Investment-Specific News Shocks in Business Cycles

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Abstract

Recent research in DSGE and VAR models have indicated that the most important drivers of business cycles are unanticipated contemporaneous IST shocks, not TFP shocks. Research in VAR models have also empirically identified IST news shocks as a significant driving force behind the U.S. business cycle. However, recent one-sector DSGE models with sticky prices found that IST news shocks do not produce comovement of aggregate variables with the share of the forecast error variance explained by IST news shocks being very small in a flexible-price model and essentially zero in a sticky-price model. This paper studies the short-run business cycle effects of IST news shocks in a two-sector DSGE model with sticky prices and collateral constraints. In our model, IST news shocks can produce comovement of aggregate variables, as opposed to existing DSGE models with flexible prices that produce comovement relying on variable capital utilization, investment adjustment costs, and preferences with small short-run wealth effects on the labor supply. Our variance decomposition exercises indicate that IST news shocks are a more relevant source of uncertainty than unanticipated contemporaneous IST shocks.

Keywords: Credit constraints; Sticky prices; News shocks; Comovement

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1. Introduction

The news-driven business cycle hypothesis, traced to Pigou (1927), attributes a significant role in business cycle fluctuations to economic agents' responses to anticipations about future fundamentals. There's been a resurgence of interest in analyzing the economic consequences of news shocks. Recent work explores whether news shocks to future fundamentals are a potentially important source of business cycle fluctuations and quantifies the relative importance of anticipated and unanticipated shocks to fundamentals (e.g., Beaudry and Portier, 2006; Jaimovich and Rebelo, 2009; Schmitt-Grohé and Uribe, 2012). Moreover, the New Keynesian model with sticky prices has been widely adopted by researchers as a baseline model to analyze a variety of macroeconomic issues and was also at the core of the dynamic stochastic general equilibrium (DSGE) models used by central banks and policy institutions throughout the world (e.g., Christiano et al., 2005; Galí, 2018). This paper studies the short-run business-cycle effects of news shocks to future investment-specific technology (henceforth, IST) in a New Keynesian model with sticky prices. We call attention to IST news shocks, rather than news shocks to total factor productivity (TFP), based on the following two reasons.

Firstly, recent research suggests that the most important driver of business cycle fluctuations are not more traditional Hicks-neutral TFP shocks, but IST shocks (e.g., Greenwood et al., 2000; Christensen and Dib, 2008). Recently, Fisher (2006) estimated a VAR model and compared the short-run business cycle effects of unanticipated TFP shocks and unanticipated IST shocks. He found that the majority of business cycle fluctuations and hours' and output's forecast errors over a three- to eight-year horizon are driven by the IST shock. In particular, Justiniano et al. (2010) studied a one-sector New Keynesian model with a variety of real and nominal frictions such as price and wage rigidities, consumption habit formation, and capital utilization. They found that over 50% of the fluctuations in output and hours, and over 80% of the fluctuations in investment were driven by IST shocks.

Next, recently, Zeev and Khan (2015) used a VAR model and empirically identified IST news shocks as a significant driving force behind the U.S. business cycle. However, in DSGE models, Jaimovich and Rebelo (2009) found that IST news shocks are a driver of business cycles only when there are variable capital utilization, adjustment costs to investment, and preferences with small wealth effects on the labor supply. Using an identical model to that of Jaimovich and Rebelo (2009), Schmitt-Grohé and Uribe (2012) uncovered that IST news shocks have very small effects on consumption and labor hours, albeit large effects on investment. The foregoing two papers study DSGE models with flexible prices. Even in a one-sector DSGE model with sticky prices, Zeev and Khan (2015) found that the impulse responses do not produce comovement in response to IST news shocks. In particular, they found that the share of the forecast error variance of real aggregate variables attributable to IST news shocks is very small in a flexible-price DSGE model (Schmitt-Grohé and Uribe, 2012) and essentially zero in a sticky-price DSGE model (Khan and Tsoukalas, 2012).

When studying IST shocks, however, one difficulty arises. In response to a positive IST shock, the impulse responses do not produce comovement of consumption and investment, because investment increases while consumption typically falls, which is at odds with the data. The comovement problem was resolved by extending the standard one-sector model to a two-sector model with consumer durables.[1] Yet, in a two-sector model with consumer durables with sticky nondurable prices, Barsky et al. (2007) found that, in response to monetary tightening, nondurable consumption decreases but consumer durables increase, causing the comovement problem. To reconcile the inconsistency, Monacelli (2009) introduced frictions in lending in a model with collateral constraints.[2] In this paper, we re-examine the short-run business cycle effects of IST news shocks by extending existing one-sector models to a two-sector model. We show that the IST news shock is a quantitatively important driver of business cycles, which contributes to the existing DSGE models that studied news shocks.

Specifically, following Barsky et al. (2007) and Monacelli (2009), we study a two-sector model with a nondurable sector producing goods for consumption and a durable sector producing goods for investment in capital and consumer durable services. Nondurable prices are sticky and durable prices are flexible, as in Bils and Klenow (2004). There are financial constraints. Following Fisher (2006), we use the inverse of the real price of capital to measure the level of IST. We carry out a τ-period ahead news shock about anticipated shifts of IST that are uncorrelated with innovations to unanticipated IST shocks. Different from Jaimovich and Rebelo (2009) and Schmitt-Grohé and Uribe (2012), our model produces comovement of aggregates in response to IST news shocks without relying on variable capital utilization, investment adjustment costs, and preferences with small wealth effects on the labor supply.[3]

We find that, in our two-sector model with sticky prices and collateral constraints, positive IST news shocks increase consumption, output, labor hours, investment, and real wages on impact, and thus generate comovement in aggregate variables. By contrast, in an otherwise identical model except collateral constraints, positive IST news shocks decrease, rather than increase, consumption, while in an otherwise identical model except sticky prices, positive IST news shocks decrease labor hours and

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[1] The comovement problem emerges, because a positive IST shock generates an intertemporal substitution effect away from consumption and toward investment, which dominates the income effect. As a result, these models do not result in comovement among macroeconomic aggregates in response to an unanticipated IST shock, unlike observed business cycles in which output, consumption, investment, hours worked, and the real wage all rise and fall together. See Justiniano et al. (2010) and Chen and Liao (2018).

[2] See also Sterk (2010) and Chen and Liao (2014).

[3] Nevertheless, we should remark that investment adjustment costs are conducive to increasing the share of the forecast error variance of some aggregate variables attributable to IST news shocks.

output. Our variance decomposition exercises indicate that IST news shocks are a more relevant source of uncertainty than unanticipated contemporaneous IST shocks.

Beaudry and Portier (2004) and Jaimovich and Rebelo (2009) have studied news shocks in a two-sector model with flexible prices. While Beaudry and Portier (2004) found that TFP news shocks in the nondurable goods sector generate a boom, Jaimovich and Rebelo (2009) uncovered that TFP and IST news shocks produce comovement only when there is a small wealth effect on the labor supply. Different from these two existing models, we study IST news shocks in a two-sector model with sticky prices.

Several authors have analyzed news shocks in New Keynesian models with nominal rigidities. Gilchrist and Leahy (2002) uncovered that TFP news shocks cause consumption to rise but labor and output to fall. Christiano et al. (2008) found that TFP news shocks cannot induce consumption to increase on impact. However, little literature scrutinizes IST news shocks in a New Keynesian model with nominal rigidities. For instance, Khan and Tsoukalas (2012) discovered that IST news shocks cannot generate business cycle fluctuations.

Finally, our model introduces lending frictions on producers and thus, is related to DSGE models with financial constraints on producers.[4] Although financial frictions are set slightly differently in existing models, basic transmission mechanisms are similar: they directly connect firms' assets with investment spending. The difference lies in that our paper studies the effect of IST news shocks, but they don't. In our model with nominal rigidities, adding financial frictions on producers not only resolves the inconsistent comovement problem between empirical evidence and theoretical results from IST news shocks in the standard DSGE model, but also increases the share of the forecast error variance of real aggregate variables attributable to IST news shocks.

The rest of this paper is organized as follows. In Section 2, we set up a baseline sticky-price two-sector model with borrowing constraints. In Section 3, we calibrate the models, and Section 4 envisages the impulse responses to a positive IST news shock. Section 5 carries out the sensitivity analysis. Finally, concluding remarks are made in Section 6.

2. The Model

Time is discrete and lasts for an infinite horizon. The economy consists of a continuum of agents with a unit mass. Following Bernanke and Gertler (1989), Carlstrom and Fuerst (1997), and Iacoviello (2005), there are two types of agents: households and entrepreneurs. Both types of agents consume, but

[4] See Carlstrom and Fuerst (1997), Bernanke and Gertler (1989), Bernanke et al. (1999), Cooley et al. (2004), Faia and Monacelli (2007), and Gerali et al. (2010).

households supply labor while entrepreneurs do not.[5] Like Iacoviello (2005) and Monacelli (2009), households have two types: patient and impatient. Patient households have the lowest time preference rate and are savers. Impatient households, along with entrepreneurs, have higher time preference rates and thus, are borrowers. Agents with varied discount rates trade nominal private debts, with borrowers being subject to collateral constraints that are tied to the expected future value of the stock of durables.

As Barsky et al. (2007) and Monacelli (2009), the economy includes two sectors: nondurable and durable sectors.[6] While nondurable final goods are used for consumption, durable final goods are used for consumption and investment. Each sector comprises a continuum of firms/producers, which produce and sell final goods at competitive prices. Final goods in one sector use only intermediate inputs produced in the sector. Each sector has a continuum of entrepreneurs that produce intermediates for the sector. Both types of households consume both types of final goods, and so do entrepreneurs.

In addition, there are retailers. While entrepreneurs sell intermediates to a continuum of retailers at competitive prices, retailers sell intermediates to final goods producers at monopolistic prices that incur adjustment costs when setting prices.

2.1 Final good producers

There is a continuum of *final goods producers* of a unit mass in each sector. The representative producer in sector $j=c$, d, produces final goods $Y_{j,t}$ by combining a continuum of intermediates $Y_{j,t}(z)$, indexed by $z \in [0, 1]$, according to the following technology

$$Y_{j,t} = [\int_0^1 (Y_{j,t}(z))^{(\varepsilon_j - 1)/\varepsilon_j} dz]^{\varepsilon_j/(\varepsilon_j - 1)}, \; j=c, d,$$

where $\varepsilon_j > 1$ is the elasticity of substitution between intermediates in sector j. Nondurable goods $Y_{c,t}$ are used for consumption only. Durable goods $Y_{d,t}$ are used for both consumer durables and capital investment, which accumulate the stock of consumer durable services and the stock of capital, respectively. Final goods markets are competitive. The laws of motion for consumer durable services and capital will be specified in the household's and the entrepreneur's problem below.

Maximization of profits in sector j gives the following demand function for intermediate z.

$$Y_{j,t}(z) = (\tfrac{P_{j,t}(z)}{P_{j,t}})^{-\varepsilon_j} Y_{j,t}, \quad z \in (0,1), \quad j=c, d, \tag{1}$$

where $P_{j,t}(z)$ is the price of an intermediate z and $P_{j,t}$ is the price index of final goods in sector j. A zero profit in sector j implies $P_{j,t} = [\int_0^1 (P_{j,t}(z))^{1-\varepsilon_j} dz]^{1/(1-\varepsilon_j)}$, $j=c$, d.

[5] On this, our setup follows from Iacoviello (2005) and is different from Bernanke and Gertler (1989) and Carlstrom and Fuerst (1997), wherein both types of agents supply labor.

[6] We go along Monacelli (2009) and refer to the nondurable consumption goods sector and the durable goods sector as sectors c and d, respectively.

2.2 Households

A typical household consumes an index of consumption X_t defined as

$$X_{i,t} \equiv [(1-\mu)^{\frac{1}{\eta}}(C_{i,t})^{\frac{\eta-1}{\eta}} + \mu^{\frac{1}{\eta}}(D_{i,t})^{\frac{\eta-1}{\eta}}]^{\frac{\eta}{\eta-1}}, \;\; i=b, \;\; s,$$

where $C_{i,t}$ is nondurables and $D_{i,t}$ is services from the stock of consumer durables for i=b, s, in which subscript b and s label values and parameters for borrowers and savers, respectively. The parameter μ>0 is the share of consumer durables in the composite consumption index, and η≥0 is the elasticity of substitution between nondurables and durables in consumption. As in Monacelli (2009), we assume the same parameters μ and η in the composite consumption index for savers and borrowers.

