ESSAYS ON INVESTMENT, ASSET PRICES AND TECHNOLOGY SHOCKS

DISSERTATION

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By

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ABSTRACT

My dissertation sheds light on the relationship between the shadow value of capital, the market value per capital stock, and investment. When the asset market is efficient, firms’ market value per capital stock, average $q$, represents the shadow value of capital, marginal $q$ or fundamental $q$.

Average $q$, however, is observed as different movements from fundamental $q$ because of i) investment adjustment specifications and goods market structure, and ii) investors’ speculative behavior. My first paper emphasizes the importance of adjustment costs and studies the interactions between average $q$, fundamental $q$, and investment. The second paper explores the relationship through the structural vector autoregressive model at the macro level. The paper allows market speculation and constructs fundamental $q$ with discounted profit rate along with average $q$.

The first paper evaluates the importance of investment installment costs in a sticky price model by comparing two different adjustment cost specifications; one depends on the investment-to-capital stock ratio, and the other depends on investment growth. The two adjustment cost specifications are considered, since the former has been adopted in the empirical literature such as Hayashi (1982) and the latter has been adopted in the theoretical literature such as Chirinko and Fazzari (1994). There is a stronger positive asset price (or average $q$) response to a positive technology shock when the adjustment cost depends on investment growth. In addition, the
investment growth specification generates a hump shaped response of investment and a semi-hump shaped response of output.

As indicated in Hayashi (1982), higher fundamental $q$ leads to higher investment purchases. Higher shadow value of capital means that additional capital stock creates net profits, enabling firms to increase investment purchases. An efficient asset market implies a close positive relation between average $q$ and fundamental $q$, and thus higher average $q$ leads to higher investment purchases. Previous literature has focused on average $q$ and investment at the micro level with a single-equation regression model, and the result was not satisfactory. I have conducted empirical research to answer whether investment is sensitive to fundamental $q$ or average $q$ through comparison of impulse responses to a technology shock. In addition, the extent to which technology shocks explain average $q$ fluctuations is studied through forecast error variance decomposition.

My empirical paper has applied the structural vector autoregressive model with the restriction that only technology shocks can alter labor productivity in the long run. Impulse responses to technology shocks indicate that there exists a positive interaction between investment and average $q$. On the other hand, fundamental $q$ is influenced by investment but not in an adverse direction; fundamental $q$ follows investment growth rate. Furthermore, without having average $q$ in the equation, fundamental $q$ alone cannot be a significant explanatory variable to predict investment. Positive technology shocks are expected to raise firms’ profits, output, and investment. The variance decomposition results suggest that technology shocks account for larger portions of output and investment when average $q$ is used without fundamental $q$. When fundamental $q$ is included in the estimation, the portion of investment
fluctuations caused by technology shocks shrink significantly, which confirms that fundamental $q$ cannot explain investment fluctuations.
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CHAPTER 1

INTRODUCTION

In this dissertation, I discuss an aggregate asset price and its role in real economic activity such as investment and output. The asset price is a leading variable which forecasts near term economic activity. Economic agents observe information carried in the asset price and this influences their decisions. First I study the asset market with computational analysis. Unlike previous research I discuss the specification of investment technology itself. The asset price has different dynamics depending upon the details of the adjustment cost specification, and the identification of the capital installation function is helpful to understand the asset price behavior. In addition, I study the effects of the asset market on economic activity using the asset market indices. This work is the first that includes market index in the structural vector autoregressive estimation.

This dissertation is organized as follows. In chapter 2, I discuss in detail the factors determining the asset price and report how two specifications of the capital installation technology affects economic dynamics. In chapter 3, using macroeconomic data series, I report the responses of economic variables to a technology shock conditional on asset market indices. The capital installation technology affects both the asset market and real economic activity. Other literature discusses the size of the
capital installation costs, but not the specification itself. Basu (1987) discusses the capital installation but he makes conclusion only about effects of adjustment costs on economic volatility. Costly installation raises the cost of future consumption, and firms are reluctant to increase investment quickly. In this dissertation I emphasize the capital installation technology itself. Although investment technology is accompanied with the same volatility of output, various specifications of the technology generate the different dynamics of the asset price and investment.

Investment builds a bridge between the asset market and real economic activity. Previous research studies the correlation between investment and an asset market index, such as Chirinko et al (1994). In this dissertation, I approach the issue with a structural vector autoregressive estimation using macro variables. The estimation makes it possible to draw a bigger picture rather than the single relationship between investment and an asset market index. I report economic dynamics resulting from the estimation. The source of the dynamics is a technology shock. Technology shocks are relatively exogenous compared to monetary shocks. To identify the effects of a shock on economic activity, I assume that only technology shocks change labor productivity in the long-run. Other shocks change labor productivity but only in the short-run. This long-run assumption excludes controversies about instantaneous effect of a shock. Gali (1999), Christiano et al (2003), Fisher (2003), and Altig et al (2005) apply the long-run structural vector autoregression to their analysis, and I use their methodology and study the role of the asset market index in economic activity.

Chapter 2 elaborates on the relationship between investment technology and the asset price. I bring the examples of an investment installation function, which satisfies characteristics of investment elasticity. Capital supply is quite elastic in the long-run,
but not in the short-run. One example is that capital installation is more efficient when the existing capital stock is larger. The other example is that capital installation is more efficient when changes in investment growth are smaller. First, the capital installation affects investment planning such that a firm, in the former case, raises investment instantly to save future adjustment costs with a positive shock. In the latter case, a firm raises investment but it avoids any drastic changes in the investment growth. Investment supplies production factor, the new capital stocks, and it is a part of aggregate demand. A firm’s revenue rises when aggregate demand increases. Smaller increases in investment result in smaller increases in aggregate demand, and also smaller increases in the revenue. In addition, a firm, in the former case, has larger adjustment costs for the early periods due to larger increase in investment and also the smaller holding capital stock. In the latter case, a firm can avoid the adjustment cost by managing the investment growth. The benefit of an investment purchase is the value of the created capital stock, while the cost is cash-outflows. When investment decreases over time, the benefits of investment dominate the costs. The benefits of investment push up the asset price. A positive technology shock raises the asset price in the investment growth technology more than the asset price in investment-capital stock technology.

In chapter 3, I conduct structural vector autoregressive estimation with various sets of variables in terms of asset market indices. I consider two market indices; one is a ratio of asset price to capital stock, average $q$, and the other is profit forecast, fundamental $q$. Average $q$ is a leading variable, and it responds immediately to an unexpected event. On the other hand, depending upon the asset market environment, fundamental $q$ responds immediately or with delays. When an economy is stable,
profit forecasts responds to an unexpected event with a lag. Average $q$ stimulates output and input when the asset market is stable in the short-run. Fundamental $q$ under such an economic circumstance has little impact on output and investment in the short-run. When an economy has experienced turbulent changes, the forecast responds without delays to a shock. In this circumstance, average $q$ provides information besides future forecasts, and fundamental $q$ filters information carried in average $q$. The estimation using only necessary variables shows that average $q$ raises output and investment, and fundamental $q$ boosts output and investment further. On the other hand fundamental $q$ without average $q$ slightly reduces output and investment. The estimation including monetary factor generates some different results such that average $q$ does not always boost up both output and investment. Average $q$ boosts output in the medium term, while it reduces investment.

