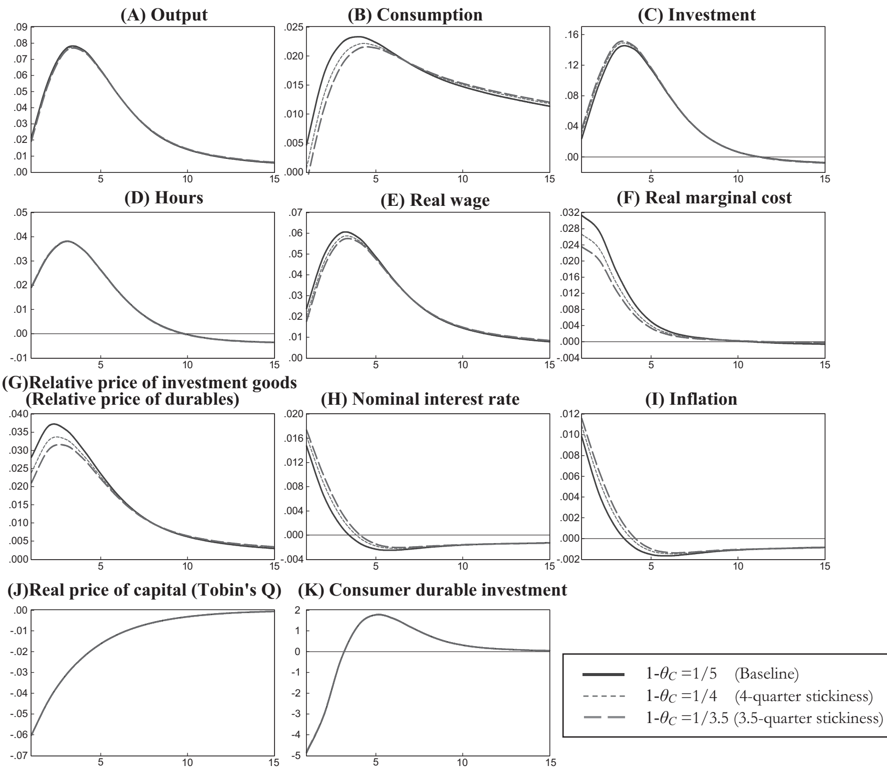

FIG. 4. Impulse Responses to a Positive Investment Shock in the Model with Less Sticky Nondurable Prices.

NOTE: The horizontal axis is quarters; the vertical axis is percentage deviations from a steady state.

more firms raise nondurable prices.[17] The durable price relative to the nondurable price is not increased as much as it is in the baseline. Then, the intratemporal substitution effect is weaker, and nondurable consumption on impact is increased by less.

Figure 4 demonstrates the impulse responses when the probability of resetting nondurable prices $(1 - \theta_C)$ is increased from 1/5 to 1/4 and then 1/3.5, which implies that the consumption price is reset more frequently at every 4 quarters and 3.5 quarters, respectively, with the corresponding parameter value of ϑ_C being decreased from 96.15 to 58.25 and then 42.68, respectively. When nondurable prices are adjusted more frequently, the relative price of durables is increased by a smaller degree (cf. Panel G), and thus, the intratemporal substitution effect becomes weaker. The figure indicates that our result of comovement is robust even when nondurable prices are

17. Consumption prices increase as a result of a rise in the real marginal cost in the consumption sector.

less sticky, as long as the frequency of nondurable price adjustment is higher than 3.5 quarters.

4.3 Elasticity of Substitution between Consumption and Consumer Durable Services

In our baseline, the elasticity of substitution between nondurable consumption and consumer durable services is set at unity. In this subsection, we envisage the robustness of the result when the elasticity of substitution between nondurable consumption and consumer durable services is different from unity.

If the elasticity of substitution between nondurable consumption and consumer durable services is higher (a larger η), the intratemporal substitution effect between nondurable consumption and consumer durable services is stronger. Then, in response to positive capital investment shocks, it is easier to obtain the comovement. By contrast, when the elasticity of substitution between nondurable consumption and consumer durable services is lower, the intratemporal substitution effect is weaker. Then, it is more difficult to generate comovement.

The impulse responses are displayed in Figure 5. We find that when the elasticity of substitution between nondurable consumption and consumer durable services is increased to 1.1 and larger values, nondurable consumption increases and comoves with other real variables. Moreover, when the elasticity of substitution is decreased to 0.9, nondurable consumption also comoves with investment. Yet, when the elasticity of substitution is too small, that is, smaller than 0.9, nondurable consumption decreases on impact and thus does not comove with other real variables.