The impatient household maximizes the expected lifetime utility function represented by

$$E_0 \sum_{t=0}^{\infty} (\beta_b)^t (\log X_{b,t} - \nu_b \tfrac{(L_{b,t})^{1+\phi_b}}{1+\phi_b}),$$

where E_t is an expectation operator conditional on information available in t. The discount factor is $\beta_b \in (0, 1)$, which is smaller than the discount factor of patient households, β_s. Thus, impatient households are borrowers. $L_{b,t}$ is hours of work. The parameter ν_b>0 is the coefficient associated with the disutility of labor, and ϕ_b>0 is the inverse of the Frisch labor supply elasticity. Labor is freely mobile across sectors.

Impatient households receive the labor income at the nominal wage rate W_t. They also obtain nominal lump-sum transfers from the government $T_{b,t}$. In addition, they may borrow by issuing one-period nominal debts $B_{b,t}$. They use the income to buy nondurables and consumer durables and to service the debt. Expressing in units of nondurables, an impatient household's budget constraint is

$$C_{b,t} + p_t[D_{b,t} - (1-\delta)D_{b,t-1}] + R_{t-1}\tfrac{b_{b,t-1}}{\pi_{c,t}} = b_{b,t} + w_t L_{b,t} + \tfrac{T_{b,t}}{P_{c,t}}, \quad (2a)$$

where R_{t-1} is the gross nominal interest rate on a loan between periods t-1 and t, $p_t \equiv P_{d,t}/P_{c,t}$ is the durable price in terms of nondurables, $b_{b,t} \equiv B_{b,t}/P_{c,t}$ is real debts, and $w_t \equiv W_t/P_{c,t}$ is real wage, with $\pi_{c,t} \equiv P_{c,t}/P_{c,t-1}$ being the gross inflation of nondurables and δ being the depreciation rate.

The loan market is imperfect, as lenders cannot force borrowers to repay their debts and thus, collateral is required in order to take loans. Consumer durables play a dual role. They are used not only for consumption but also for collateral when households take loans (e.g., Kiyotaki and Moore, 1997; Iacoviello, 2005). The value of the stock of consumer durables is an upper limit of loans. If borrowers repudiate their debt obligations, lenders can liquidate borrowers' collateral by paying transactions costs at a proportion (1-m_b)∈(0,1) of collateral. Thus, the amount that a borrower agrees to pay back in the following period ($R_t B_{b,t}$) is tied to $m_b E_t[(1-\delta)P_{d,t+1}D_{b,t}]$, the expected value of non-depreciated consumer durables one period ahead. In real terms, this borrowing constraint is

$$R_t b_{b,t} \leq m_b (1-\delta) E_t (p_{t+1} D_{b,t} \pi_{c,t+1}) = m_b (1-\delta) p_t E_t (D_{b,t} \pi_{d,t+1}), \tag{2b}$$

where $\pi_{d,t} \equiv P_{d,t}/P_{d,t-1}$, and m_b is an impatient household's "loan-to-value" ratio. The expected gross inflation of durables in the next period affects the constraint.

Let $\lambda_{b,t}$ and $\lambda_{b,t}\psi_{b,t}$ be current-valued Lagrange multipliers of constraints (2a) and (2b), respectively. We denote $MU_{i,t}^C$, $MU_{i,t}^D$, and $MU_{i,t}^L$, respectively, as the marginal utility of nondurables, consumer durables, and labor for households i=b, s, in t. The first-order conditions for $C_{b,t}$, $L_{b,t}$, $D_{b,t}$, and $b_{b,t}$ are

$$MU_{b,t}^C = \lambda_{b,t}, \tag{3a}$$

$$\frac{-MU_{b,t}^L}{MU_{b,t}^C} = w_t, \tag{3b}$$

$$\frac{MU_{b,t}^D}{MU_{b,t}^C} = p_t - \beta_b (1-\delta) E_t \left(\frac{MU_{b,t+1}^C}{MU_{b,t}^C} p_{t+1} \right) - m_b (1-\delta) \psi_{b,t} p_t E_t (\pi_{d,t+1}), \tag{3c}$$

$$R_t \psi_{b,t} = 1 - \beta_b E_t \left(\frac{MU_{b,t+1}^C}{MU_{b,t}^C} \frac{R_t}{\pi_{c,t+1}} \right), \tag{3d}$$

along with the transversality conditions, $\lim_{t\to\infty}(\beta_b)^t \lambda_{b,t} D_{b,t}=0$ and $\lim_{t\to\infty}(\beta_b)^t \lambda_{b,t}\psi_{b,t} b_{b,t}=0$.

These conditions are the same as those obtained in Monacelli (2009). While (3a) equalizes the marginal utility of nondurables to the shadow value of the flow budget constraint, (3b) equalizes the marginal rate of substitution between labor and nondurables to real wage. In (3c), the marginal rate of substitution between durable services and nondurables equals what is called by Erceg and Levin (2006), the *user cost of durables*. The user cost of durables is the relative price of durables p_t, net of two marginal gains. One of the marginal gains is the expected discounted marginal utility of nondurables in the next period stemming from the non-depreciated consumer durables (the second term), and the other is the marginal utility of relaxing collateral constraints (the third term). Note that if the shadow price of collateral constraints is zero ($\psi_{b,t}$=0), the marginal utility of relaxing collateral constraints is zero.

Finally, (3d) is a modified Euler equation, which reduces to the standard Euler condition if $\psi_{b,t}$=0. However, if $\psi_{b,t}$>0, (3d) suggests that $MU_{b,t}^C > \beta_b E_t (MU_{b,t+1}^C \frac{R_t}{\pi_{c,t+1}})$, and thus the marginal utility of nondurables exceeds the expected discounted marginal utility of shifting a unit of nondurables to the next period. An increase in $\psi_{b,t}$ indicates a tighter collateral constraint. When $\psi_{b,t}$ is larger, the net marginal benefit of consumer durables today is higher, since one more unit of consumer durables relaxes collateral constraints at the margin, which allows for extra consumption today.

It is worth noting that the shadow price of borrowing constraints affects the user cost of durables with two opposing effects at work. First, a higher shadow price of borrowing constraints directly increases the gain from the marginal utility of relaxing collateral constraints (the third term in the right-hand side of (3c)), which decreases the user cost of durables. Next, through the modified Euler equation in (3d), a higher shadow price of borrowing constraints reduces the gain of the expected discounted marginal utility of nondurables in the next period (the second term in (3c)), which indirectly increases the user cost of durables. The indirect effect usually dominates the direct effect. Thus, a higher shadow price of borrowing constraints increases the user cost of durables.

As for patient households, a patient household maximizes the following expected lifetime utility

$$E_0\sum_{t=0}^{\infty}(\beta_s)^t(\log X_{s,t}-\nu_s\tfrac{(L_{s,t})^{1+\phi_s}}{1+\phi_s}),$$

which is otherwise identical to that of an impatient household except for variables and parameters labeled by subscript *s*. Patient households are savers, because their discount factor is larger than that of impatient households, $\beta_s>\beta_b$.

The representative patient household faces the following flow budget constraint

$$C_{s,t}+p_t[D_{s,t}-(1-\delta)D_{s,t-1}]+R_{t-1}\tfrac{b_{s,t-1}}{\pi_{c,t}}=b_{s,t}+w_tL_{s,t}+\tfrac{T_{s,t}}{P_{c,t}}+\tfrac{F_t}{P_{c,t}}. \quad (4)$$

Remark that (4) is otherwise the same as (2a) except for the term F_t, which is a nominal lump-sum profit remitted from retailers, as patient households are savers and thus own the share of retailers. The representative patient household chooses $C_{s,t}$, $L_{s,t}$, $D_{s,t}$, and $b_{s,t}$. The first-order conditions are otherwise the same as (3a)-(3d) except for subscripts replaced by *s*, and $\psi_{s,t}$=0.

2.3 Entrepreneurs

Each sector has a continuum of entrepreneurs, indexed by $z\in[0, 1]$. Entrepreneurs are both producers and consumers. As producers, entrepreneurs in sector *j* produce intermediates that are used for producing final goods in sector *j*. The representative entrepreneur produces an intermediate variety *z* in sector *j* according to the following technology.

$$Y_{j,t}(z)=A_jK_{j,t}(z)^{\alpha_j}L_{j,t}(z)^{1-\alpha_j},\ \ j=c, d, \quad (5a)$$

where $K_{j,t}(z)$ and $L_{j,t}(z)$ are, respectively, capital and labor used by an entrepreneur *z* in sector *j*, $\alpha_j\in(0,1)$ is the capital share, and $A_j>0$ is a coefficient. Following Bernanke et al. (1999) and Iacoviello (2005), entrepreneurs do not sell intermediates directly to final goods producers. There are retailers. An entrepreneur *z* in sector *j* sells an intermediate to retailers at the wholesale price $P_{j,t}^W(z)$, and retailers then sell the intermediate to final goods producers in sector *j* at price $P_{j,t}(z)$.

As consumers, an entrepreneur's expected lifetime utility is $E_0\sum_{t=0}^{\infty}(\beta_j)^t\log(X_{j,t})$, [7] where $\beta_j\leq\beta_s$, $j=c, d$. An entrepreneur's flow budget constraint is

[7] Thus, like Iacoviello (2005), the utility is risk averse, which is different from a risk neutral utility in Bernanke et al. (1999), wherein the entrepreneur's utility is linear in consumption.

$$C_{j,t}+p_t[D_{j,t}-(1-\delta)D_{j,t-1}]+R_{t-1}\tfrac{b_{j,t-1}}{\pi_{c,t}}+w_tL_{j,t}+p_tI_{j,t}=\tfrac{P^W_{j,t}(z)}{P_{j,t}}\tfrac{P_{j,t}}{P_{c,t}}Y_{j,t}(z)+b_{j,t},\ \ j=c,\ d, \qquad (5b)$$

where $P_{j,t}/P_{j,t}^W(z)$ is the markup of final goods in sector j over intermediates. An entrepreneur uses the flow income to pay for nondurables, consumer durables, and the cost of labor and investment. The relative price of investment p_t is the relative price of durables, since durables can be used for consumption and investment. The evolution of the capital stock is

$$K_{j,t+1}-(1-\delta)K_{j,t}=\xi_t\left[1-\Phi_j(\tfrac{I_{j,t}}{I_{j,t-1}})\right]I_{j,t},\ \ j=c,\ d, \qquad (5c)$$

where $0<\delta<1$ is the depreciation rate of capital. For tractability of analysis, we assume that capital depreciates at the same rate as consumer durables.[8]

The function Φ_j is the investment adjustment cost. Following Christiano et al. (2005) and Justiniano et al. (2010), the adjustment cost takes the quadratic form $\Phi_j(\tfrac{I_{j,t}}{I_{j,t-1}})=\tfrac{\varphi_j}{2}(\tfrac{I_{j,t}}{I_{j,t-1}}-1)^2$, $\varphi_j\geq 0$, $j=c,\ d$. As for the accumulation of consumer durable services, we follow Iacoviello (2005), Barsky et al. (2007), and Monacelli (2009), and set a zero adjustment cost for consumer durables.

Following Greenwood et al. (1997, 2000) and Justiniano et al. (2010), we include a factor ξ_t in the accumulation of capital, which specifies the current state of the technology for capital formation. It is an exogenous variation in efficiency, which determines the amount of capital in the next period that is formed from one unit of investment in this period. Changes in ξ_t formalize the notion of IST changes. For simplicity, we assume that the efficiency in the accumulation of capital is the same in both sectors. As in existing work on IST shocks, we assume that ξ_t follows a first-order stochastic process given by

$$\log\xi_t=\rho\log\xi_{t-1}+e_t+\nu_{t-\tau}, \qquad (5d)$$

where innovations in relation to the IST shock e_t are assumed to be independent and identically distributed normally with mean 0 and variance σ^2. The term $\nu_{t-\tau}$ is an IST news shock, which provides a τ-period ahead news about an expected shift in future IST shocks. The IST news shock is uncorrelated with innovations to the IST, e_t.