Chapter 4 concludes.
CHAPTER 2

THE ASSET PRICE AND INVESTMENT TECHNOLOGY

2.1 Introduction

Whereas in the long-run the supply of new capital, i.e. investment, is relatively elastic, in the short-run investment is inelastic. One modeling technique to incorporate the elasticity of investment is adjustment costs, which describe higher short-run installment costs of capital than the long-run costs. This paper compares two adjustment cost specifications; one is a function of the investment-per-capital ratio, and the other is a function of investment growth. Both specifications explain the properties of investment elasticity which are more elastic in the long-run than in the short-run. The former emphasizes the scale efficiency that a firm holding a larger capital stock faces smaller installment costs. Chirinko and Fazzari (1994), and Blanchard et al (1993) adopt this specification in their empirical research to detect the relationship between investment and the stock market. The latter emphasizes investment rigidity that a firm conducting stable investment spending faces smaller installment costs. Dupor (2001) and Christiano et al (2005) conduct computational analysis with investment growth adjustment costs.

Much empirical research of investment is based on Hayashi (1982), which refines Tobin’s $Q$ theory. The theory is that a firm raises investment when the ratio of market
value to replacement cost of capital stock, average $q$, rises. Firms decide on investment based on shadow value of capital stock, marginal $q$, since it represents potential profits that an additional capital stock generates. Hayashi (1982) provides foundation for employing average $q$ instead of marginal $q$ in empirical research. It provides convenience to empirical research since average $q$ is observable but not marginal $q$. Hayashi explains that average $q$ is equivalent to marginal $q$ under three conditions: the completely competitive goods market, a linear homogeneous production function, and a linear homogeneous adjustment cost function with investment and capital. The adjustment cost specification of the ratio of investment-per-capital stock satisfies the third condition and the studies test correlation of investment and average $q$.

The cost specification of the ratio of investment-per-capital stock does not explain the investment behavior suggested in empirical research employing vector autoregressive estimation. Structural vector autoregression (SVAR) estimation reports a hump-shaped response of investment and output such as Altig et al (2006) and Christiano et al (2005). The hump-shaped response of investment implies investment rigidities and the investment-growth adjustment cost describes them quite well. Significant changes in investment growth raise installment costs while a firm minimizes installment costs by gradual changes of investment. The other specification implies that a small-sized firm faces larger capital installment costs than a large-sized firm rather than investment rigidities. Economic models explaining SVAR results employ the adjustment cost specification of investment growth.

Suppose a company that purchases investment goods the same amount each period. It has optimal staff and equipment for capital installment each period. It does
not need to employee more staff and equipment and also it does not have any resources. Significant increase in investment compared to lagged investment is followed by significant increase of installation costs since it is harder to find experienced staff. The adjustment cost specification of the investment growth describes that a constant spending on investment goods over time reduces the capital installation costs. Suppose two different capital size companies purchase the same amount of investment goods. A large-sized company faces smaller installment costs than a small-sized company does because a large-sized company has accumulated knowledge and technology for the capital installation. The cost specification of a ratio of investment-capital describes that the size of the capital stock reduces the installation costs.

This paper studies the relationship between asset prices and investment technology in a general equilibrium framework. I emphasize the adjustment cost specifications, which generate various characteristics of investment such as rigidity and scale efficiency. Furthermore the cost specification changes the relationship between asset price and the value of capital stock. When the adjustment cost is linear homogeneous with investment and capital, asset price is equivalent to the value of capital stock. The other cost function implies that asset price is smaller than the value of capital stock by the adjustment cost.

Asset price signals the value of current capital stock. The value of capital stock measures potential profits that capital stock generates in the future. Investment-capital adjustment cost indicates that capital stock contributes in goods production and also in creating new capital stock. In other words, the installation costs of new capital stock are reflected in the value of capital stock. On the other hand, investment growth adjustment cost indicates that capital stock contributes only in goods
productions and previous investment effects the current installation costs. Investment is cash-outflows and the adjustment cost is reflected cash-flows not in the value of capital stock. Consequently asset price shows the difference from the value of capital stock by the adjustment cost.

Basu (1987) explains the role of the adjustment cost in asset price movements. He uses a parameter that represents the effect of adjustment cost at the steady state to explain the role of the cost. The larger adjustment costs are accompanied with the lower volatility of both investment and asset price. He assumes that supply of capital stock is not flexible both in the long-run and short-run, and it exaggerates the effect of the adjustment cost on an economy. My paper excludes the long-run effect of adjustment costs on resources, and assumes that supply of capital is flexible in the long-run. Both adjustment cost specifications conclude that the larger adjustment costs, both investment and asset price have lower volatility.

A positive technology shock raises output and investment. The productivity of capital stock rises when output increases faster than capital stock does. Investment rigidity generates gradual changes in investment and a more sluggish accumulation of capital stock. Consequently I observe a higher productivity of capital when there is investment rigidity. Productivity of capital stock is a main factor in determining asset price since asset price measures the value of capital stock by the contribution to potential profits. Investment growth adjustment cost reports larger and more persistent responses of asset price to a positive shock than the other cost specification.

This paper assumes that a monetary authority changes short-term interest rates to stabilize economic fluctuations. Without additional monetary shocks, the authority implements contractionary policy to positive technology shocks. When the policy
sticks to interest-rate smoothing, asset prices in an economy with investment rigidities change very little. On the other hand, asset prices in an economy without the rigidities display smaller responses with stronger interest-rate smoothing.

Many papers analyze the effect of technology shocks in business cycle, such as Gali, Fisher and Christiano et al (2003). They do not agree on the empirical effects on production input such as working hours. Basu et al (2004) discusses the effect of technology shocks and suggests that a monetary policy rule could counter-act a positive technology shock. The monetary authority implements contractionary policy when it targets economic stability. There are discussions about asset prices as a monetary policy instrument such as Dupor (2001, 2002, and 2005) and Carlstrom and Fuerst (2003). My paper discusses monetary policy and asset prices whose policy instrument is short-term nominal interest rates.

Section 2 explains an economic model and it discusses the role of adjustment costs in detail. Section 3 presents a complete macroeconomic framework, and discusses adjustment costs with computational simulation results. In this section, I deliberate asset prices and the adjustment cost with an alternative interest-rate smoothing rule. Section 4 concludes.

2.2 Economic Model

There are three types of agents in the economy: firms, households and the government. A firm produces output with labor and its own capital. A capital market does not exist so each firm accumulates its own capital stock by investment. Calvo type price stickiness is adopted such that each firm has a chance to optimize its price with probability \( (1 - \theta) \) for each period.
Infinite-lived households consume the final goods and supply labor. The households save wealth with government issued risk-free bonds and the stocks of firms. The monetary policy follows the Taylor rule and government spending is assumed to be zero for simplicity.

The labor market is completely competitive, while the final goods market is monopolistically competitive and the elasticity of substitution among goods of monopolist is $\varepsilon$. The aggregate output and price index are denoted with $Y_t$ and $P_t$ and a firm $z$’s output and price are $Y_t^z$ and $P_t^z$ on time $t$. The demand for final goods is assumed to have constant elasticity of substitution such that the aggregate output is expressed as $Y_t = \left( \int_0^1 (Y_t^z)^{-\varepsilon} dz \right)^{-\frac{1}{\varepsilon}}$ and price index is $P_t = \left( \int (P_t^z)^{1/\varepsilon} dz \right)^{\varepsilon}$. Optimal consumption decisions will imply,

$$\frac{Y_t^z}{Y_t} = \left( \frac{P_t^z}{P_t} \right)^{-\frac{1}{\varepsilon}}$$

where the elasticity of substitution $\varepsilon$ is positive.

