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Munechika Katayama and Kwang Hwan Kim

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Graduate School of Economics
Kyoto University
Yoshida-Hommachi, Sakyo-ku
Kyoto City, 606-8501, Japan

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Inter-sectoral Labor Immobility, Sectoral Co-movement, and News Shocks[*]

Munechika Katayama
Kyoto University
katayama@econ.kyoto-u.ac.jp

Kwang Hwan Kim
Yonsei University
kimkh01@yonsei.ac.kr

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Abstract

The sectoral co-movement of output and hours worked is a prominent feature of business cycle data. However, most two-sector neoclassical models fail to generate this sectoral co-movement. We construct and estimate a two-sector neoclassical DSGE model that generates the sectoral co-movement in response to both anticipated and unanticipated shocks. The key to our model's success is a significant degree of inter-sectoral labor immobility, which we estimate using data on sectoral hours worked. Furthermore, we demonstrate that imperfect inter-sectoral labor mobility provides a better explanation for the sectoral co-movement than some alternative model emphasizing the role of labor-supply wealth effects.

Keywords: Sectoral Co-movement; Labor Immobility; Non-separable Preferences; Unanticipated Shocks; News Shocks.

JEL Classification: E32; E13

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1 Introduction

Sectoral co-movement is an important characteristic of business cycles. Output, hours worked, and investment tend to co-move across sectors over business cycles. Synchronization of sectoral variables leads to the co-movement of aggregate macroeconomic variables, and it is crucial for business cycle models to generate sectoral co-movement.

However, standard neoclassical business cycle models fail to generate sectoral co-movement in response to contemporaneous (unanticipated) shocks. For example, Christiano and Fitzgerald (1998) show that the two-sector neoclassical model driven by aggregate contemporaneous total factor productivity (TFP) shocks cannot generate sectoral co-movement of hours worked across industries that produce consumption and investment goods. Greenwood et al. (2000) show that co-movement between the consumption and investment sectors is also difficult to generate in the two-sector model with contemporaneous investment-specific technology shocks.

Recently, there has been a resurgent interest in understanding the source of sectoral co-movement. This has been stimulated by a revival of interest in the idea that changes in expectations about future fundamentals, (i.e., news shocks or anticipated shocks) might be important drivers of economic fluctuations. News shocks pose an additional challenge to business cycle models in generating sectoral co-movement. As Beaudry and Portier (2004) and Jaimovich and Rebelo (2009) demonstrate, it is difficult for news shocks to generate the co-movement in output, hours worked, and investment across sectors of the economy.

In this study, we construct and estimate a two-sector neoclassical business cycle model that can generate sectoral co-movement in response to both contemporaneous and news shocks.[1] We restrict our attention to a neoclassical environment in order to better understand the nature of sectoral co-movement with respect to contemporaneous and news shocks and to maintain comparability with earlier studies, such as those by Christiano and Fitzgerald (1998), Greenwood et al. (2000), and Jaimovich and Rebelo (2009).

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[1] There is a strand of literature on news shocks that has examined the co-movement of aggregate macroeconomic variables in one-sector business cycle models. Several recent papers have proposed a one-sector model that produces the aggregate co-movement. Examples include Christiano, Ilut, Motto, and Rostagno (2008), Den Haan and Kaltenbrunner (2009), Dupor and Mehkari (2014), Eusepi and Preston (2009), Gunn and Johri (2011), Guo et al. (2015), Karnizova (2010), Pavlov and Weder (2013), and Wang (2012). However, we focus on the sectoral co-movement problem because aggregate co-movement does not necessarily imply sectoral co-movement in a two-sector setup. In contrast, once we generate sectoral co-movement, aggregate co-movement naturally follows.

In our model, imperfect inter-sectoral labor mobility and non-separable preferences between consumption and leisure are key to generating sectoral co-movement. To show their importance, we analytically illustrate a condition for sectoral co-movement. In fact, our co-movement condition is based on equilibrium conditions. Thus, our mechanism not only works for responses to anticipated shocks, but also applies to contemporaneous shocks.[2] We then estimate key model parameters related to sectoral co-movement using Bayesian techniques. The data support our proposed mechanism of generating sectoral co-movement. In particular, we find that imperfect labor mobility across sectors plays a crucial role in sectoral co-movement. Although the estimated degree of non-separability is moderate, non-separable preferences help generate the co-movement.

There is abundant empirical evidence supporting the main feature of our model, inflexible intersectoral labor mobility. Davis and Haltiwanger (2001) find limited labor mobility across sectors in response to monetary and oil shocks. Horvath (2000) reports a relatively low estimate for the elasticity of substitution of labor across sectors, using sectoral U.S. labor hours data. Beaudry and Portier (2011) present evidence of labor market segmentation through various panel estimations based on PSID data. In particular, their results suggest that the mobility across sectors is not sufficient to equate the returns to labor between individuals initially attached to different sectors. This evidence is probably the closest to the spirit of the model considered in this paper. Non-separable preferences also play an important role in the transmission of monetary policy shocks in New Keynesian models (e.g., Guerron-Quintana, 2008; Kim and Katayama, 2013).

Another important contribution of this study is that our approach to generating sectoral co-movement in response to contemporaneous and news shocks is more consistent with the data than an alternative mechanism is. In particular, our study is closely related to a two-sector version of the model by Jaimovich and Rebelo (2009), which is considered a leading mechanism for generating sectoral co-movement in the literature. In their model, a very weak wealth effect on the labor supply is a source of sectoral co-movement. To show this, they introduce a new class of preferences, featuring a parameter that governs the strength of the wealth effect of labor supply. To compare the empirical performance of our model with theirs, we also estimate their two-sector model. We show that our model outperforms theirs in terms of the Bayes factor and matching business cycle

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[2] In this study, we use the terms contemporaneous shocks and unanticipated shocks interchangeably. Similarly, we use news shocks and anticipated shocks interchangeably.

moments.

Why does the data support our model over that of Jaimovich and Rebelo (2009)? We find that the estimated degree of the labor supply wealth effect is very close to zero in their two-sector model, so in principle, the model could deliver sectoral co-movement. Our estimate of the labor supply wealth effect is consistent with the results of Schmitt-Grohé and Uribe (2012), who estimate the one-sector version of Jaimovich and Rebelo (2009). However, the estimated two-sector version of the Jaimovich and Rebelo (2009) model does not generate the observed positive correlations of output and hours worked across sectors even with the near-zero wealth effect, and thus, the data favor our model over theirs. We demonstrate that the ability of the Jaimovich and Rebelo (2009) model to generate sectoral co-movement is in turn related to the marginal cost of varying capital utilization, which is also crucial in their model. To support sectoral co-movement, the cost must be small; however, this cost is estimated to be too high in the consumption sector, which prevents their two-sector model from generating sectoral co-movement.

Although we restrict ourselves to a neoclassical environment, our finding has an implication for sectoral co-movement in a New Keynesian setup.[3] Khan and Tsoukalas (2012) estimate a one-sector New Keynesian model featuring Jaimovich–Rebelo preferences. Unlike Schmitt-Grohé and Uribe (2012), they find that the estimated size of the labor supply wealth effect is non-negligible in a one-sector New Keynesian setup. The findings in Khan and Tsoukalas (2012) and our study suggest that it may be difficult to rely on Jaimovich–Rebelo preferences to generate sectoral co-movement in a two-sector New Keynesian model, and imperfect labor mobility across sectors may be a useful device for this purpose.

There are several other studies on generating the sectoral co-movement to news shocks in multi-sector neoclassical business cycle models as well.[4] For example, Beaudry and Portier (2004) show that strong complementarity between non-durable and durable goods in the momentary utility function can overcome the sectoral co-movement problem. Beaudry and Portier (2007) identify the cost complementarity among intermediate goods firms in a multi-sector setting (i.e., economies of scope) as a key feature that generates co-movement. Beaudry et al. (2011) analyze a two-country

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[3] For example, Davis (2007), Fujiwara et al. (2011), and Khan and Tsoukalas (2012) use one-sector New Keynesian models to assess the quantitative importance of news shocks.

[4] See Beaudry and Portier (2013) for an exhaustive list of studies that may generate the sectoral co-movement in response to news shocks.

two-sector model and discuss conditions for business cycle fluctuations driven by news shocks. Although these mechanisms are interesting possible mechanisms of producing the sectoral co-movement, prior studies explore only theoretical perspectives.[5] Our study is different in that we not only propose a potential explanation for the co-movement problem, but also show that it is supported by the data.

We also evaluate the importance of news shocks in accounting for business cycle fluctuations. Although existing studies typically use one-sector DSGE models to empirically evaluate the importance of news shocks, we tackle the same question through the lens of our two-sector model. As in Khan and Tsoukalas (2012) and Schmitt-Grohé and Uribe (2012), we find that the news components of wage markup shocks play an important role in explaining business cycle fluctuations. In particular, variations in hours growth are largely attributed to news components in wage markup shocks. Even though technology news shocks typically play negligible roles in Khan and Tsoukalas (2012) and Schmitt-Grohé and Uribe (2012),[6] we find that they are non-negligible. In fact, our results are quantitatively similar to the findings in Fujiwara et al. (2011). However, the overall contribution of technology news shocks is not so significant, relative to unanticipated counterparts (contemporaneous technology shocks).

The remainder of the paper is organized as follows. Section 2 presents our two-sector neoclassical DSGE model. Section 3 characterizes the necessary condition for sectoral co-movement in hours worked analytically, and provides numerical simulations to illustrate our model. Section 4 presents the Bayesian estimation of the structural parameters of our model. Section 5 compares the empirical performance of our model with that of a two-sector version of the model proposed by Jaimovich and Rebelo (2009). Finally, Section 6 concludes the paper.

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[5] For example, existing empirical studies seem to suggest that the consumption of non-durable and of durable goods are generally not complements. For instance, Ogaki and Reinhart (1998) estimate the intratemporal elasticity of substitution between non-durable and durable goods consumption. They find that this elasticity is greater than one, implying that non-durable goods and consumer durable goods are substitutes. Piazzesi, Schneider, and Tuzel (2007) find that non-durables and housing are substitutes.

[6] The exception is anticipated components in stationary investment-specific technology shocks in Schmitt-Grohé and Uribe (2012) for investment growth.

2 The Model

Our model adopts the basic structure of the two-sector model of Jaimovich and Rebelo (2009), but differs from their model in two respects. Jaimovich and Rebelo (2009) use a new class of preferences parameterizing the strength of wealth effects on the labor supply. These preferences nest the class of the utility functions proposed by King et al. (1988) (i.e., KPR preferences) and by Greenwood, Hercowitz, and Huffman (1988) (i.e., GHH preferences), which eliminates the wealth effects on the labor supply, as special cases. In contrast, we restrict our focus to the standard King–Plosser–Rebelo utility function to show that our model is capable of generating the business cycle sectoral co-movement without assuming very low wealth effects on the labor supply. In addition, we assume that labor is not perfectly mobile across sectors and thus wages are not equalized across the sectors, in contrast to Jaimovich and Rebelo (2009).

