Are All Economic Fluctuations Bad for Consumers?*

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Abstract

Are business cycles always costly? This paper sheds new light on this question in the context of a two-sector neoclassical business cycle model by focusing on the roles of the origin of shocks and the degree of real frictions that restrict factor reallocation both inter-temporally (investment adjustment cost) and intra-temporally (inter-sectoral factor immobilities). We find that under the benchmark parameterization, investment-specific technology shocks are welfare-improving while consumption-specific technology shocks are welfare-detrimental, regardless of the degree of real frictions. While aggregate TFP shocks can be both depending on the degree of real frictions, welfare-improving business cycles are not supported by empirical evidence.

JEL classification: E32, E39

Keywords: Welfare Cost of Business Cycles, Two-Sector Neoclassical Model, Nature of Shocks, Factor Mobility, Investment Adjustment Cost

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1 Introduction

Economists have long believed that economic fluctuations make consumers worse off. Risk-averse consumers unambiguously prefer a smooth stream of consumption to a volatile one, which can be referred to as the *fluctuations* effect of uncertainty. Recent papers by Cho, Cooley, and Kim (2015) and Lester, Pries, and Sims (2014) challenge this view of economic fluctuations and show that economic uncertainty can be welfare-improving: Consumers can leverage this uncertainty by increasing work and investment during high productivity periods so that the mean level of output can increase more than the size of the shock (convex response of output with respect to exogenous shock). As a result, the economy with business cycles can enjoy a higher mean level of consumption than its deterministic steady state counterpart, which can be referred to as the *mean* effect of the uncertainty. Whenever the mean effect dominates the fluctuations effect, business cycles are not costly.

Are then economic fluctuations good or bad for consumers? This paper sheds a new light on this important question in the context of a two-sector real business cycles (RBC) model that consists of consumption and investment sectors. Earlier studies by Cho, Cooley, and Kim (2015) and Lester, Pries, and Sims (2014) restrict their attention to a standard one-sector RBC model that does not have any friction in reallocating factors of production across the sectors and changing the level of investment. In contrast, we show that whether the economic fluctuations are welfare-detrimental or not depends on the very features that previous work has ignored: i) real frictions preventing resource allocations, including inter-sectoral factor mobility and adjustment costs to investments, and ii) the origin of productivity shocks. To our best knowledge, Otrok (2001a) is the only previous research introducing the two-sector model to examine the welfare cost of business cycles. Our paper is distinctive from his paper in mainly two directions: First, while he overlooked sector-specific technology shocks, we highlight their significance. Second, unlike his paper that abstains from studying the utility from leisure because of the failure to resolve the sectoral labor comovement problem, we are able to consider the utility from leisure since our model can resolve the problem.

Specifically, we demonstrate that the degree of inter-sectoral labor mobility and investment adjustment costs play a crucial role in determining the mean effect of the uncertainty. The extent to which these two factors exert the mean effect of uncertainty depends on where the economic fluctuations originate from. For the types of shocks that directly influence the expected return to investment, such as aggregate TFP and investment-specific technology shocks, the more inflexible factor mobility and higher adjustment costs to investment substantially weaken the mean effect of uncertainty. On the contrary, the mean effect of uncertainty is almost unaffected regardless of the degree of inflexible inter-sectoral factor mobility and investment adjustment costs when the consumption-specific technology shocks generates the business cycles because they don't influence the expected return on investment. As a result, the aggregate labor response is significantly muted.

The economic mechanism through which inter-sectoral factor (or labor) mobility and investment adjustment costs affect the mean effect is straightforward. When the expected returns to investment are high because of a rise in the aggregate TFP or investment-sector TFP, consumers wish to take advantage of it by working more and investing more. The increase in investment would be greater if there are no adjustment costs to investment and more capital and labor resources can be reallocated from the production of consumption goods toward the production of the investment goods. However, if there are adjustment costs to investment and factors cannot freely flow across the sectors, the extent to which consumers can make use of the times with higher expected return to investment is limited, resulting in a weaker mean effect. Obviously, as consumption-sector TFP shocks do not alter the expected return to investment, consumers do not find periods with higher consumption-sector productivity a better opportunity to work and invest more. As a result, the mean effect of the uncertainty itself is small and is thus unaffected by the presence of investment adjustment costs and inter-sectoral factor mobility.

More interestingly, the relative strength of the mean effect to the fluctuations effect, which determines the sign of the welfare costs of economic fluctuations, varies according to the origin of productivity shocks. When the economy is buffeted by investment-specific technology shocks, the mean effect dominates the fluctuation effect, so that consumers prefer a more volatile environment. Strikingly, this result survives even though substantial frictions to inter-sectoral factor mobility and investment adjustment result in a much weaker mean effect. In contrast, aggregate TFP shocks can be either welfare-improving or welfare-detrimental, depending on the degree of inter-sectoral factor mobility and the size of investment adjustment costs. In a frictionless economy with no adjustment costs to investment and perfect inter-sectoral mobility, the mean effect of aggregate TFP shocks is strong enough to dominate the fluctuations effect, resulting in a welfare-improving economic fluctuations. However, under a reasonable degree of inter-sectoral factor immobility and size of investment adjustment costs, the mean effect becomes significantly weaker and thus dominated by the fluctuations effect. Hence, aggregate TFP-driven business cycles are costly to the consumers. Finally, consumption-sector TFP shocks, which do not induce the strong mean effect, hurt consumers, irrespective of the degree of the factor mobility and size of investment adjustment costs. In this case, the mean effect is almost zero and hence is always dominated by the fluctuations effect.

We finally assess the normative implication of the changes in the business cycle properties observed in the U.S. In particular, we study the welfare consequences of changes in the relative importance of sectoral shocks in explaining the aggregate dynamics and of the Great Moderation. We find that whether the welfare cost of business cycles becomes smaller depends on which sector plays an important role in shaping dynamics of GDP, a finding consistent with our main analysis, and the Great Moderation together with increased importance of sectoral shocks (Foerster, Sarte, and Watson (2011)) has substantially lowered the welfare cost.

Our findings enrich our understanding of the welfare costs of economics fluctuations. First, regarding the welfare costs of aggregate TFP shocks, our result stands in sharp contrast with that of Cho, Cooley, and Kim (2015) and Lester, Pries, and Sims (2014). They show that aggregate TFP shocks can be beneficial to the consumers in a one-sector real business cycle model. The underlying economic structure of the one-sector model is the two-sector model featuring perfect factor mobility and no adjustment costs to investment. Hence, their results can be thought of as a special case in which the mean effect of business cycles is maximized. Here, we show that a departure from the assumption of perfect factor mobility and the introduction of investment adjustment costs lead to a different conclusion about the welfare costs of business cycles.

Second, we clearly identify the case for welfare-improving business cycles: The shock should originate from investment-sector TFP under the benchmark calibration. Despite the fact that the presence of inter-sectoral factor immobility and investment adjustment costs hinders consumers from enjoying the mean effect, investment-specific technology shocks are beneficial to them. This result can be viewed as a generalization of Cho, Cooley, and Kim (2015) and Lester, Pries, and Sims (2014), who reach the same conclusion in a frictionless economy.

Finally, in contrast to Cho, Cooley, and Kim (2015), we show that not all multiplicative technology shocks increase economic welfare even in an economy with no frictions: Consumption-specific technology shocks reduce the economic welfare of consumers since the mean effect is negligible due to the muted endogenous response of labor to the shock.

We believe that our attempt to measure the welfare costs of business cycles in the two-sector model is well backed by empirical evidence. Atalay (2017) shows that sectoral shocks are the main source of GDP fluctuations in the US; Foerster, Sarte, and Watson (2011) and Garín, Pries, and Sims (2018) suggest that the importance of sectoral shocks in accounting for the business cycles has increased since the mid-1980s. Our paper, hence, contributes to the literature on the business cycles by studying welfare implications of the sectoral shocks. In particular, our finding indicates that U.S. business cycles could have been beneficial, rather than harmful, to the representative consumers, depending on which shock drove the fluctuations.

The notion that factors cannot be instantaneously reallocated across sectors after a shock has also been well documented.[1] The one-sector model cannot analyze the effects of shocks with different origins and imperfect factor mobility on the welfare costs of business cycles. Furthermore, while the positive implications of sectoral shocks, imperfect factor mobility, and adjustment costs to investment have been widely studied[2], few papers have investigated their normative implication. We contribute to the literature by examining the welfare consequence of such features in the context of a two-sector real business cycle model.

The rest of the paper is organized as follows. Section 2 introduces the main model for the analysis. Section 3 compares the welfare cost from our benchmark economy to its one-sector counterpart. Section 4 demonstrates why our model economy generates different results from the previous literature and Section 5 studies the welfare implication of changes in the aggregate dynamics. Section 6 concludes.

2 The Model

We simplify the model introduced in Katayama and Kim (2018) and among the many shocks introduced in their model, we only consider aggregate TFP shock and two sector-specific technology shocks in our analysis to make our analysis comparable to previous literature. In addition, we assume that all markets

[1] For instance, Ramey and Shapiro (2001) show that there is a substantial mobility cost for capital using the data from aerospace plant; Horvath (2000), Katayama and Kim (2018), and Moura (2018) find that perfect reallocation of labor across the sectors is not supported by the data.

[2] For instance, Boldrin, Christiano, and Fisher (2001) show that the sectoral labor comovement problem can be resolved when the composition of labor between sectors is determined before the shock is realized. Huffman and Wynne (1999) argue that cross-sector behavior of employment observed in the data can be well reproduced with imperfect labor substitutability, assuming sector-specific technology shock. Katayama and Kim (2018) find that such a feature is important to obtain plausible business cycle fluctuations with news shocks. Christiano, Eichenbaum, and Evans (2005) demonstrate that adjustment costs to investment is the key to replicating the response of investment to monetary policy shocks.

are perfectly competitive.

2.1 The Setup

The economy consists of identical households and firms.

Households. The economy is populated by a constant number of identical and infinitely-lived households. The representative household, who takes price and factor prices as given, draws utility from consumption and disutility from allocating labor hours to the consumption and investment goods sectors. Households maximize expected lifetime utility given by:

$$U_0 = \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t U(C_t, N_t) \right] \tag{2.1}$$

where $\beta \in (0, 1)$ is the subjective discount factor and C_t and N_t respectively denote period t consumption and an aggregate labor index.

The specific form of U nests King-Plosser-Rebelo (KPR, hereafter) preference (King, Plosser, and Rebelo (1988)) as a special case[3]:

$$U(C_t, N_t) = \frac{(C_t)^{1-\frac{1}{\sigma}} \left(1 + \left(\frac{1}{\sigma} - 1\right) v(N_t)\right)^{\frac{1}{\sigma}} - 1}{1 - \frac{1}{\sigma}} \tag{2.2}$$

where $v(N_t) = \nu \frac{\eta}{1+\eta} N_t^{\frac{\eta+1}{\eta}}$. $v(N_t)$ measures the disutility incurred from hours worked with $v^{'} > 0$ and $v'' > 0$. η represents a Frisch labor elasticity of aggregate labor supply when preference is separable.

It is assumed that the representative household is endowed with one unit of time in each period and the aggregate labor index N_t takes the following form:

$$N_t = \left[N_{c,t}^{\frac{\theta+1}{\theta}} + N_{i,t}^{\frac{\theta+1}{\theta}} \right]^{\frac{\theta}{\theta+1}}, \quad \theta \geq 0 \tag{2.3}$$

Here, $N_{c,t}$ and $N_{i,t}$ respectively denotes labor hours devoted to the consumption and investment sector. This equation (2.3) hence captures the idea that reallocating market hours from one sector to other sector incurs positive costs, following Huffman and Wynne (1999) and Horvath (2000). In particular, the elasticity of intratemporal substitution, θ, which controls the degree to which labor can move across sectors, satisfies the following property:

[3] In contrast to Katayama and Kim (2018), habit formation in consumption is abstracted from the utility function. This is to make a clear comparison with the existing literature that does not consider habit formation. As argued by Dolmas (1998) and Otrok (2001b), time-non-separability of the utility function, including habit formation, raises the welfare cost. Therefore, this implies that our welfare metric can be interpreted as the lower bound in this regard.

$$\frac{d\ln\left(\frac{N_{i,t}}{N_{c,t}}\right)}{d\ln\left(\frac{w_{i,t}}{w_{c,t}}\right)} \propto \theta \tag{2.4}$$

where the above condition comes from the labor supply equation.

θ measures the extent to which the relative labor in different sectors respond to the relative wage. If $\theta \to \infty$, all sectors should pay the same hourly wage. If not, only the high-wage sector will hire the workers. Hence, labor hours devoted to different sectors are perfect substitutes in this case. One can interpret the usual one-sector model as the nested version of our model when $\theta \to \infty$ (when capital is also perfectly mobile across the sectors). In contrast, when $\theta \to 0$, changing the composition of labor hours between sectors is impossible since relative hours do not respond to changes in relative wages, i.e., it incurs infinite costs to move labor from one sector to the other sector.[4] In the intermediate case, $0 < \theta < \infty$, the worker allocates positive hours in each sector. In this case, wage may vary in different sectors. Hence, the labor market setup employed in our paper is more flexible and convenient than the previous papers in the sense that we can simply change the value of the parameter θ to alter the degree of inter-sectoral labor immobility. In other words, θ captures the intra-temporal real friction in the labor market in a reduced form. This environment also captures the idea that there can be a sector-specific human capital so that one cannot easily change the composition of labor in different sectors.