### 2.2.1 Investment and Price Setting

A firm $z$ purchases investment goods($I_t^z$) and labor($N_t^z$), and it optimizes its price $P_t^z$ with probability $(1 - \theta)$ each period. The firm pays its profits as dividends to stockholders after it pays labor cost and purchases investment goods. The value of a firm $z$, $V_t(z)$, is defined as the present value of life-time cash flow ($CF_t^z$). The firm maximizes its value with investment ($I_t^z$), employment ($N_t^z$), and output price($P_t^z$);

$$V_t(z) = \max_{I_t^z, N_t^z, K_t^z, P_t^z} E_t \sum_{k=0}^{\infty} \beta^k \Lambda_{t+k}^z CF_t^{z+k}$$

s.t. $K_t^z = \Psi_t^z + (1 - \delta) K_{t-1}^z \forall z$ \hspace{1cm} (2.3)

where $CF_t^z = \frac{P_t^z}{P_t^z} A_t^z \left( K_{t-1}^z \right)^{\alpha} \left( H_t^z \right)^{1-\alpha} - w_t H_t^z - I_t^z$
where $\Lambda_{t,t+k}$ denotes the intertemporal substitution of the household and $A_t^z$ is total factor productivity. Capital installment technology, $\Psi_t^z$, denotes an adjustment cost function of a firm $z$ at time $t$. When assuming a complete set of state contingent claim, a firm’s time dependent discount factor is the intertemporal substitution. The investment adjustment cost is a function of investment growth rate, $\Psi_t = \left( 1 - s \left( \frac{I_t}{I_{t-1}} \right) \right) I_t$, and it is increasing and convex in investment. In addition, adjustment costs have no effect on the steady state, $s(1) = s(1)' = 0$ and $s(1)'' = \kappa > 0$.

To simplify notation, the superscript $z$ is dropped from all variables except output price, $P_t^z$. The optimal investment makes marginal cost equal to the marginal benefit each period:

$$
\lambda_t \left( 1 - s_t - \frac{I_t}{I_{t-1}} s'_t \right) + \beta E_t \Lambda_{t,t+1} \lambda_{t+1} \left( \frac{I_{t+1}}{I_t} \right)^2 s'_{t+1} = 1
$$

(2.4)

where $\lambda_t$ is the Lagrangian multiplier for the capital evolution process (2.3) and $s_t$ is defined as $s(I_t/I_{t-1})$. The right-hand side of equation (2.4) is the price of investment purchase, which is one since the final goods are used for investment or consumption. The benefits of investment purchases are the value of created capital and the present value of net adjustment cost saving, which are in the left hand side of equation (2.4). The first term in the left-hand side of equation (2.4) is the value of the created capital with marginal investment, where $s_t$ and $s'_t$ measure the efficiency of capital installment. When the capital installment is less efficient, then the created capital stock is smaller; $s_t$ and $s'_t$ are larger, created capital stock per investment $\left( 1 - s_t - \frac{I_t}{I_{t-1}} s'_t \right)$ is smaller. Increased investment reduces the cost of investment in the following period. When current investment purchases create enough capital, it decreases the need for investment and also installment cost in the next period. The
installment costs savings from current investment are \( \lambda_{t+1} \left( \frac{I_{t+1}}{I_t} \right)^2 s'_{t+1} \), the second term of the left hand side.

Equation (2.5) shows that productivity of capital stock determines the value of capital stock.

\[
\lambda_t - \beta E_t \Lambda_{t,t+1} \lambda_{t+1} (1 - \delta) = \alpha E_t \left\{ \Lambda_{t,t+1} \left( 1 - \frac{1}{\varepsilon} \right) \frac{P_{t+1}^2 Y_{t+1}}{P_{t+1} K_t} \right\}
\]  

(2.5)

The shadow value of capital, marginal \( q \), rises when marginal revenue product of capital increases. Additional capital stock is more efficient in production, the value of capital stock is higher. Equation (2.5) indicates that instantaneous value of marginal \( q \) relies on the present value of the marginal revenue stream.

The optimal capital stock equation (2.5) is transformed as follows,

\[
\lambda_t K_t - \beta E_t \Lambda_{t,t+1} \lambda_{t+1} K_{t+1} = \beta E_t \Lambda_{t,t+1} \left\{ \frac{CF_{t+1} - \frac{P_{t+1}^2 Y_{t+1}}{P_{t+1} K_{t+1}}}{\varepsilon} + \left( I_{t+1} - (1 - s) I_t \lambda_{t+1} \right) \right\}
\]  

(2.6)

\[
V_t - \beta E_t \Lambda_{t,t+1} V_{t+1} = CF_t
\]  

(2.7)

where \( CF_t \) is cash flows for time \( t \). Equation (2.7) is drawn from the definition of firms value, \( V_t \), which is the present value of expected cash flow stream. Substitution of cash flow in equation (2.6) with (2.7) builds up the relationship between marginal \( q \) and a firm’s value, i.e. asset price.

Cash flow, not reflected in the value of capital stock, makes asset price different from the value of capital stock. Mark-up profits are additional cash inflows due to market structures but not productivity of the capital stock (the second term in the bracket of equation (2.6)). In addition, adjustment cost, increasing with the investment growth, indicates that capital stock has no contribution for reducing installment costs. Consequently, installment cost is not reflected in the value of capital.
stock. Current investment reduces next period installment cost, and the cost is measured with investment, cash outflows. Adjustment cost, the last term in the bracket of equation (2.6), are additional cash outflows due to investment technology and it makes asset price lower than the value of capital stock.

Alternative adjustment cost specifications imply a different relationship between the goods market and the asset market. As I specify the adjustment cost as a function of investment-per-capital ratio, \( \Psi_t = \left( 1 - \tilde{s} \left( \frac{I_t}{K_{t-1}} \right) \right) I_t \), investment rigidity disappears. I assume that adjustment cost is convex and increasing with investment, \( \tilde{s} (I_t/K_{t-1})' > 0 \), and \( \tilde{s} (I_t/K_{t-1})'' > 0 \). In addition, the adjustment cost has no impacts on the steady state, that is, \( \tilde{s} (\delta) = \tilde{s}' (\delta) = 0 \) and \( \tilde{s} (\delta)'' = \tilde{\kappa} > 0 \).

A firm’s optimal investment and capital stock conditions are changed as follows,

\[
\lambda_t \left( 1 - \tilde{s}_t - \frac{I_t}{K_{t-1}} \tilde{s}'_t \right) = 1 \tag{2.8}
\]

\[
\lambda_t - E_t \beta \lambda_{t,t+1} (1 - \tilde{s}) \lambda_{t+1} = \beta E_t \lambda_{t,t+1} \left\{ \frac{\alpha (1 - \frac{1}{\tilde{\varepsilon}}) P_{t+1} \gamma_{t+1}}{P_{t+1} K_t} \right\} \tag{2.9}
\]

where \( \tilde{s}_t \) is a function of investment-per-capital ratio at period \( t \), \( \tilde{s}_t = \tilde{s} (I_t/K_{t-1}) \).

The optimal investment equates marginal benefits to marginal costs as reported in equation (2.8). Marginal purchasing cost is one, the price of investment goods, and installment costs are the value of foregone capital stock, \( \lambda_t \left( \tilde{s}_t + \frac{I_t}{K_{t-1}} \tilde{s}'_t \right) \). Inefficiency of installment is measured with \( \tilde{s}_t \) and \( \frac{I_t}{K_{t-1}} \tilde{s}'_t \) such that the created capital stock is smaller when \( \tilde{s}_t \) and \( \frac{I_t}{K_{t-1}} \tilde{s}'_t \) are larger. Marginal benefits of investment are the value of created capital stock, the left-hand side of equation (2.8).