2.1 Households

The economy is populated by a constant number of identical and infinitely lived households. The representative household receives utility from consumption and incurs disutility from providing labor hours to the consumption and investment goods sectors. Let C_t and N_t denote the consumption in period t and an aggregate labor index, respectively. Households maximize their expected lifetime utility, given by

$$U_0 = E_0\left[\sum_{t=0}^{\infty} \beta^t b_t U(C_t - hC_{t-1}, N_t)\right], \tag{1}$$

where $\beta \in (0, 1)$ is the subjective discount factor and $h \in [0, 1)$ governs the degree of internal habit formation. The variable b_t denotes an exogenous and stochastic preference shock in period t. This type of disturbance has been found to be an important source of consumption fluctuations in most existing econometric estimations of DSGE macroeconomic models (e.g., Smets and Wouters, 2007; Justiniano et al., 2010).

In this study, we use the following specific form of the King–Plosser–Rebelo utility function:

$$U(C_t - hC_{t-1}, N_t) = \frac{(C_t - hC_{t-1})^{1-\frac{1}{\sigma}}\left(1 + \left(\frac{1}{\sigma} - 1\right)v(N_t)\right)^{\frac{1}{\sigma}} - 1}{1 - \frac{1}{\sigma}}, \quad \sigma \le 1, \tag{2}$$

where $v(N_t) = \varphi \frac{\eta}{1+\eta} N_t^{\frac{\eta+1}{\eta}}$. This class of the King–Plosser–Rebelo utility function is also used in Basu and Kimball (2002), Shimer (2009), Kim and Katayama (2013), and Katayama and Kim (2013). The term $v(N_t)$ measures the disutility incurred from hours worked, with $v^{'} > 0$, $v'' > 0$. The parameter η is the Frisch elasticity of aggregate labor supply in the absence of habit formation (i.e., $h = 0$), measuring the intertemporal elasticity of aggregate labor supply.[7] For lower values of η, agents are unwilling to substitute aggregate labor supply over time.

Our formulation of the momentary utility function nests the non-separable and separable preferences in consumption and leisure. In (2), the degree of non-separability is controlled by the parameter for intertemporal elasticity of substitution for consumption, σ. The non-separable cases arise when $\sigma < 1$, which implies that consumption and leisure are substitutes, as predicted by theory of time allocation (Becker, 1965). In other words, the marginal utility of consumption is decreasing in leisure. Lower values for this parameter imply a larger substitutability between consumption and leisure displayed by the utility function. The separable case corresponds to the limiting case $\sigma \rightarrow 1$,

$$\lim_{\sigma \rightarrow 1} U(C_t - hC_{t-1}, N_t) = \log(C_t - hC_{t-1}) - v(N_t).$$

This separable preference is used in most business cycle models.

We assume that the representative household is endowed with one unit of time in each period, and that the aggregate leisure index, L_t, takes the following form:

$$L_t = 1 - N_t = 1 - \left[N_{c,t}^{\frac{\theta+1}{\theta}} + N_{i,t}^{\frac{\theta+1}{\theta}} \right]^{\frac{\theta}{\theta+1}}, \quad \theta \geq 0. \tag{3}$$

Here N_t is an aggregate labor hours index, and $N_{c,t}$ and $N_{i,t}$ denote labor hours devoted to the consumption and the investment sector, respectively. This specification is considered by Huffman and Wynne (1999) and Horvath (2000) to capture some degree of sector specificity to labor without deviating from the representative worker assumption. The degree to which labor can move across sectors is controlled by the elasticity of *intra*temporal substitution in labor supply, θ. As $\theta \rightarrow \infty$,

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[7] It can be easily shown that the inverse Frisch elasticity of labor supply (i.e., the marginal utility of consumption (λ) constant elasticity) is

$$\left(\frac{\partial logW}{\partial logN} \right)_{\lambda=const.} = \left[U_{NN} - (U_{CN})^2 / U_{CC} \right] / U_N,$$

where λ is the marginal utility of consumption and W is the real wage. After some algebra, one can show that the inverse Frisch elasticity reduces to $1/\eta$.

labor hours become perfect substitutes for the worker, implying that the worker would devote all time to the sector paying the highest wage. Hence, at the margin, all sectors pay the same hourly wage. For $\theta < \infty$, hours worked are not perfect substitutes for the worker. The worker has a preference for diversity of labor, and hence would prefer working positive hours in each sector, even when the wages are different among sectors. As $\theta \to 0$, it becomes impossible to alter the composition of labor hours. In other words, there is an infinite cost of doing so and, consequently, the labor hours in two different sectors will be perfectly correlated. Below, we will derive the threshold level of θ needed to produce the sectoral co-movement of hours worked.

The household faces the following standard budget constraint:

$$C_t + \left(\frac{P_{i,t}}{P_{c,t}}\right)(I_{c,t} + I_{i,t}) \leq \sum_{j=c,i}\left(\frac{W^*_{j,t}}{P_{c,t}}\right)N_{j,t} + \sum_{j=c,i}\left(\frac{R_{j,t}}{P_{c,t}}\right)u_{j,t}K_{j,t} + \Pi_t, \tag{4}$$

where the subscripts c and i denote variables that are specific to the consumption and investment sectors, respectively. Then, $P_{j,t}$ is the nominal price of goods produced in sector $j = c, i$, $I_{j,t}$ represents newly purchased capital for sector j, $W^*_{j,t}$ is the nominal wage rate received by supplying labor to firms in sector j, and Π_t denotes the total profit received from firms. In addition, $K_{j,t}$ is the productive capital stock in sector j, and $u_{j,t}$ denotes the capital utilization rate in sector j. Hence, $u_{j,t}K_{j,t}$ represents the capital services and $R_{j,t}$ the rental rate of capital services in sector j.

The capital stock in each sector, $j = c, i$, evolves according to

$$K_{j,t+1} = I_{j,t}\left[1 - \phi\left(\frac{I_{j,t}}{I_{j,t-1}}\right)\right] + \left[1 - \delta(u_{j,t})\right]K_{j,t}, \quad j = c, i. \tag{5}$$

Here the function $\phi(\cdot)$ represents the investment adjustment costs of the form proposed by Christiano et al. (2005). We assume that the function $\phi(\cdot)$, evaluated at the steady-state growth rate of investment, satisfies $\phi = \phi' = 0$ and $\phi'' > 0$. In addition, we assume that increasing the intensity of capital utilization entails a cost in the form of a faster rate of depreciation. More specifically, we assume that the depreciation rate is convex in the rate of utilization: $\delta' > 0, \delta'' \geq 0$.

2.2 Firms

The two types of final goods produced in the economy are consumption goods produced in the consumption sector, and capital goods produced in the investment sector. Firms in the investment sector provide new investment goods to both sectors. Output in each sector is produced by perfectly competitive firms with a Cobb–Douglas production function that takes capital services ($u_{j,t}K_{j,t}$) and labor services ($N^d_{j,t}$) as inputs. Formally, the production function is given by

$$C_t = A_t a_t \left(u_{c,t}K_{c,t}\right)^{\alpha} \left(N^d_{c,t}\right)^{1-\alpha}, \tag{6}$$

$$I_t = A_t a_t z_{i,t} \left(u_{i,t}K_{i,t}\right)^{\alpha} \left(N^d_{i,t}\right)^{1-\alpha}, \tag{7}$$

where A_t is a permanent aggregate TFP shock, a_t is a transitory aggregate TFP shock, and $z_{i,t}$ is a transitory investment-specific TFP shock. The growth rate of the permanent aggregate TFP shock, $g_t \equiv \frac{A_t}{A_{t-1}}$, is assumed to be an exogenous stationary stochastic process with a steady-state value equal to g. The shock $z_{i,t}$ affects both the rate of transformation of consumption goods into investment goods and the rate of transformation of investment goods into productive capital. [8]

To clear the market for the investment good, we have $I_t = I_{c,t} + I_{i,t}$. Unlike Beaudry and Portier (2007), we do not incorporate a multi-product good producer that sells potentially different intermediate goods to the consumption and investment sectors. Hence, our setup does not allow for the property that the marginal cost of producing an intermediate good for one sector decreases when producing a different intermediate good for another sector, generally referred to as a cost complementarity.

2.3 Wage Setting

We assume that the labor market as imperfectly competitive to introduce an exogenously time-varying markup in wages. This assumption is mainly for estimation of our model since this type of shock has been identified as an important driver of fluctuations in hours worked in earlier DSGE model-based econometric studies of the U.S. business cycle (e.g., Smets and Wouters, 2007; Schmitt-Grohé and Uribe, 2012). We follow the approach of Schmitt-Grohé and Uribe (2012) to

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[8] Justiniano et al. (2011), Schmitt-Grohé and Uribe (2012), and Khan and Tsoukalas (2012) distinguish between these two types of investment shocks. Here, we ignore such a distinction and interpret $z_{i,t}$ as capturing these two types of investment shocks together.

our two-sector economy in modeling the labor market. We assume that there are continua of monopolistically competitive type-specific labor unions in each sector, j, selling differentiated labor services to firms.

Firms in each sector demand a composite labor input, given by

$$N^d_{j,t} = \left[\int_0^1 N_{j,t}(s)^{\frac{1}{\mu_{j,t}}} ds \right]^{\mu_{j,t}},$$

where $N_{j,t}(s)$ is the differentiated labor input of type $s \in [0, 1]$. Here, $\mu_{j,t}$ is the exogenous sectoral wage markup shock, whose process is specified below, with a steady-state value $\mu \geq 1$. Solving the labor-cost minimization problem gives us the conditional demand for type-s labor in sector j, which is given by

$$N_{j,t}(s) = \left(\frac{W_{j,t}(s)}{W_{j,t}} \right)^{-\frac{\mu_{j,t}}{\mu_{j,t}-1}} N^d_{j,t}, \tag{8}$$

where $W_{j,t}(s)$ represents the wage posted by the labor union in sector j for type-s workers. Here,

$$W_{j,t} = \left[\int_0^1 W_{j,t}(s)^{\frac{1}{\mu_{j,t}-1}} ds \right]^{\mu_{j,t}-1}$$

is the cost of one unit of the composite labor input in sector j.

The labor unions in each sector choose the wage for type-s worker in sector j, $W_{j,t}(s)$, to maximize their profit, $\left(W_{j,t}(s) - W^*_{j,t} \right) N_{j,t}(s)$, subject to the labor demand schedule (8). The solution of this profit maximization problem is given by

$$W_{j,t}(s) = \mu_{j,t} W^*_{j,t}.$$

This implies that all labor unions in sector j charge the same wage rate, $W_{j,t}$, which in turn implies that firms in sector j will demand identical quantities of each type of labor, $N_{j,t}(s) = N^d_{j,t}$, for all s. The profit of union s in sector j, given by $\frac{\mu_{j,t}-1}{\mu_{j,t}} W_{j,t}(s) N_{j,t}(s)$, is assumed to be given as a lump-sum rebate to households.

Lastly, the total number of hours demanded by the unions in sector j must equal the total labor supply to sector j, $\int_0^1 N_{j,t}(s) ds = N_{j,t}$. Combining this with $N_{j,t}(s) = N^d_{j,t}$ yields $N^d_{j,t} = N_{j,t}$.