In general, the estimated elasticity of substitution between nondurable consumption and consumer durable services is greater than 0.95. Using quarterly data in the United States from the National Income and Product Account (NIPA) and Gordon (1990), Ogaki and Reinhart (1998a) estimated the values for η and obtained the range of 0.97 to 1.17 over the period 1947–83. Moreover, Ogaki and Reinhart (1998b) estimated and obtained the value of 0.98 for η when they used annual data in the US from the NIPA over the period 1929–90. Thus, to generate the comovement, the required elasticity of substitution between nondurable consumption and consumer durable services is within the range of the estimated values in the United States.

4.4 Elasticity of Labor Supply

Finally, in our baseline, the elasticity of the Frisch labor supply is set equal to unity. Our results of comovement are robust for a wide range of the elasticity of the Frisch labor supply.

If the elasticity of the Frisch labor supply is higher (a smaller ϕ), we would anticipate that hours of work are more volatile. Thus, in response to positive investment shocks, hours of work are raised by more so that output in both sectors is increased by more. By contrast, if the elasticity of the Frisch labor supply is lower, hours of work are raised by less so that output in both sectors is increased by less.

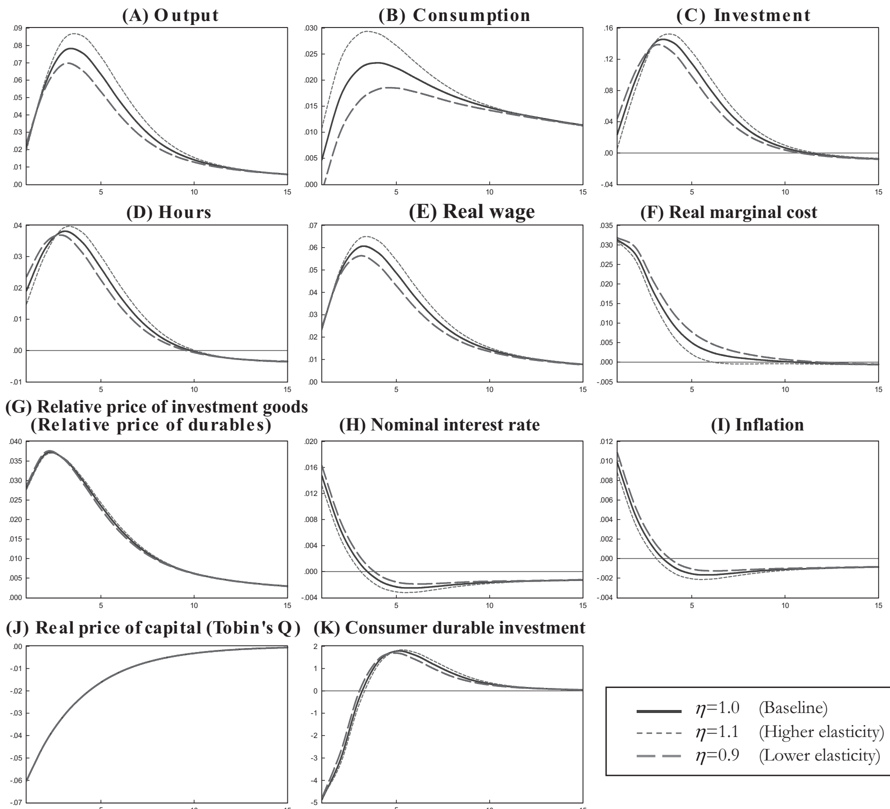

FIG. 5. Impulse Responses to a Positive Investment Shock in the Models with Different Elasticities of Substitution between Consumption and Consumer Durable Services.

NOTE: The horizontal axis is quarters; the vertical axis is percentage deviations from a steady state.

Figure 6 illustrates the impulse responses when the Frisch labor supply elasticity deviates from unity. It is clear that in response to a positive capital investment shock, output, nondurable consumption, investment, and hours of work all increase by more when the Frisch labor supply elasticity is larger, and increase by less when the Frisch labor supply elasticity is smaller. We find that nondurable consumption increases and comoves with other real variables under a wide range of the elasticity of the Frisch labor supply at $\phi \in [0, 10]$.

5. CONCLUDING REMARKS

Recent research based on sticky-price models suggests that capital investment shocks are an important driver of business cycle fluctuations in the postwar U.S.