The optimal capital stock condition (2.9) indicates that the value of capital rises when the expected marginal revenue product of capital increases. Current capital is
more valuable when the adjustment costs are expected to rise. Both productivity of capital and adjustment cost are reflected in the value of capital stock. The value of capital stock reflects contribution of capital on both production and investment technology. Depending upon investment technology, the role of capital stock in potential profits is different. Investment growth adjustment cost reports the contribution of capital stock only in production (equation 2.5), and investment-per-capital reports it in both production and investment technology (equation 2.9).

The optimal capital stock equation (2.9) builds up the relation of the firm’s value per capital \( V_{t+1} \) and the value of capital \( \lambda_t \) by transformation:

\[
\begin{align*}
\lambda_t K_t - E_t \Lambda_{t,t+1}\lambda_{t+1} K_{t+1} &= \beta E_t \Lambda_{t,t+1} \left\{ CF_{t+1} - \frac{1}{\varepsilon} \frac{P_{t+1}}{P_{t+1}} Y_{t+j} \right\} \\
CF_t &= V_t - \beta E_t \Lambda_{t,t+1} V_{t+1}
\end{align*}
\]

(2.10)

Asset price signals the value of capital stock. Asset price measures lifetime cash flows and the value of capital stock measures its contribution to lifetime profits. Mark-up profits are cash flows from market-structure and they are not reflected in the value of capital stock. When adjustment cost is a function of investment-per-capital ratio, the mark-up profits raise asset price above the value of capital stock. Comparison of equation (2.6) and (2.10) indicates that rigidity in investment amplifies the role of investment in the asset price.

Two adjustment cost specifications show the difference in the value of capital stock and in the relationship between asset price and the capital value. The capital value corresponds only to the marginal revenue product of capital with investment growth adjustment costs; whereas the capital value corresponds to both the marginal revenue product of capital and the adjustment cost with investment-per-capital adjustment.
cost. Asset price corresponds to the capital value and to mark-up profits in both adjustment cost specifications. Only investment growth adjustment cost reports that asset price corresponds to the capital value.

The first order conditions for labor demand and price decisions are given as follows:

\[(1 - \alpha) \left( 1 - \frac{1}{\varepsilon} \right) \frac{P^z_t}{P^z_t} Y_t / H_t = w_t \]  
\[P^z_t / P_t = \pi P^z_{t-1} / P_t \text{ with prob.} \theta \]  
\[P^*_z / P_t \text{ with prob.} (1 - \theta) \]  

The optimal labor demand condition, equation (2.11), equates marginal cost of labor to the marginal revenue product of labor. Equation (2.12) shows that a firm \( z \) optimizes its optimal price with probability \( (1 - \theta) \). When a firm can not choose its optimal price, it updates its price with the average inflation rate. (Yun, 1996)

A firm maximizes present value of profit stream with price after taking into account the probability \( \theta \), marginal cost of production and price elasticity of demand.

\[
\max_{\{p_t\}} \sum_{k=0}^{\infty} \theta^k \beta^k E_t \left\{ \Lambda_{t,t+k} \left( \frac{P^z_t}{P_{t+k}} - mc_{t+k} \right) \left( \frac{P^z_t}{P_{t+k}} \right)^{-\varepsilon} Y_{t+k} \right\} 
\]  
\[\text{(2.13)}\]

The price optimizing problem (2.13) shows that the economy faces monopolistic competition and Calvo style price stickiness. A firm \( z \)'s outputs are determined with the relative price of its good \( (P^z_t) \) to the average price \( (P_{t+k}) \), and the mark-up depends on price elasticity of demand and the expected real marginal cost of production. The solution of the problem (2.13) is the following,

\[P^z*_{t} = \frac{1}{\varepsilon - 1} \sum_{k=0}^{\infty} \theta^k \beta^k E_t \left\{ \Lambda_{t,t+k} Y_{t+k} P^z_{t+k}^e mc_{t+k} \right\} \]
\[\text{(2.14)}\]
The average price \((P_t)\) on period \(t\) is composed with two parts; \((1 - \theta)\) portion of producers set their prices at \(t\) and the other portion \(\theta\) of producers update price levels with the average inflation rate \(\pi\). Price index \(P_t\) at time \(t\) is summarized as follows:

\[
P_t = \left\{ (1 - \theta) \left( P_t^{z*}\right)^{1/\varepsilon} + \theta \left( \pi P_{t-1}\right)^{1/\varepsilon} \right\}^{\varepsilon}
\]  

(2.15)

2.2.2 Households

Infinite lived households maximize lifetime utility with consumption\((C_t)\), and labor supply\((H_t)\). Households save income for future consumption with risk free bond\((B_t)\) and stock\((x_t)\). A firm \(z\)'s stock purchase is denoted with \(P_t^x (z) x_t (z)\), and stock purchase over all firms is denoted with \(P_t^x x_t \left( = \int P_t^x (z) x_t (z) dz. \right)\), where \(P_t^x (z)\) is the stock price of a firm \(z\) in terms of consumption goods and \(P_t^x\) is the stock price index. Each firm pays its profit to stockholders in forms of dividend \((D_t (z) x_t (z))\) each period and the aggregate dividends are \(D_t x_t \left( = \int D_t (z) x_t (z) dz. \right)\).

Risk free bond purchases are \(B_t/P_t\) and it pays nominal interest \(R_{t+1}\) to the holder in the following period. The government transfer payments \((T_t)\) are added to the household income on time \(t\).

A household’s lifetime utility maximization problem is summarized as follows,

\[
\max \{C_{t+k}, H_{t+k}, B_{t+k}, x_{t+k}\}_{k=0}^{\infty} \sum_{k=0}^{\infty} \beta^k E_t \left\{ \ln C_{t+k} + \eta \ln (1 - H_{t+k}) \right\} \\
\text{s.t. } C_t + P_t^x x_t + \frac{1}{R_t} \frac{B_t}{P_t} \leq w_t H_t + (D_t + P_t^x) x_{t-1} + \frac{B_{t-1}}{P_t} + T_t
\]

(2.16)

where \(\eta\) is a leisure preference parameter and \(C_t \left( = \left( \int C_t(z)^{\frac{1}{1-\varepsilon}} dz \right)^{\frac{\varepsilon}{\varepsilon-1}} \right)\) is the consumption index over all diversified goods. Labor supply to a firm \(z\) is denoted to
as $H_t(z)$ and the aggregate labor supply is $H_t(= \int H_t(z) \, dz)$. The labor market is completely competitive and production technology is assumed to be identical across firms, such that all firms pay real wage $w_t$ and labor income of the household is $w_t H_t$.

The first order condition of the problem (2.16) with $x_t$ is,

$$E_t P^x_t - \beta E_t \Lambda_{t,t+1} P^x_{t+1} = \beta E_t \Lambda_{t,t+1} D_{t+1}$$

(2.17)

A firm $z$ distributes profits $(CF_{t+k}(z))$ to shareholders, $j = 1...J$, as dividends $(D_{t+k}(z))$ per share($x_{t+k}$) at period $(t+k)$, and \( \int x_{t+k-1} D_{t+k}(z) \, dj = CF_{t+k}(z) \).