Some remarks are in order. As is standard, capital investment is accumulated into the stock of capital and ready for use as an input in production in the next period in (5c). On the other hand, in terms of value, consumer durables are mainly accounted for by residential houses. When these consumer durables are purchased, they are ready for use as consumption services, as in the conventional wisdom in Barsky et al. (2007), Monacelli (2009), and Sudo (2012). Hence, in (2a), (4), and (5b), the stock of consumer durable services is formed from the flow of consumer durables in the same period.

Moreover, we posit that only capital investment has IST shocks. Our formulation is based on the

[8] The existing literature usually set the same depreciation rate for consumer durables and capital (e.g., Carlstrom and Fuerst, 2010 and Sudo, 2012, among others).

following reasons. First, in Greenwood et al. (1997, 2000), both equipment capital and structure capital are accumulated from final goods produced in the same sector, but only equipment capital has IST shocks while structure capital is not affected by IST shocks. Second, and more importantly, existing studies, such as Chung et al. (2010), argued that there are two categories of consumer durables, and they are different in the way affected by IST shocks. The first category of consumer durables comprises personal computers and home appliances. It is likely that production of these goods receives a favorable impact from a positive IST shock. The second category includes residential investment. Existing studies agree that productivity of residential investment is not affected by IST shocks. In terms of value, the majority of consumer durables is residential houses. Thus, we can think of consumer durables in our paper as residential houses, and their productivity is not affected by IST shocks.

In the budget constraint (5b), in addition to revenues from sales of intermediates, an entrepreneur may borrow by issuing one-period nominal debts. Like impatient households, the amount of real loans $b_{j,t}$ is limited by the following collateral constraint.

$$R_t b_{j,t} \leq m_j (1-\delta) E_t [p_{t+1} D_{j,t} \pi_{c,t+1}] = m_j (1-\delta) p_t E_t [D_{j,t} \pi_{d,t+1}], \quad j=c,\ d, \tag{5e}$$

where $D_{j,t}$ is the stock of consumer durables that an entrepreneur in sector j holds and $m_j \in (0,1)$ is the entrepreneur's loan-to-value ratio.

As in Iacoviello (2005), capital is not used as collateral by entrepreneurs.[9] Since we will focus on an economy in which entrepreneurs' borrowing constraints are binding, we assume that entrepreneurs' discount rates are no less than savers' discount rates. Then, entrepreneurs would not postpone consumption and would not quickly accumulate wealth to completely self-finance, so as not to give a nonbinding borrowing constraint.

An entrepreneur in sector $j=c$, d maximizes expected lifetime utility, subject to the technology (5a), the flow budget constraint (5b), capital accumulation (5c), and the borrowing constraint (5e). Let $\lambda_{j,t}$, $q_{j,t}$, and $\lambda_{j,t}\psi_{j,t}$ be the current-valued Lagrange multipliers on constraints (5b), (5c) and (5e), respectively. We denote $MU_{j,t}^C$, $MU_{j,t}^D$, $MP_{j,t}^L$, and $MP_{j,t}^K$, respectively, as the marginal utility of nondurables and consumer durables, and the marginal product of labor and capital for entrepreneurs in sector $j=c$, d in period t. The first-order conditions for $C_{j,t}$, $L_{j,t}$, $D_{j,t}$, $b_{j,t}$, $K_{j,t+1}$, and $I_{j,t}$, $j=c$, d, are

$$MU_{j,t}^C = \lambda_{j,t}, \tag{6a}$$

$$\frac{P_{j,t}^W(z)}{P_{c,t}} MP_{j,t}^L = w_t, \tag{6b}$$

$$\frac{MU_{j,t}^D}{MU_{j,t}^C} = p_t - \beta_j (1-\delta) E_t \left(\frac{MU_{j,t+1}^C}{MU_{j,t}^C} p_{t+1} \right) - m_j (1-\delta) \psi_{j,t} p_t E_t (\pi_{d,t+1}), \tag{6c}$$

[9] Later, we will consider the situation when capital is used as a collateral by entrepreneurs.

$$R_t\psi_{j,t} = 1 - \beta_j E_t\left(\frac{MU^C_{j,t+1}}{MU^C_{j,t}}\frac{R_t}{\pi_{c,t+1}}\right), \tag{6d}$$

$$p_t q_{j,t} = \beta_j E_t\left[MU^C_{j,t+1}\frac{P^W_{j,t+1}(z)}{P_{c,t+1}}MP^K_{j,t+1} + p_{t+1}q_{j,t+1}(1-\delta)\right], \tag{6e}$$

$$p_t MU^C_{j,t} = p_t q_{j,t}\xi_t\left[1 - \Phi_j\left(\frac{I_{j,t}}{I_{j,t-1}}\right) - \frac{I_{j,t}}{I_{j,t-1}}\Phi'_j\left(\frac{I_{j,t}}{I_{j,t-1}}\right)\right] + \beta_j E_t\left[p_{t+1}q_{j,t+1}\xi_{t+1}\left(\frac{I_{j,t+1}}{I_{j,t}}\right)^2\Phi'_j\left(\frac{I_{j,t+1}}{I_{j,t}}\right)\right], \tag{6f}$$

along with transversality conditions $\lim_{t\to\infty}(\beta_j)^t\lambda_{j,t}D_{j,t}=0$, $\lim_{t\to\infty}(\beta_j)^t\lambda_{j,t}\psi_{j,t}b_{j,t}=0$, and $\lim_{t\to\infty}(\beta_j)^t q_{j,t}K_{j,t+1}=0$.

Conditions (6a) and (6b) are standard. Conditions (6c) and (6d) are similar to (3c) and (3d) for impatient households, respectively. Condition (6e) determines the demand for capital in the next period, in which the marginal cost of capital is the effective relative price of durables evaluated by $q_{j,t}$, the shadow value of installed capital in t. The marginal benefit of capital includes the expected discounted sum of the marginal value product of capital (in terms of consumption) and the effective relative price of non-depreciated capital evaluated by the shadow value of installed capital in t+1.

Like Justiniano et al. (2010), Tobin's Q is the marginal value of installed capital relative to foregone consumption, $\frac{q_{j,t}}{\lambda_{j,t}}$, which is the real price of capital. Thus, in (6f), capital investment is optimal when the foregone value of capital investment is equal to the marginal value of capital investment. The marginal value of capital investment includes the shadow value of installed capital net of adjustment costs 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 of no investment adjustment costs (i.e. Φ_j=0 and Φ'_j=0, j=c, d.), (6f) reduces to $\frac{q_{j,t}}{\lambda_{j,t}} = \frac{1}{\xi_t}$, and Tobin's Q equals the reciprocal of IST shocks. Thus, a positive IST shock reduces the real price of capital and raises the demand for capital investment.

2.4 Retailers and the price setting

There is a continuum of retailers indexed by $z\in(0,1)$. A retailer buys intermediates from entrepreneurs in sector j at the competitive wholesale price $P_{j,t}^W(z)$ and then sells them to final goods producers in sector j. As is standard in the existing literature that motivates sticky prices, retailers have monopoly powers when selling intermediates. Following Rotemberg (1982), in setting its monopolistic price $P_{j,t}(z)$, a retailer faces a quadratic cost of adjusting nominal prices in proportion to the value of the sectoral final output, $\Theta(P_{j,t}(z)) = \frac{\vartheta_j}{2}(\frac{P_{j,t}(z)}{P_{j,t-1}(z)} - 1)^2 P_{j,t}Y_{j,t}$, j=c, d, where ϑ_j is the degree of nominal rigidities in sector j, with ϑ_j=0 under flexible prices.

The representative retailer in sector j chooses a sequence of sale prices $\{P_{j,t}(z)\}_{t=0}^{\infty}$ that maximizes the following expected discounted sum of nominal profits

$$E_0 \sum_{t=0}^{\infty} \Lambda_t \left[P_{j,t}(z) Y_{j,t}(z) - P_{j,t}^W(z) Y_{j,t}(z) - \Theta(P_{j,t}(z)) \right], \; j=c,\, d,$$

subject to the corresponding demand function for intermediates in (1).

The stochastic discount factor $\Lambda_t \equiv \frac{\beta_s{}^t \lambda_{s,t}}{\lambda_{s,0}}$ is relevant to the period-t discount factor and the marginal utility of consumption for patient households. The optimal condition for $P_{j,t}(z)$, $j=c$, d, is

$$\Lambda_t \left[\left(\tfrac{P_{j,t}(z)}{P_{j,t}}\right)^{-\varepsilon_j} - \varepsilon_j \tfrac{P_{j,t}(z) - P_{j,t}^W(z)}{P_{j,t}} \left(\tfrac{P_{j,t}(z)}{P_{j,t}}\right)^{-\varepsilon_j - 1} - \vartheta_j (\pi_{j,t}(z) - 1) \tfrac{P_{j,t}}{P_{j,t-1}(z)} \right] Y_{j,t} + E_t \left\{ \Lambda_{t+1} \left[\vartheta_j (\pi_{j,t+1}(z) - 1) \pi_{j,t+1}(z) \tfrac{P_{j,t+1}}{P_{j,t}(z)} Y_{j,t+1} \right] \right\} = 0, \quad (7)$$

where $\pi_{j,t}(z) \equiv P_{j,t}(z)/P_{j,t-1}(z)$ is the gross inflation of an intermediate $Y_{j,t}(z)$ in sector j. By imposing the symmetry condition $\frac{P_{j,t}(z)}{P_{j,t}} = 1 = \frac{P_{j,t}^W(z)}{P_{j,t}^W}$ for z and j, (7) gives

$$\frac{P_{j,t}}{P_{j,t}^W} = \frac{\varepsilon_j}{\varepsilon_j - \Omega_{j,t}}, \quad j= c,\ d, \tag{8}$$

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

In a steady state, $\pi_{j,t} = \pi_{j,t+1} = 1$ for $j= c$, d, and thus $\Omega_{j,t} = \Omega_{j,t+1} = 1$ and the mark-up $P_{j,t}/P_{j,t}{}^W = \varepsilon_j/(\varepsilon_j - 1)$ is a constant. In the special case when $\vartheta_j = 0$, it is clear that $\Omega_{j,t} = 1$ for all t, and therefore prices are flexible. In this case, even out of a steady state, the mark-up $P_{j,t}/P_{j,t}{}^W = \varepsilon_j/(\varepsilon_j - 1)$ is a constant for all t.

2.5 Equilibrium

In equilibrium, nondurable and durable final goods markets clear.

$$Y_{c,t} = C_t + \tfrac{\vartheta_c}{2}(\pi_{c,t} - 1)^2 Y_{c,t}, \tag{9a}$$

$$Y_{d,t} = [D_t - (1-\delta) D_{t-1}] + I_t + \tfrac{\vartheta_d}{2}(\pi_{d,t} - 1)^2 Y_{d,t}, \tag{9b}$$

where $C_t \equiv C_{s,t} + C_{b,t} + C_{c,t} + C_{d,t}$ is aggregate nondurable consumption, $D_t \equiv D_{s,t} + D_{b,t} + D_{c,t} + D_{d,t}$ is the stock of aggregate consumer durables, and $I_t \equiv I_{c,t} + I_{d,t}$ is aggregate capital investment.

Moreover, the capital market and the labor market clear.

$$K_t = K_{c,t} + K_{d,t}, \tag{10a}$$

$$L_{c,t} + L_{d,t} = L_{s,t} + L_{b,t}. \tag{10b}$$

Further, the debt market clears.

$$b_{s,t} + b_{b,t} + b_{c,t} + b_{d,t} = 0. \tag{10c}$$

We abstract from redistribution via the fiscal policy. Hence,

$$T_{s,t} = T_{b,t} = 0\,.$$

Finally, the model is closed by the following monetary policy rule.

$$\frac{R_t}{R} = \left(\frac{\pi_t}{\pi}\right)^{\chi}, \quad \chi>1, \tag{11}$$

where $\pi_t \equiv (\pi_{c,t})^{1-\mu}(\pi_{d,t})^{\mu}$ is a composite inflation index with the weight for the inflation of durables being the share of durables in the composite consumption index, and R and π are steady-state values. We assume χ>1, which ensures equilibrium determinacy.