A household's utility maximization problem is subject to the following budget constraint:

$$C_t + \left(\frac{P_{i,t}}{P_{c,t}}\right)(I_{c,t} + I_{i,t}) \leq \sum_{j=c,i}\left(\frac{W_{j,t}}{P_{c,t}}\right)N_{j,t} + \sum_{j=c,i}\left(\frac{R_{j,t}}{P_{c,t}}\right)K_{j,t} \tag{2.5}$$

where the subscript c and i denote variables that are specific to the consumption and investment sector, respectively. $P_{j,t}$ is the nominal prices in sector $j = c, i$, $I_{j,t}$ represents newly purchased capital in sector j, and $W_{j,t}$ is the nominal wage rate paid by firms in sector j. In addition, $K_{j,t}$ is a physical capital stock and $R_{j,t}$ is the rental rates of capital services in sector j.

The law of motion for capital stock in each sector $j = c, i$ is given by

$$K_{j,t+1} = I_{j,t}\left[1 - \phi\left(\frac{I_{j,t}}{I_{j,t-1}}\right)\right] + (1-\delta)K_{j,t}, \quad j = c, i \tag{2.6}$$

[4]An alternative setup is employed by Boldrin, Christiano, and Fisher (2001); they assumed that labor decision is made before the shock hits the economy, i.e., the composition of labor devoted in each sector is fixed at the realization of the shock. As is pointed out by Katayama and Kim (2018), however, this setup cannot (1) generate persistent inter-sectoral wage differentials and (2) fully resolve the sectoral labor comovement issue.

We note that different types of real frictions might apply to existing capital ($K_{j,t}$) and new capital (I_t). The first friction restricts inter-sectoral reallocation of capital, which is implicitly captured by the above equation: Since capital in each sector ($K_{j,t}$) is predetermined, rental rates of capital can differ across the sectors. Hence, this friction can be interpreted as the friction on the already installed capital ($K_{j,t}$). The effect of such a margin can be analyzed by considering an alternative economy that is the limit case of the two-sector economy with infinite degree of inter-sectoral capital mobility. Hence, in this alternative economy, rental rates of capital should be equalized, i.e., $R_{c,t} = R_{i,t}$. The law of motion for capital stock is then described as follows:

$$K_{t+1} = I_t + (1 - \delta)K_t, \tag{2.7}$$

where $K_t = K_{c,t} + K_{i,t}$ and $I_t = I_{c,t} + I_{i,t}$.

The second friction, in contrast, applies to the newly purchased capital (I_t) and is introduced as the form of adjustment cost for investment, denoted as $\phi(\cdot)$. Since the adjustment cost incurs when the level of investment changes over time, this captures the friction that hinders inter-temporal adjustment of capital. In particular, we assume that ϕ and $\phi^{'} = 0$, and $\phi^{''} > 0$ in the steady state and the specific functional form takes the following quadratic form:

$$\phi\left(\frac{I_{j,t}}{I_{j,t-1}}\right) = \frac{\kappa_j}{2}\left(\frac{I_{j,t}}{I_{j,t-1}} - 1\right)^2 \tag{2.8}$$

We can vary the parameter κ_j in order to capture the changes in the degree of inter-temporal friction in the capital market.

In summary, both labor and capital face real frictions when agents respond to changes in exogenous shocks. First, a friction in the labor market limits inter-sectoral labor reallocation, meaning labor in one sector cannot be freely reallocated to the other sector. Second, there exists a real friction on the already-installed capital that hinders inter-sectoral capital reallocation. In contrast, the last real friction, which is applied to the newly purchased capital, prevents costless inter-temporal capital allocation.

Firms. A representative firm in each sector, which is assumed to be perfectly competitive and hence takes price and factor prices as given, faces the usual profit maximization problem.

$$\max P_{j,t}Y_{j,t} - W_{j,t}N^d_{j,t} - R_{j,t}K^d_{j,t} \tag{2.9}$$

where $j = \{c, i\}$, superscript d denotes demand, and output in each sector (Y_{jt}) is assumed to take Cobb-Douglas form:

$$Y_{c,t} = A_{c,t}(K^d_{c,t})^{\alpha}(N^d_{c,t})^{1-\alpha} \tag{2.10}$$

$$Y_{i,t} = A_{i,t}(K^d_{i,t})^{\alpha}(N^d_{i,t})^{1-\alpha} \tag{2.11}$$

where $A_{c,t} \equiv Z_t Z_{c,t}$ is a consumption-sector total factor productivity (TFP) shock and $A_{i,t} \equiv Z_t Z_{i,t}$ is an investment-sector TFP shock. In particular, Z_t is a common aggregate TFP shock and $Z_{c,t}$ is a sectoral TFP shock in the consumption sector (henceforth C-shock) and $Z_{i,t}$ is a sectoral TFP shock in the investment sector (henceforth I-shock). Z_t follows an AR (1) process[5]:

$$Z_t = (1 - \rho_Z) + \rho_Z Z_{t-1} + \xi_{Z,t} \tag{2.12}$$

where $\xi_{Z,t} \sim iid\, \mathbb{N}(0, \sigma^2_Z)$.

We also assume stationary sectoral TFP shocks. Again, both of them follow an AR (1) process:

$$Z_{j,t} = (1 - \rho_j) + \rho_j Z_{j,t-1} + \xi_{j,t} \tag{2.13}$$

where $\xi_{j,t} \sim iid\, \mathbb{N}(0, \sigma^2_j)$ for $j = \{c, i\}$.

Given (factor) prices, demand for the production factors are determined as follows.

$$W_{j,t} = (1 - \alpha)P_{j,t} Z_t Z_{j,t} {K^d_{j,t}}^{\alpha} {N^d_{j,t}}^{-\alpha} \tag{2.14}$$

$$R_{j,t} = \alpha P_{j,t} Z_t Z_{j,t} {K^d_{j,t}}^{\alpha-1} {N^d_{j,t}}^{1-\alpha} \tag{2.15}$$

where $j = \{c, i\}$.

Market Clearing. In our model economy, there are four markets, which are cleared at the equilibrium. In other words, consumption goods market clearing condition ($C_t = Y_{ct}$), investment goods market clearing condition ($I_{c,t} + I_{i,t} = Y_{it}$), labor market clearing condition ($N_{j,t} = N^d_{j,t}$), and capital

[5]There are two reasons why we use the level shock instead of the log-level shock. First, this makes our analysis to be comparable to Lester, Pries, and Sims (2014), which also uses the level shock. Second, log-level specification as in Cho, Cooley, and Kim (2015) might suffer from a problem of overestimating the welfare gain (Heiberger and Maußner (2020)).

market clearing condition ($K_{j,t} = K^d_{j,t}$) for $j = \{c, i\}$ are all satisfied.

Equilibrium. A competitive equilibrium of the model economy consists of quantity variables $\{C_t, I_{j,t}, N_{j,t}, N^d_{j,t}, K_{j,t}, K^d_{j,t}\}_{t=0}^{\infty}$ and price variables $\{P_{j,t}, W_{j,t}, R_{j,t}\}_{t=0}^{\infty}$ for $j = \{c, i\}$ such that

1. Household's utility is maximized: Given prices, the household's optimal choice $\{C_t, I_{j,t}, N_{j,t}, K_{j,t}\}_{t=0}^{\infty}$ for $j = \{c, i\}$ solves the household utility maximization problem (2.2) subject to the budget constraint (2.5) and the aggregate labor index (2.3).

2. Firms' profits are maximized: Given prices, firms optimally choose $\{N^d_{j,t}, K^d_{j,t}\}_{t=0}^{\infty}$ for $j = \{c, i\}$.

3. Markets clear: All markets clear.

All equilibrium conditions and market clearing conditions are provided in Appendix A. We solve the model by the perturbation method with the second-order approximation (Schmitt-Grohé and Uribe (2004)).

2.2 Parameterization

In order to determine the parameter values, we take two steps. We first take some key parameters from the previous literature, especially Lester, Pries, and Sims (2014), to make our analysis directly comparable to them. For instance, α, β, and δ are taken from Lester, Pries, and Sims (2014). Parameters of main interests, which will be altered during the quantitative exercises, are first chosen to be in line with the previous literature. θ, the parameter governing the degree of inter-sectoral labor mobility, is taken from Katayama and Kim (2018). η, Frisch labor supply elasticity, and σ, elasticity of intertemporal substitution, are chosen to be in line with the usual convention.[6] Calibrated parameters are reported in the first panel of Table 2.1.

Remaining parameters are estimated by the generalized method of moments (henceforth GMM). In particular, we estimate parameters by minimizing the distance between the key second moments of the data and the corresponding theoretical moments based on the pruned state-space representation of the perturbation solution. In doing so, we utilize key macro variables (GDP, consumption, investment, and hours worked in each sector) and three data series of TFP (economy-wide average TFP, consumption-sector TFP, and investment-sector TFP) constructed by Fernald (2014)[7] where consumption-sector

[6] For example, Chang and Kim (2006) show that aggregate Frisch labor supply elasticity is one. σ is chosen to benchmark welfare gain to be fully comparable with Lester, Pries, and Sims (2014); aggregate TFP shock is welfare-improving in the benchmark analysis under the benchmark parameterization. Different values for σ do not change our findings.

[7] We download data from `https://www.johnfernald.net/TFP`.

Table 2.1: Benchmark Parameterization

Parameter	Value	Description
		Calibrated Parameters
α	0.36	capital income share
β	0.995	discount factor
δ	0.025	capital depreciation rate
η	1	Frisch labor supply elasticity
θ	0.24	labor substitution elasticity
σ	1.2	elasticity of intertemporal substitution
		Estimated Parameters
κ_c	0.2396	consumption sector capital adjustment cost
κ_i	0.0987	investment sector capital adjustment cost
ρ_z	0.8363	persistence of common aggregate TFP shock
σ_z	0.0046	volatility of common aggregate TFP shock
ρ_c	0.8109	persistence of C-shock
σ_c	0.0056	volatility of C-shock
ρ_i	0.7983	persistence of I-shock
σ_i	0.0349	volatility of I-shock

TFP corresponds to $A_{c,t}$, Investment-sector TFP corresponds to $A_{i,t}$, and an economy-wide average TFP (A_t) is defined as $A_{i,t}^{\omega}A_{c,t}^{1-\omega}$ with $\omega = 0.22$ being the investment share which is the time-average of the investment share observed in the data.

For the estimation, we target the following moments: variance of economy-wide average TFP, investment-sector TFP, consumption-sector TFP, output, consumption, investment and hours worked, contemporaneous covariance of output, consumption, investment and hours, and autocovariance of output, consumption, investment and hours up to lag 1. Detailed descriptions on the data (1964Q1 $\sim$ 2019Q4)[8] and the procedure for the GMM estimation are provided in Appendix D.

Table 2.2 and 2.3 compare the target moments of the data and those obtained from the model simulation using the parameter values reported in Table 2.1, which show that our model can match the target moments well. Detailed information on the estimated parameters are reported in Appendix E (Table E.1).

2.3 Computation of Welfare Cost

We compare the values of lifetime utility when the economy faces the fluctuations driven by the shock process reported in Table 2.1 (low-uncertainty economy) and those from the alternative economy with greater volatility in which the standard deviation of the shocks

[8]We do not use the data after 2020 due to Covid-19 crisis.

Table 2.2: Second Moments: Data vs. Model

Moments	Data Moments	Model Moments
$\sigma(A_c)$	0.0176	0.0127
$\sigma(A_i)$	0.0653	0.0586
$\sigma(A)$	0.0186	0.0170
$\sigma(Y)$	0.0157	0.0283
$\sigma(C)/\sigma(I)$	0.1825	0.2229
$\sigma(C)/\sigma(Y)$	0.5055	0.5948

Table 2.3: Autocorrelation: Data (left panel) vs. Model (right panel)

Data\Lag	1	2	3	4
C	0.8837	0.7114	0.5226	0.2910
I	0.9100	0.7695	0.5923	0.3908
Y	0.9062	0.7524	0.5660	0.3332
N_c	0.9258	0.7709	0.5777	0.3756
N_i	0.9227	0.7643	0.5617	0.3429

Model\Lag	1	2	3	4
C	0.8914	0.7988	0.7226	0.6600
I	0.8413	0.7042	0.5924	0.5005
Y	0.8735	0.7321	0.6172	0.5246
N_c	0.8671	0.7033	0.5692	0.4596
N_i	0.8671	0.7033	0.5692	0.4596

increases by 0.01 (high-uncertainty economy). This is to make our analysis directly comparable to Lester, Pries, and Sims (2014).[9] Formally, the value of living in the low-uncertainty economy is given by

$$V^L = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t^L, N_t^L\right) \tag{2.16}$$

where superscript L denotes the low-uncertainty economy.

Then the value of living in the high-uncertainty economy with a factor λ is defined as

$$V^{H,\lambda} = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U\left((1+\lambda)C_t^H, N_t^H\right) \tag{2.17}$$

and

$$V^H = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t^H, N_t^H\right) \tag{2.18}$$

[9]Results are almost identical when we compute the welfare cost by comparing the steady-state economy with the economy fluctuating around the steady-state (Cho, Cooley, and Kim (2015)).

where superscript H denotes the high-uncertainty economy.

Hence, λ is the compensating variation as it is commonly defined in the literature; it measures the percentage by which average consumption has to be increased for the consumer to be indifferent between the low-uncertainty economy and the high-uncertainty one. In other words, λ is the solution of the following equation:

$$V^L = V^{H,\lambda} \tag{2.19}$$

where $\lambda > 0$ (resp. $\lambda < 0$) means that there is a welfare loss (resp. gain) from greater volatility.

As shown in Appendix B, we compute the welfare cost (gain) using the following equation:

$$\lambda = \left(\frac{\bar{V}^L}{\bar{V}^H}\right)^{\frac{\sigma}{\sigma-1}} - 1 \tag{2.20}$$

where $\bar{V}^L = V^L + \frac{1}{(1-\beta)\left(1-\frac{1}{\sigma}\right)}$ and $\bar{V}^H = V^H + \frac{1}{(1-\beta)\left(1-\frac{1}{\sigma}\right)}$.