3 Inspecting the Mechanism

Before we take our model to the data, we study the key mechanism generating the co-movement analytically, and then numerically investigate our model. To this end, it is useful to focus on the special case in which there is no habit formation in the preferences and the labor market is perfectly competitive (i.e., $h = 0$ and $\mu_{j,t} = 1$).

3.1 Analytical Discussion

We provide an analytical characterization on the exact condition for our model to display the sectoral co-movement in hours worked, assuming no habit formation in the utility function and a perfectly competitive labor market. To organize the discussion, we start with the equilibrium condition for employment in the consumption sector. This is obtained by equating the labor demand in the consumption sector, determined by the marginal product of labor, with the labor supply, determined by the marginal rate of substitution between leisure and consumption:

$$-\frac{\frac{\partial U}{\partial L}\frac{\partial L}{\partial N_c}}{\frac{\partial U}{\partial C}} = \frac{1}{\sigma}\frac{C_t}{\left(1+\left(\frac{1}{\sigma}-1\right)v(N_t)\right)}\varphi N_t^{\frac{1}{\eta}}\left(\frac{N_{c,t}}{N_t}\right)^{\frac{1}{\theta}} = (1-\alpha)\frac{C_t}{N_{c,t}}. \tag{9}$$

In contrast with a conventional equilibrium condition with perfect labor substitutability (i.e., $\theta = \infty$), there is an additional term, $\left(\frac{N_{c,t}}{N_t}\right)^{\frac{1}{\theta}}$, that makes the sectoral co-movement of hours worked possible. To see this, let us define aggregate nominal wage as $W_t = \left[W_{c,t}^{1+\theta} + W_{i,t}^{1+\theta}\right]^{\frac{1}{\theta+1}}$.[9] From this, it is easy to show that $\left(\frac{N_{c,t}}{N_t}\right)^{\frac{1}{\theta}}$ is equal to the relative wage in the consumption sector, $\frac{W_{c,t}}{W_t}$.

Suppose now that aggregate hours worked increase because of an expansion in the investment sector and, thus, the marginal disutility of aggregate hours worked increases. Then, the aggregate nominal wage and the nominal wage in the investment sector increase relative to the nominal wage in the consumption sector. In the case of perfect labor substitutability, labor flows from the consumption sector toward the investment sector until the nominal wage rates are equalized across sectors (i.e., $W_{c,t} = W_{i,t} = W_t$). Hence, hours worked in the consumption sector move countercyclically, and the general co-movement problem that most multi-sector neoclassical models experience arises. In contrast, if hours worked are not perfect substitutes, workers are reluctant to substitute labor

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[9] The expression for W_t is obtained from the following two conditions: $W_t N_t = W_{c,t}N_{c,t} + W_{i,t}N_{i,t}$, and $\frac{W_{c,t}}{W_{i,t}} = \left(\frac{N_{c,t}}{N_{i,t}}\right)^{\frac{1}{\theta}}$.

across sectors. Thus, nominal wage rates will not be equalized across sectors, and the relative wage in the consumption sector will remain low. This low relative wage in the consumption sector makes consumption-good producing firms demand more labor, which mitigates the co-movement problem.

To derive the condition for the sectoral labor co-movement, we log-linearize (9) around a steady state[10] and obtain

$$\left(1+\frac{1}{\theta}\right)\hat{N}_{c,t}=\left(\frac{1}{\theta}+\omega_N-\frac{1}{\eta}\right)\hat{N}_t, \tag{10}$$

where $\omega_N \equiv \frac{(\frac{1}{\sigma}-1)v'(N)N}{(1+(\frac{1}{\sigma}-1)v(N))}$ and $\lim_{\sigma\to 1}\omega_N = 0$. We can show that $\omega_N = (1-\sigma)\left(\frac{N}{N_c}\right)^{\frac{1}{\theta}+1}\frac{W_cN_c}{P_cC} \geq 0$, for $\sigma \leq 1$. Note that (10) holds for all t.

Therefore, our model displays sectoral labor co-movement if the following condition holds:

$$\frac{1}{\theta}+\omega_N-\frac{1}{\eta}>0. \tag{11}$$

Our mechanism does not need to rely on preferences exhibiting no wealth effects on the labor supply or intermediate goods sectors exhibiting cost complementarity.

In contrast, it is easy to see that this condition does not hold when preferences are additively separable and labor is perfectly mobile (i.e., $\omega_N \to 0$ and $\theta \to \infty$), which most neoclassical business cycle models assume. As discussed above, in this case, labor hours in the consumption sector move in the opposite direction of aggregate hours. Again, this is the general co-movement problem that has drawn a lot of attention in the literature. Condition (11) has some interesting implications that deserve further comment.

First, notice that (11) is obtained using a temporal equilibrium condition. In other words, we derive it using the current market clearing condition for labor. Hence, (11) guarantees a sectoral co-movement of labor in response to a change in expectation about future fundamentals, irrespective of whether it is correctly forecasted or whether it is based on false perceptions. Furthermore, since (11) does not depend on the nature of shocks, it is not specific to the case of the anticipated shocks. Therefore, (11) also ensures sectoral co-movement in response to an unanticipated aggregate TFP shock, investment-sector TFP shock, and a preference shock. While we assume a perfectly competitive

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[10] In so doing, we implicitly assume that the growth rate of a permanent aggregate TFP shock, (g), is 1.

labor market (i.e., $\mu_{j,t} = 1$, for all t) in this analytical discussion, it is easy to show that introducing an imperfect competitive labor market does not change the aforementioned characteristics of the sectoral labor condition, (11). In the case of an imperfectly competitive labor market (i.e., $\mu_{j,t} > 1$), the equation analogous to (10) is

$$\left(1 + \frac{1}{\theta}\right)\hat{N}_{c,t} = \left(\frac{1}{\theta} + \tilde{\omega}_N - \frac{1}{\eta}\right)\hat{N}_t - \hat{\mu}_{c,t},$$

where $\tilde{\omega}_N = (1-\sigma)\left(\frac{N}{N_c}\right)^{\frac{1}{\theta}+1} \frac{W_c N_c}{P_c C} \frac{1}{\mu_c}$. Note that $\tilde{\omega}_N$ is slightly different to ω_N owing to the imperfect competition in the labor market. Apparent from this equation, our model predicts the sectoral labor co-movement of labor in response to any kind of the anticipated and unanticipated shocks, with the exception of a contemporaneous consumption-sector wage markup shock, as long as condition (11) is satisfied.

Second, the non-separability in itself is not sufficient to generate the sectoral employment co-movement with perfect labor mobility. The reason is that the condition for the model to generate the co-movement when there is perfect labor mobility violates the normality of consumption and leisure. When building models with non-separable preferences to analyze business cycle fluctuations, Bilbiie (2009) emphasizes that one needs to check the conditions for overall concavity of the momentary utility function and the normality of consumption and leisure. It is straightforward to show that if $\sigma \leq 1$, the overall concavity of $U(\cdot)$ is guaranteed (i.e., $U_{CC} \leq 0$, $U_{LL} \leq 0$ and $U_{CC}U_{LL} - (U_{CL})^2 \geq 0$). To ensure that consumption and leisure are normal goods, the constant-consumption labor supply needs to be upward sloping.[11] In other words, the following restriction to $U(\cdot)$ needs to hold:

$$-\left(N\frac{U_{LL}}{U_L} - N\frac{U_{CL}}{U_C}\right) = -\omega_N + \frac{1}{\eta} > 0. \tag{12}$$

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[11] More precisely, Bilbiie (2009) shows that both consumption and leisure are normal goods if

$$\frac{(U_{CL}/U_L) - (U_{CC}/U_C)}{(U_{LL}/U_L) - (U_{CL}/U_C)} < 0.$$

It is straightforward to show that the numerator is always positive in our momentary utility function. Hence, to ensure the normality of consumption and leisure, the denominator, the constant-consumption labor supply, should be positive.

However, when $\theta \to \infty$, (11) reduces to

$$-\omega_N + \frac{1}{\eta} < 0.$$

This condition contradicts the normality condition of consumption and leisure, given in (12). Thus, non-separability *per se* cannot guarantee sectoral co-movement.

Third, even though non-separability alone cannot guarantee the co-movement, it expands the threshold level of the intratemporal elasticity of labor supply, θ, needed to generate sectoral employment co-movement.

Fourth, when the intertemporal elasticity of aggregate labor supply (the Frisch elasticity) is equal to the intratemporal elasticity of labor supply (i.e., $\eta = \theta$), $v(N_t)$ takes the form $v(N_t) = N_{c,t}^{\frac{\theta+1}{\theta}} + N_{i,t}^{\frac{\theta+1}{\theta}}$. This effectively isolates each sector's labor supply pool, which insulates sectors from rising costs in other areas of the economy. In this case, it is essential to have the non-separability in consumption and labor supply for the model to generate the co-movement. The economic intuition is simple: The non-separability in consumption and leisure implies that consumption and aggregate labor are complements. Therefore, it is likely that hours worked in the consumption sector move together with aggregate hours worked.

Finally, note that while (11) would produce the sectoral employment co-movement, it is silent about whether it would generate economic fluctuations observed in business cycle data in response to anticipated shocks. If aggregate labor decreases in response to a positive anticipated TFP shock because of wealth effects, for example, then (11) would imply a drop in employment in both the consumption and investment sectors. In the next subsection, we demonstrate numerically that the size of the investment adjustment costs determine whether aggregate labor and investment increase on receipt of a positive news shock, so that (11) generates an increase in labor in both sectors.

3.2 Anatomy of the Model

We numerically illustrate responses of our model to different types of shocks to obtain more insight into the underlying mechanism. In particular, we show how (i) frictions in labor mobility, (ii) non-separable preferences, (iii) investment adjustment costs, and (iv) variable capital utilization play a role in generating sectoral co-movement. Even though we have introduced more shocks in our model for estimation purposes, we focus on the dynamic responses of macroeconomic variables to aggregate TFP and investment-specific technology shocks, which are also analyzed in Jaimovich and Rebelo (2009).

The parameter values used for the numerical simulations are as follows. To be comparable, we use the same values for the following parameters as Jaimovich and Rebelo (2009). We set the discount factor (β) to 0.985 and the capital share (α) to 0.36. We assume that the steady-state depreciation rate is the same across sectors, and set it to 0.025. We choose the second derivative of the investment-adjustment costs function evaluated at the steady state, ϕ'', to equal 1.3. The elasticity of $\delta'(\cdot)$, evaluated in the steady state ($\kappa \equiv \delta''(u_j)u_j/\delta'(u_j)$, where u_j is the level of utilization in sector $j = c, i$ in the steady state) is assumed to be the same across sectors and is set to 0.15.

Following Basu and Kimball (2002), we set the intertemporal elasticity of substitution in consumption (σ) to 0.5, which implies that consumption and labor are complements in the utility function. The parameter θ, which determines the elasticity of substitution between hours worked in different sectors, is set to one, based on the empirical work by Horvath (2000).[12] We set the Frisch elasticity of aggregate labor supply (η) to 1.[13] The consumption share in the steady state ($\frac{C}{C+pI}$) is set to 0.78, consistent with the U.S. data.