3. Calibration and Solution Method

Before studying the effects of a positive investment-specific news shock, we calibrate the parameters. Most structural parameters in the model are calibrated so the resulting values of key variables in the steady state match with the long-term features of the postwar US economy. In particular, we use the data from the Federal Reserve Economic Data and the U.S. Bureau of Labor Statistics. Baseline parameter values are summarized in Table 1.

[Insert Table 1 here]

The time frequency is in a quarter. The steady-state real rate of return R is pinned down by savers' discount factor β_s. We choose the real rate of return per annum of 4%. This implies a quarterly discount factor of β_s=0.99. Impatient households (β_b) and entrepreneurs (β_c and β_d) are borrowers and thus have higher discount rates. As in Monacelli (2009), we set β_b=0.98, and as in Iacoviello (2005), we set β_c=β_d=0.98. Following Hansen (1985) and Schmitt-Grohe and Uribe (2012), we choose the quarterly depreciation rate of consumer durables and capital at δ=0.025. As in Acemoglu and Guerrieri (2008), the capital shares in the nondurable and the durable goods sectors are set at α_c=0.47 and α_d=0.27, respectively, to match with their average capital shares in 1987-2005. The coefficients of production functions in both sectors are normalized to unity, so A_c=A_d=1.

We set the coefficient of the adjustment cost in capital investment to zero, which is different from Jaimovich and Rebelo (2009). While the investment adjustment cost plays a key role in generating the comovement in response to a news shock in Jaimovich and Rebelo (2009), it does not play such a role in our model. In order to underline the role of borrowing constraints in generating the comovement, we choose zero adjustment cost in the baseline model. In the next section, we will add in a positive adjustment cost and envisage the robustness of our results in the baseline model.

We choose the impatient household's loan-to-value ratio at m_b=0.77 so as to match with the average ratio in the US from 1990 to 2018. According to Iacoviello (2005), entrepreneur's loan-to-value ratio is higher than household's. Hence, we set an entrepreneur's loan-to-value ratio at m_c=m_d=0.80, which is the maximum regulatory loan-to-value ratio of conventional mortgages in the US. The elasticity of substitution between nondurables and durables is set to η=1, implying the Cobb-Douglas form for the composite consumption index. We choose the share of durables in the composite consumption index at μ=0.2 in order to match with the share of consumer durables spending in total private spending in the US. The elasticity of substitution between intermediate varieties in the final goods production ε_j is set to be 6 in both the nondurable sector and the durable sector, which implies a steady-state markup rate of 20%. In addition, following Barsky et al. (2007) and Monacelli (2009), we employ the value of the inverse of the Frisch labor supply elasticity at ϕ_s=ϕ_b=1, which is within the range of values used in the existing literature.

The degree of nominal rigidities in nondurable prices ϑ_c is set to generate a frequency of price adjustments about five quarters, which lies within the range of the estimated values in the US.[10] We pin down the value of ϑ_c in the following way. Let θ be the probability of not resetting prices in the standard Calvo-Yun model. We parameterize θ=0.8, which implies 1/(1-θ)=5 and thus, a frequency of price adjustments of five quarters. Let $\tilde{x}_t$ be a percentage deviation of a variable x_t from its steady-state level x. Log-linearization of retailers' optimal pricing condition (8) gives a New Keynesian Phillips curve $\tilde{\pi}_{j,t} = \frac{\varepsilon_j - 1}{\vartheta_j}\tilde{\omega}_{j,t} + \beta_s E_t(\tilde{\pi}_{j,t+1})$, where $\omega_{j,t} \equiv P_{j,t}^W / P_{j,t}$. Thus, the slope of the Phillips curve is $(\varepsilon_j - 1)/\vartheta_j$, j= c, d. Moreover, the slope of the New Keynesian Phillips curve in the Calvo-Yun model is $(1-\theta)(1-\beta_s\theta)/\theta$.[11] Equating these two slopes gives $\vartheta_j=(\varepsilon_j-1)\theta/[(1-\theta)(1-\beta_s\theta)]$. We set the value of the elasticity of substitution between intermediates in the nondurable final goods production equal to ε_c=6 which is standard. With patient households' discount factor being β_s=0.99, we pin down the value for the degree of nominal price rigidities in nondurables to ϑ_c=96.15. As for the degree of durable price-stickiness, we set ϑ_d=0, so durable prices are flexible, as shown in Bils and Klenow (2004).[12]

We normalize each household's time endowment at unity. According to the American Time Use Survey, average hours worked per person are about 30% of the time endowment. We use the same value for both patient and impatient households in a steady state and thus set L_s=L_b=0.3. We use the consumption-leisure tradeoff equation for impatient households in (3b) to calibrate the parameter of leisure in preference at ν_b=10.842. In the same fashion, we use the consumption-leisure tradeoff equation for patient households to calibrate the parameter of leisure in preference and obtain ν_s=6.011.

As for the monetary policy rule, we set the reaction coefficient at χ=1.5, which is a standard value in the literature regarding Taylor rules.

Finally, as regards the autocorrelation of the IST and the standard deviation of innovations to the IST, i.e., ρ and σ in (5d), we follow Fisher (2006) and use the inverse of the real price of capital to

[10] Justiniano et al. (2010) estimated the price-stickiness of consumption goods at over six quarters (with 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 (with the probability of not resetting prices being 0.77).
[11] See Galí and Gertler (1999) and Sbordone (2002).
[12] See also Monacelli (2009), Carlstrom and Fuerst (2010), Bouakez et al. (2011), and Sudo (2012).

measure the level of the IST. The measure of the real price of capital is based on Gordon (1990) and Cummins and Violante (2002) and constructs the (quality-adjusted) real price of equipment and software by dividing the equipment and software deflator by the consumption deflator.[13] Then ρ and σ are estimated to be 0.73 and 0.01, respectively, which are within the range of the estimated values in the literature, such as Smets and Wouters (2007), Justiniano et al. (2010), and Khan and Tsoukalas (2011).

4. Effects of Positive Investment-Specific Technology News Shocks

This section studies the effects of a positive IST news shock. We analyze the effects of an IST news shock on the impulse responses of aggregate macro and other variables in the same way as that in Jaimovich and Rebelo (2009). The timing of the news shock is as follows. In period zero, the economy is in the steady state. In period one, an unanticipated news shock arrives, wherein agents learn that there will be a one-standard-deviation increase in ξ_t beginning three periods later, in period four.

To underscore the role of financial frictions and sticky prices, we will illustrate models without either sticky prices or financial frictions, which fail to generate consistent impulse responses of macro variables. We start with a model without investment adjustment costs, sticky prices, and financial constraints, followed by an otherwise identical model without sticky prices and financial constraints, and then an otherwise identical model without financial constraints. Finally, we study our baseline model. To underline the result that financial frictions and sticky prices are necessary for generating consistent impulse responses but investment adjustment costs are not, our baseline model here will not consider investment adjustment costs.[14]

4.1 A Model without Investment Adjustment Costs, Sticky Prices, and Financial Frictions

First, we envisage the impulse responses of aggregate variables in response to IST news shocks in an otherwise standard two-sector real-business-cycle (RBC) model without investment adjustment costs, sticky prices, and financial frictions.

Without investment adjustment costs, the coefficient of investment adjustment costs is zero, $\varphi_c=\varphi_d=0$. Next, without sticky prices, then $\vartheta_c=\vartheta_d=0$. Moreover, without financial frictions, the shadow prices of collaterals are zero, and thus $\psi_{b,t}=\psi_{c,t}=\psi_{d,t}=0$. In order for (3d) and (6d) to be consistent with $\psi_{b,t}=\psi_{c,t}=\psi_{d,t}=0$, it requires that $\beta_b=\beta_c=\beta_d=\beta_s=0.99$. We now carry out an unanticipated news shock, wherein agents learn that there will be a one-standard-deviation increase in the IST level beginning in

[13] The source of the data is from the Federal Reserve Economic Data, published by the Federal Reserve Bank of St. Louis, over the period 1980:Q1–2011:Q4. 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.

[14] Nevertheless, as we will see later, the introduction of investment adjustment costs does smooth the magnitude of the impulse responses.

period four. The impulse responses of aggregate variables are illustrated in Figure 1.

[Insert Figure 1 here]

It is clear from the figure that, in response to a positive IST news shock (cf. Panel L), real variables are not affected on impact (cf. Panels A-H). Moreover, the real price of capital (Tobin's Q) does not go down until quarter four when an unanticipated IST news shock is realized (cf. Panel K). A decrease in real prices of capital in and after quarter four indicates that the real price of capital is inversely correlated with IST shocks. Thus, in response to a positive IST news shock, an otherwise standard two-sector RBC model without investment adjustment costs, sticky prices, and financial frictions fails to generate consistent impulse responses of macro variables.

4.2 The Model with Investment Adjustment Costs

Next, we analyze a model identical to that in Subsection 4.1 except allowing for investment adjustment costs. Hence, parameter values for $\psi_{b,t}$, $\psi_{c,t}$, $\psi_{d,t}$, β_b, β_c, β_d, β_s, ϑ_c, and ϑ_d in Subsection 4.1 still hold. Now, with investment adjustment costs, we set coefficients of investment adjustment costs at φ_c=φ_d=2, which is within the range of Christiano et al. (2005) and Jaimovich and Rebelo (2009). The model in this case degenerates to the Jaimovich and Rebelo (2009) model except for GHH preferences featuring small wealth effects on the labor supply (Greenwood et al., 1988) and variable capital utilization. The impulse responses are displayed in Figure 2.

[Insert Figure 2 here]

In response to a positive IST news shock (cf. Panel L), output, labor hours, investment, capital, and real wages all increase on impact (cf. Panels A, C-F). As compared to inactive responses of these variables on impact in Figure 1, it is clear from Figure 2 that investment adjustment costs give agents an incentive to respond immediately to news about future fundamentals. However, consumption does not go up but it goes down (cf. Panel B), due to an intertemporal substitution effect away from consumption and toward investment and thus, future consumption. Hence, in response to a positive IST news shock, a DSGE model with investment adjustment costs cannot generate consistent impulse responses. This is the reason why Jaimovich and Rebelo (2009) needed to incorporate GHH preferences and variable capital utilization to reconcile with the comovement problem.

4.3 The Model with Investment Adjustment Costs and Sticky Prices

Now, we proceed to analyze a model identical to that in Subsection 4.2 except for taking into account sticky prices. Hence, this is a sticky-price DSGE model with investment adjustment costs without financial frictions. Consequently, parameter values for $\psi_{b,t}$, $\psi_{c,t}$, $\psi_{d,t}$, β_b, β_c, β_d, β_s, φ_c, and φ_d in Subsection 4.2 still hold. Now, durable prices are still flexible, but nondurable prices are sticky with the coefficient of price adjustment being ϑ_c=96.15. This case degenerates to a two-sector version of the

Khan and Tsoukalas (2012) model. The impulse responses are depicted in Figure 3.

[Insert Figure 3 here]

As seen from the figure, in response to a positive IST news shock (cf. Panel L), output, labor hours, investment, and capital all increase on impact (cf. Panels A, C-E). Yet, as compared with Figure 2, real wages drop (cf. Panel F). Moreover, consumption drops by more (cf. Panel B). Price stickiness not only reduces real wages but also reinforces the fall in consumption. Hence, in response to an IST news shock, the model with sticky prices without financial constraints still cannot generate consistent impulse responses.

4.4 The Baseline Model

Finally, we turn to our baseline model that is a two-sector model with sticky prices and financial constraints. As investment adjustment costs are not necessary for consistent impulse responses, this subsection considers a baseline model that is identical to the model in Subsection 4.3 except with financial constraints but without investment adjustment costs. Hence, parameter value ϑ_c=96.15 is the same as in Subsection 4.3, but $\varphi_c=\varphi_d=0$. As to binding financial constraints for impatient households and entrepreneurs, it requires $\beta_s>\beta_b$, β_c, and β_d, so there are positive shadow prices of collaterals and thus, $\psi_{b,t}>0$, $\psi_{c,t}>0$, and $\psi_{d,t}>0$. The impulse responses are illustrated in Figure 4.