3 One-Sector Economy vs. Two-Sector Economy

We start from comparing our model economy with the economy without any real frictions, which nests one-sector model (Lester, Pries, and Sims (2014) and Cho, Cooley, and Kim (2015)) as a special case: In doing so, we set $\theta = \infty$ and $R_{C,t} = R_{I,t}$ for all t so that both labor and capital are perfectly mobile across the sectors and hence our model economy collapses into the one-sector RBC economy.[10]

We first investigate the extent to which the welfare cost obtained from our benchmark two-sector model is different from the one obtained in the one-sector counterpart. Figure 3.1 plots the welfare cost as a function of the Frisch labor supply elasticity (η), which is the key parameter to obtain welfare-improving business cycles as described below. In the left (resp. right) panel of the figure, we plot the welfare costs of business cycles in the one-sector frictionless (resp. two-sector benchmark) economy.

[10] In order to check if our model can replicate the findings by Lester, Pries, and Sims (2014) well, we construct the one-sector counterpart of our benchmark economy ($\theta = 10,000$, $\kappa_c = \kappa_j = 0$, and $R_{C,t} = R_{I,t}$ for all t so that both labor and capital are perfectly mobile across the sectors) and compute the welfare cost of business cycles by exactly following Lester, Pries, and Sims (2014): For the replication exercise, we compute the welfare costs by comparing the unconditional welfare of the high-volatility regime ($\sigma_k = 0.02$) and low-volatility regime ($\sigma_k = 0.01$) for $k = \{z, i\}$ and replication results are reported in Table E.2 $\sim$ E.4 in Appendix E. While the results are comparable to each other, there exist some differences in the results reported in Table E.2. This is because the model is not exactly the same between the two. In particular, the utility function used in our model (equation (2.2)) is not directly the same to the utility function that they used; if we instead compare the welfare cost with a similar utility function (KPR utility, Table E.3), the results are quite comparable to the ones reported in Lester, Pries, and Sims (2014).

Solid red line indicates the welfare gain when the aggregate TFP shock is the source of the business cycles; there is a welfare gain (resp. cost) from the business cycles if it is below (resp. above) zero. Dotted blue and green lines denote the welfare cost under the I-shock and C-shock, respectively.

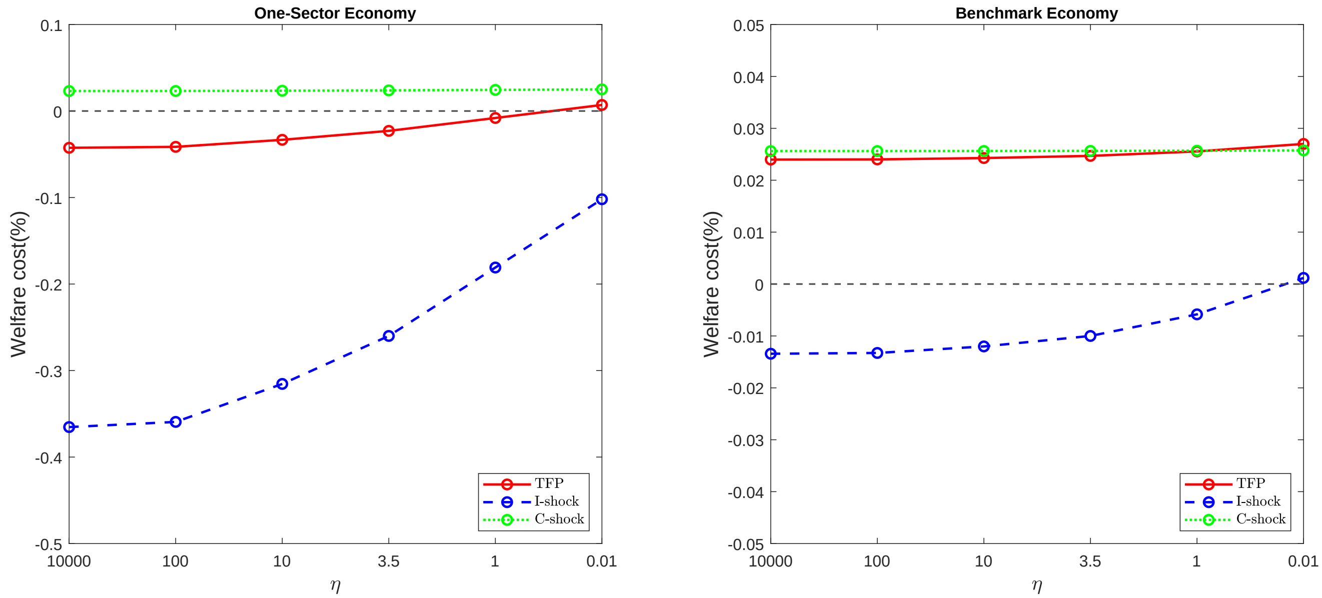


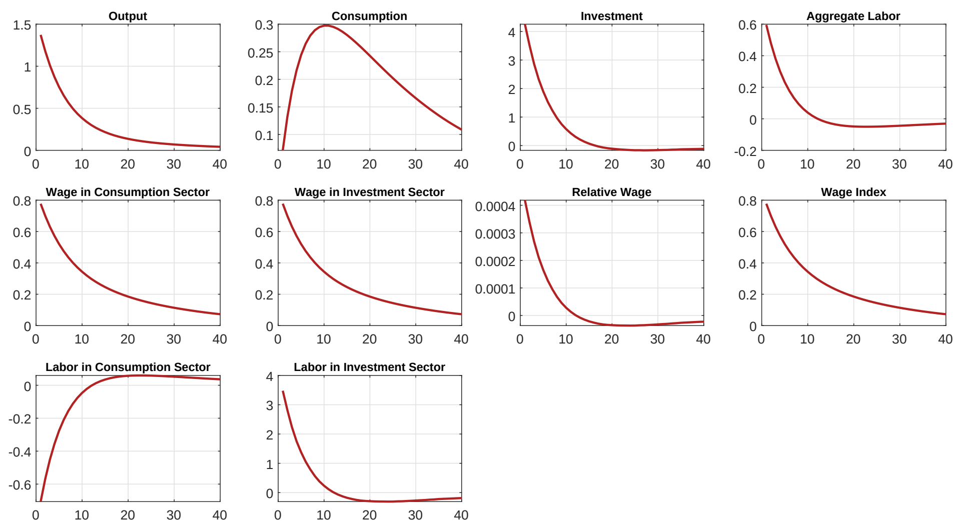
Figure 3.1: Welfare Cost: One-Sector Economy vs. Two-Sector Economy

We first notice that business cycles can be welfare-improving in the one-sector frictionless economy when either aggregate- or I-shock is the source of business cycles, which is basically a replication of the findings by Cho, Cooley, and Kim (2015) and Lester, Pries, and Sims (2014): Consumers take advantage of the uncertainty by varying working hours in favor of them when they can supply labor in a flexible manner and thus business cycles can be welfare-improving. As was emphasized by the previous literature, the welfare gain is increasing in the labor supply elasticity. Interestingly, C-shock is welfare-detrimental regardless of the value of η, showing the possibility that the origin of the shock may matter.

If we instead consider our two-sector benchmark economy (right panel of Figure 3.1), however, only I-shock can be welfare-improving while the size of welfare gain becomes much smaller than the one in the one-sector counterpart. Under the benchmark parameterization, aggregate TFP shock is welfare-detrimental even when the Frisch labor supply elasticity is substantially high. The nature of C-shock is invariant to the model; it is still welfare-detrimental under our benchmark parameterization.

Impulse response of key macro variables to one-time one-unit aggregate TFP shock in Figure 3.2 and 3.3 provides us a hint on the underlying mechanism of why the findings are different between the two economies; in each figure, relative wage refers to $\frac{w_{i,t}}{w_{c,t}}$, wage index denotes $\frac{w_{c,t}N_{c,t}+w_{i,t}N_{i,t}}{N_t}$, and the unit of Y-axis is $100 * (\log(x_t) - \log(x_{ss}))$ for any variable x. It is noteworthy that response of the aggregate labor is muted in our two-sector benchmark model compared to that of in the one-sector counterpart despite the Frisch labor supply elasticity being identical across the two. Importantly, this is accompanied with a large positive response of hours worked in the investment sector in the one-sector economy (Figure 3.2); this is because consumers allocate more labor into the investment sector by reducing labor supply in the consumption sector, which results in the well-known sectoral comovement problem (Katayama and Kim (2018)). This is not possible in our two-sector economy (see Figure 3.3) because reallocation of labor across the sectors is restricted by small θ. Thus, hours worked in both sectors increase after the shock hits the economy, resulting in i) no sectoral comovement problem and ii) muted aggregate labor response.[11]

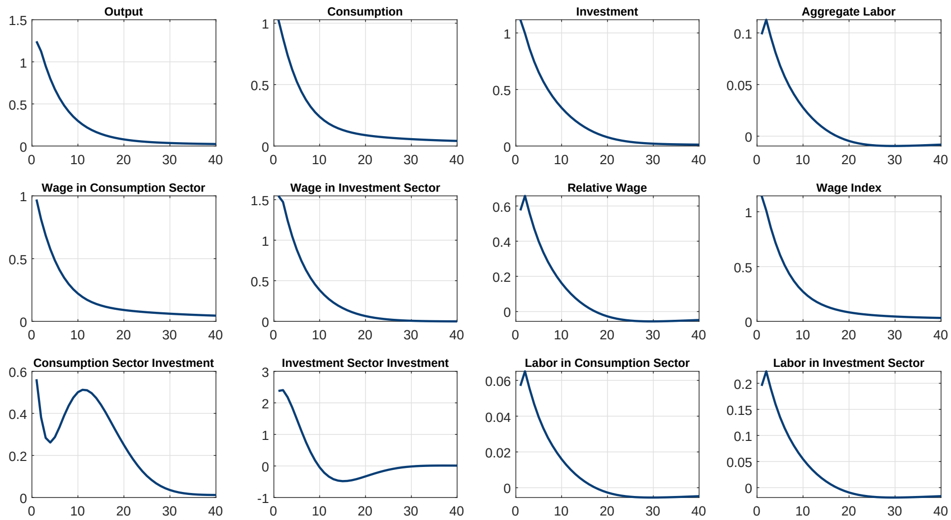
Figure 3.2: IRFs to Aggregate TFP Shock in One-Sector Frictionless Economy



In sum, the finding of the previous literature that welfare-improving business cycles are supported by a wide range of parameters seems to hold in the relatively restricted environment. In addition, whether the business cycles are good or bad for consumers seems to crucially depend on the nature of the shock. In the next section, we inspect i) why the source of the shock matters for the business cycles and ii) the extent to which each real friction matters for the welfare cost in details.

[11] We further plot the impulse response functions to C-shock and I-shock in Appendix E (Figure E.1 to E.4).

Figure 3.3: IRFs to Aggregate TFP Shock in Two-Sector Benchmark Economy



4 Role of Shocks and Real Frictions for the Welfare Cost

In this section, we analyze step-by-step why the welfare cost obtained in our model is different from the previous literature; we first study why the nature of the shock matters and then inspect the role of real frictions in determining the welfare cost. In particular, we alter assumptions on the real frictions that restrict the reallocation of resources both intra-temporally and inter-temporally since elastic usage of the production factors is the most important feature of the RBC type model in obtaining welfare-improving business cycles (Cho, Cooley, and Kim (2015) and Lester, Pries, and Sims (2014)). The former friction is captured by varying degrees of inter-sectoral factor immobilities and the latter friction is incorporated in the different size of investment adjustment cost.

4.1 Role of Shocks

In this section, we discuss the role of different productivity shocks in determining the welfare cost of business cycles. One of the most important observations from the previous section is that there exists a welfare loss, or a negative welfare cost, from lowering aggregate volatility when the I-shock generates the business cycles. On the contrary, when the C- or the aggregate TFP shocks are instead introduced, the welfare costs are computed to be positive, implying that stabilization can be welfare-improving.

Why, then, do the signs of the welfare costs of business cycles depend on the nature of shocks? As described by Cho, Cooley, and Kim (2015), there are two channels through which economic fluctuations affect the welfare of consumers; the mean effect, which increases welfare due to a higher mean level of consumption achieved from flexible factor supply under uncertainty, and the fluctuations effect, which lowers welfare as consumers are risk-averse and dislike uncertainty. In particular, when the utility function $u(C,N)$ takes the form of equation (2.2), it can be shown as in Appendix C following Flodén (2001) and Cho, Cooley, and Kim (2015), that the welfare cost, λ, can be decomposed as follows:

$$\lambda = \lambda_{mean} + \lambda_{fluctuations} \tag{4.1}$$

where λ_{mean} satisfies $u(\mathbb{E}(C_t^L), \mathbb{E}(N_t^L)) = u((1+\lambda_{mean})\mathbb{E}(C_t^H), \mathbb{E}(N_t^H))$. It is required that the mean effect be negative ($\lambda_{mean} < 0$) for the welfare-improving business cycles ($\lambda < 0$) since $\lambda_{fluctuations} > 0$ always holds when the utility function is concave. In Table 4.1, we decompose the welfare cost into the mean effect and fluctuations effect.

Table 4.1: Mean Effect and Fluctuations Effect in Benchmark Economy

	Welfare Cost (%)	Mean Effect (%)	Fluctuations Effect (%)
I-shock	-0.0058	-0.0115	0.0056
C-shock	0.0257	0.0005	0.0252
Aggregate TFP shock	0.0256	-0.0078	0.0333

Notes: Mean effect is computed as described in Appendix C.

The mean effect is sizable for the I-shock and the aggregate TFP shock while it is negligibly low for the C-shock. The total welfare gain from the I-shock is positive as the mean effect dominates the fluctuations effect. Although the mean effect from the aggregate TFP shock is comparable to that of the I-shock, there exists a welfare loss from more volatile economic fluctuations since the fluctuations effect is much larger. The mean effect is hardly generated from the C-shock, and hence, there is a welfare loss when the economy faces greater volatility.