Taking into account a firm’s profits are the difference of firm’s value and the expected value of a firm in the following period $\beta (E_t \Lambda_{t,t+1} V_{t+1} - \beta E_t \Lambda_{t,t+2} V_{t+2})$ and it is equivalent to $E_t P^x_t x_{t-1} - \beta E_t \Lambda_{t,t+1} P^x_{t+1} x_t$. Without loss of generality, I assume that aggregate outstanding stock is one for all periods.

### 2.3 General Equilibrium

#### 2.3.1 log linearization

This section presents the general equilibrium condition in the log-linearized formula. In the log linearized equations the lower-case letter of each variable denotes a percentage deviation around its steady state value and the upper-case letter without time subscript denotes steady state value.

A firm’s investment decision (2.4) and the optimal capital condition (2.5) are log-linearized around steady state as follows,
\[ \mu_t - \beta(1 - \delta) * E_t \{ c_t - c_{t+1} + \mu_{t+1} \} \]  
\[ = \alpha \beta \left(1 - \frac{1}{\varepsilon}\right) \frac{Y}{K} E_t \{ c_t - c_{t+1} + w_{t+1} + h_{t+1} - k_t \} \]
\[ \kappa E_t \{ \Delta i_t - \beta \Delta i_{t+1} \} = \mu_t \]  

where \( \mu_t \) is the deviation of marginal \( q \) from the steady state, and \( \Delta x_t \) denotes the growth of \( x_t \). Marginal \( q \) measures contribution of capital stock on profits, and major role of capital is a factor of production. Marginal revenue product of capital is a factor in marginal \( q \) movements (equation 2.18), where log-linearized revenue is equivalent to \( w_t + h_t \) drawn from the labor demand condition.

The adjustment cost specification is revealed as the response of investment to the capital value such that investment growth responds to marginal \( q \) (equation 2.19). Increase of marginal \( q \) signals that additional capital stock creates more profits, and a firm builds up more capital with investment. When adjustment cost, \( \kappa \), is too large, a firm raises investment little more. In other words, to minimize installment cost, a firm keeps the investment growth rate and it avoids occasions of change investment speed.

The asset price equation (2.6) is log-linearized after the asset price \( P_t^x \) replaces the firm’s value \( E_t \{ \Delta_{t,t+1} V_{t+1} \} \).

\[ \left(1 + \frac{1}{\varepsilon} \frac{\beta Y}{1 - \beta K} \right) E_t \Delta_t P_t^x = E_t \Delta_t (\mu_t + k_t) + \frac{\beta Y}{\varepsilon} E_t (w_{t+1} + h_{t+1}) \]  
\[ - \beta \delta E_t (i_{t+1} - i_t - \mu_{t+1}) \]  

Time difference of a variable \( \Delta_t x_t \) takes into account the discount factor such as \( \Delta_t x_t = \{ x_t - \beta E_t (c_t - c_{t+1} + x_{t+1}) \} \). Equation (2.20) reveals that the capital value
corresponds to the role of capital stock only in production. Costs occurred with creating capital stock are not reflected in the capital value, but in the asset price. Asset price measures the potential profit that a capital stock creates, and it also measures cash flows resulted from non-production activity such as mark-up profits and capital installment cost. Mark-up profits, the second bracket in equation (2.20), result from the market structure, and the installment cost, the third bracket in equation (2.20), results from investment technology. A firm benefits from investment by the value of the created capital stock, \( (i_t + \mu_{t+1}) \), and investment costs the price of investment goods, \( i_{t+1} \). The size of the created capital stock measures the costs of the capital installation. Investment activity is not reflected in the value of capital stock, since the capital stock does not work in the capital installation. The limited role of the capital stock in the installment implies that the capital accumulation process is not an important factor of the value of capital. On the other hand, investment is a part of cash-flows and the asset price should adjust the cash-flows which are not reflected in the value of capital. When the benefits of investment are larger than the costs, the net benefits of investment pushes the asset price up.

I compare alternative adjustment cost specification, a function of investment-per-capital ratio. The optimal investment and capital stock conditions (2.19, and 2.18) are changed as follows:

\[
\begin{align*}
\mu_t - \beta (1 - \delta) E_t \{ c_t - c_{t+1} + \mu_{t+1} \} &= \beta E_t \left\{ \alpha \left(1 - \frac{1}{\delta}\right) \sum_{K} \left( c_t - c_{t+1} + w_{t+1} + h_{t+1} - k_t \right) \right\} \\
\delta \tilde{\kappa} (i_t - k_{t-1}) &= \mu_t
\end{align*}
\]

(2.22)

where \( \kappa \) is the adjustment cost parameter and \( \mu_t \) is the log-linearized shadow value of capital, marginal \( q \). Capital works as a production factor and it also works in creating
new capital stock. Marginal $q$ measures the value of capital stock based on its role in
the marginal revenue productivity, the first bracket in the right hand side of equation
(2.21) and also in the efficiency of capital installation, the second bracket of equation
(2.21). Marginal $q$ rises when the marginal revenue of capital stock increases; or
marginal $q$ rises when adjustment costs fall due to capital stock.

Equation (2.22) represents investment decision, such as investment-per capital
rises when marginal $q$ increase. Investment decision shows the adjustment cost spec-
ification such that investment-per-capital ratio responds to marginal $q$. A firm raises
investment purchase if marginal $q$ increases. When benefits of additional capital stock
rise, a firm builds up more capital stock with investment. When the adjustment cost,
$\kappa$, is larger, the investment-per-capital ratio is less sensitive. Unlike equation (2.19)
investment growth rate is not restricted to any costs, however installment cost falls
with larger capital stock.

The asset price equation (2.10) is modified with an alternative adjustment cost
function.

\[
\left(1 + \frac{1}{\varepsilon} \frac{\beta}{1 - \beta} \frac{Y}{K} \right) E_t \Delta p_{t+1}^x = E_t \Delta_t \left( \mu_t + k_t \right) + \frac{\beta}{\varepsilon} \frac{Y}{K} \left( w_t + h_t \right) \tag{2.23}
\]

The asset price rises when the value aggregate capital stock is larger (equation 2.23).
When current capital stock creates larger cash flow, the asset market raises the firm’s
value. The installment cost adjusts marginal $q$, and it changes the asset price through
marginal $q$.

Equation (2.24) is derived from Calvo-style staggered price setting (equations
2.14 and 2.15). It captures the marginal cost of production in the labor market for
computational convenience.
\[
\pi_t = \beta E_t \pi_{t+1} + \frac{1 - \theta}{\theta} (1 - \beta \theta) (w_t + h_t - y_t)
\] (2.24)

Equations (2.25) and (2.26) are log-linearized Euler equations of the household. Households have logarithmic utility over consumption and it implies that the intertemporal elasticity of consumption is the real interest rate (2.25). In addition, household preference is separable over leisure and consumption, and the marginal rate of substitution of consumption and leisure is the ratio of working hours to leisure time, equation (2.26).

\[
\begin{align*}
    r^n_t &= E_t (c_{t+1} - c_t) + E_t \pi_{t+1} \\
    c_t &= w_t - \frac{H}{1 - H} h_t
\end{align*}
\] (2.25) (2.26)

Equation (2.27) is the log-linearized production function. The capital evolution process is described in equation (2.28). The installment cost has no impact on the capital evolution process because of the assumption of an adjustment cost function, \( s = s' = 0 \).