[Insert Figure 4 here]

Figure 4 indicates that a positive IST news shock increases all of the real variables on impact and thus, output, consumption, labor hours, investment, capital, and real wages all comove on impact (cf. Panels A-F). In addition, real debts also go up (cf. Panel G). Intuitively, as a result of a positive news shock to the marginal efficiency of capital investment, the demand for investment goods increases on impact (cf. Panel D), which induces a rise in the relative price of investment (cf. Panel G), like those in Figures 2 and 3. A procyclical relative price of investment is consistent with the data (See Beaudry et al., 2015, among others). With binding borrowing constraints, the increase in the relative price of investment raises the value of asset. This increases the borrowing ability, which in turn leads to more capital investment for business. As a consequence, labor demand rises and output increases (cf. Panels A and C). As the wealth effect of relaxing the collateral constraint on consumption is larger than the intertemporal substitution effect, consumption goes up (cf. Panel B). Hence, a positive IST news shock causes the business cycle comovement.

In order to compare whether the source of aggregate fluctuations comes from contemporaneous IST shocks or from IST news shocks, we carry out variance decompositions. Table 2 presents the variance decomposition of six variables of our baseline model presented in Figure 4. As seen from the top panel, IST news shocks are a more relevant source of uncertainty than contemporaneous IST shocks in the baseline model. Moreover, even when we add investment adjustment costs into the baseline model, the results are the same, and the shares of the forecast error variance of output, consumption, hours, and inflation attributable to IST news shocks are raised (cf. bottom panel in Table 2).

[Insert Table 2 here]

5. Sensitivity Analysis

This section carries out sensitivity analysis for the results of our baseline model. First, to underline the role of sticky prices and financial constraints, our baseline model does not consider the investment adjustment cost. As the investment adjustment cost plays a key role in Jaimovich and Rebelo (2009), this section analyzes the role of the investment adjustment cost. Next, although we set sticky nondurable prices every 5 quarters in the baseline model, it is interesting to see the robustness of the results if nondurable prices are adjusted in less than 5 quarters. Besides, the baseline model does not separate the role of financial constraints on households from that of financial constraints on entrepreneurs, and we separate their roles in this section. Finally, capital is not in entrepreneurs' financial constraints in the baseline model, and thus it is interesting to understand the robustness of the results if capital is in entrepreneurs' financial constraints. This section carries out these sensitivity analyses.

5.1 Investment Adjustment Costs

In our baseline model, there is no investment adjustment cost. Now, we study the robustness of our results when there is the investment adjustment cost.

We choose two distinct values for the coefficient of investment adjustment costs, φ_c=φ_d=2 and φ_c=φ_d=10. While the smaller value is within the estimates in Christiano et al. (2005), Jaimovich and Rebelo (2009), and Khan and Tsoukalas (2012), the larger value is set according to Schmitt-Grohe and Uribe (2012). The impulse responses are in Figure 5.

[Insert Figure 5 here]

The figure also demonstrates the impulse responses in the baseline model. It is clear to see that all real aggregate variables increase and thus, comove. When the investment adjustment cost increases, all of the real aggregate variables increase by less on impact, as compared to the baseline model with a zero investment adjustment cost (cf. Panels A-F). The results arise, because a larger investment adjustment cost reduces agents' incentives to respond immediately to IST news shocks.

5.2 Price Stickiness

In our baseline, the nondurable price is reset every 5 quarters. This subsection shows if nondurable prices are less sticky and eventually become flexible, an IST news shock cannot generate comovement. Our baseline sets ϑ_c=96.15, so the probability of resetting nondurable prices is 1-θ=1/5. To see how the results change when nondurable prices are less sticky, we increase the probability of resetting nondurable prices and thus lower the cost of nondurable price adjustments, ϑ_c. Figure 6 demonstrates the impulse responses when the probability of resetting nondurable prices increases from 1/5 to 1/3 and then 1, which implies that the nondurable consumption price is reset more frequently from every 5 quarters to every 3 quarters and then every quarter, respectively, with the corresponding adjustment cost parameter value of ϑ_c being decreased from 96.15 to 29.48 and then 0, respectively.

[Insert Figure 6 here]

With less sticky nondurable prices, more firms raise nondurable prices in response to a positive IST news shock. Then, the durable price relative to the nondurable price is not increased on impact as much as it is in the baseline (cf. Panel H), so the real debt is less influenced by collateral prices on impact (cf. Panel G). Therefore, the collateral effect becomes weaker, and real aggregate variables either rise by less, or even decline.

The figure indicates that our results of comovement are robust as long as the frequency of nondurable price adjustment is higher than 3 quarters, which lie within the estimates of the degree of price stickiness in the literature.

5.3 Collateral Constraints: Households vs. Entrepreneurs

This subsection differentiates the role played by households' collateral constraints from the role played by entrepreneurs' collateral constraints. We start by the case of an identical baseline model except households' collateral constraints, followed by the case of an identical baseline model except entrepreneurs' collateral constraints, and then by the case of an identical baseline model except both collateral constraints. The impulse responses are in Figure 7.

[Insert Figure 7 here]

First, when households' collateral constraints are not binding, output, consumption, labor hours, investment, capital, and real wages all rise and comove on impact (cf. red dashed lines).[15] However, in the Figure, when entrepreneurs' collateral constraints are not binding, no matter whether households' collateral constraints are binding (cf. green solid lines with circles) or are not binding (cf. black dashed lines with triangles), real variables do not comove on impact. In particular, the relative price of investment goes down (cf. Panel H). Then, entrepreneurs cannot raise their funding (borrowing capacity) via relaxing the collateral constraint to meet the increase in the demand for capital investment (cf.

[15] The scale of the impulse responses for output, hours, real wages and real debt in both the baseline model and the baseline model without households' collateral constraints is only 0.01 times of the scale in both the baseline model without entrepreneurs' collateral constraints and the baseline model without both households' and entrepreneurs' collateral constraints. As a result, the impulse responses for the former two models are relatively invisible in Figure 7. For a better visibility, we illustrate the impulse responses of only the two former models in Appendix Figure 1.

Panels D and E) before a positive IST shock is realized in the fourth quarter. A decrease in the relative price of investment causes agents to substitute away from consumption (cf. Panel B).

In summary, entrepreneurs' collateral constraints play a crucial role in driving the comovement of real variables in response to an IST news shock, while households' collateral constraints play only a minor role.

5.4 Capital in Collateral Constraints on Entrepreneurs

In the baseline model, we followed Iacoviello (2005) and considered the case when only consumer durables serve as a collateral. This subsection studies the case when capital can serve as a collateral for lending. When capital is used as a collateral, the entrepreneur's collateral constraint (5d) becomes

$$R_t b_{j,t} \leq m_j (1-\delta) E_t [p_{t+1}(D_{j,t} + K_{j,t+1})\pi_{c,t+1}] = m_j (1-\delta) p_t E_t [(D_{j,t} + K_{j,t+1})\pi_{d,t+1}], \quad j=c,\ d. \qquad (5d)'$$

In this case, the first-order conditions in (6a)-(6d) and (6f) remain unchanged, and (6e) for $K_{j,t+1}$, $j=c$, d, are revised as follows.

$$p_t q_{j,t} = \beta_j E_t \left[MU^C_{j,t+1} \frac{P^W_{j,t+1}(z)}{P_{c,t+1}} MP^K_{j,t+1} + p_{t+1} q_{j,t+1}(1-\delta) \right] + m_j (1-\delta) MU^C_{j,t} \psi_{j,t} E_t [p_{t+1}\pi_{c,t+1}], \qquad (6e)'$$

where the marginal benefit of capital is augmented by the marginal gain of relaxing the collateral constraint from capital (cf. the second term in the right-hand side).

The impulse response is illustrated in Figure 9. As is clear from the figure, when capital is also in entrepreneurs' collateral constraints, the results of comovement still hold true and moreover, the impulse responses of all real variables are amplified. In the meantime, when we drop households' collateral constraints, the impulse responses of all real aggregate variables are mitigated, except for labor hours, which are enlarged more than those in the baseline model. A larger response of labor hours arises here, because the collateral effect (i.e., the wealth effect) on leisure is weakened due to the absence of households' collateral constraints. The effect is similar to Panel (C), Figure 7, where the increase in labor hours is strengthened on impact, due to the absence of households' collateral constraints.

[Insert Figure 9 here]

Table 3 exhibits unconditional correlations with output in the data and conditional correlations with output in the baseline model and in the baseline models with some variations. The correlations with output conditional on the baseline model match with those in the data reasonably well. Moreover, with varied investment adjustment costs and with capital also in entrepreneurs' collateral constraints, our baseline model matches with those in the data even better. The positive and strong conditional correlations imply that IST news shocks are capable of generating business cycle comovement.

[Insert Table 3 here]

6. Conclusion

Recent research in DSGE models and VAR models have suggested that the most important drivers of business cycle fluctuations are unanticipated IST shocks, not unanticipated TFP and other shocks. Moreover, research in VAR models also empirically identified IST news shocks as a significant driving force behind the U.S. business cycle. However, recent one-sector DSGE models found that IST news shocks do not produce comovement of real aggregate variables with the share of the forecast error variance explained by IST news shocks being very small in a flexible-price model and essentially zero in a sticky-price model. This paper studies the short-run business cycle effects of IST news shocks in a two-sector DSGE model with consumer durables that is characterized by sticky prices and collateral constraints. In our model, IST news shocks can produce comovement of aggregate variables, as opposed to existing DSGE models with flexible prices that produce comovement relying on variable capital utilization, investment adjustment costs, and preferences with weak short-run wealth effects on the labor supply. Our variance decomposition exercises indicate that IST news shocks are a more relevant source of uncertainty than unanticipated contemporaneous IST shocks.

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TABLE 1

Baseline Parameter Values (Frequency: Quarterly)

Description	Parameter	
TFP in nondurable/durable goods sector (normalized)	A_c, A_d	1
elasticity of substitution between nondurables and durables	η	1
elasticity of substitution for nondurable/durable goods	ε_c, ε_d	6
share of durable goods in the composite consumption index	μ	0.2
inverse of elasticity of labor supply of patient/impatient households	ϕ_s, ϕ_b	1
discount factor of patient households	β_s	0.99
discount factor of impatient households	β_b	0.98
discount factor of entrepreneurs in nondurable/durable sector	β_c, β_d	0.98
capital share of the nondurable sector	α_c	0.47
capital share of the durable sector	α_d	0.27
depreciation rate of consumer durables and capital	δ	0.025
hours worked of patient or impatient households	L_s, L_b	0.3
borrowers' loan-to-value ratio	m_b	0.77
entrepreneurs' loan-to-value ratio in nondurable/durables sector	m_c, m_d	0.80
costs of investment adjustment in nondurable/durable sector	φ_c, φ_d	0
coefficient of price adjustment in nondurable sector	ϑ_c	96.15
coefficient of price adjustment in durable sector	ϑ_d	0
autocorrelation of the IST shock	ρ	0.73
coefficient of inflation rate for Taylor rule	χ	1.5
parameter of labor in utility for patient households	ν_s	6.011
parameter of labor in utility for impatient households	ν_b	10.84

TABLE 2
Variance decomposition in the baseline model (in percent)