In order to understand different degrees of the mean effect across shocks, it is convenient to express equilibrium consumption, C^*, as a function of exogenous shocks and state variable (time subscript is dropped for simplicity):

$$C^* = C(\underbrace{Z, Z_c}_{\text{direct level effect}}, \underbrace{K_c(Z, Z_i)}_{\text{capital accumulation effect}}) \tag{4.2}$$

Most importantly, the mean effect can be further decomposed into two sub-effects. The first sub-effect is the direct effect on the consumption sector (*direct level effect*): A shock directly increases the productivity of consumption goods production so that more labor inputs are used, which results in the convex response of equilibrium consumption to the exogenous shock (Cho, Cooley, and Kim (2015)). Among the three exogenous shocks we consider, this channel works for the aggregate TFP shock and the C-shock. However, the C-shock does not generate a sizable mean effect since the response of labor is much more muted than other exogenous shocks due to the income effect (see Figure 4.1 for a comparison between the aggregate TFP shock (red line) and the C-shock (blue line)). In contrast, the aggregate TFP shock (and I-shock) generates a greater response of labor, and hence equilibrium consumption is more convexly related to exogenous shocks.

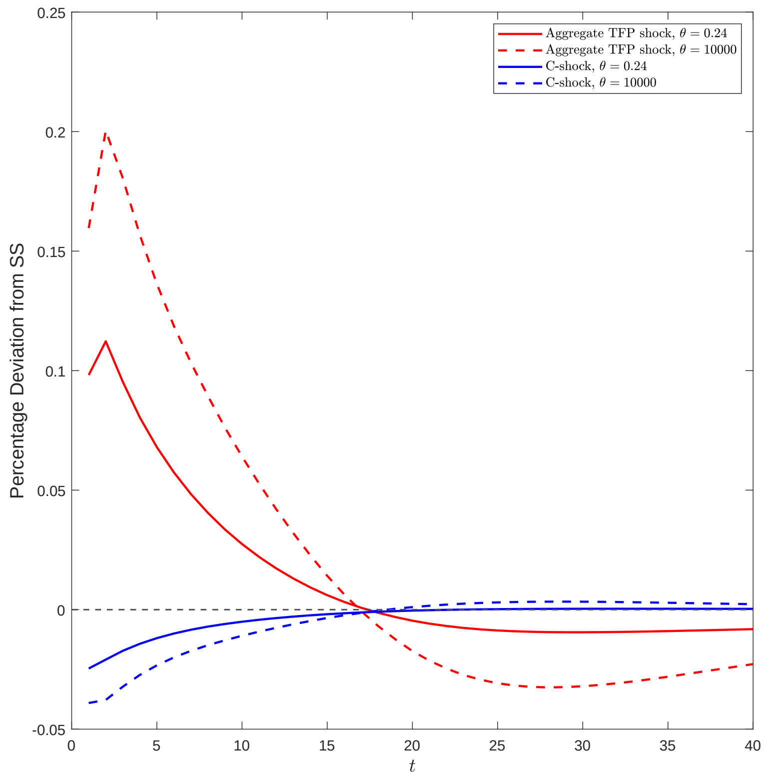


Figure 4.1: Impulse Responses of Hours Worked

Notes: Horizontal axes take model periods and vertical axes measure percentage deviations from the steady-state values. Solid line (resp. dotted line) represents impulse response of aggregate hours worked to the one-time-one-unit the technology shock when inter-sectoral labor immobility is large (resp. small).

The second sub-effect is *capital accumulation effect*: When either an aggregate TFP shock or an I-shock hits the economy, it raises productivity in the investment sector. Factor reallocation to the investment sector is more desirable for consumers, hence, more capital and labor will be devoted to the investment sector so that more capital accumulation is possible. This results in a higher mean level of consumption. We note that the first channel is absent from the I-shock generated business cycles while the second channel is absent from the C-shock generated economic fluctuations.

In sum, the mean effect would be substantial if the above-mentioned effects are substantially large. With the benchmark parameter values, it turns out that capital accumulation effect from the I-shock is large enough to generate similar or larger mean effect than that generated from the aggregate TFP shock. In Table 4.2, we compute the percentage deviation of the mean level consumption obtained under each shock from its low-volatility counterpart, which is an approximation of the mean effect originated from consumption.

Table 4.2: Mean Effect and Fluctuations Effect in Benchmark Economy: Mean vs. Volatility of Consumption

	$\frac{\mathbb{E}(C_{\text{high vol}})-\mathbb{E}(C_{\text{low vol}})}{\mathbb{E}(C_{\text{low vol}})} \times 100$	$\sigma(C_{\text{high vol}}) - \sigma(C_{\text{low vol}})$
I-shock	0.0085	0.0144
C-shock	-0.0003	0.0819
Aggregate TFP shock	0.0060	0.0960

Notes: $\mathbb{E}(C)$ is the average of consumption of the simulated economies and $\sigma(C_t)$ is the standard deviation of simulated consumption.

Interestingly, there is a sizable fluctuations effect under the aggregate TFP shock. We note that the fluctuations effect is explained by consumption volatility, following Lucas (1987). Comparing the first and third rows of Table 4.2, consumption volatility, measured as the standard deviation of consumption, is much smaller when the I-shock hits the economy than when the aggregate TFP shock does, leading to a lower fluctuations effect. The difference arises because the aggregate TFP shock directly affects the equilibrium consumption path, while the I-shock indirectly influences it through the capital accumulation channel (equation (4.2)).

4.2 Role of Real Frictions In the previous section, we analyzed the extent to which the origin of shocks is important in determining the sign of the welfare cost. In this section, we further explore the welfare cost of business cycles by focusing on the interaction between real frictions that restrict factor reallocations and the origin of shocks to understand why our two-sector model yields different welfare costs compared to the one-sector counterpart (Figure 3.1). In particular, we vary the degree of factor immobility that restricts inter-sectoral factor reallocation and the size of the investment adjustment cost that restricts inter-temporal reallocation of capital, which are often overlooked by previous literature.

We consider the aggregate TFP-driven business cycle as a benchmark, since it is directly comparable to the existing studies. Figure 4.2 and 4.3 plot the welfare cost and the corresponding mean effect, respectively, under different assumptions on parameters that govern real frictions. The starting point of the analysis is the welfare cost in the economy with the highest degree of real friction (where all real frictions are present, termed the 'Maximal friction economy'). Given the maximized real friction, the welfare cost is naturally the highest. We then gradually reduce each friction to isolate its individual effect.

Inter-sectoral Labor Mobility. Keeping other parameters fixed, increasing θ (following red arrow), which governs inter-sectoral reallocation of labor, lowers the welfare cost, i.e., welfare gain increases as θ becomes higher. This observation is straightforward to understand: Suppose that an aggregate TFP shock hits the economy. Then it is optimal for the consumer to supply more labor to the investment sector for consumption smoothing through capital accumulation. Moreover, relative wage in the investment sector is high, which eventually contributes to more accumulation of capital resulting in higher mean effect. Fortunately, it becomes easier for the consumer to reallocate labor from the consumption sector to the investment sector as θ becomes higher so that more capital can be accumulated. As a result, the mean effect increases as θ becomes greater (Figure 4.3). Furthermore, it is noteworthy that the effect of other real frictions on the welfare cost becomes smaller as θ diminishes toward zero, which emphasizes the importance of inter-sectoral labor immobility. As a result, the aggregate TFP shock-driven business cycle is still costly even when other real frictions are removed if θ is low enough.

Inter-sectoral Capital Mobility. The second real friction that we consider is inter-sectoral capital immobility: The welfare cost becomes smaller as capital flow across the sectors becomes totally free (from the solid red line to the dotted black line, denoted by the black arrow). The economic intuition behind this mechanism is omitted since it is similar to the case of changing θ. We only note that the changes in the welfare cost due to the relaxation of capital immobility (solid red line to dotted black line) depends on the size of labor immobility, θ.

Inter-temporal Capital Mobility. Lastly, we remove the friction that restricts the inter-temporal allocation of capital. As can be expected, the welfare gain from business cycles becomes greater as the size of the investment adjustment cost becomes smaller. The welfare cost of the alternative economy (dashed blue line with dots) is much smaller than that of the benchmark economy (solid red line,

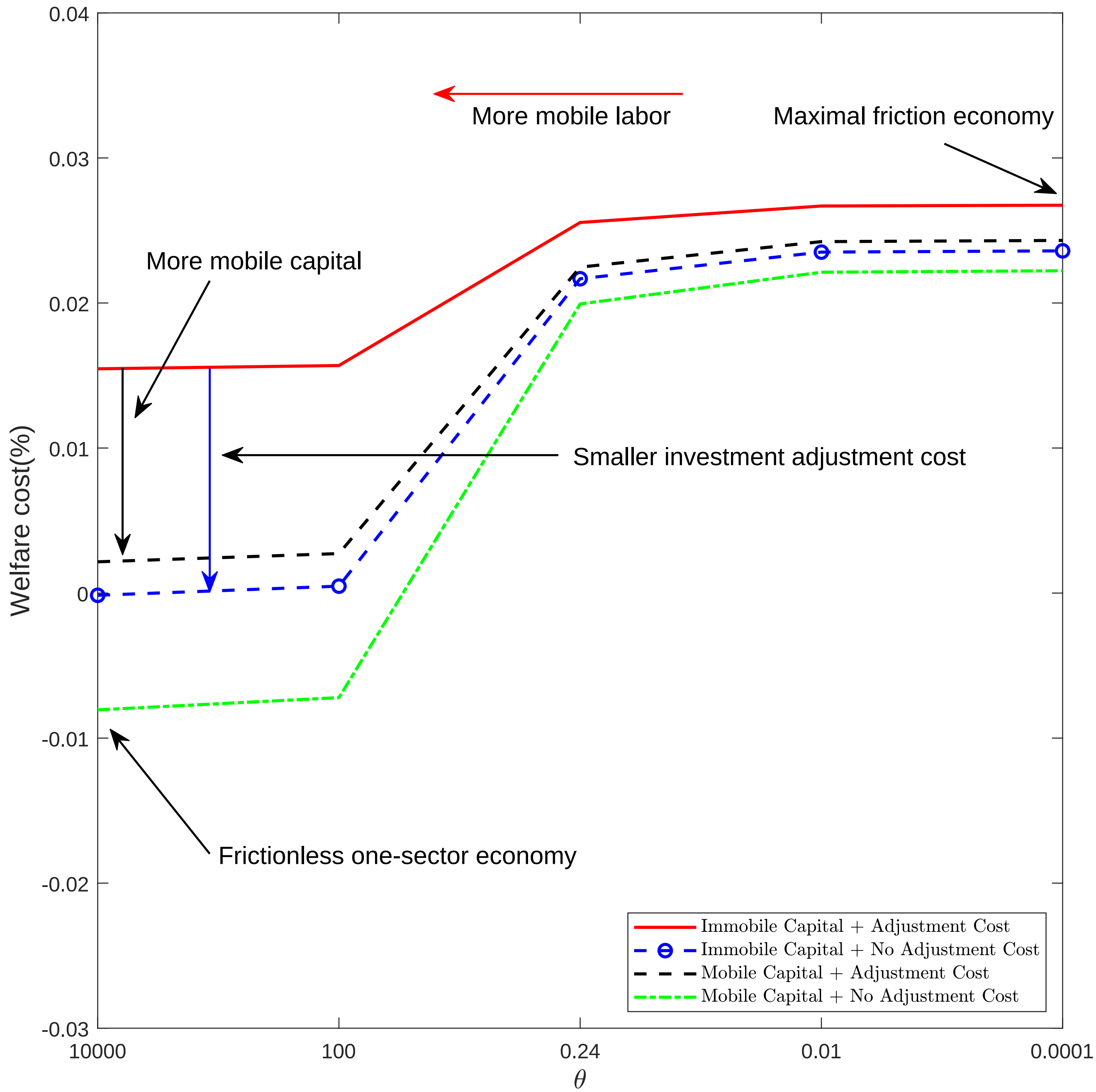


Figure 4.2: Aggregate TFP Shock: Welfare Cost

Notes: Direction of each arrow indicates that each friction becomes smaller.

following the blue arrow). The economic intuition behind the effect of the investment adjustment cost on the welfare cost is also similar. When there exists an investment adjustment cost, inter-temporal capital reallocation is restricted. A positive shock provides an incentive for the consumer to increase investment but the changes in investment is less than those in the frictionless economy, as there is a loss associated with the changes (equation (2.8)). As a result, our theory predicts that a smaller investment