\[
\begin{align*}
    y_t &= a_t + \alpha k_t + (1 - \alpha) h_t \\
    k_{t+1} &= \frac{I}{K} i_t + (1 - \delta) k_t
\end{align*}
\] (2.27) (2.28)

Equation (2.29) is the log-linearized resource constraint. Aggregate expenditures are household consumption \( c_t \) and investment.

\[
y_t = \frac{C}{Y} c_t + \frac{I}{Y} i_t
\] (2.29)
Monetary authority uses short-term interest rates as a policy instrument, equation (2.30). It adjusts the current interest rate to the lagged interest rate, current inflation and output, that is the Taylor rule. Monetary authority cannot separate out if the variation of output is due to supply shocks or demand shocks.

\[ r_t^n = \rho^n r_{t-1}^n + (1 - \rho^n) \left( \rho^n \pi_t + \rho^\gamma \gamma_t \right) + m s_t^\pi \]  

(2.30)

Monetary shock \( m s_t^\pi \) follows independent and identical distribution with the variance \( \sigma^\pi \).

\[ a_t = (1 - \rho^a) \ln(A) + \rho^a a_{t-1} + a s_t^a \]  

(2.31)

Technology follows stationary autoregressive process with the coefficient \( \rho^a \). The shock \( a s_t^a \) is independent and identically distributed with variance \( \sigma^a \).

### 2.3.2 Model Simulations

In this section a quantitative analysis is performed to illustrate the effect of investment adjustment costs on asset prices in a sticky price framework. I choose quite conventional values for most parameters. The discount parameter \( \beta \) and total factor productivity \( A \) are set to 0.99 and one respectively. The capital share \( \alpha \) is 0.32 and the depreciation rate \( \delta \) is 0.025. The labor disutility parameter \( \eta \) is taken to be 2.75. The probability a firm does not change its price for each period is set to 0.6, and the firm makes the average period of price adjustment is two and a half quarters. The serial correlation coefficient for the technology shocks is assumed to be 0.95.

The autoregressive parameter \( \rho^m \) in the monetary policy rule is set to 0.5 and the coefficients on inflation \( \rho^n \) and output \( \rho^\gamma \) are 1.5 and 0.1 respectively. The nominal
interest rate rises 1.5 percent in response to a permanent one percent increase in inflation rate.

I compare two adjustment cost functions, investment growth versus investment-per-capital. The investment elasticity parameter $\kappa$ is taken to be 2.6 at which output volatility is equivalent in two cases.

I consider an alternative value of $\rho^n$, and adjust elasticity parameter $\kappa$. When the autoregressive parameter rises to 0.9, elasticity of investment parameter $\kappa$ increases to 3.6 that equates output volatility of two cases.

2.3.3 Results

This section draws the impulse responses of economic variables to one standard deviation technology shock. Two cases display different features of investment, and it affects the asset price movements. 1) Efforts to reduce adjustment costs generate the responses of investment in two cases. In the $(i - k)$ case, a firm has a motivation to accumulate capital in the early periods, since the larger capital stock reduces adjustment costs. In the $\Delta i$ case, a firm has a motivation to avoid the drastic changes in the growth of investment, since it generates larger installation costs. 2) As long as investment is positive, it generates adjustment costs in the $(i - k)$ case. On the other hand a firm, in the $\Delta i$ case, has zero adjustment costs when investment spending is constant over all periods. Current investment raises current adjustment costs, but it reduces next adjustment costs. The smaller adjustment costs indicate that the same size of investment creates more capital stock, and consequently the larger value of created capital stock. The costs of an investment purchase are smaller than the benefits of an investment purchase, and it is observed when the investment
growth falls. 3) The responses of the asset price in the $\Delta i$ case are larger than the $(i-k)$ case, because of the smaller present value of adjustment costs. The benefits of optimal management of the investment growth push up the asset price. 4) Monetary policy suppresses the initial increase of aggregate demand and the smaller increase of aggregate demand results in the smaller increase of asset price. The stronger interest rate smoothing rule of the policy suppresses more the initial increase of aggregate demand. Consequently, both marginal revenue product of capital and marginal $q$ fall.

The adjustment cost specification affects investment decisions through efforts to reduce installation costs. Depending on the investment technology, a firm takes into account lagged investment or its accumulated capital stock for investment decision. Figure 2.1 draws the investment responses to a positive technology shock and the main variable affecting investment decision, marginal $q$.

The marginal revenue product of capital stock measures the contribution of the capital stock in production, figure 2.1(a). Price and capital productivity are the factors leading movements of marginal revenue product of the capital stock. A positive technology shock raises productivity and it reduces production costs. Lower production costs push down the price level, while the price rigidity mitigates pressure on price movements. When an increase in output is larger than a decrease in price, the higher productivity causes the higher marginal revenue product of capital. The marginal revenue of the $\Delta i$ case, the first parenthesis of equation (2.18), jumps up when the positive shock is realized. It rises for 3 quarters and then falls continuously since the effects of the shock on productivity diminishes continuously. The $(i-k)$ case also shows that marginal revenue, the first parenthesis of equation (2.21), jumps up in the first period. After 3 quarters it continuously falls along with the capital
productivity. Compared to the \((i-k)\) case, marginal revenue in the \(\Delta i\) case shows gradual changes due to investment rigidity. Changes in productivity result from the relative changes of output to the capital stock. Investment rigidity generates gradual changes in aggregate demand and a more gradual accumulation of the capital stock.

Figure 2.1\((b)\) describes the shadow value of the capital stock, marginal \(q\). The \(\Delta i\) case shows that marginal \(q\) jumps up in the first quarter, and it decreases from the 3rd quarter. The \((i-k)\) case displays the positive responses to a positive technology shock such that it jumps up in the first quarter and converges to zero from third quarter. Both cases demonstrate that marginal \(q\) decreases faster than marginal revenue, since marginal \(q\) measures the present value of marginal revenue product of capital, equation (2.18) and (2.21). Only for the \((i-k)\) case, marginal \(q\) captures the costs and benefits of investment since the capital stock reduces adjustment costs. In early periods, investment is larger than the capital accumulation, and the costs, investment spending, are larger than the benefits, more efficient creation of the capital stock. In later periods, effects of a technology shock on investment decrease, and saving effects on adjustment costs increase. Reflection of investment technology on marginal \(q\) results the larger initial response in the \(\Delta i\) case than the \((i-k)\) case. In addition, marginal \(q\) in the \(\Delta i\) case decreases faster than in the \((i-k)\) case.

The higher marginal \(q\) raises investment, and the investment responses are different depending upon the investment technology. Figure 2.1\((c)\) displays each investment response to a percent standard deviation technology shocks. Investment in the \(\Delta i\) case has a hump-shaped response. It jumps up 5 percent in the first quarter, and then gradually rises for ten quarters and converges to zero. Monetary policy suppresses the increase of aggregate demand since its priority is economic stability. Effects of policy
diminish and for two quarters aggregate demand rises. The larger aggregate demand causes the higher marginal revenue product of capital, and it raises marginal $q$. Investment in the $(i - k)$ case shows similar features to marginal $q$. It jumps up in the first quarter, rises for 2 quarters and converges to zero from 4th quarter. Compared to the $(i - k)$ case, the $\Delta i$ case displays gradual changes due to the investment rigidity, the characteristic that the $(i - k)$ case does not have. The investment technology in the $(i - k)$ case generates scale efficiency of capital stock. The larger capital stock is the more efficient in creating the capital stock, and a firm raises investment instantly to accumulate capital stock quickly.