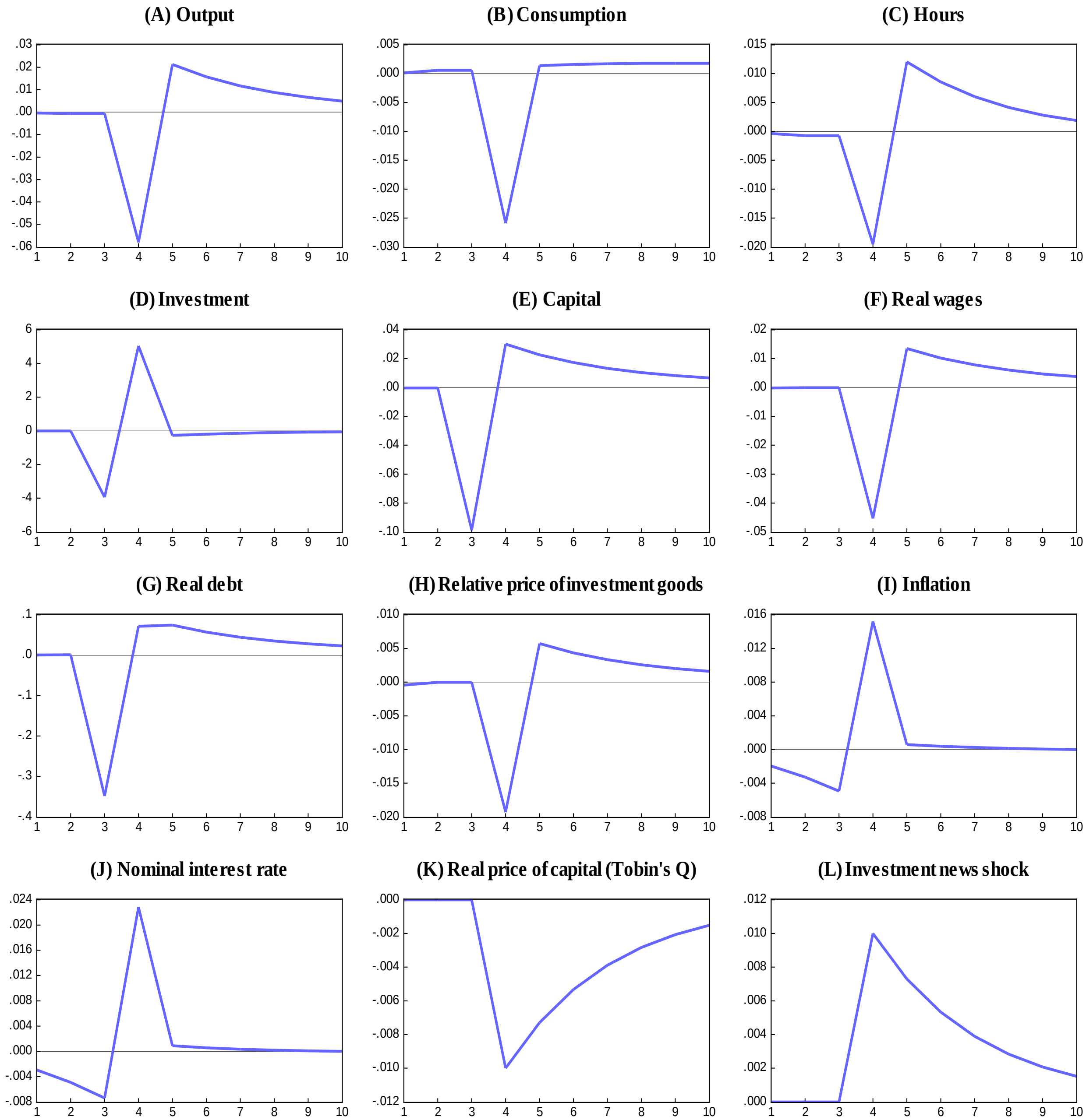
	Investment-specific technology shock	
	News	Contemporaneous
	With $\varphi_c=\varphi_d=0$	
Output	56	44
Consumption	55	45
Hours	50	50
Investment	90	10
Real wage	65	35
Inflation	65	35
	With $\varphi_c=\varphi_d=2$	
Output	57	43
Consumption	56	44
Hours	56	44
Investment	60	40
Real wage	61	39
Inflation	71	29

TABLE 3
Correlations with Output

	Data* (1947Q1-2019Q2)	Baseline model	Baseline models with some variations		
			$\varphi_c=\varphi_d=2$	$\varphi_c=\varphi_d=10$	with capital in ECC**
Output	1	1	1	1	1
Consumption	0.83	0.84	0.90	0.94	0.85
Hours	0.64	0.47	0.58	0.75	0.72
Investment	0.78	0.57	0.79	0.85	0.65

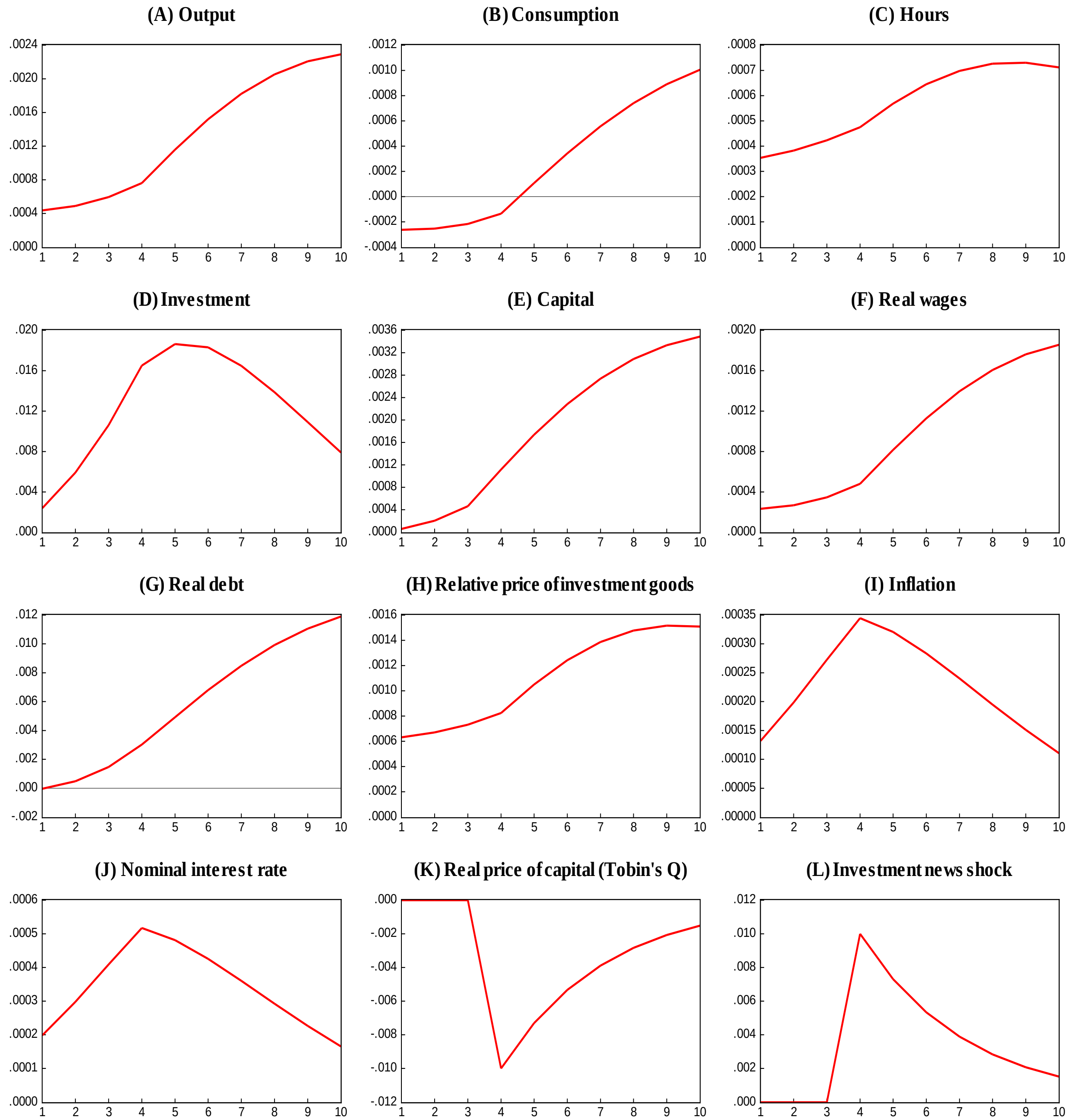
Note: * The quarterly data are seasonally adjusted, expressed in logarithms, deflated by the GDP deflators, and detrended using the Hodrick-Prescott filter with a smoothing parameter of 1,600.

** ECC stands for entrepreneurs' collateral constraints.



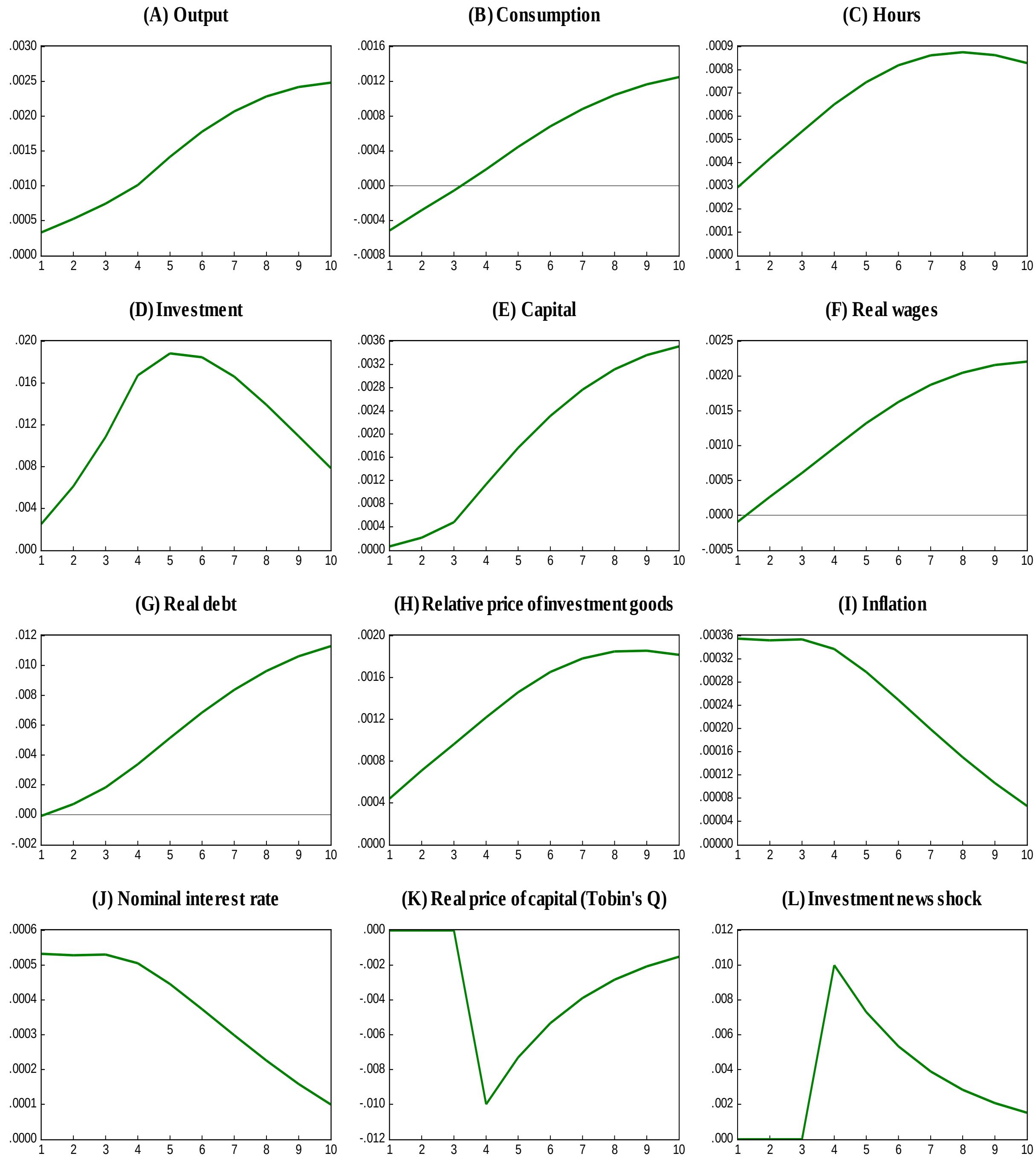
Note: The horizontal axis is quarters; the vertical axis is percentage deviations from the steady state.