Figure 1 presents impulse responses of model variables to the two-period-ahead news shocks to aggregate TFP and investment-sector TFP. The timing of the news shock we consider is as follows. At time zero, the economy is in the steady state. At time one, a news shock arrives. Agents learn that there will be a one-percent temporary increase in aggregate TFP, A_t, or investment-sector TFP, $z_{i,t}$, two periods later (at time three), with a persistent parameter equal to 0.95. Note that the dynamic path of the economy after the anticipated shock materializes corresponds to the one that the economy would follow in response to a contemporaneous shock. Therefore, Figure 1 allows us to show the ability of our model to generate the sectoral co-movement to both anticipated and unanticipated shocks. The thick lines with circles represent dynamic responses of the variables to the anticipated aggregate TFP shocks, and the thin lines denote those to the anticipated investment-specific technology shocks.

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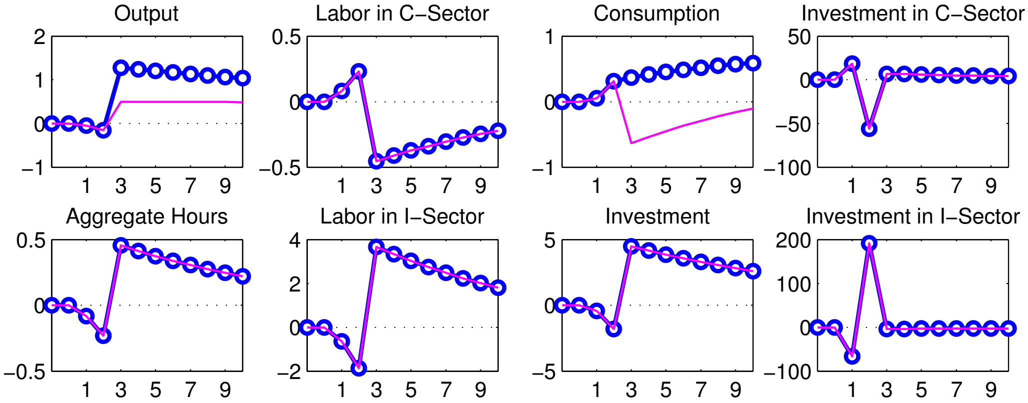
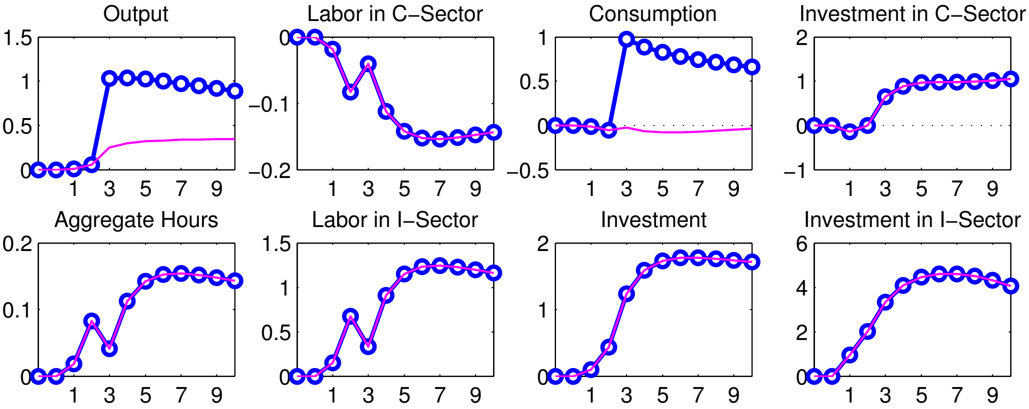
[12] Horvath (2000) uses the fact that relative labor hour percentage changes in one sector are related to relative labor's share percentage changes in that sector by the elasticity $\theta/(\theta+1)$. He estimates this elasticity from an ordinary least square regression of the change in the relative labor supply on the change in the relative labor share using sectoral U.S. data, and finds $\theta = 0.9996$, with a standard error of 0.0027.

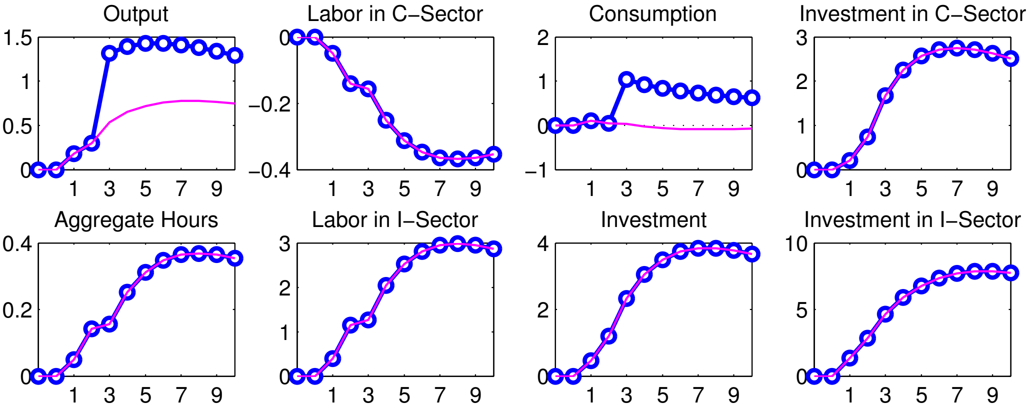
[13] This value is a lower bound on the Frisch elasticity used in existing literature. Jaimovich and Rebelo (2009) assume a relatively elastic labor supply. They set η to 2.5. As (11) shows, setting η to 2.5 would be favorable to our results because it would expand the range of θ, consistent with sectoral labor co-movement.



(a) Case 1: Barebones Two-Sector RBC Model



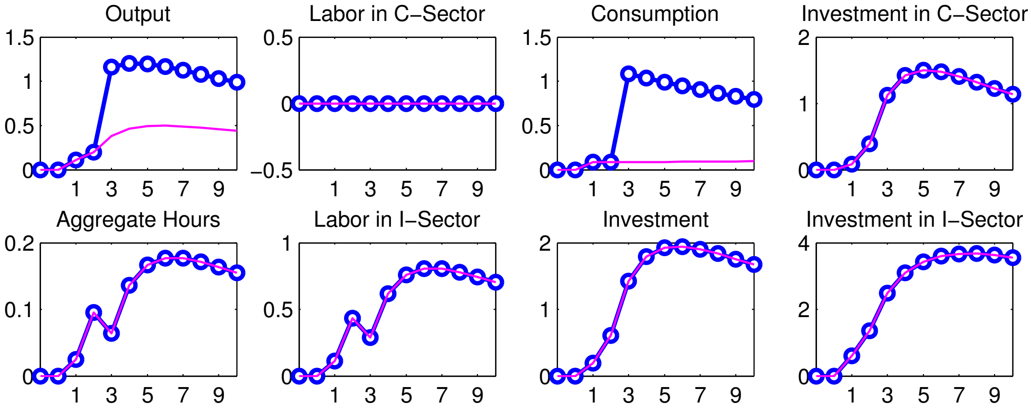
(b) Case 2: Only with Investment Adjustment Costs



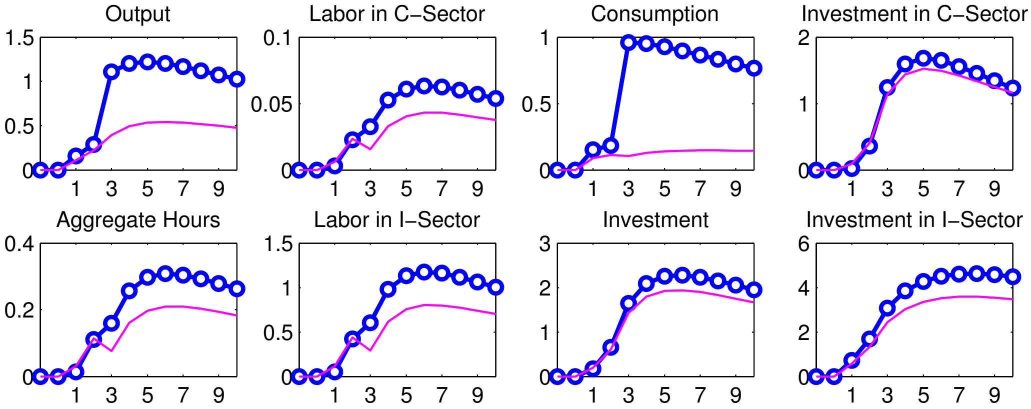
(c) Case 3: Investment Adjustment Costs + Capital Utilization

Figure 1: IRFs to the Two-period-ahead News Shocks to Aggregate TFP and Investment-sector TFP

Note: Horizontal axes take model periods and vertical axes measure percentage deviations from the steady-state values. Thick lines with circles represent impulse responses to the two-period-ahead news shock to aggregate TFP. Thin lines show responses to the two-period-ahead news shock to investment-sector TFP.



(d) Case 4: Investment Adjustment Costs + Capital Utilization + Imperfect Mobility



(e) Case 5: Full Specification (with Non-separability)

Figure 1: IRFs to the Two-period-ahead News Shocks to Aggregate TFP and Investment-sector TFP (Cont'd.)

We start with a two-sector bare bones RBC model, in which all elements are turned off, and introduce each element one by one. Figure 1a presents the responses of the economy to positive news in the plain vanilla two-sector neoclassical setup. As we saw in the analytical discussion, the sectoral labor co-movement condition is not satisfied in this setup, and thus, we expect to see negative sectoral co-movement. When the positive news shocks hit the economy, consumption increases, but aggregate investment and labor decrease. The good news about future productivity induces a strong wealth effect, increasing consumption and leisure at the expense of aggregate investment. To meet the increase in the demand for consumption goods, productive resources must be shifted away from producing investment goods and into producing consumption goods. As a result, $N_{c,t}$ in period one and two and $I_{c,t}$ in period one increase, but $N_{i,t}$ in period one and two and $I_{i,t}$ in period one decrease. Until the positive news shocks materialize at time three, aggregate output barely moves, since increases in consumption are offset by drops in investment. The dynamics of this economy after the news shocks materialize is identical to that of contemporaneous shocks. Since the sectoral labor co-movement condition does not hold, the negative sectoral co-movement of labor persists. As Christiano and Fitzgerald (1998) show, this is the classical sectoral co-movement problem associated with aggregate, contemporanesous TFP shocks that most of neoclassical business cycles models suffer from. For investment-specific technology shocks, the negative sectoral co-movement of hours worked is translated into the negative sectoral output co-movement after the positive anticipated investment-specific technology shocks materialize in period three. This negative co-movement problem between consumption and investment in response to contemporaneous investment-specific technology shocks has been emphasized by Greenwood et al. (2000). Since there are no costs to adjusting investment, sectoral investments exhibit an extremely large response to the shocks.