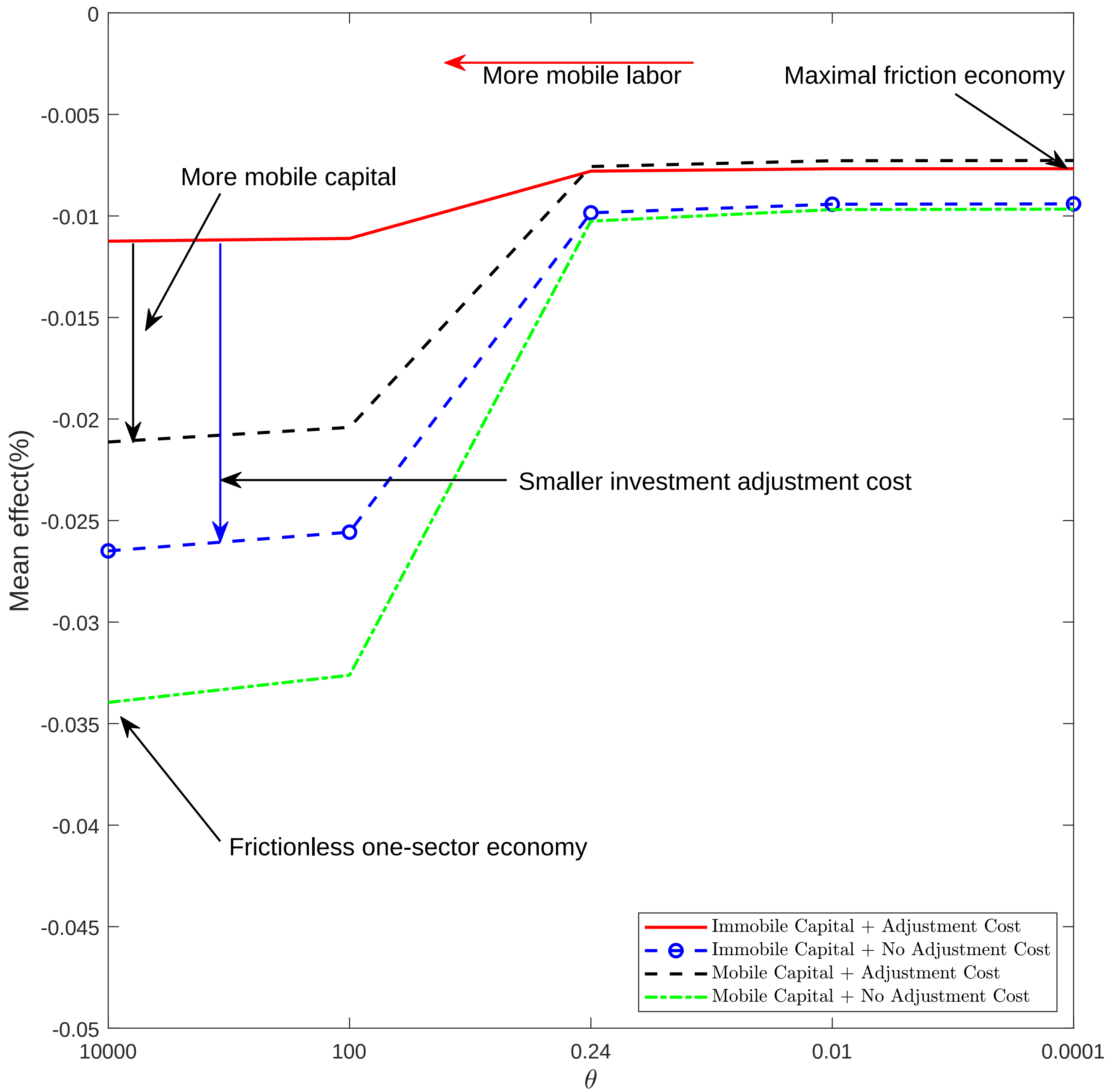


Figure 4.3: Aggregate TFP Shock: Mean Effect

Notes: Direction of each arrow indicates that each friction becomes smaller.

adjustment cost implies a greater welfare gain. Furthermore, it turns out that this margin has a more substantial effect on the welfare cost when compared to the inter-sectoral capital reallocation channel. The additional welfare gain is greater when the investment adjustment cost becomes negligible (dashed blue line with dots) compared to the change in the welfare gain when capital becomes mobile across the sectors (dotted black line). Figure 4.4 further shows that there is a positive relationship between the size of investment adjustment cost and the welfare cost of business cycles, a finding consistent with the theory.[12]

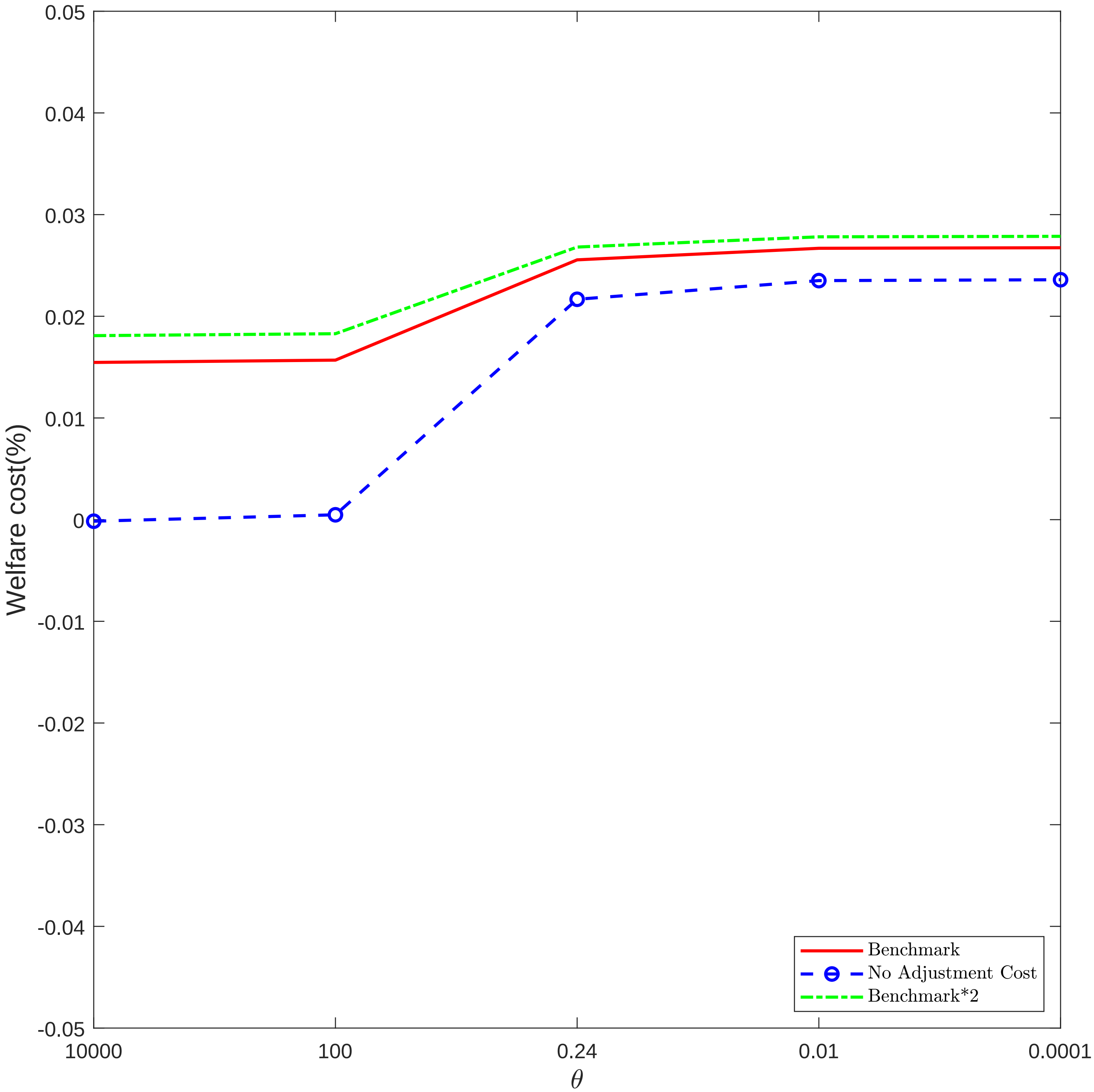


Figure 4.4: Welfare Cost with various Investment Adjustment Cost

Notes: $\kappa_c = \kappa_i$ are set to be zero for blue line, the benchmark value in Table 2.1 for red line, and twice of the benchmark value for green line.

[12] The conclusion is robust to the I-shock and higher value for κ_c and κ_i.

Summarizing, the welfare cost of business cycles is an increasing function of the degree of real frictions. As real friction becomes weaker, usage of production factors becomes more elastic, and hence the mean effect (welfare gain from economic fluctuations) becomes greater. Importantly, our analysis emphasizes the role of investment adjustment costs and inter-sectoral labor immobility as key factors of the welfare cost. When compared to the friction on inter-sectoral capital immobility, effects of both margins on the welfare cost are more substantial. In particular, the sign of the welfare cost dramatically changes as the degree of inter-sectoral labor immobility and investment adjustment cost becomes smaller; for instance, business cycles are welfare-detrimental for substantially low value of θ but it becomes welfare-improving as θ becomes significantly higher. These observations together imply that previous findings with the frictionless one-sector economy that state aggregate TFP-driven business cycles are welfare-improving in the wide parameter region might be overstated.

We now turn our focus to alternative exogenous shocks, sectoral TFP shocks. Similarly to Figure 4.2 and 4.3, Figure 4.5a and 4.6a plot the welfare cost of business cycles and Figure 4.5b and 4.6b plot the corresponding mean effect under different parameterizations, respectively. There are two important observations: First, when business cycles are driven by the I-shock, the behavior of the welfare cost under different parameter values is very similar to that of an economy under the aggregate TFP shock. Unlike the aggregate TFP-driven business cycles, however, I-shock driven business cycles are generally welfare-improving. This appears to result from the muted fluctuations effect under the I-shock, as previously discussed. The discussion about the relationship between real friction and welfare cost is omitted, as it mirrors our earlier discussion on the aggregate TFP shock.

Second, contrary to the other two exogenous shocks, C-shock driven business cycles are welfare-detrimental, regardless of real frictions. Furthermore, both the welfare cost and the mean effect are hardly affected by the degree of real frictions. The reason why the welfare cost in an economy driven solely by the C-shock remains largely unaffected by any real friction is consistent with our earlier discussions. Most importantly, the mean effect is not generated from the C-shock under any circumstances since investment efficiency does not increase when there is a positive shock specific to the consumption sector. As a result, the response of labor to the C-shock is much smaller when compared to other shocks (Figure 4.1). For example, the effect of θ on the welfare cost crucially depends on the mechanism that a higher θ does allow agents to fully utilize high investment efficiency. In the economy with the C-shock, this channel does not work.