Figure 1. Impulse responses to a positive IST news shock in a two-sector RBC model without financial frictions, sticky prices, and investment adjustment costs



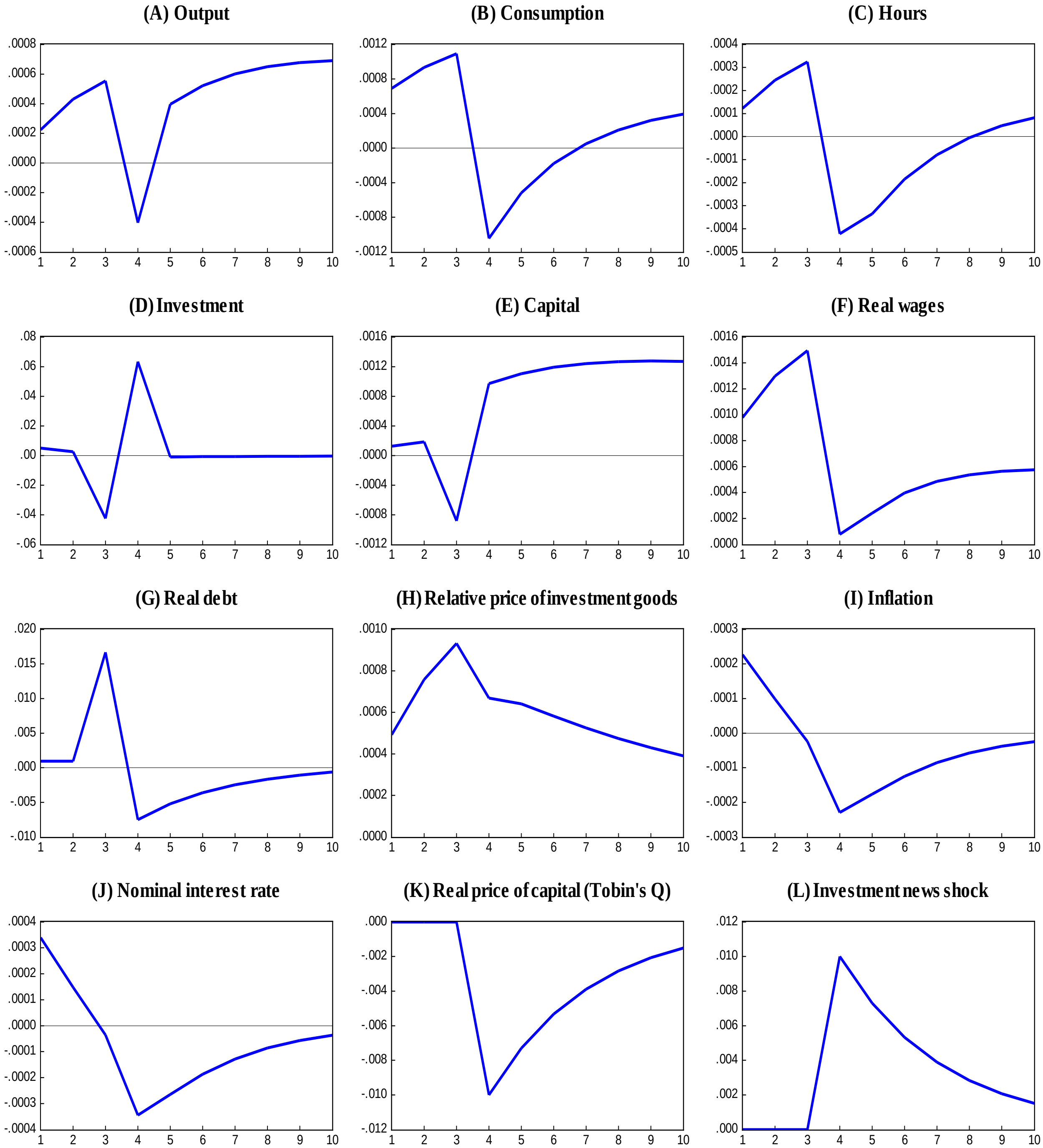
Note: The horizontal axis is quarters; the vertical axis is percentage deviations from the steady state.

Figure 2. Impulse responses to a positive IST news shock in an identical model to that in Figure 1 except adding investment adjustment costs.



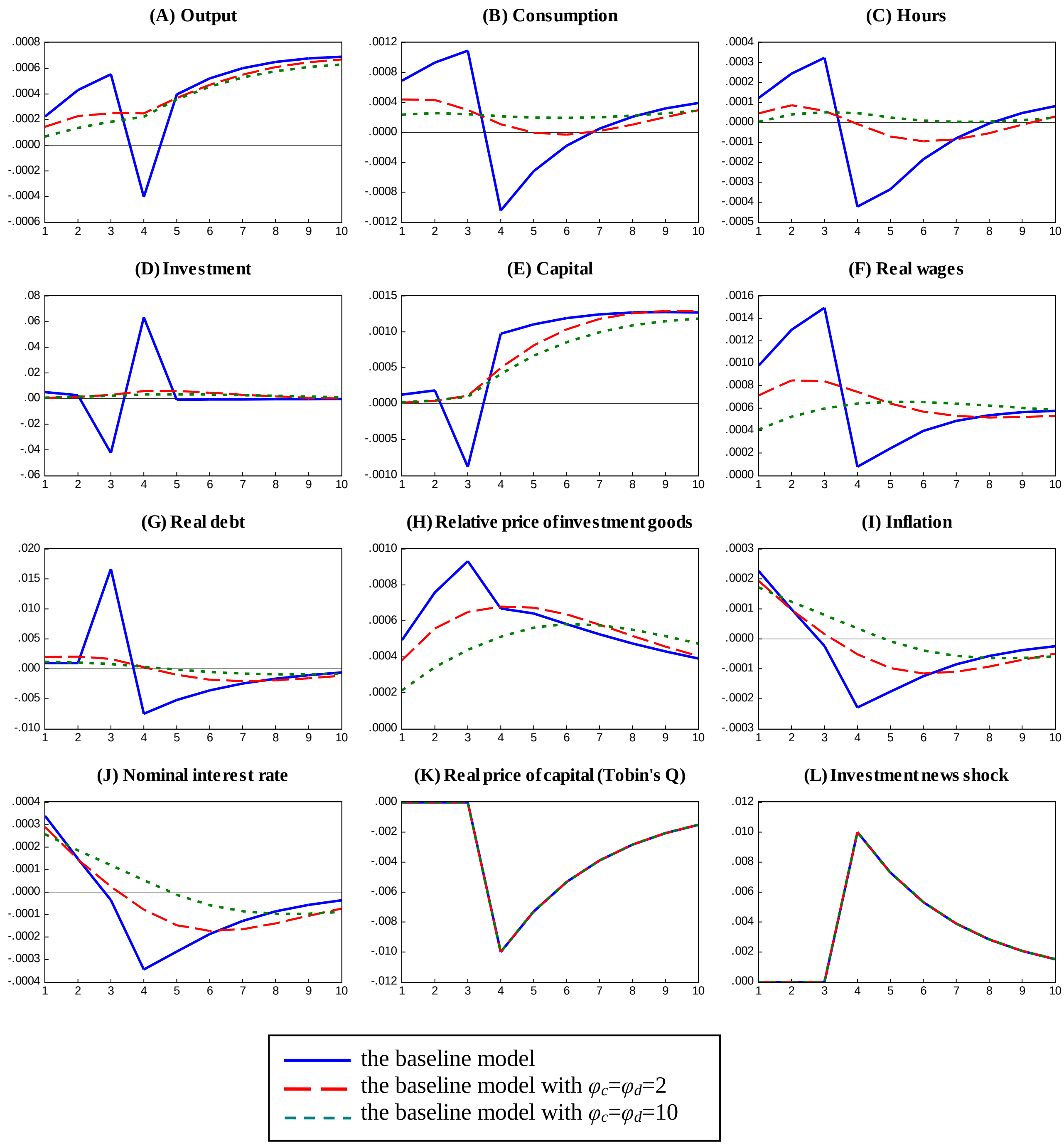
Note: The horizontal axis is quarters; the vertical axis is percentage deviations from the steady state.

Figure 3. Impulse responses to a positive IST news shock in an identical model to that in Figure 2 except adding sticky prices.



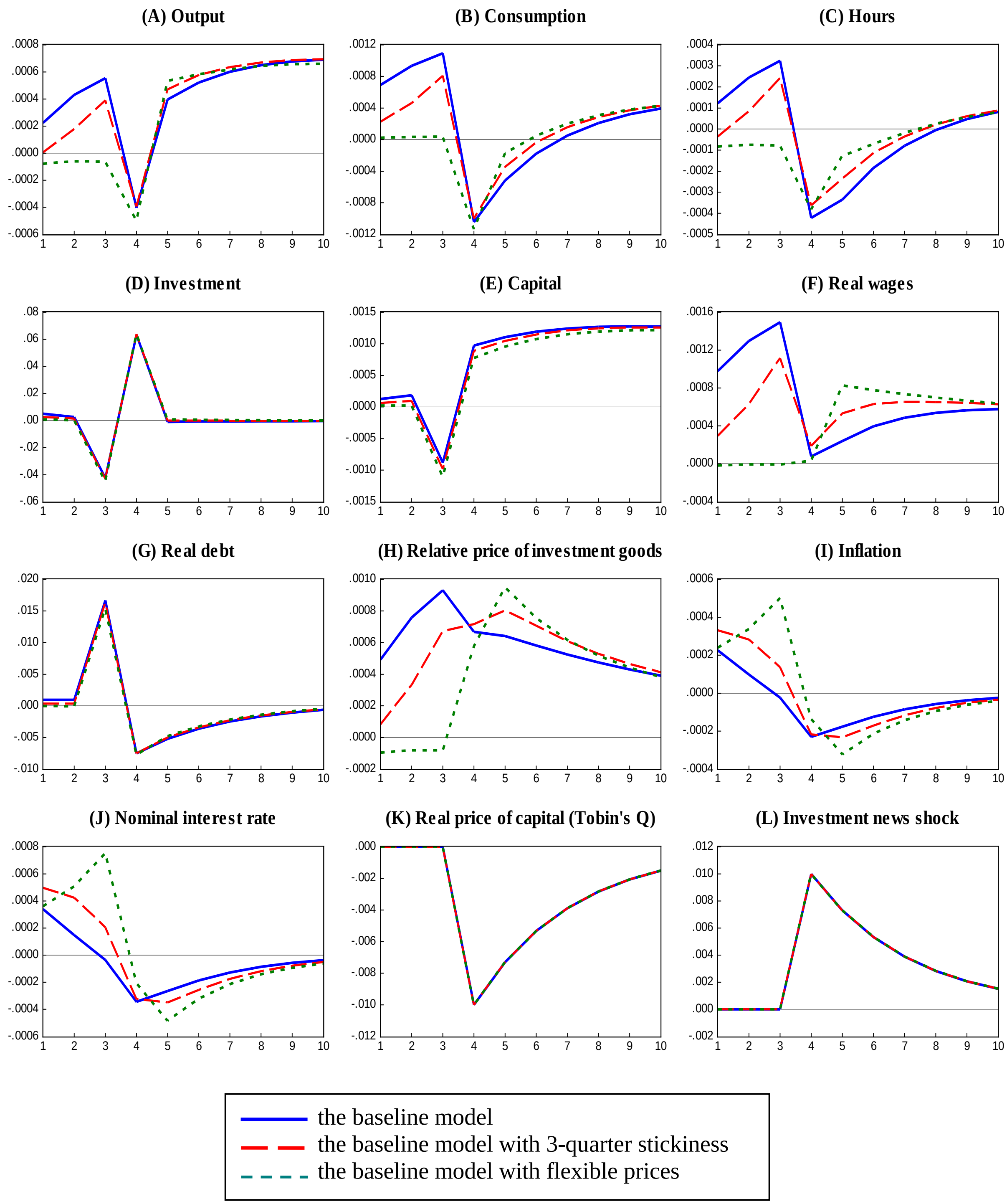
Note: The horizontal axis is quarters; the vertical axis is percentage deviations from the steady state.