We then introduce investment adjustment costs to the two-sector standard RBC model, leaving other features of the model turned off. Figure 1b displays the responses of the economy to the positive news shock. While consumption declines following the positive news shock, the adjustment costs to investment in each sector generate a positive response in aggregate hours worked and investment. As Jaimovich and Rebelo (2009) clearly explain, adjustment costs to investment make it optimal to smooth investment over time and, thus, provide a reduced-form representation of the economic mechanism that would operate immediately in response to the positive news shock. With high enough adjustment costs, the intertemporal substitution effect might dominate the wealth effect, so that aggregate hours worked and investment might increase in response to the positive news shock. In fact, this is exactly what is happening in Figure 1b and they respond positively to the news shocks in the first two periods. However, the sectoral co-movement problem still exists. That is, hours worked and investment in each sector move in the opposite direction. However, adjustment costs to investment in each sector seem to alleviate the problem of sectoral co-movement in investment. Even though $I_{c,t}$ and $I_{i,t}$ do not move together in response to the news shocks in the initial period, the difference between these two is substantially reduced compared to the standard two-sector RBC model. As before, the negative sectoral co-movement of labor still persists after news shocks materialize.

In addition to the investment adjustment costs, we now allow the rate of capital utilization in each sector to vary, maintaining the assumption of perfect labor mobility and separable preferences. Figure 1c depicts the responses of the economy with the investment adjustment costs and the variable capital utilization. The most significant change in the reaction of the economy is that the variable capital utilization combined with the investment adjustment costs generates the co-movement in sectoral investment. Both $I_{c,t}$ and $I_{i,t}$ increase in response to the positive news shocks. However, the investment adjustment costs and the variable capital utilization do not solve the problem of co-movement in hours worked across the consumption and investment sectors. There still exists the co-movement problem, that is that $N_{c,t}$ and $N_{i,t}$ move in the opposite direction. Furthermore, consumption still stagnates until the positive news materializes at time three, and aggregate investment increases in periods one and two. Hence, the model still fails to generate the strong co-movement in output across two sectors.

Along with variable capital utilization and investment adjustment costs, we now introduce friction in labor allocation, maintaining the separable preferences. Figure 1d portrays the responses of the economy with the separable preferences. It clearly shows that frictions in labor mobility significantly alleviate the problem of co-movement in hours worked across sectors. Here, $N_{c,t}$ has decreased before the friction in labor mobility is introduced, but now it does not respond at all to the news shocks. This invariant response of hours worked in the consumption sector is already anticipated by (11). Given our parameterization that $\theta = \eta = 1$ and $\sigma = 1$, (11) implies that $N_{c,t}$ does not change in response to the news shock. Note that (11) also applies to the contemporaneous shocks, $N_{c,t}$ also does not move after news shocks materialize.

Finally, Figure 1e presents the response of the economy to the news shocks with the full specification, allowing for non-separable preferences between consumption and labor. There is an expansion in periods one and two in response to both positive news about aggregate TFP (A_t) and sectoral TFP in the investment sector ($z_{i,t}$). Output, employment, and investment in the consumption and investment sectors increase together in periods one and two, even though the positive shock only materializes in period three. Therefore, our model successfully produces the business cycle co-movement in response to news about future values of A_t and $z_{i,t}$. Furthermore, in our model, output, employment, and investment in the consumption and investment sectors continue to move together, even after the shock materializes (in period three). This implies that our model can also generate the sectoral co-movement in those variables in response to contemporaneous aggregate

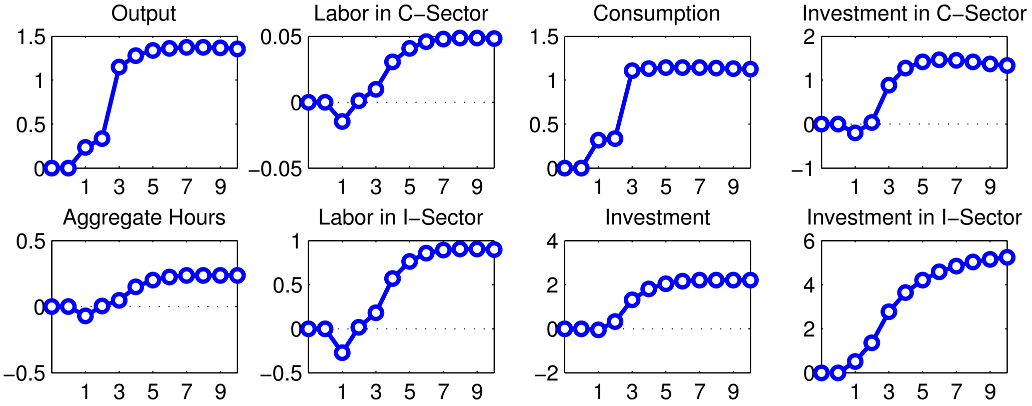


Figure 2: IRFs to the Two-period-ahead News Shocks to Aggregate TFP with High Persistence

Note: Horizontal axes take model periods and vertical axes measure percentage deviations from the steady-state values. Thick lines with a circle represent impulse responses to the one-period-ahead news shock to aggregate TFP. Thin lines show responses to the two-period-ahead news shock to investment-sector TFP. Here, the persistence parameter of aggregate TFP process is set to 0.99.

TFP shocks and sectoral shocks to TFP in the investment sector. As previously discussed, the non-separable preferences imply the complementarity between consumption and aggregate hours worked. When hours worked increase, agents also wish to increase their consumption, implying that labor in the consumption sector also increases. Thus, theoretically, non-separable preferences can play an important role in sectoral co-movement.

As mentioned in the previous analytical discussion, our sectoral labor co-movement condition, (11), does not *per se* guarantee the sectoral labor co-movement of the kind expected in response to anticipated TFP shocks. For example, when the size of investment adjustment costs is small relative to the persistence of anticipated aggregate TFP shocks, the wealth effects might still dominate the intertemporal substitution effects. As a result, even when the sectoral labor co-movement condition is satisfied, sectoral labor may respond negatively together to the positive anticipated TFP shocks. This is the situation depicted in Figure 2. Those impulse response functions are drawn with the same parameter values as in Figure 1, but the persistence parameter of aggregate TFP shocks is set to 0.99. Sectoral labor decreases together on receipt of the anticipated positive aggregate TFP shock. In this case, the quantitative importance of anticipated shocks in accounting for the business cycle will be significantly undermined. This provides our motivation to estimate our model to assess the quantitative importance of anticipated disturbances in explaining the business cycle.

4 Estimation

We take our model to the data using Bayesian methods and estimate model parameters. Of particular importance among the estimated parameters are those governing the degree of inter-sectoral labor mobility and non-separability, the elasticity of marginal cost of capital utilization, the size of investment adjustment costs, and those defining the stochastic processes of anticipated and unanticipated innovations.

4.1 Specification

We now formally describe the exogenous structural disturbances that drive the business cycles in our model. Hence, our model of the business cycle is composed of six structural shocks: the stationary TFP shock (a_t), the non-stationary TFP shock (A_t), the stationary investment-specific technology shock ($z_{i,t}$), the two sectoral wage markup shocks ($\mu_{c,t}$ and $\mu_{i,t}$), and the preference shock (b_t).

Following Fujiwara et al. (2011) and Schmitt-Grohé and Uribe (2008), we model the information structure on the contemporaneous and anticipated shocks in the following way. We assume that all exogenous shocks, $f_t = a_t, g_t (\equiv A_t/A_{t-1}), z_{i,t}, \mu_{c,t}, \mu_{i,t}$, except for b_t, evolve over time according to the following law of motion:

$$\log(f_t/f) = \rho_f \log(f_{t-1}/f) + v^0_{f,t} + v^1_{f,t-1} + v^2_{f,t-2} + v^3_{f,t-3} + v^4_{f,t-4}, \tag{13}$$

where $v^h_{f,t}$, for $h = 0, 1, \cdots, 4$, and $f = \{a, g, z_i, \mu_c, \mu_i\}$ is assumed to be an i.i.d. normal disturbance a with mean of zero and a standard deviation of σ^h_f. Then, $v^0_{f,t}$ are the unanticipated contemporaneous shocks and $v^h_{f,t}$, for $h = 1, \cdots, 4$ represent the h-period-ahead news shock anticipated at time t. Here, we assume that agents receive the news up to four periods ahead. This is consistent with Schmitt-Grohé and Uribe (2012), who find that four-quarter-ahead anticipated shocks are the most important driver of business cycles in the estimated one-sector version of Jaimovich and Rebelo (2009). For preference shocks, we do not introduce anticipated shocks and assume an AR(1) process with contemporaneous shocks, namely, $\log(b_t/b) = \rho_b \log(b_{t-1}/b) + v^0_{b,t}$, with $v^0_{b,t} \sim \text{i.i.d.}\, N(0, (\sigma^0_b)^2)$.

In our model, consumption, aggregate investment, sectoral investment, sectoral capital, and sectoral real wages fluctuate around a stochastic balanced growth path, since the exogenous forcing process, A_t, displays a stochastic trend. We perform a stationarity-inducing transformation of the endogenous variables by dividing them by their trend component. We then compute the non-stochastic steady state of the transformed model and log-linearize it around this steady state. Finally, we solve the resulting linear system of rational expectation equations to obtain its state-space representation. This representation forms the basis for the estimation procedure, which is discussed in the next subsection.

In order to incorporate sectoral characteristics into the estimation, we utilize sector-specific data, rather than aggregate data. Here, we will use the following five observables: the real per capita consumption growth (dC_t), the growth rate of hours worked in the consumption sector ($dh_{c,t}$), the real per capita investment growth (dI_t), the growth rate of hours worked in consumption sector ($dh_{i,t}$), and the growth rate of aggregate real wage (dw_t).[14] Sectoral labor data are constructed from the Current Employment Statistics of the BLS. The Appendix describes the data construction in detail. The sample period starts from 1964:II and ends at 2013:IV. All variables are de-meaned before the estimation.

More specifically, the measurement equations in a state-space representation relate observable variables and the model counterpart in the following way:

$$dC_t = \hat{C}_t - \hat{C}_{t-1}, \tag{14}$$

$$dh_{c,t} = \hat{N}_{c,t} - \hat{N}_{c,t-1}, \tag{15}$$

$$dI_t = \hat{I}_t - \hat{I}_{t-1}, \tag{16}$$

$$dh_{i,t} = \hat{N}_{i,t} - \hat{N}_{i,t-1}, \tag{17}$$

$$dw_t = s_c(\hat{w}_{c,t} - \hat{w}_{c,t-1}) + (1 - s_c)(\hat{w}_{i,t} - \hat{w}_{i,t-1}), \tag{18}$$

where s_c is the share of the consumption sector.

We fix some of the structural parameters. We set the discount factor (β) to 0.985, and the capital share (α) to 0.36. We assume that the steady-state depreciation rate at the steady state is 0.025, which is the same in both sectors. These values are adapted from the values used in Jaimovich and Rebelo (2009), and are also used for previous simulations. The steady-state consumption share is set to

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[14] We assume that the consumption sector consists of firms producing non-durable goods and services and that the investment sector produces durable goods and goods used for non-residential and residential investment.

0.78, which is the average over the sample period. The steady-state wage markup in each sector is assume to be the same, and fixed at 1.15.