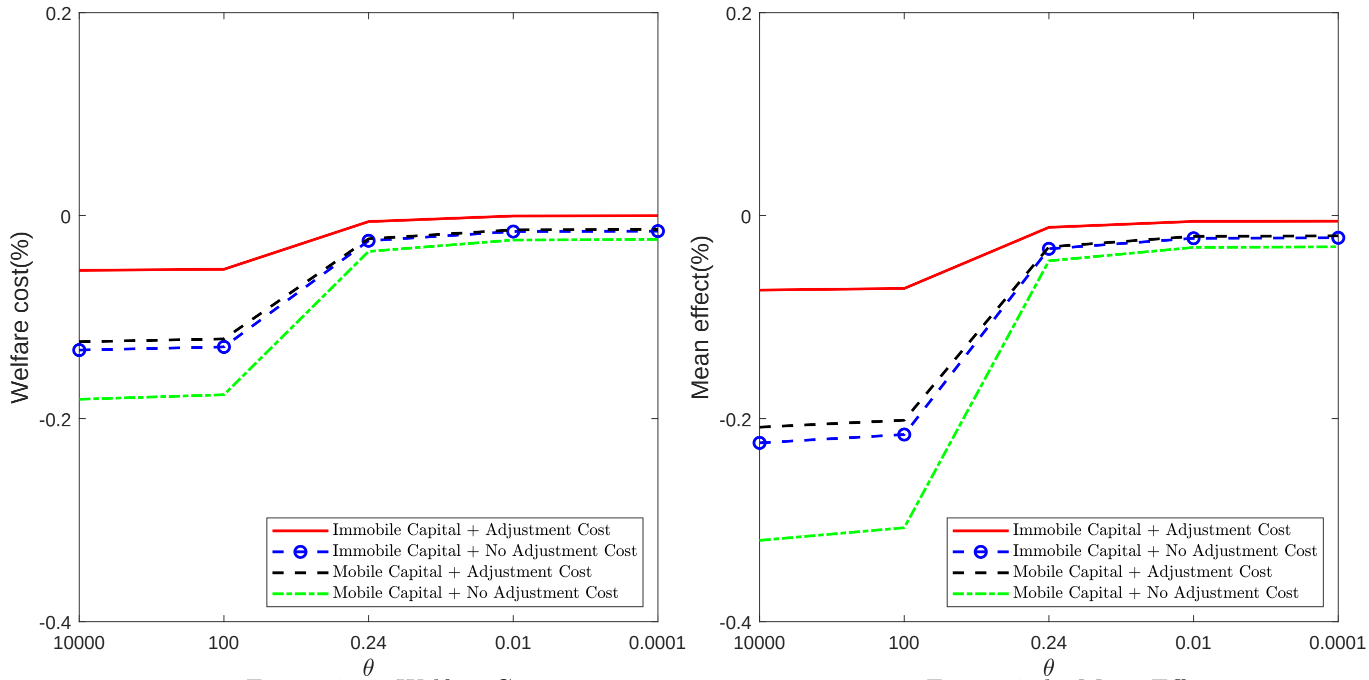


Figure 4.5a: Welfare Cost　　Figure 4.5b: Mean Effect

Figure 4.5: Investment-Specific Technology Shock

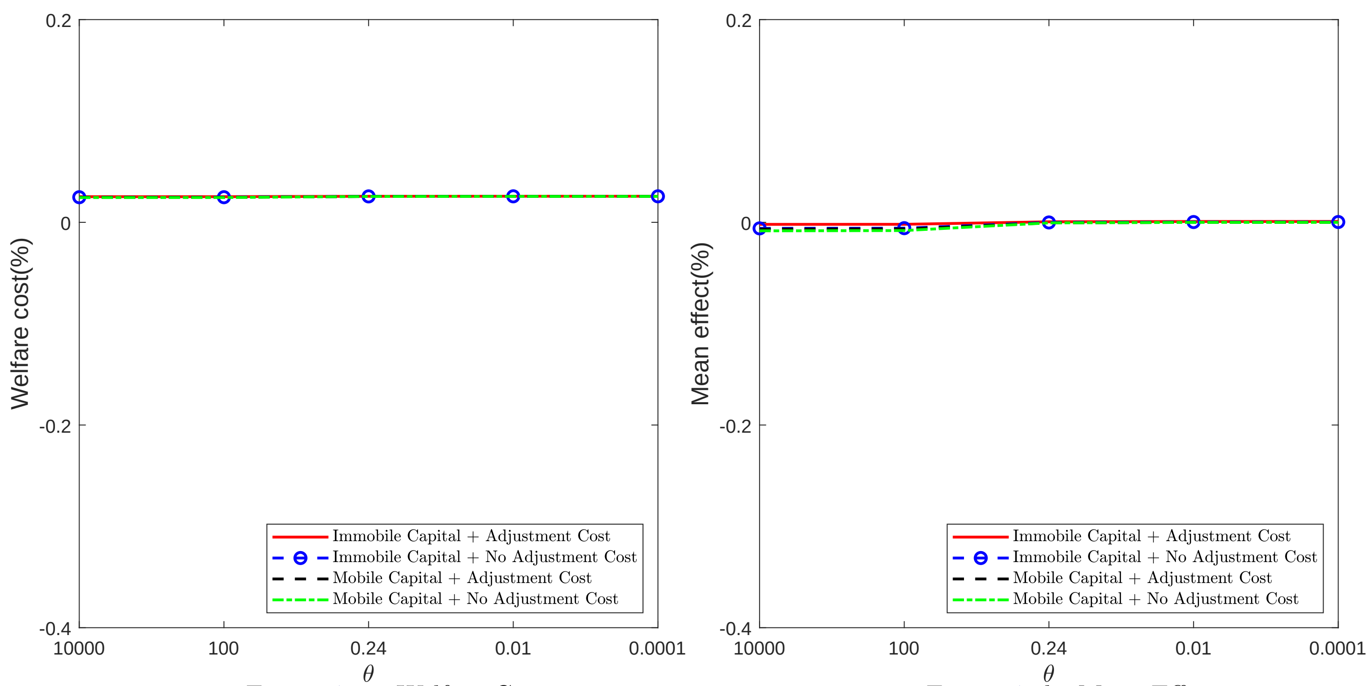


Figure 4.6a: Welfare Cost　　Figure 4.6b: Mean Effect

Figure 4.6: Consumption-Specific Technology Shock

Discussions. We now revisit one of the main arguments in Cho, Cooley, and Kim (2015) that for an exogenous shock to be welfare-improving, it should be multiplicative. The above findings indicate that the multiplicativeness of the shock is not a sufficient condition for welfare-improving business cycles:

Economic fluctuations generated from the I-shocks (resp. C-shocks) are in general welfare-improving (resp. welfare-detrimental) regardless of the value of θ, κ_j for $j = \{c, i\}$, and the degree of capital immobility. Hence, we find that in the case of C-shock generated business cycles, a multiplicative shock cannot be welfare-improving, which is a contradictory finding to Cho, Cooley, and Kim (2015). On the other hand, our findings from the I-shock is consistent with Cho, Cooley, and Kim (2015). Even in an economy with a lot of frictions that prevent effective usage of production factors, when the shock originates from the sector that produces investment-related goods, economic fluctuations can be welcomed by consumers. While there is no consensus on whether the I-shock is the main driver of the business cycles[13], our finding indicates that if the business cycles can be good for consumers, it should be related to the investment sector. In summary, for an exogenous shock to be welfare improving, i) it should be multiplicative and ii) it must affect the productivity of investment goods production in a direct manner.

We additionally point out that when the aggregate TFP shock is welfare-improving (Figure 4.2), labor market behavior implied by the model is not consistent with the data. In particular, sectoral labor comovement problem arises: As is pointed out by Katayama and Kim (2018), sectoral labor comovement is plausible in the economy when θ is low enough as in our benchmark case. When θ is infinite, for example, so that economic fluctuations are favored by consumers (Figure 4.2), the model-implied correlation coefficient between detrended total employment and detrended employment of the consumption sector is -1 while that between detrended total employment and detrended employment of investment sector is 1. Hence, a sectoral labor comovement problem arises (see Christiano and Fitzgerald (1998) and Boldrin, Christiano, and Fisher (2001) for related discussions), implying that empirical evidence does not support the notion of welfare-improving business cycles when shocks to the aggregate TFP is the source of business cycles.

[13] Some studies on the source of economic fluctuations find that a bulk of economic fluctuations in the U.S. is explained by investment-specific technology shocks, not by aggregate TFP shocks. See Fisher (2006); Justiniano and Primiceri (2008); and Justiniano, Primiceri, and Tambalotti (2010) suggesting evidence supporting this argument. On the contrary, there also exist studies that argue that the I-shock is not the main driver of the business cycles (see Justiniano, Primiceri, and Tambalotti (2011); Schmitt-Grohé and Uribe (2012); Christiano, Motto, and Rostagno (2014); and Moura (2018)).

5 Application: Welfare Implication of the Great Moderation and Changes in Importance of Sectoral Shocks

Business cycle properties in the U.S. are well-known to have significantly changed since the mid-1980s (see Galí and Gambetti (2009); Foerster, Sarte, and Watson (2011); Garín, Pries, and Sims (2018); and Galí and van Rens (2021) among many others). For example, the standard deviation of detrended GDP[14] was 0.0222 between 1964 and 1983 but lowered to be 0.0106 after 1984 (until 2019), known as "the Great Moderation." Foerster, Sarte, and Watson (2011) argued that the period of the Great Moderation is also associated with a rise in the importance of sectoral shocks. Galí and van Rens (2021) argued that reduced hiring frictions can explain the observed changes in business cycle dynamics since the mid-1980s.

What are the normative implication of the findings reported by the previous literature?[15] In order to quantitatively evaluate the welfare consequences of the above-mentioned changes, we calculate the welfare cost of business cycles with the model in which all three exogenous shocks contribute to the fluctuations.[16] As a benchmark, we first calculate the welfare cost of business cycles in the model economy in which i) the standard deviation of detrended GDP is 0.0222 and ii) aggregate TFP shock explains 80% of the variation of GDP. These two features are to match the empirical facts before the mid-1980s presented by Foerster, Sarte, and Watson (2011). We then compute the welfare cost of the alternative economy relative to the benchmark to evaluate the welfare consequences of the structural changes in the aggregate economy. We particularly consider three cases; i) when the importance of sectoral shocks increases from 20% to 50% (finding by Foerster, Sarte, and Watson (2011)), ii) when the standard deviation of detrended GDP becomes 0.0106 (capturing the Great Moderation), and iii) when both changes happen at the same time. Table 5.1 presents the results. The first (resp. second) column refers to the economy where the I-shock (resp. C-shock) is three-times more important than the C-shock (resp. I-shock). This distinction helps us analyze the relative importance of sectoral shock for our finding.[17]

[14] We use the H-P filter to obtain detrended series.

[15] We thank a referee for suggesting this exercise.

[16] For this exercise, we compute the welfare cost by comparing the steady-state with the economy fluctuating around the steady-state.

[17] The magnitude of the relative importance of each shock is not crucial, so we arbitrarily choose the contribution of the I-shock to the aggregate volatility to be three-times of that of the C-shock.

Table 5.1: Changes in the Welfare Cost

Scenario	Dominant I-shock	Dominant C-shock
Importance of sectoral shocks ↑	0.63	1.10
The Great Moderation	0.23	0.23
Importance of sectoral shocks ↑ and the Great Moderation	0.14	0.26

Notes: Each number represents the ratio between the welfare cost of business cycles under each scenario and that before the mid-1980s. The first column (Dominant I-shock) corresponds to a scenario where the I-shock contributes three times more to the variation of GDP than the C-shock while the second column (Dominant C-shock) represents the opposite.

The first row of Table 5.1 indicates that as relative importance of sectoral shocks increases, the welfare cost decreases when the I-shock outweighs the C-shock. Specifically, the welfare cost drops by about 40% when the I-shock's contribution to GDP variation rises from 15% to 37.5%. In contrast, it slightly rises when the C-shock's contribution increases in the same range. This is in line with the finding in the previous section that the C-shock is welfare-detrimental while the I-shock is welfare-improving. The second row shows the changes in the welfare cost when the variation of GDP, measured by the standard deviation of detrended GDP, lowers by half. Here, the fluctuations effect decreases substantially, leading to a reduced welfare cost. The third row represents the changes in the welfare cost when both changes simultaneously occur (Foerster, Sarte, and Watson (2011)). The welfare cost drops more when the I-shock is dominant over the C-shock. In summary, changes in the U.S. aggregate economy after the mid-1980s have cut the welfare cost by at least three-quarters.

6 Conclusion

This paper uncovers the distinct roles of different productivity shocks. Economic fluctuations improve welfare when driven by investment sector-specific technology shocks. In contrast, consumption sector-specific technology shocks have the opposite effect. Aggregate technology shocks can either improve or harm welfare. A central insight from our finding is that for a shock to enhance welfare, it must directly influence capital accumulation.

We then show that the welfare cost increases according to the degree of real frictions, in particular the degree of inter-sectoral labor immobility and the investment adjustment cost. The role of inter-sectoral capital immobility is relatively small. This implies that the welfare cost obtained from the typical one-sector model without any real frictions might be biased downward. In sum, our findings enhance the previous understanding on the welfare cost of business cycles that the optimal response of agents to exogenous changes is, together with the origin of shocks, the key to determining the welfare cost. In addition to multiplicativeness necessary for the shocks to be welfare-improving (Cho, Cooley, and Kim (2015)), we specify a further condition for exogenous shocks to be welfare-improving; the shock should directly improve the productivity of producing investment-related goods.

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A Appendix A. Equilibrium Conditions

A.1 Households

Define $q_t \equiv P_{I,t}/P_{C,t}$, $w_{j,t} \equiv W_{j,t}/P_{C,t}$, and $r_{j,t} \equiv R_{j,t}/P_{C,t}$ for $j = \{c, i\}$.

Objective and constraints

$$Max \ \ \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\frac{1}{\sigma}} \left(1 + \left(\frac{1}{\sigma} - 1\right) \nu \frac{\eta}{1+\eta} N_t^{\frac{1+\eta}{\eta}}\right)^{\frac{1}{\sigma}} - 1}{1 - \frac{1}{\sigma}}$$

$$s.t \tag{A.1}$$

$$C_t + q_t(I_{c,t} + I_{i,t}) = w_{c,t} N_{c,t} + w_{i,t} N_{i,t} + r_{c,t} K_{c,t} + r_{i,t} K_{i,t}$$

$$K_{c,t+1} = \left(1 - \frac{\kappa_c}{2}\left(\frac{I_{c,t}}{I_{c,t-1}}\right)^2\right) I_{c,t} + (1-\delta) K_{c,t} \tag{A.2}$$

$$K_{i,t+1} = \left(1 - \frac{\kappa_i}{2}\left(\frac{I_{i,t}}{I_{i,t-1}}\right)^2\right) I_{i,t} + (1-\delta) K_{i,t} \tag{A.3}$$

$$N_t = \left(N_{c,t}^{\frac{1+\theta}{\theta}} + N_{i,t}^{\frac{1+\theta}{\theta}}\right)^{\frac{\theta}{1+\theta}} \tag{A.4}$$

First order conditions

$$C_t^{-\frac{1}{\sigma}} \left(1 + \left(\frac{1}{\sigma} - 1\right)) \nu \frac{\eta}{1+\eta} N_t^{\frac{1+\eta}{\eta}}\right)^{\frac{1}{\sigma}} = \lambda_t \tag{A.5}$$

$$\frac{1}{\sigma} C_t^{1-\frac{1}{\sigma}} \left(1 + \left(\frac{1}{\sigma} - 1\right) \nu \frac{\eta}{1+\eta} N_t^{\frac{1+\eta}{\eta}}\right)^{\frac{1}{\sigma}-1} \nu N_t^{\frac{1}{\eta}} N_t^{-\frac{1}{\theta}} N_{c,t}^{\frac{1}{\theta}} = \lambda_t w_{c,t} \tag{A.6}$$

$$\frac{1}{\sigma} C_t^{1-\frac{1}{\sigma}} \left(1 + \left(\frac{1}{\sigma} - 1\right) \nu \frac{\eta}{1+\eta} N_t^{\frac{1+\eta}{\eta}}\right)^{\frac{1}{\sigma}-1} \nu N_t^{\frac{1}{\eta}} N_t^{-\frac{1}{\theta}} N_{i,t}^{\frac{1}{\theta}} = \lambda_t w_{i,t} \tag{A.7}$$

$$\mu_t^c = \beta \mathrm{E}_t \left(\lambda_{t+1} r_{c,t+1} + \mu_{t+1}^c (1-\delta)\right) \tag{A.8}$$

$$\mu_t^i = \beta \mathrm{E}_t \left(\lambda_{t+1} r_{i,t+1} + \mu_{t+1}^i (1-\delta)\right) \tag{A.9}$$

$$\lambda_t q_t = \mu_t^c \left(1 - \frac{\kappa_c}{2}\left(\frac{I_{c,t}}{I_{c,t-1}} - 1\right)^2 - \kappa_c \left(\frac{I_{c,t}}{I_{c,t-1}} - 1\right) \frac{I_{c,t}}{I_{c,t-1}}\right) \tag{A.10}$$

$$+\beta \mathrm{E}_t \left(\mu_{t+1}^c \kappa_c \left(\frac{I_{c,t+1}}{I_{c,t}} - 1\right)\left(\frac{I_{c,t+1}}{I_{c,t}}\right)^2\right) \tag{A.11}$$

$$\lambda_t q_t = \mu_t^i \left(1 - \frac{\kappa_i}{2}\left(\frac{I_{i,t}}{I_{i,t-1}} - 1\right)^2 - \kappa_i \left(\frac{I_{i,t}}{I_{i,t-1}} - 1\right) \frac{I_{i,t}}{I_{i,t-1}}\right) + \tag{A.12}$$

$$\beta \mathrm{E}_t \left(\mu_{t+1}^i \kappa_i \left(\frac{I_{i,t+1}}{I_{i,t}} - 1\right)\left(\frac{I_{i,t+1}}{I_{i,t}}\right)^2\right) \tag{A.13}$$

A.2 Firms

A.2.1 Consumption Good Production Sector

Objective

$$Max \;\; Z_t Z_{c,t} {K_{c,t}^d}^{\alpha} {N_{c,t}^d}^{1-\alpha} - w_{c,t} N_{c,t}^d - r_{c,t} K_{c,t}^d$$

First order conditions

$$w_{c,t} = (1-\alpha) Z_t Z_{c,t} {K_{c,t}^d}^{\alpha} {N_{c,t}^d}^{-\alpha} \tag{A.14}$$

$$r_{c,t} = \alpha Z_t Z_{c,t} {K_{c,t}^d}^{\alpha-1} {N_{c,t}^d}^{1-\alpha} \tag{A.15}$$

A.2.2 Investment Good Production Sector

Objective

$$Max \;\; q_t Z_t Z_{i,t} {K_{c,t}^d}^{\alpha} {N_{c,t}^d}^{1-\alpha} - w_{i,t} N_{i,t}^d - r_{i,t} K_{i,t}^d$$

First order conditions

$$w_{i,t} = (1-\alpha) q_t Z_t Z_{i,t} {K_{i,t}^d}^{\alpha} {N_{i,t}^d}^{-\alpha} \tag{A.16}$$

$$r_{i,t} = \alpha q_t Z_t Z_{i,t} {K_{i,t}^d}^{\alpha-1} {N_{i,t}^d}^{1-\alpha} \tag{A.17}$$

A.3 Market Clearing

$$C_t = Z_t Z_{c,t} K_{c,t}^{\alpha} N_{c,t}^{1-\alpha} \tag{A.18}$$

$$I_t = I_{c,t} + I_{i,t} = Z_t Z_{i,t} K_{i,t}^{\alpha} N_{i,t}^{1-\alpha} \tag{A.19}$$

$$N_{j,t} = N_{j,t}^d \tag{A.20}$$

$$K_{j,t} = K_{j,t}^d \tag{A.21}$$

for $j = \{c, i\}$.