Figure 4. Impulse responses to a positive IST news shock in the baseline model



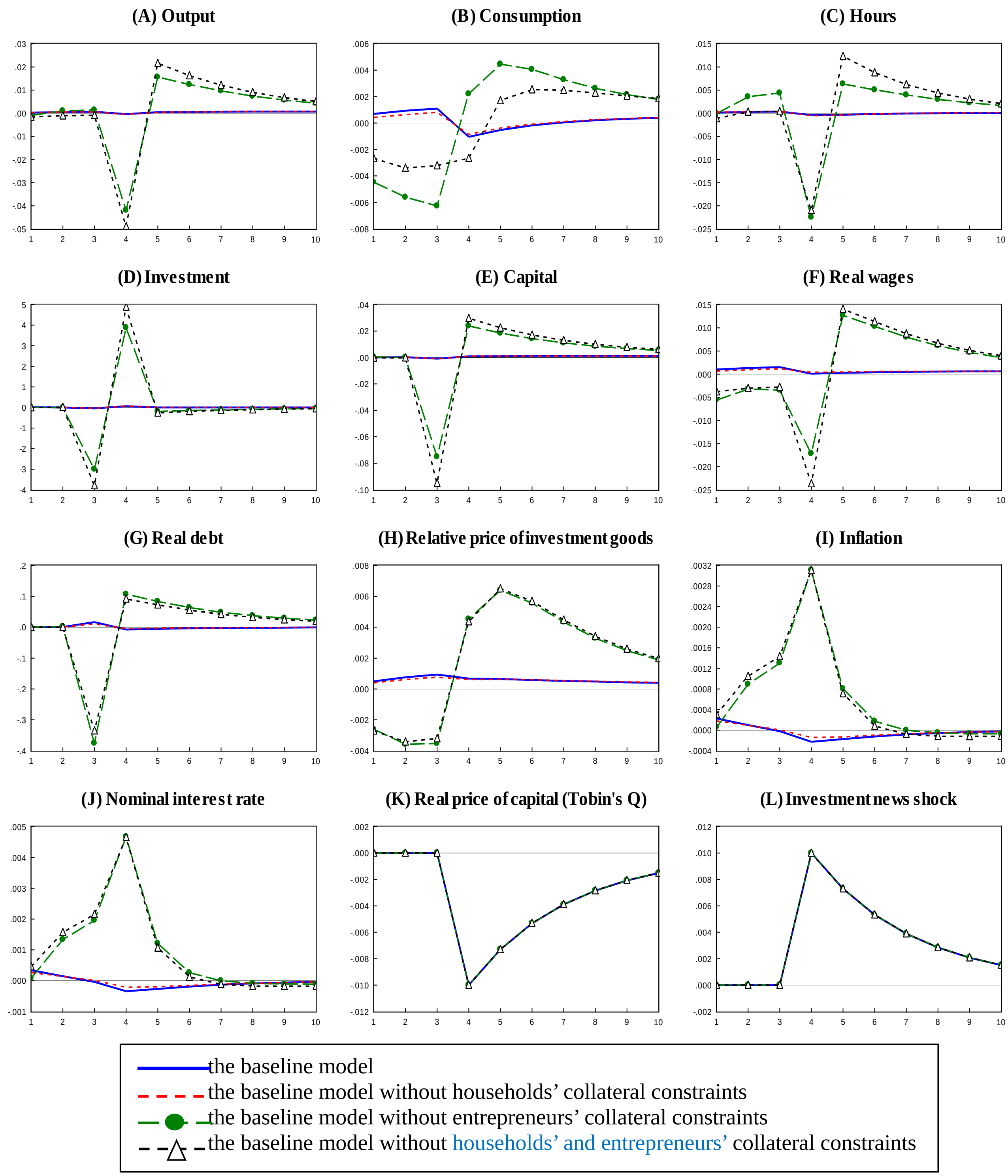
Note: The horizontal axis is quarters; the vertical axis is percentage deviations from the steady state.

Figure 5. Impulse responses to a positive IST news shock in the baseline model and an identical baseline model except for degrees of investment adjustment costs.



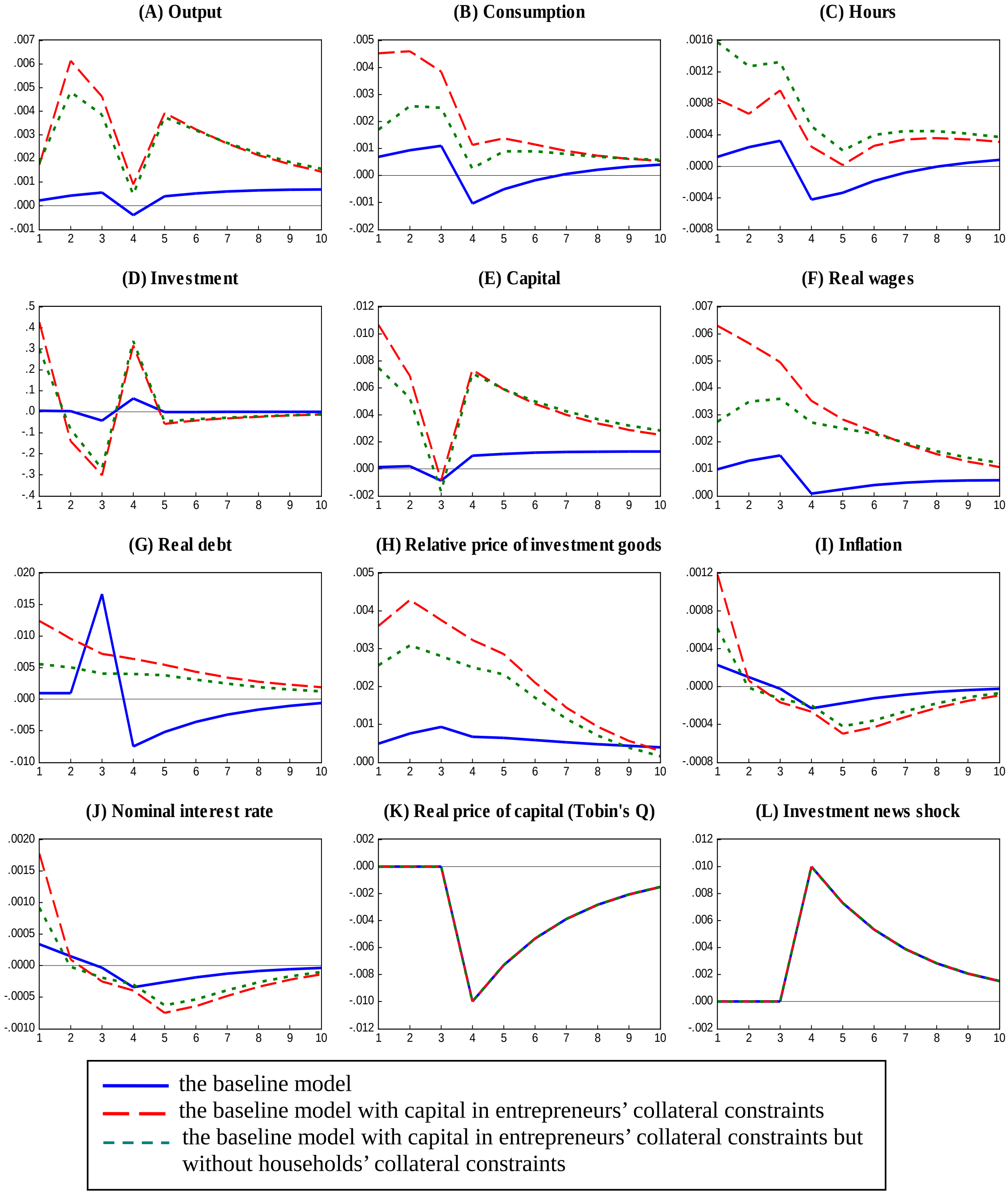
Note: The horizontal axis is quarters; the vertical axis is percentage deviations from the steady state.

Figure 6. Impulse responses to a positive IST news shock in the baseline model and an identical baseline model except for degrees of nondurable price stickiness.



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

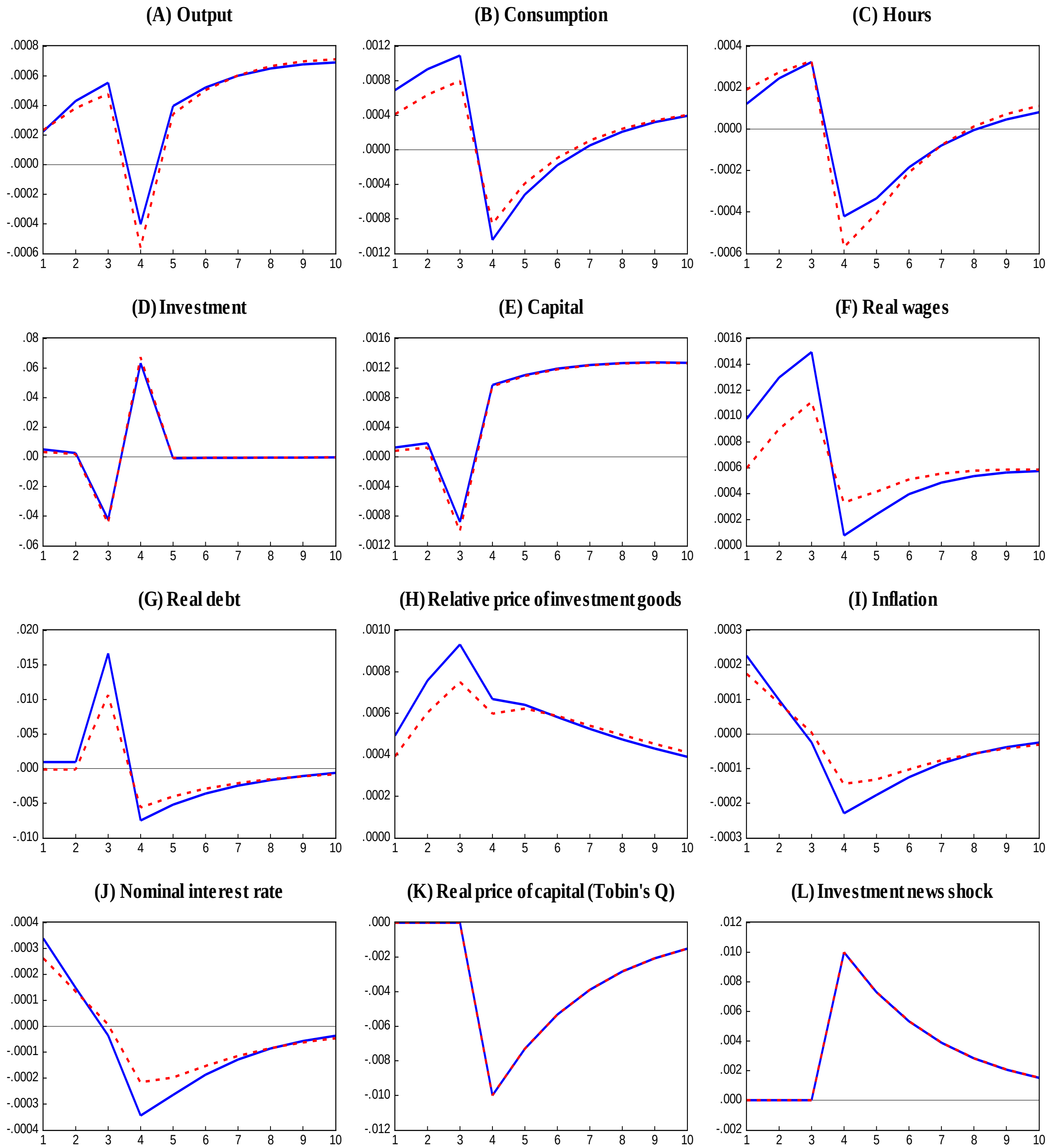
Figure 7 Impulse responses to a positive IST news shock in the baseline model with and without households' or entrepreneurs' collateral constraints.



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

Figure 8. Impulse Responses to a positive IST news shock in the baseline model, and identical baseline models with capital in entrepreneurs' collateral constraints and with or without households' collateral constraints.

Appendix



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

Appendix Figure 1. Impulse responses to a positive IST news shock in the baseline model and the baseline model without households' collateral constraints.