Figure 2.2 illustrates the responses of the asset price and major variables affecting the asset price movements. The asset price is a leading variable that forecasts potential profits a firm creates in the future, and the value of the capital stock measures profits the aggregate capital stock generates. Consequently the value of capital stock is a major determinant of the asset price movements.

The asset price rises when a technology shock raises profits, as in figure 2.2(a). In the $\Delta i$ case, the asset price displays a short-term and a long-term hump-shaped response. It jumps up in the first quarter and displays short-term fluctuations for 5 quarters. Beyond the 5th quarter the asset price draws hump-shaped responses with a peak at the 30th quarter. The asset price in the $(i - k)$ case shows more gradual changes. It jumps up in the first period, gradually rises for 6 years, and then gradually approaches zero. The long-run responses of the asset price in the both cases are similar to the value of capital stock, the first term in equation (2.20) and (2.23). The short-run responses of asset price in the $(i - k)$ case are due to the higher mark-up profits. On the other hand, the short-run responses of the asset price
in the $\Delta i$ case are related to both net benefits of investment and mark-up profits. Marginal $q$, in the $(i - k)$ case, incorporates the capital accumulation process, but not in the $\Delta i$ case. Since the capital stock reduces adjustment cost, the value of capital stock should adopt the costs and savings of the capital creation. In the $\Delta i$ case, the capital stock does not affect the capital creation process, and marginal $q$ is irrelevant to the capital accumulation process. The asset price reflects the value of the aggregate capital stock, and also cash-flows which are not incorporated in the value of the capital stock. The costs and benefits of investment in the $(i - k)$ case are reflected in the asset price through marginal $q$, but not in the $\Delta i$ case. The asset price in the $\Delta i$ case incorporates the net benefits of investment directly. Investment spending is cash-outflows, but an appropriate management of investment growth results in net savings in capital installation, which is discussed in figure 2.2(c). The value of the created capital stock from current investment ($\mu_t + i_t$), and a firm will spend $i_{t+1}$ in the following quarter. Current investment raises adjustment costs, but it reduces the future investment and raises the efficiency of the capital creation. When the benefits of investment surpass the costs of an investment purchase, the net benefits push up price to 6 percent.

The value of aggregate capital stock shows different responses depending upon the investment technology, as in figure 2.2 (b). The $\Delta i$ case displays a slow increase in the value of capital stock for 5 quarters, and it starts to increase more rapidly for the 30 quarters. The capital value for the $(i - k)$ case draws a concave curve; it rises faster in the early periods and the growth rates are smaller in the long-run. The initial responses of the two cases are very similar, but not the growth rates. For the
\( (i - k) \) case, the growth rate continuously falls, while the growth rate of the \( \Delta i \) case rises from the 5th quarter.

Movements of the value of capital stock are decomposed into the movements of the capital accumulation and of marginal \( q \), the first term in the left-hand side of equation (2.20) and (2.23). Capital accumulation dominates the marginal \( q \) effect in the capital value movements. The difference in investment for the two cases is larger than marginal \( q \). Furthermore, the direction of the marginal \( q \) response is opposite to the value of capital stock such that marginal \( q \) falls continuously from the 5th quarter in both cases, but not for the capital value. In the \( (i - k) \) case, the larger capital stock reduces installation costs and a firm has incentive to create more capital stock in the short-run. A firm conducts more investment at the present time than the future, and the capital accumulation speed decreases. In the \( \Delta i \) case, the smaller variation of investment growth reduces the installation costs. A positive technology shock raises investment but the initial growth of investment is negligibly small. The history of positive investment growth easily generates larger investment, and the capital accumulation is then accelerated.

Figure 2.2\((c)\) compares the responses of the capital installation costs in the two cases. Adjustment costs in the \( (i - k) \) case jump up when the shock is realized, rise for 3 quarters, and then decrease gradually following the 4th quarter. The costs move along with the relative movements between investment and capital stock, equation (2.21). Since new capital installation is more efficient with the larger capital stock, a firm raises investment in the first quarter. The costs decrease as investment falls and the capital accumulation rises. The investment costs in the \( \Delta i \) case jump up, gradually decreases for 6 years and slowly converges to zero. Except the first 7
quarters, the costs are negative over all periods. A firm reduces the costs through minimizing changes in investment growth rates, but the effects of one time shock do not last forever. Investment growth rates are negative from the 10th quarter, and it means the costs of investment falls significantly. The gap between investment growth and marginal $q$ makes the asset price different from marginal $q$, equation (2.20). Investment, in terms of cash-flows, is reflected in the asset price movements, and marginal $q$, in terms of the benefits of investment, is reflected in the asset price also. Compared to the $\Delta i$ case, the $(i - k)$ case has larger investment costs over all periods. In the early periods, a firm in the $(i - k)$ case focuses on the capital accumulation to save future adjustment costs. In the following periods, the larger capital stock saves adjustment costs. Although the decrease of the installation costs is accelerated over time, a positive investment is accompanied with the positive costs all the time. In the $\Delta i$ case, a firm manages the growth of investment. Initial increase of investment is not significant since the adjustment cost function is convex. Current investment raises current adjustment costs but it reduces future adjustment costs. The smaller adjustment costs raise the amount of the created capital stock, and the benefits of investment rise. In addition, falling investment growth indicates that the future purchasing costs are falling. When the present value of savings is larger than the costs, the investment costs accompanied with current investment could be negative. Although investment is positive, the decrease of investment growth results in the negative investment costs.

Figure 2.3 describes the responses of nominal variables along with output. In the $(i - k)$ case, there are nominal rigidities which include rigidities in both inflation and interest rates, and interest rates affect consumption and investment planning. In
addition to the nominal rigidities, in the $\Delta i$ case there is an investment rigidity which affects production and also aggregate demand. Investment supplies a production factor, capital, and it is also a component of aggregate demand. The investment rigidity is caused by the adjustment cost specification, and it is observed only in the $\Delta i$ case.

Figure 2.3(a) compares the aggregate demand movements of the two cases. Output in the $\Delta i$ case rises gradually for 20 quarters, and converges to zero gradually. Output in the $(i - k)$ case jumps up 7 percent, rises relatively dramatically for 3 quarters, and then increases gradually for another 7 quarters. Compared to the $(i - k)$ case, output in the $\Delta i$ case shows gradual changes over all periods and it reflects the real rigidity located in investment. Investment directly affects the responses of output, as a component of the aggregate demand, equation (2.29). The investment rigidity is totally reflected in output through aggregate demand, as the goods market equilibrium indicates.

A positive technology shock reduces the price of output, and lowering the price level boosts aggregate demand. Responses of inflation rates are drawn in figure 2.3(b). Inflation rate in the $\Delta i$ case drops 2 percent and displays medium-run fluctuations. It rises for 3 quarters relatively quickly, falls gradually from the 4th quarter, and then rises again from 23rd quarter. Inflation rate in the $(i - k)$ case also has the medium-run fluctuations. It jumps down in the first quarter, rises for 3 quarters, falls gradually over 20 quarters and then rises again gradually. The responses of inflation in both cases are quite similar. The price decision rule, equation (2.24), indicates that the marginal cost of production and expectation of future inflation are the major
determinants of current inflation. Effects of the lower marginal costs of production due to a positive shock are similar across the two cases.