B Appendix B. Derivation of Equation (2.20)

Under our utility specification, we can obtain the following expressions:

$$\begin{aligned} V^L &= \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\left(C_t^L\right)^{1-\frac{1}{\sigma}} \left(1 + \left(\frac{1}{\sigma} - 1\right) v(N_t^L)\right)^{\frac{1}{\sigma}} - 1}{1 - \frac{1}{\sigma}} \right] \\ &= \underbrace{\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\left(C_t^L\right)^{1-\frac{1}{\sigma}} \left(1 + \left(\frac{1}{\sigma} - 1\right) v(N_t^L)\right)^{\frac{1}{\sigma}}}{1 - \frac{1}{\sigma}} \right]}_{\equiv \bar{V}^L} - \frac{1}{(1-\beta)\left(1 - \frac{1}{\sigma}\right)} \end{aligned} \tag{B.1}$$

so that $\bar{V}^L = V^L + \frac{1}{(1-\beta)\left(1-\frac{1}{\sigma}\right)}$.

Now

$$\begin{aligned} V^{H,\lambda} &= \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\left((1+\lambda) C_t^H\right)^{1-\frac{1}{\sigma}} \left(1 + \left(\frac{1}{\sigma} - 1\right) v(N_t^H)\right)^{\frac{1}{\sigma}} - 1}{1 - \frac{1}{\sigma}} \right] \\ &= (1+\lambda)^{1-\frac{1}{\sigma}} \underbrace{\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\left(C_t^H\right)^{1-\frac{1}{\sigma}} \left(1 + \left(\frac{1}{\sigma} - 1\right) v(N_t^H)\right)^{\frac{1}{\sigma}}}{1 - \frac{1}{\sigma}} \right]}_{\equiv \bar{V}^H} - \frac{1}{(1-\beta)\left(1 - \frac{1}{\sigma}\right)} \end{aligned} \tag{B.2}$$

hence $V^{H,\lambda} = (1+\lambda)^{1-\frac{1}{\sigma}}\bar{V}^H - \frac{1}{(1-\beta)\left(1-\frac{1}{\sigma}\right)}$.

Note that

$$\begin{aligned} V^H &= \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\left(C_t^H\right)^{1-\frac{1}{\sigma}} \left(1 + \left(\frac{1}{\sigma} - 1\right) v(N_t^H)\right)^{\frac{1}{\sigma}} - 1}{1 - \frac{1}{\sigma}} \right] \\ &= \underbrace{\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\left(C_t^H\right)^{1-\frac{1}{\sigma}} \left(1 + \left(\frac{1}{\sigma} - 1\right) v(N_t^H)\right)^{\frac{1}{\sigma}}}{1 - \frac{1}{\sigma}} \right]}_{\equiv \bar{V}^H} - \frac{1}{(1-\beta)\left(1-\frac{1}{\sigma}\right)} \end{aligned} \tag{B.3}$$

hence $\bar{V}^H = V^H + \frac{1}{(1-\beta)\left(1-\frac{1}{\sigma}\right)}$.

Now one can compute the welfare cost (gain) using the following equation:

$$\lambda = \left(\frac{\bar{V}^L}{\bar{V}^H}\right)^{\frac{\sigma}{\sigma-1}} - 1 \tag{B.4}$$

C Appendix C. Mean Effect

Flodén (2001) showed in Proposition 1 that a welfare gain from a policy change (exogenous shock in our paper) can be approximately obtained by summing up isolated welfare gains if $u(\lambda C, N) = f(\lambda)u(C, N) + g(\lambda)$ holds for any λ. This appendix shows that the utility function used in our paper satisfies the condition to apply his Proposition 1 so that we can compute the mean effect as in Cho, Cooley, and Kim (2015).

Recall that the utility function takes the form 2.2. Let $\Lambda \equiv 1 + \lambda$. Then

$$\begin{aligned} u(\Lambda C, N) &= \frac{(\Lambda C)^{1-\frac{1}{\sigma}} \left(1 + \left(\frac{1}{\sigma} - 1\right) v(N)\right)^{\frac{1}{\sigma}} - 1}{1 - \frac{1}{\sigma}} \\ &= \Lambda^{1-\frac{1}{\sigma}} \left[\frac{(C)^{1-\frac{1}{\sigma}} \left(1 + \left(\frac{1}{\sigma} - 1\right) v(N)\right)^{\frac{1}{\sigma}} - \frac{1}{\Lambda^{1-\frac{1}{\sigma}}}}{1 - \frac{1}{\sigma}} \right] \\ &= \Lambda^{1-\frac{1}{\sigma}} \left[\frac{(C)^{1-\frac{1}{\sigma}} \left(1 + \left(\frac{1}{\sigma} - 1\right) v(N)\right)^{\frac{1}{\sigma}} - 1 + 1 - \frac{1}{\Lambda^{1-\frac{1}{\sigma}}}}{1 - \frac{1}{\sigma}} \right] \\ &= \Lambda^{1-\frac{1}{\sigma}} \left[\frac{(C)^{1-\frac{1}{\sigma}} \left(1 + \left(\frac{1}{\sigma} - 1\right) v(N)\right)^{\frac{1}{\sigma}} - 1}{1 - \frac{1}{\sigma}} \right] + \Lambda^{1-\frac{1}{\sigma}} \left[\frac{1 - \frac{1}{\Lambda^{1-\frac{1}{\sigma}}}}{1 - \frac{1}{\sigma}} \right] \\ &= \underbrace{\Lambda^{1-\frac{1}{\sigma}}}_{\equiv f(\Lambda)} \underbrace{\left[\frac{(C)^{1-\frac{1}{\sigma}} \left(1 + \left(\frac{1}{\sigma} - 1\right) v(N)\right)^{\frac{1}{\sigma}} - 1}{1 - \frac{1}{\sigma}} \right]}_{\equiv U(C,N)} + \underbrace{\left[\frac{\Lambda^{1-\frac{1}{\sigma}} - 1}{1 - \frac{1}{\sigma}} \right]}_{\equiv g(\Lambda)} \end{aligned} \tag{C.1}$$

Hence, our utility function satisfies the sufficient condition for Proposition 1; we can compute the mean effect as in Cho, Cooley, and Kim (2015) and the residual (whole welfare cost-mean effect) can be interpreted to measure the fluctuation effect.

We compute the mean effect following Cho, Cooley, and Kim (2015). Let λ^m measure the mean effect. Then it satisfies the following relationship:

$$u(\mathbb{E}(C_t^L), \mathbb{E}(N_t^L)) = u((1 + \lambda^m)\mathbb{E}(C_t^H), \mathbb{E}(N_t^H)) \tag{C.2}$$

Using our utility specification,

$$\frac{\left(\mathbb{E}(C_t^L)\right)^{1-\frac{1}{\sigma}}\left(1+\left(\frac{1}{\sigma}-1\right)v(\mathbb{E}(N_t^L))\right)^{\frac{1}{\sigma}}-1}{1-\frac{1}{\sigma}} = \frac{\left((1+\lambda^m)\mathbb{E}(C_t^H)\right)^{1-\frac{1}{\sigma}}\left(1+\left(\frac{1}{\sigma}-1\right)v(\mathbb{E}(N_t^H))\right)^{\frac{1}{\sigma}}-1}{1-\frac{1}{\sigma}}$$

$$\underbrace{\left(\mathbb{E}(C_t^L)\right)^{1-\frac{1}{\sigma}}\left(1+\left(\frac{1}{\sigma}-1\right)v(\mathbb{E}(N_t^L))\right)^{\frac{1}{\sigma}}}_{\equiv V(\mathbb{E}(C_t^L),\mathbb{E}(N_t^L))} = \underbrace{(1+\lambda^m)^{1-\frac{1}{\sigma}}\left(\mathbb{E}(C_t^H)\right)^{1-\frac{1}{\sigma}}\left(1+\left(\frac{1}{\sigma}-1\right)v(\mathbb{E}(N_t^H))\right)^{\frac{1}{\sigma}}}_{\equiv V(\mathbb{E}(C_t^H),\mathbb{E}(N_t^H))} \tag{C.3}$$

One can solve for λ^m:

$$\lambda^m = \left[\frac{V(\mathbb{E}(C_t^L),\mathbb{E}(N_t^L))}{V(\mathbb{E}(C_t^H),\mathbb{E}(N_t^H))}\right]^{\frac{\sigma}{\sigma-1}} - 1 \tag{C.4}$$

Note that $\lambda^m < 0$ when $V(\mathbb{E}(C_t^H),\mathbb{E}(N_t^H)) > V(\mathbb{E}(C_t^L),\mathbb{E}(N_t^L))$. Hence, under the above utility specification, the mean effect is captured as a negative value.

D Appendix D. Data Description and GMM Estimation

D.1 Data for Aggregate Variables The aggregate-level data for GMM estimation are constructed following the method used in Katayama and Kim (2018). All data covers the period of 1964Q1 ∼ 2019Q4. The listings of raw data are as follows.

- Personal Consumption Expenditures Nondurable Goods (PCND), Data Source: FRED
- Personal Consumption Expenditures Services (PCESV), Data Source: FRED
- Population Level (CNP16OV), Data Source: FRED
- Personal Consumption Expenditures Durable Goods (PCDG), Data Source: FRED
- Private Nonresidential Fixed Investment (PNFI), Data Source: FRED
- Private Residential Fixed Investment (PRFI), Data Source: FRED
- Personal consumption expenditures Nondurable goods (chain-type price index) (DNDGRG3Q086SBEA), Data Source: FRED
- Personal consumption expenditures Services (chain-type price index) (DSERRG3Q086SBEA), Data Source: FRED
- Nonfarm Business Sector Hourly Compensation for All Workers (COMPNFB), Data Source: FRED
- Investment Deflator (INVDEF), Data Source: FRED
- Production and Nonsupervisory Employees, Nondurable Goods (CES3200000006), Data Source: FRED
- Production and Nonsupervisory Employees, Private Service-Providing (CES0800000006), Data Source: FRED
- Production and Nonsupervisory Employees, Construction (CES2000000006), Data Source: FRED
- Production and Nonsupervisory Employees, Durable Goods (CES3100000006), Data Source: FRED
- Average Weekly Hours of Production and Nonsupervisory Employees, Nondurable Goods (CES3200000007), Data Source: FRED
- Average Weekly Hours of Production and Nonsupervisory Employees, Private Service-Providing(CES0800000007), Data Source: FRED

- Average Weekly Hours of Production and Nonsupervisory Employees, Construction (CES2000000007), Data Source: FRED
- Average Weekly Hours of Production and Nonsupervisory Employees, Durable Goods (CES3100000007), Data Source: FRED

We generated time-series variables for consumption (C_t), investment (I_t), output (Y_t), hours worked in the consumption sector ($N_{c,t}$), and hours worked in the investment sector ($N_{i,t}$) using the raw data. The consumption variable (C_t) is constructed by summing nondurable and service consumption and then dividing it by the noninstitutional population (population levels). Instead of using the raw population-level data, We used the HP-trend component of the population level to prevent irregular jumps caused by occasional changes in population estimates. In order to address the effect of inflation, we modified the consumption series by deflating it through the price index (P_c). This index is formulated by employing two price index data (nondurable, service) and applying the Törnqvist method.

$$C_t = \frac{\text{Nondurable (PCND)} + \text{Services (PCESV)}}{P_c \times \text{Non-Institutional Population (CNP16OV)}}$$

Investment(I_t) series is the sum of durable, non-residential investment, and residential investment divided by the noninstitutional population. Similar to the consumption case, we deflated the investment series using the same price index(P_c).

$$I_t = \frac{\text{Durable (PCDG)} + \text{Nonresidential Investment (PNFI)} + \text{Residential Investment (PRFI)}}{P_c \times \text{Non-Institutional Population (CNP16OV)}}$$

Naturally, the output (Y_t) is formulated by adding together C_t and $q_t I_t$, where q_t represents the relative price of investment goods. We adopt the investment deflator series established by DiCecio (2009), which is adjusted by dividing by P_c (given that the model's numéraire is a consumption good), as the data counterpart for the relative price of investment (q_t).

$$Y_t = C_t + q_t I_t$$

We assume that the consumption sector consists of both non-durable goods and service industries. The total hours worked in each of these industries is calculated by multiplying the number of employees by the average weekly working hours and then multiplying by 13. The total hours worked in the consumption sector is obtained by summing up the combined hours worked in the two industries and then dividing by the population level. Similarly, the hours worked in the investment sector is constructed using the same approach while using data from the construction and durable goods industries.

$$N_{c,t} = \frac{\text{Total Hours in Nondurable Industry} + \text{Total Hours in Service Industry}}{\text{Non-Institutional Population (CNP16OV)}}$$
$$N_{i,t} = \frac{\text{Total Hours in Construction Industry} + \text{Total Hours in Durable Industry}}{\text{Non-Institutional Population (CNP16OV)}}$$

Finally, We transformed all 5 variables($C_t, I_t, Y_t, N_{c,t}, N_{i,t}$) in log and extracted cyclical component using the HP-filter.