The left side of Table 1 summarizes the prior distributions we employ. We use a Gamma distribution for $1/\eta$ with mean 1 and standard deviation of 0.25. We assume a Gamma distribution for $1/\theta$ with mean 1 and standard deviation of 0.5. This choice of the prior mean is consistent with the estimate of Horvath (2000). We use a Beta distribution for σ with mean 0.5 and standard deviation of 0.2. This prior mean is much more conservative than the posterior mean obtained in the two-sector model of Kim and Katayama (2013) and the non-separability parameter found in Guerron-Quintana (2008). Based on the prior distributions of $1/\eta$, $1/\theta$, and σ, in the absence of internal habit formation, the implied prior probability of satisfying the normality condition is about 89% and that of satisfying the sectoral co-movement condition is roughly 73%.

Prior distributions of h, $\kappa_j \equiv \frac{\delta''(u_j)u_j}{\delta'(u_j)}$ for $j = c, i$, and ϕ'' are adopted from Schmitt-Grohé and Uribe (2010). The prior distribution of h is a Beta distribution with mean 0.5 and standard deviation 0.2. We assume that κ_j is distributed as an Inverse Gamma distribution with mean 1 and standard deviation of 1, and that ϕ'' follows a Gamma distribution with mean 4 and standard deviation of 1. We use a Gamma distribution with mean 1.65 and standard deviation of 1 for a prior distribution of $g \times 400$. We use a Beta distribution as a prior for the persistence parameters. The prior means for ρ_a and ρ_b are assumed to be 0.7, and those for ρ_{z_i}, ρ_{μ_c}, and ρ_{μ_i} are set to 0.5. The prior mean of ρ_g is assumed to be 0.2. All standard deviations for ρ's are set to 0.2.

For prior distributions of the standard deviations of exogenous shocks in the model, we use Gamma distributions.[15] As discussed in Schmitt-Grohé and Uribe (2012), this choice imposes a conservative stance on the importance of anticipated shocks. This is because, unlike the typical Inverse Gamma distributions, the Gamma distribution allows a positive density at zero. That is, our prior incorporates the possibility that the news shocks are not operating. Furthermore, we impose the 75-percent rule on the prior means of the standard deviations of the anticipated shocks, as in Schmitt-Grohé and Uribe (2012). Our priors restrict the variance of the unanticipated shock accounts to 75 percent of the total variance of the shock, and we assume that the four types of anticipated shocks are equally important to account for the remaining portion of the total variance. Our choice of priors are more conservative than those used in Fujiwara et al. (2011), which put equal weights

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[15] The only exception is that of the discount factor shock, which uses the typical inverse Gamma distribution.

Table 1: Prior and Posterior Distributions for the Benchmark Model

	Prior Distribution			Posterior Distribution		
Parameter	Distribution	Mean	Std. Dev.	Mean	5 %	95 %
$1/\eta$	Gamma	1	0.25	0.8372	0.6386	1.0366
$1/\theta$	Gamma	1	0.5	3.3835	2.8139	3.9424
σ	Beta	0.5	0.2	0.7389	0.5607	0.9376
h	Beta	0.5	0.2	0.3216	0.2375	0.4066
κ_c	Inv. Gamma	1	1	4.8452	3.7056	5.9234
κ_i	Inv. Gamma	1	1	1.0719	0.3888	1.7699
$\phi''(1)$	Gamma	4	1	1.3198	1.0344	1.6030
$\bar{g} \times 400$	Gamma	1.65	1	0.6722	0.0954	1.2403
ρ_a	Beta	0.7	0.2	0.9682	0.9352	0.9999
ρ_g	Beta	0.2	0.2	0.4687	0.1037	0.7784
ρ_i	Beta	0.5	0.2	0.9458	0.9206	0.9709
ρ_b	Beta	0.7	0.2	0.9322	0.9075	0.9547
ρ_{μ_c}	Beta	0.5	0.2	0.9854	0.9759	0.9958
ρ_{μ_i}	Beta	0.5	0.2	0.9424	0.9113	0.9733
σ_a^0	Gamma	0.015	0.015	0.0030	0.0024	0.0037
σ_a^1	Gamma	0.0043	0.0043	0.0007	0.0000	0.0015
σ_a^2	Gamma	0.0043	0.0043	0.0006	0.0000	0.0013
σ_a^3	Gamma	0.0043	0.0043	0.0007	0.0000	0.0014
σ_a^4	Gamma	0.0043	0.0043	0.0007	0.0000	0.0014
σ_g^0	Gamma	0.015	0.015	0.0011	0.0000	0.0021
σ_g^1	Gamma	0.0043	0.0043	0.0009	0.0000	0.0019
σ_g^2	Gamma	0.0043	0.0043	0.0012	0.0000	0.0024
σ_g^3	Gamma	0.0043	0.0043	0.0012	0.0000	0.0024
σ_g^4	Gamma	0.0043	0.0043	0.0013	0.0000	0.0024
σ_i^0	Gamma	0.015	0.015	0.0146	0.0132	0.0162
σ_i^1	Gamma	0.0043	0.0043	0.0013	0.0000	0.0028
σ_i^2	Gamma	0.0043	0.0043	0.0016	0.0000	0.0033
σ_i^3	Gamma	0.0043	0.0043	0.0015	0.0000	0.0032
σ_i^4	Gamma	0.0043	0.0043	0.0016	0.0000	0.0035
σ_b	Inv. Gamma	0.0173	0.0173	0.0635	0.0531	0.0734
$\sigma_{\mu_c}^0$	Gamma	0.015	0.015	0.0025	0.0000	0.0050
$\sigma_{\mu_c}^1$	Gamma	0.0043	0.0043	0.0023	0.0000	0.0049
$\sigma_{\mu_c}^2$	Gamma	0.0043	0.0043	0.0030	0.0000	0.0060
$\sigma_{\mu_c}^3$	Gamma	0.0043	0.0043	0.0027	0.0000	0.0057
$\sigma_{\mu_c}^4$	Gamma	0.0043	0.0043	0.0030	0.0000	0.0064
$\sigma_{\mu_i}^0$	Gamma	0.015	0.015	0.0068	0.0000	0.0144
$\sigma_{\mu_i}^1$	Gamma	0.0043	0.0043	0.0296	0.0000	0.0576
$\sigma_{\mu_i}^2$	Gamma	0.0043	0.0043	0.0255	0.0000	0.0586
$\sigma_{\mu_i}^3$	Gamma	0.0043	0.0043	0.0038	0.0000	0.0087
$\sigma_{\mu_i}^4$	Gamma	0.0043	0.0043	0.0126	0.0000	0.0381
Log Marginal Density		3361.21				

Note: The posterior distributions are obtained using the random walk Metropolis–Hastings algorithm with 300,000 draws (the first 10% of draws are discarded as a burn-in period). We use the modified Harmonic mean estimator of Geweke (1999) to obtain the log marginal density.

on anticipated and contemporaneous components in terms of the role of the news shocks.

4.2 Posterior Estimates

We find the posterior mode numerically and use it as a starting point of the random-walk Metropolis–Hastings algorithm. The subsequent results are all based on 300,000 Metropolis–Hastings draws.[16] We adjust the scaling factor in the Metropolis–Hastings algorithm such that the acceptance rate becomes about 25%.

The right side of Table 1 presents the posterior distributions of the parameters in our model. The posterior mean of $1/\theta$ is estimated to be 3.38 and, thus, the implied estimates of θ are much smaller than the one estimated by Horvath (2000). This suggests a substantial degree of inter-sectoral labor immobility in the labor market. The posterior mean of σ is estimated to be 0.74, so that the degree of non-separability in the utility function is moderate. Our estimate of the degree of the non-separability is smaller than that reported in Kim and Katayama (2013) and closer to the estimates of Smets and Wouters (2007) and Fujiwara et al. (2011). The estimate of the posterior mean of $1/\eta$ is 0.84, implying that the Frisch elasticity of labor supply is about 1.19. Therefore, our estimates of θ, σ, and η satisfy the sectoral labor co-movement condition (11) and a significant degree of inter-sectoral labor immobility plays a crucial role in attaining the condition. Note that the sectoral labor co-movement condition (11) is derived in the absence of habit formation, and also that it is not sufficient to ensure the sectoral co-movement of hours worked in response to the consumption-sector wage markup shock. It turns out that our estimated two-sector neoclassical DSGE model with habit formation does display the sectoral co-movement of hours worked, as described below.

Turning to the estimates of the remaining parameters, the estimated degree of internal habit formation, h, is 0.32. This estimate is much lower than found by earlier DSGE-based Bayesian econometric studies. However, this is consistent with the micro-evidence reported by Dynan (2000) and Ravina (2007), and the impulse-response-matching estimate in Guerron-Quintana (2008). The investment adjustment cost parameter, ϕ'', is also estimated to be significantly smaller than those in DSGE-based macroeconometric literature. In particular, while Schmitt-Grohé and Uribe (2012) estimate ϕ'' to be equal to 9.11 in their one-sector version of the Jaimovich and Rebelo (2009)

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[16] The first 30,000 draws are discarded as a burn-in period.

neoclassical DSGE model, our estimate of ϕ'' is 1.32.

The low estimates of h and ϕ'' might be attributable to the sectoral labor co-movement condition, (11), which makes hours growth in both sectors mimic each other. The persistent pattern of investment-sector hours growth due to the presence of investment adjustment costs is transmitted to the hours growth in the consumption sector through the sectoral labor co-movement condition. This in turn makes it possible for our model to match the observed positive autocorrelation of consumption growth with a smaller degree of habit formation. The same logic can be applied to explain the low estimate of ϕ''. The presence of habit formation leads to a persistent process of consumption-sector hours growth, resulting in a similar persistent process of investment-sector hours growth through the sectoral labor co-movement condition. Again, this reduces the magnitude of the investment adjustment costs required to match the observed positive autocorrelation of consumption growth in the data. In Section 5.3, we revisit this aspect and show that even with these low estimates of h and ϕ'', our model maintains the ability to match the observed autocorrelations of consumption and investment growth.

Regarding the elasticity of marginal cost of capital utilization, the estimates of κ_c and κ_i display a substantial sectoral difference. Varying utilization in the consumption sector is much more costly than in the investment sector. Our estimates of κ_c and κ_i seem to capture the property of the data that investment is much more volatile than consumption. The low estimate of κ_i makes the level of utilization highly responsive to shocks, resulting in a powerful amplification of the shocks in the investment sector. In contrast, the consumption sector does not need as large an amplification mechanism, resulting in a large estimate of κ_c.

Finally, the posterior 90% probability intervals of the standard deviations of anticipated shocks typically contain zero. The only exception is the four-period-ahead investment-sector wage markup shock. This might suggest a limited role of anticipated shocks in explaining business cycle fluctuations.