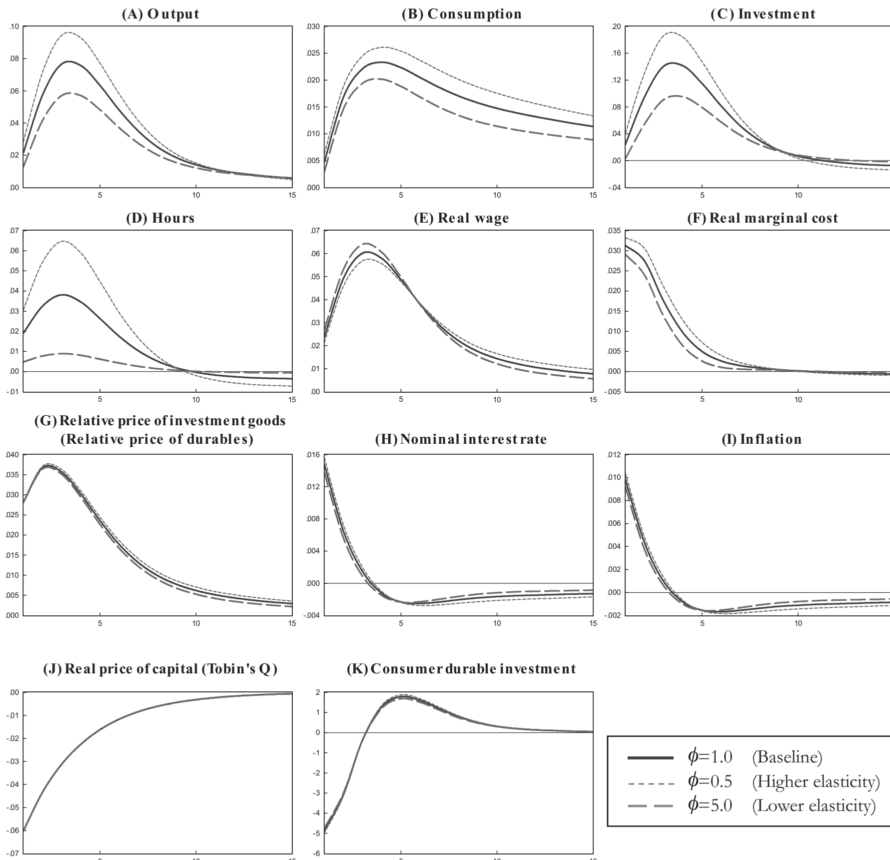

FIG. 6. Impulse Responses to a Positive Investment Shock in the Model with Different Elasticities of the Frisch Labor Supply.

NOTE: The horizontal axis is quarters; the vertical axis is percentage deviations from a steady state.

economy. Despite their quantitative importance in explaining business cycle fluctuations, a comovement problem emerges because a positive capital investment shock generates an intertemporal substitution effect away from consumption and toward investment. Thus, investment increases but consumption decreases. In this paper, we estimate a VAR model and offer empirical evidence showing that consumption and investment comove in response to a positive capital investment shock. Then, we resolve the comovement problem by extending the standard neoclassical sticky-price model to a two-sector model with consumer durable services. With consumer durable services in a two-sector sticky-price model, a positive capital investment shock also generates an intratemporal substitution effect away from consumer durable services toward nondurable consumption whose effect dominates the intertemporal substitution effect. As a result, nondurable consumption increases and comoves with investment, output, hours worked, and the real wage.

APPENDIX

The appendix explains how we obtain the coefficient of the cost of price adjustment ϑ_j. Let a variable with a cap "$\sim$" denote a percentage deviation of the variable from its steady-state level. Log-linearization of the optimal pricing condition in (6c) gives the following New Keynesian Phillips curve,

$$\tilde{\pi}_{jt} = \frac{\varepsilon_j - 1}{\vartheta_j}\tilde{\lambda}_{jt} + \beta E_t(\tilde{\pi}_{jt+1}), \quad j = C, I, \tag{A1}$$

where the slope is $(\varepsilon_j - 1)/\vartheta_j$. The slope of the New Keynesian Phillips curve in the Calvo–Yun model is $(1 - \theta_j)(1 - \beta\theta_j)/\theta_j$, where θ_j is the probability of not resetting prices (see, for example, equation (3) in Galí and Gertler 1999). By equating these two slopes, we can obtain the coefficient of the cost of price adjustment ϑ_j.

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