D.2 Data for Shocks We used the updated TFP series of Fernald (2014) (dtfp_util, dtfp_I_ util, dtfp_C_util, 1964Q1 ∼ 2019Q4) to estimate shock process parameters in the model. Since raw data is represented in the unit of annualized log-growth rate ($400 \cdot \Delta \log(Z)$), we transformed the data into the level form and applied the H-P filter to extract cyclical components.

D.3 Procedure for GMM Estimation In this subsection, we describe the procedure for GMM estimation in detail. We need to estimate six shock process parameters $(\rho_z, \rho_c, \rho_i, \sigma_z, \sigma_c, \sigma_i)$ and two investment adjustment cost parameters κ_c, κ_i. We take the following steps:

1. Transform the three data series of TFP, which are provided in the growth rate, into the level to be consistent with model processes. Then, apply the H-P filter to the three data series to obtain their cyclical components. Construct time-series data for aggregate variables (Output, Consumption, Investment, Labor) and obtain cyclical components by applying the H-P filter.
2. Define three variables, ZZ_c (shocks to the consumption sector in the model corresponding to dtfp_C_util), ZZ_i (shock to the investment sector in the model corresponding to dtfp_I_util), and $ZZ_i^{\omega} Z_c^{1-\omega}$ (aggregate shock corresponding to dtfp_util), in the model. When constructing the last variable, we use the time-average value of ω (investment share=0.22). Compute theoretical moments based on the pruned state-space representation of the perturbation solution (Taylor-approximation around the non-stochastic steady-state).
3. Run two-step GMM estimation using the data generated in the first step where moment conditions are the variance of ZZ_c, ZZ_i, $ZZ_i^{\omega} Z_c^{1-\omega}$, output, consumption, investment and hours, contemporaneous covariance of output, consumption, investment and hours, and autocovariance of output, consumption, investment and hours up to lag 1. Stop when the improvement in the estimation becomes smaller than the tolerance level (0.000001).

E Appendix E. Additional Tables and Figures

Table E.1: Estimation Results

Parameter	Estimate	s.d	t-stat
κ_c	0.2396	0.0969	2.4728
κ_i	0.0987	0.0220	4.4865
ρ_z	0.8363	0.0312	26.7766
σ_z	0.0046	0.0006	7.3672
ρ_c	0.8109	0.0246	32.9227
σ_c	0.0056	0.0007	8.2924
ρ_i	0.7983	0.0040	197.5121
σ_i	0.0349	0.0014	25.6132

Table E.2: Replication (TFP shock, Separable Utility): Table 1 of Lester, Pries, and Sims (2014) (Left panel) vs. Frictionless One-Sector Economy (Right panel)

	σ=2	σ=1	σ=2/3	σ=1/3	σ=1/5		σ=2	σ=1.1	σ=2/3	σ=1/3	σ=1/5
$\eta=\infty$	-0.2915	-0.0493	0.0405	0.1376	0.1794	η=10000	-0.0732	-0.0532	-0.0302	0.0060	0.0209
η=2.5	-0.1275	0.0149	0.0854	0.1767	0.2218	η=2.5	-0.0349	0.0067	0.0553	0.1468	0.2302
η=1	-0.0599	0.0452	0.1075	0.2008	0.2530	η=1	-0.0129	0.0357	0.0923	0.2010	0.3043
η=1/3	-0.0083	0.0706	0.1268	0.2297	0.3004	η=1/3	0.0086	0.0604	0.1215	0.2412	0.3571
η=1/10	0.0156	0.0832	0.1369	0.2522	0.3484	η=1/10	0.0206	0.0728	0.1354	0.2595	0.3807

Notes: σ denotes elasticity of intertemporal substitution and η represents Frisch labor supply elasticity. We set $\theta = 10,000$ and $\kappa_j = 0$ for $\{j = c, i\}$ with perfect capital mobility across sectors for Frictionless One-Sector Economy. Welfare costs are calculated by comparing the unconditional welfare of the high-volatility regime ($\sigma_z = 0.02$) and low-volatility regime ($\sigma_z = 0.01$).

E.1 Tables

Table E.3: Replication (TFP shock, KPR Preference): Table 2 of Lester, Pries, and Sims (2014) (Left panel) vs. Frictionless One-Sector Economy (Right panel)

	σ=2	**σ=1**	**σ=2/3**	**σ=1/3**	**σ=1/5**		**σ=2**	**σ=1.1**	**σ=2/3**	**σ=1/3**	**σ=1/5**
η=∞	n/a	-0.0493	0.0466	0.1775	0.2867	**η=10000**	-0.0732	-0.0532	-0.0302	0.0060	0.0209
η=2.5	n/a	0.0149	0.0802	0.2035	0.3149	**η=2.5**	-0.0349	0.0067	0.0553	0.1468	0.2302
η=1	-0.0689	0.0452	0.1016	0.2229	0.3369	**η=1**	-0.0129	0.0357	0.0923	0.2010	0.3043
η=1/3	0.0020	0.0706	0.1233	0.2456	0.3637	**η=1/3**	0.0086	0.0604	0.1215	0.2412	0.3571
η=1/10	0.0200	0.0832	0.1356	0.2600	0.3814	**η=1/10**	0.0206	0.0728	0.1354	0.2595	0.3807

Notes: σ denotes elasticity of intertemporal substitution and η represents Frisch labor supply elasticity. We set $\theta = 10,000$ and $\kappa_j = 0$ for $\{j = c, i\}$ with perfect capital mobility across sectors for Frictionless One-Sector Economy. Welfare costs are calculated by comparing the unconditional welfare of the high-volatility regime ($\sigma_z = 0.02$) and low-volatility regime ($\sigma_z = 0.01$).

Table E.4: Replication (I-shock): Table 4 of Lester, Pries, and Sims (2014) (Left panel) vs. Frictionless One-Sector Economy (Right panel)

	σ=2	**σ=1**	**σ=2/3**	**σ=1/3**	**σ=1/5**		**σ=2**	**σ=1.1**	**σ=2/3**	**σ=1/3**	**σ=1/5**
η=∞	-0.3172	-0.2030	-0.1679	-0.1343	-0.1212	**η=10000**	-0.4063	-0.2273	-0.1157	-0.0244	0.0109
η=2.5	-0.2212	-0.1389	-0.1085	-0.0766	-0.0632	**η=2.5**	-0.3026	-0.1571	-0.0757	-0.0098	0.0199
η=1	-0.1812	-0.1086	-0.0796	-0.0470	-0.0327	**η=1**	-0.2419	-0.1231	-0.0586	-0.0041	0.0230
η=1/3	-0.1504	-0.0832	-0.0547	-0.0201	-0.0033	**η=1/3**	-0.1819	-0.0940	-0.0451	0.0000	0.0252
η=1/10	-0.1361	-0.0707	-0.0420	-0.0053	0.0149	**η=1/10**	-0.1477	-0.0794	-0.0387	0.0020	0.0262

Notes: σ denotes elasticity of intertemporal substitution and η represents Frisch labor supply elasticity. We set $\theta = 10,000$ and $\kappa_j = 0$ for $\{j = c, i\}$ with perfect capital mobility across sectors for Frictionless One-Sector Economy. Welfare costs are calculated by comparing the unconditional welfare of the high-volatility regime ($\sigma_i = 0.02$) and low-volatility regime ($\sigma_z = 0.01$).

E.2 Figures - Note for subsequent figures: Relative wage refers to $\frac{w_{i,t}}{w_{c,t}}$, wage index denotes $\frac{w_{c,t}N_{c,t}+w_{i,t}N_{i,t}}{N_t}$, and the unit of Y-axis is $100 * (\log(x_t) - \log(x_{ss}))$.

Figure E.1: IRF to I-shock in One-Sector Economy

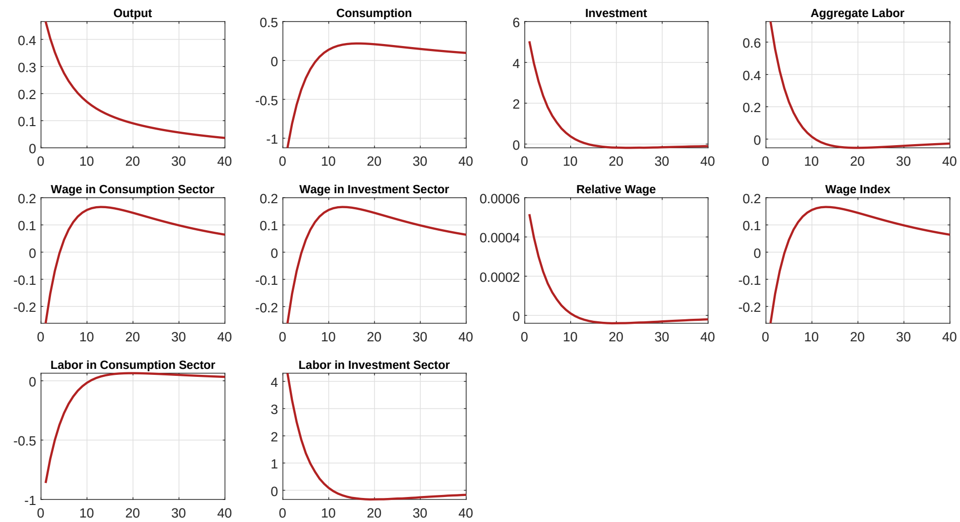

Figure E.2: IRF to C-shock in One-Sector Economy

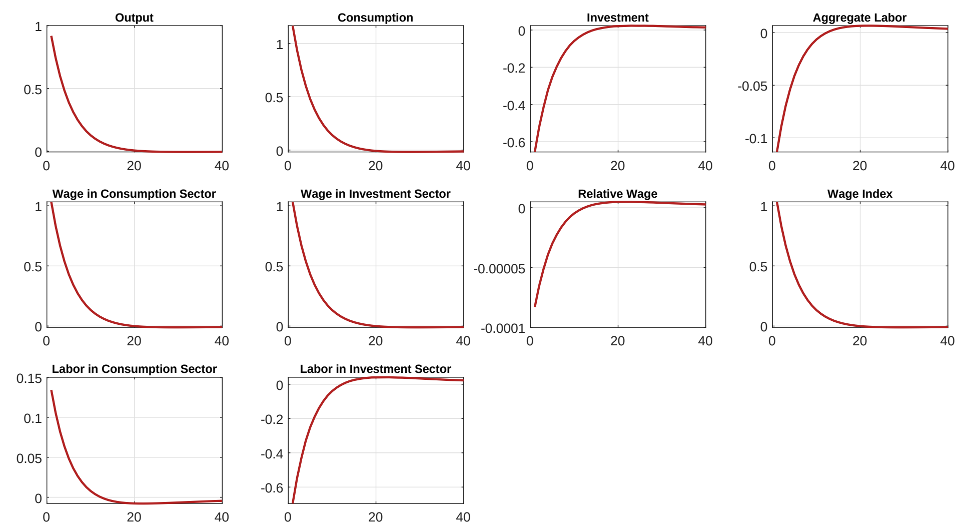

Figure E.3: IRF to I-shock in Two-Sector Economy

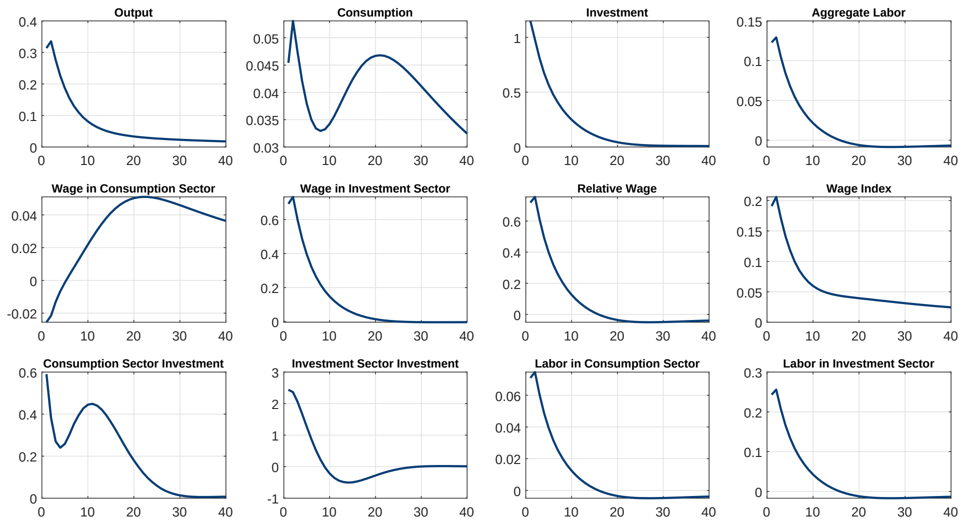

Figure E.4: IRF to C-shock in Two-Sector Economy