4.3 Variance Decomposition

We investigate the quantitative importance of our estimated shocks as sources of business-cycle fluctuations. Table 2 displays the contribution of all shocks to the unconditional variance of the

Table 2: Variance Decomposition (Percentage)

	Consumption		Investment		Aggregate
	Output	Hours	Output	Hours	Wage
Stationary Aggregate TFP	32.37	7.97	2.91	0.49	26.36
Unanticipated	22.93	2.79	1.95	0.21	15.47
News	9.44	5.18	0.95	0.28	10.90
Non-stationary Aggregate TFP	24.89	4.58	1.29	0.72	3.24
Unanticipated	18.49	3.71	0.96	0.43	2.20
News	6.40	0.87	0.34	0.29	1.04
Investment TFP	2.70	2.92	61.52	5.25	7.60
Unanticipated	2.51	2.67	58.53	4.69	6.74
News	0.18	0.24	2.99	0.56	0.86
Consumption Wage Markup	17.07	32.38	0.33	0.77	0.46
Unanticipated	0.02	0.03	0.00	0.00	0.00
News	17.05	32.35	0.33	0.77	0.46
Investment Wage Markup	20.64	33.85	20.91	54.44	37.75
Unanticipated	1.05	1.62	1.06	2.49	1.02
News	19.59	32.23	19.85	51.95	36.73
Preference	2.33	18.30	13.04	38.33	24.58

Note: Numbers reported here are the relative contribution of corresponding shocks to the five observables used in the estimation. For example, Stationary Aggregate TFP reports the relative contribution of both unanticipated and anticipated shocks to the aggregate TFP. The row labeled "Unanticipated" under Stationary Aggregate TFP represents contributions of unanticipated (contemporaneous) stationary aggregate TFP shocks. Similarly, the row labeled "News" under Stationary Aggregate TFP is the total contribution of four different types of news shocks to the stationary aggregate TFP.

observables. We group different horizons of anticipated shocks together.

We start by quantifying the contribution of the different sources of uncertainty to explaining business-cycle fluctuations without differentiating between anticipated and unanticipated shocks. The majority of the variance of consumption is explained by aggregate TFP shocks, including stationary and non-stationary shocks, followed by the two sectoral wage markup shocks. The investment-specific technology shock is the most important in accounting for variations in investment, followed by the investment-sector wage markup shock. Sectoral wage markup shocks account for a large fraction of the movements in sectoral hours worked. Overall, these findings are broadly in line with variance decomposition reported in Justiniano et al. (2010), who estimate a one-sector New Keynesian DSGE model without news shocks.

Turning to the quantitative importance of news shocks, our two-sector estimated model displays both similarities and differences when compared to earlier DSGE-based macroeconometric studies of news shocks. Several results stand out. First, we find a dominant role of the news component of sectoral wage markup shocks in explaining business cycle fluctuations. For example, the combined two sectoral wage markup news shocks account for about 64.58% and 52.72% of the variation in hours worked in the consumption and investment sectors, respectively. In contrast, unanticipated wage markup shocks explain only about 1.65% and 2.49% of the variance of hours worked in the consumption and investment sectors. It is the news shock components that matter for accounting for business cycle fluctuations. This is consistent with findings in Khan and Tsoukalas (2012) and Schmitt-Grohé and Uribe (2012). Quantitatively speaking, the news components of the wage markup shocks appear to be more important than earlier studies.

Second, the contribution of aggregate TFP news shocks remains relatively small. This is consistent with the findings in earlier studies. For example, the anticipated stationary and non-stationary aggregate TFP shocks, combined together, account for about 16% of the variance of consumption growth. This is the value reported in Fujiwara et al. (2011), but is quantitatively larger than those reported by Khan and Tsoukalas (2012) and Schmitt-Grohé and Uribe (2012).

Third, in our model, the majority of the variation in investment is accounted for by unanticipated investment-specific technology shocks (with a variance share of 58.53%). The news component of the investment-specific technology shocks plays virtually no role in explaining business cycles. This result is similar to that of Khan and Tsoukalas (2012). In contrast, Schmitt-Grohé and Uribe (2012) report that about 20% of the variance of investment is due to the anticipated component of the investment-specific technology shocks.

Finally, the differences in the importance of the anticipated shocks relative to Schmitt-Grohé and Uribe (2012) might be explained by the lower estimates of habit formation and investment adjustment costs in our model. As discussed in Section 3.2, a lower value of the investment adjustment cost parameter dampens the response of investment on receipt of an anticipated investment-specific technology shock. As a result, our model predicts that the news component of investment-specific technology shocks has little influence on the variance of investment. In Schmitt-Grohé and Uribe (2012), a sizable fraction of the variation in investment is attributable to the anticipated investment-specific technology shocks because of the larger estimate of investment adjustment costs. In contrast, a decline in the estimated degree of habit persistence results in a more pronounced response of consumption to an anticipated TFP shock. Hence, anticipated TFP shocks play a larger role in explaining variations in consumption than they do in Schmitt-Grohé and Uribe (2012).

5 A Comparison with the Jaimovich and Rebelo (2009) Model

In this section, we evaluate the empirical performance of our model relative to that of a two-sector version of the Jaimovich and Rebelo (2009) model. Jaimovich and Rebelo (2009) introduce preferences featuring a parameter that governs the wealth elasticity of labor supply, and show that wealth effects on the labor supply play a crucial role in determining sectoral labor co-movement. We estimate a two-sector version of the Jaimovich and Rebelo (2009) model, and investigate whether our proposed mechanism of generating sectoral labor co-movement (i.e., imperfect inter-sectoral mobility) is favored by the data, as against using the Jaimovich–Rebelo preferences.[17]

5.1 Specification

The novel feature in Jaimovich and Rebelo (2009) is to introduce a particular class of preferences that has a parameter governing the size of the wealth effect on labor supply. Following Schmitt-Grohé and Uribe (2012), we modify the Jaimovich–Rebelo preferences to allow for internal habit formation in consumption. In particular, the habit-augmented Jaimovich–Rebelo utility function is given by

$$U(C_t - hC_{t-1}, N_t) = \log\left(C_t - hC_{t-1} - \psi N_t^{\zeta} X_t\right), \tag{19}$$

where X_t evolves according to

$$X_t = (C_t - hC_{t-1})^{\gamma} X_{t-1}^{1-\gamma}. \tag{20}$$

The parameter $\zeta > 1$ determines the Frisch elasticity of labor supply in the special case in which $\gamma = h = 0$. The parameter $\gamma \in [0, 1]$ controls the size of the wealth effect on the labor supply. When $\gamma = 0$, the period utility function corresponds to the preference specification proposed by Greenwood et al. (1988), in the absence of habit formation. This special case induces a zero wealth effect on the labor supply, referred to as the GHH preferences. As γ increases, the wealth elasticity of labor supply increases. When $\gamma = 1$, the period utility function reduces to the standard King–Plosser–Rebelo preferences. Finally, as in Jaimovich and Rebelo (2009), labor is perfectly mobile between two sectors (i.e., $N_t = N_{c,t} + N_{i,t}$). The rest of the model structure is identical to that presented in Section 2.

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[17] Schmitt-Grohé and Uribe (2012) estimate the one-sector version of the Jaimovich and Rebelo (2009) model.

We assume that the same exogenous structural disturbances drive the business cycles, as before. We also perform a stationary-inducing transformation of the endogenous variables before the Bayesian estimation. We follow the prior distributions used in Schmitt-Grohé and Uribe (2010) for the structural parameters absent in our model, namely γ and ζ. We adopt a uniform prior distribution over 0 and 1 for γ, controlling the size of the labor-supply wealth effect, and a Gamma prior distribution with mean 4 and standard deviation of 1 for ζ, controlling the Frisch labor supply elasticity. The prior distributions for the rest of the parameters are identical to those used in estimating our model. The same observables and measurement equations (14)-(18) are used in the Bayesian estimation.

5.2 Posterior Estimates

Table 3 presents the posterior distributions of the parameters in the two-sector version of Jaimovich and Rebelo (2009), together with the associated prior distributions. Overall, our estimates of the two-sector version of the Jaimovich–Rebelo model are in line with Schmitt-Grohé and Uribe (2012), who estimate a one-sector version. The posterior mean of γ is estimated to be very close to zero. This estimate implies that, in the absence of habit formation, the model would display a labor supply schedule with a near-zero wealth effect of labor supply. The habit persistent parameter, h, is estimated to be around 0.99. The estimate of h is similar to the one reported in Schmitt-Grohé and Uribe (2012), but it is substantially larger than our estimate with the limited labor mobility presented in Section 4.2. The parameter ζ, governing the Frisch labor elasticity, is estimated to be around 1.71, significantly smaller than the estimate of Schmitt-Grohé and Uribe (2012) (4.74). The investment adjustment cost parameter, ϕ'', is estimated to be around 2.85, which lies between our estimate and that of Schmitt-Grohé and Uribe (2012). As in our estimated model, the estimates of κ_c and κ_i display a substantial sectoral difference, implying that it is much more costly to vary the rate of capital utilization in the consumption sector than in the investment sector.

5.3 Model Comparison

We now quantitatively compare the two competing models that might display the sectoral labor co-movement. By using the Bayes factor, we can formally compare the performance of our model

Table 3: Prior and Posterior Distributions for the Two-sector Jaimovich and Rebelo (2009) Model

	Prior Distribution			Posterior Distribution		
Parameter	Distribution	Mean	Std. Dev.	Mean	5 %	95 %
γ	Uniform	0.5	0.2887	0.0455	0.0218	0.0682
ζ	Gamma	4	1	1.7135	1.4884	1.9371
h	Beta	0.5	0.2	0.9896	0.9868	0.9925
κ_c	Inv. Gamma	1	1	6.3727	5.1453	7.6043
κ_i	Inv. Gamma	1	1	0.6862	0.4309	0.9405
$\phi''(1)$	Gamma	4	1	2.8543	1.9062	3.8002
$\bar{g} \times 400$	Gamma	1.65	1	0.5608	0.0930	1.0207
ρ_a	Beta	0.7	0.2	0.9899	0.9818	0.9985
ρ_g	Beta	0.2	0.2	0.4847	0.3939	0.5794
ρ_i	Beta	0.5	0.2	0.9869	0.9785	0.9962
ρ_b	Beta	0.7	0.2	0.6351	0.3557	0.8828
ρ_{μ_c}	Beta	0.5	0.2	0.9176	0.8908	0.9413
ρ_{μ_i}	Beta	0.5	0.2	0.9324	0.8929	0.9709
σ_a^0	Gamma	0.015	0.015	0.0013	0.0000	0.0025
σ_a^1	Gamma	0.0043	0.0043	0.0024	0.0011	0.0035
σ_a^2	Gamma	0.0043	0.0043	0.0007	0.0000	0.0016
σ_a^3	Gamma	0.0043	0.0043	0.0005	0.0000	0.0010
σ_a^4	Gamma	0.0043	0.0043	0.0006	0.0000	0.0013
σ_g^0	Gamma	0.015	0.015	0.0005	0.0000	0.0010
σ_g^1	Gamma	0.0043	0.0043	0.0009	0.0000	0.0015
σ_g^2	Gamma	0.0043	0.0043	0.0015	0.0006	0.0025
σ_g^3	Gamma	0.0043	0.0043	0.0012	0.0001	0.0021
σ_g^4	Gamma	0.0043	0.0043	0.0015	0.0004	0.0025
σ_i^0	Gamma	0.015	0.015	0.0147	0.0133	0.0161
σ_i^1	Gamma	0.0043	0.0043	0.0016	0.0000	0.0035
σ_i^2	Gamma	0.0043	0.0043	0.0010	0.0000	0.0022
σ_i^3	Gamma	0.0043	0.0043	0.0011	0.0000	0.0024
σ_i^4	Gamma	0.0043	0.0043	0.0015	0.0000	0.0030
σ_b	Inv. Gamma	0.0173	0.0173	0.0139	0.0060	0.0218
$\sigma_{\mu_c}^0$	Gamma	0.015	0.015	0.0391	0.0346	0.0434
$\sigma_{\mu_c}^1$	Gamma	0.0043	0.0043	0.0060	0.0000	0.0109
$\sigma_{\mu_c}^2$	Gamma	0.0043	0.0043	0.0041	0.0000	0.0093
$\sigma_{\mu_c}^3$	Gamma	0.0043	0.0043	0.0023	0.0000	0.0058
$\sigma_{\mu_c}^4$	Gamma	0.0043	0.0043	0.0025	0.0000	0.0068
$\sigma_{\mu_i}^0$	Gamma	0.015	0.015	0.0062	0.0001	0.0102
$\sigma_{\mu_i}^1$	Gamma	0.0043	0.0043	0.0018	0.0000	0.0040
$\sigma_{\mu_i}^2$	Gamma	0.0043	0.0043	0.0082	0.0003	0.0137
$\sigma_{\mu_i}^3$	Gamma	0.0043	0.0043	0.0073	0.0007	0.0123
$\sigma_{\mu_i}^4$	Gamma	0.0043	0.0043	0.0063	0.0000	0.0119
Log Marginal Density		3245.33				

Note: The posterior distributions are obtained using the random walk Metropolis–Hastings algorithm with 300,000 draws (the first 10% of draws are discarded as a burn-in period). We use the modified Harmonic mean estimator of Geweke (1999) to obtain the log marginal density.

with that of the Jaimovich–Rebelo model in fitting the data. The Bayes factor tells us the strength of evidence provided by the data. We use the modified Harmonic mean estimator of Geweke (1999) to obtain the log marginal density. The log data density associated with our model is 3360.38, as reported in Table 1, whereas that of the Jaimovich and Rebelo (2009) model, shown in Table 3, is 3245.33. In order to choose the Jaimovich–Rebelo specification over ours, we need to assign a prior probability of the Jaimovich–Rebelo preferences exp(115.88) $\approx 2.12 \times 10^{50}$ times larger than that over the non-separable King–Plosser–Rebelo preferences, with imperfect inter-sectoral labor mobility. This difference seems to be overwhelmingly large, which suggests that the data decisively support our model.

To better understand why the empirical fit of our model is superior to that of the Jaimovich–Rebelo specification, we compare the second moments predicted by our model and their model. Table 4 compares the standard deviations, autocorrelations, and cross-correlations predicted by our model with the estimated two-sector Jaimovich–Rebelo model. Overall, our estimated model matches the empirical second moments well. It replicates the observed volatility in consumption, investment, hours worked in consumption and investment sectors, and real wages. The model also effectively captures the autocorrelations of consumption growth, investment growth, and real wages growth. As mentioned above, even with low estimates of habit persistence and investment adjustment costs, our model is capable of matching the positive autocorrelations of consumption growth and investment growth in the data. However, there is a discrepancy between the model prediction and the data. The predicted autocorrelations of hours growth in both sectors are somewhat weaker than in the data.

The most noticeable difference between the two models stems from the ability to replicate the observed sectoral co-movement of hours worked and output. Our estimated model produces the observed positive correlations between sectoral labors and between sectoral outputs. As mentioned earlier, it has been a challenge for multi-sector neoclassical DSGE models to produce the sectoral co-movement of output and hours worked. The estimated model overcomes this challenge and successfully generates the sectoral co-movement.

In contrast, the estimated Jaimovich–Rebelo model does not capture the positive correlations of sectoral hours worked and sectoral outputs well. This might be an important factor contributing to the data favoring our model over the Jaimovich-Rebelo model. In other dimensions, our

Table 4: Comparison of the Second Moments

		Data	Our Model	Jaimovich and Rebelo
Standard Deviation	dC	0.0052	0.0048	0.0050
	dI	0.0215	0.0197	0.0310
	dw	0.0082	0.0080	0.0083
	dh_c	0.0060	0.0056	0.0072
	dh_i	0.0203	0.0203	0.0314
AR(1)	dC	0.4853	0.3526	0.4434
	dI	0.4102	0.3744	0.7379
	dw	-0.0401	-0.0639	0.0343
	dh_c	0.6910	0.2609	0.1945
	dh_i	0.6406	0.2151	0.7491
Correlation	Corr(dC, dI)	0.5118	0.4005	0.0098
	Corr(dh_c, dh_i)	0.8753	0.8509	0.0920
	Corr(dh_c, dw)	-0.0847	-0.1632	-0.0267
	Corr(dh_i, dw)	-0.0656	-0.1041	-0.0974

estimated model matches the observed levels of volatility in the observable variables better than the estimated two-sector Jaimovich–Rebelo model does, which slightly over-predicts the observed levels of volatility in investment and sectoral hours worked. To a certain extent, both models have difficulty in replicating the observed serial correlations of some of the observable variables.

One might wonder why the Jaimovich–Rebelo model cannot generate the sectoral co-movement of hours worked, despite the near-zero estimate of the labor-supply wealth effect. While it is essential to have a very low labor-supply wealth effect to obtain the sectoral co-movement of labor, the absence of the wealth effect does not guarantee the co-movement in the Jaimovich-Rebelo model. To do so, it must be accompanied by the low elasticity of the cost of utilization with respect to the rate of utilization (i.e., lower values of κ_c). Put differently, the absence of the labor-supply wealth effect serves as the necessary, but not sufficient condition for sectoral co-movement.

To organize the discussion, it is useful to consider an analogous equation to (9) for the case of GHH preferences. Combining the first-order conditions for consumption and labor for the case of $\gamma = 0$ and $h = 0$ yields the following expressions:

$$\begin{aligned}\psi\zeta(N_{c,t} + N_{i,t})^{\zeta-1} &= (1-\alpha)\frac{C_t}{N_{c,t}} \\ &= (1-\alpha)A_t a_t \left(\frac{u_{c,t}K_{c,t}}{N_{c,t}}\right)^{\alpha}. \end{aligned} \tag{21}$$

Equation (21) shows that it is possible for $N_{c,t}$ and $N_{i,t}$ to move in the same direction. However, at the same time, a careful inspection also shows that higher values of κ_c make it more difficult for $N_{c,t}$ and $N_{i,t}$ to move in the same direction. Suppose, for example, that $N_{i,t}$ increases, so that the marginal disutility of work increases. Capital utilization in the consumption sector ($u_{c,t}$) must increase substantially for $N_{c,t}$ to increase as well, in the absence of a positive contemporaneous aggregate TFP shock. In other words, $u_{c,t}$ also needs to react significantly for GHH preferences to exhibit the sectoral co-movement when the economy is buffeted by various types of shocks other than contemporaneous aggregate TFP shocks. This, in turn, requires a lower elasticity of the marginal cost of utilization in the consumption sector (i.e., lower values of κ_c). Hence, it is necessary to have an elastic response of utilization in the consumption sector for GHH preferences to generate the sectoral co-movement of hours worked. However, since the consumption sector is not as volatile as the investment sector, it does not need a powerful amplification mechanism, resulting in a large value for the estimate of κ_c. As a result of the high elasticity of the cost of utilization in the consumption sector, the current estimated two-sector Jaimovich–Rebelo model does not display the sectoral co-movement of hours worked, even though the estimated labor-supply wealth effect is almost zero.

6 Conclusion

The sectoral co-movement of output and hours worked is a prominent feature of business cycle data. However, most two-sector neoclassical models fail to generate sectoral co-movement. In this study, we constructed and estimated a two-sector neoclassical DSGE model that generates sectoral co-movement when business cycles are driven by both anticipated and unanticipated shocks. Our model incorporates limited labor mobility between sectors and non-separable preferences between consumption and leisure. To quantify the importance of these elements in generating the sectoral co-movement, we applied Bayesian methods to estimate our model. The key to our model's success in generating the co-movement is the significant degree of inter-sectoral labor immobility, estimated using data on sectoral hours worked.

Furthermore, we investigated whether the data favor our model over alternative models, emphasizing the role of labor-supply wealth effects in generating sectoral co-movement. To this end, we performed a Bayesian estimation of a two-sector version of the Jaimovich and Rebelo (2009) model, using the same structural shocks. Our model fits the data better than does the Jaimovich and Rebelo (2009) model. The contributing factor to this result is that the estimated two-sector Jaimovich–Rebelo model does not display sectoral co-movement, even though the labor-supply wealth effects are estimated to be near zero. Despite the near-zero wealth effects on the labor supply, the elasticity of the cost of utilization in the consumption sector is not low enough to support sectoral co-movement. Therefore, our model provides a better explanation for sectoral co-movement than does the Jaimovich–Rebelo model.

Finally, our study contributes to DSGE-based macroeconometric literature on the quantitative importance of news shocks as sources of business cycles. Previous estimated DSGE models examined the role of news shocks in driving business cycles in the context of a one-sector economy. We assessed the quantitative importance of news shocks in the context of a two-sector estimated DSGE model that displays sectoral co-movement. In our estimated model, a non-negligible fraction of the variance of the growth rate of consumption, investment, and sectoral hours is attributable to anticipated shocks.

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Appendix

Data Construction

We assume that the consumption sector consists of firms producing non-durable goods and services, and that the investment sector produces durable goods and goods used for non-residential investment and residential investment. We construct the real per-capita consumption growth and the real per-capita investment growth as follows.

$$
\begin{aligned}
dC_t &= \Delta \log\left(\frac{\text{Non-durable (PCND)} + \text{Services (PCESV)}}{\text{GDP Deflator (GDPDEF)} \times \text{Civilian Non-institutional Population (CNP16OV)}}\right) \\
dI_t &= \Delta \log\left(\frac{\text{Durable (PCDG)} + \text{Non-Residential Investment (PNFI)} + \text{Residential Investment (PRFI)}}{\text{GDP Deflator (GDPDEF)} \times \text{Civilian Non-institutional Population (CNP16OV)}}\right)
\end{aligned}
$$

We use compensation per hour in the nonfarm business sector (COMPNFB), deflated by CPI (CPIAUCSL) to construct the growth rate of the aggregate real wage. These data are retrieved from the FRED of the St. Louis Fed. The series IDs are in parentheses. The monthly CPI is converted to a quarterly CPI by taking the average. In order to avoid infrequent discrete jumps in the civilian noninstitutional population due to changes in population estimates, we use the HP trend instead. The end-of-quarter observations are used to construct a quarterly population series.

For the sectoral labor, we use data on production and nonsupervisory employees from Table B-6 and the average weekly hours from Table B-7 of the Current Employment Statistics of the BLS.[18] We define the consumption sector as the union of non-durable and services industries and assume that the investment sector consists of construction and durable firms. We simply construct the quarterly total hours worked in each sector. We calculate the growth rate of average hours worked in each sector by using the HP-trend population.

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[18] Available at http://www.bls.gov/ces/cesbtabs.htm