Figure 2.3(c) draws the responses of nominal interest rates to a positive technology shock. The interest rate in the $\Delta i$ case has medium-run fluctuations. It initially falls 1.2 percent, continues to fall for 4 quarters, and then reaches a trough around negative 1.6 percent. The interest rate in the $(i - k)$ case does not have the medium-run fluctuations. It gradually decreases for 5 years and then slowly converges to zero. The monetary authority changes nominal interest rates to stabilize economic fluctuations, equation (2.30). In the $(i - k)$ case, the initial increase in aggregate demand is expected to be significant. The larger aggregate demand lessens the pressure lowering the price level. On the other hand, in the $\Delta i$ case, the initial increase in aggregate demand is less significant due to the investment rigidity. The higher productivity is not connected to the larger output, but to the lower factor demand and the lower price level. Due to the lower inflation, the monetary authority lowers interest rates in both cases. The interest rate in the $\Delta i$ case falls more than the $(i - k)$ case, and real interest rate in the $(i - k)$ case rises more than the $\Delta i$ case. In the $(i - k)$ case, nominal interest rates suppress the initial increase of aggregate demand, but the effects of the policy diminish quickly. The interest rate gradually falls over 20 quarters. In the $\Delta i$ case, the gradual increase of aggregate demand accompanied by speedy increase of inflation. Because of the speedy increase of inflation, the interest rate falls quickly to reduce the effects of inflation on consumption.

The authority takes into account three variables when it sets the interest rates: aggregate demand, inflation and lagged interest rates. The larger output and lower inflation lead the monetary authority to raise real interest rate. While the interest rate
in the \((i - k)\) case gradually decreases for periods, it displays medium-run fluctuations in the \(\Delta i\) case. The \((i - k)\) case has only nominal rigidities but not real rigidities, and it helps the authority to achieve its target. Monetary policy is effective in the short-run rather than in the long-run, and the initial increase of aggregate demand is not significant due to real rigidity.

Figure 2.4 shows the responses of economic activity under an alternative policy which has stronger interest rate smoothing. The previous interest rate smoothing parameter \(\rho^r\) is set to 0.5, and it is set to 0.9 with the new policy. Since stronger interest rate smoothing excludes rapid changes of the interest rate, it generates stronger effects of monetary policy on the economic activity. The monetary policy suppresses the initial changes of aggregate demand. Because of the smaller increases of economic activity, the asset price rises less than the previous policy. The asset price displays smaller initial responses under new policy in both cases, figure 2.4(a). It reaches the responses of the previous policy in 3 quarters and the responses are similar with old policy from the fourth quarter.

Marginal \(q\) in both cases has smaller initial responses than the previous policy, as seen in figure 2.4(b). Marginal \(q\) in the \(\Delta i\) case falls negative 2 percent in the first quarter. It rises to 1 percent in the 3rd quarter and it displays similar responses to previous policy afterwards. Marginal \(q\) in the \((i - k)\) case falls to negative 2 basis points and increases to 1.7 basis points in the fifth quarter. Compared to the \(\Delta i\) case, the \((i - k)\) case has more sensitive marginal \(q\) to monetary policy such that it has larger negative initial response and its peak also larger than \(\Delta i\) case. In addition, marginal \(q\) changes more gradually with new policy. Marginal revenue falls in the
first quarter, and it lowers contribution of the capital stock on the profit generating process.

Output in both cases have smaller initial responses under the new policy, figure 2.4(c). The initial response of output is about a half of that relative to the previous policy in the $\Delta i$ case. From the 5th quarter it shows similar response to the previous policy. In the $(i - k)$ case, output has negligibly small initial responses and it rises to the previous policy level for 5 quarters. The monetary policy raises real interest which affects consumption and savings decision of the households. The new policy implies that the higher interest rate lasts longer than the previous policy, and the households raise saving and reduces consumption. The smaller increases in consumption results in the smaller increases in aggregate demand.

Figure 2.4(d) draws the investment responses under the new policy. Investment in the $\Delta i$ case displays the similar responses to previous policy except that it is slightly smaller over all periods. Investment in the $(i - k)$ case falls negative 20 percent in the first quarter and it rises to 20 percent for 7 quarters. A positive technology shock raises productivity of factors. Nominal rigidities hinder the increase in aggregate demand, and a firm reduces inputs with higher productivity and a smaller increase in aggregate demand. In the $\Delta i$ case, investment does not fall in the first quarter. Although a firm has an incentive to reduce production factors, it raises investment slightly. Negative investment in the first quarter is followed by the larger investment growth in the following quarter. The higher growth of investment hampers efficiency in capital installation. Therefore a firm raises investment slightly and manages the growth of investment over all periods.
The new policy generates similar responses of inflation rates in two cases to each other, as seen in figure 2.4(e). In each case, the inflation rate in the first period falls negative 5.5 percent, which doubles that of the previous policy. Likewise, the interest rates in both cases are similar to each other, figure 2.4(f). Stronger interest-rate smoothing generates smaller initial response of interest rates. It decreases to negative 1.5 percent through 5 quarters and it takes longer than old policy to reach negative 1.5 percent.

2.4 Conclusion

This paper elaborates the relationship between the asset price and the investment technology. The relationship is built on efforts to reduce investment adjustment costs, since the efforts affect investment spending. Investment plays a role in production such as supplying a production factor, and also it is a part of aggregate demand. I consider two adjustment cost specifications; one is a convex function of an investment-capital stock ratio, the \( (i - k) \) case, and the other is a convex function of the growth of investment, the \( \Delta i \) case.

In the \( (i - k) \) case, a firm raises investment in the early periods of positive shocks realized. The larger capital stock reduces investment adjustment costs, and the contribution of the capital stock on the capital installation is reflected in the value of the capital stock. In the \( \Delta i \) case, a firm avoids drastic changes of investment, and it draws a hump-shaped response to a positive technology shock. Adjustment costs are not reflected in the value of the capital stock since the capital stock has no role in the capital installation.
The value of capital stock is a major determinant of the asset price movements. In the \((i - k)\) case, the asset price moves along the value of capital stock. In the \(\Delta i\) case, the asset price is different from the value of the capital stock by the present value of net benefits of an investment spending. Appropriate management of investment growth reduces adjustment costs and raises the benefits of an investment. It pushes up asset price. The net benefits of investment are not adjusted in the value of capital stock in the \(\Delta i\) case, since the capital stock has no role in capital installation. The capital accumulation behavior is not reflected in the value of capital stock. The asset prices adjust the net benefits of an investment purchase. In the \((i - k)\) case, adjustment costs always occur as long as investment is positive, and it is reflected in the value of capital stock already.

The priority of monetary policy is the economic stability, and the policy hinders the increase of aggregate demand. The policy is effective only in the short run, and the stronger interest rate smoothing suppresses more of the increase of aggregate demand. The slight increase of aggregate demand lowers marginal revenue of capital, and it results in smaller marginal \(q\) in the early periods.
Note: The parameter $\kappa(\bar{k})$ is the adjustment cost parameter for the $\Delta i$ case (for the $(i - k)$ case). The stronger interest rate smoothing set $\rho'^n$ to 0.9, and the adjustment cost parameter, $\kappa(\bar{k})$, is set to 3.6.

Table 2.1: The value of parameters used in simulation

<table>
<thead>
<tr>
<th>$A$</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>0.32</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.99</td>
</tr>
<tr>
<td>$\delta$</td>
<td>0.025</td>
</tr>
<tr>
<td>$(\kappa = \hat{k}, \rho'^n)$</td>
<td>(2.6, 0.5)</td>
</tr>
<tr>
<td>$\eta$</td>
<td>2.75</td>
</tr>
<tr>
<td>$\theta$</td>
<td>0.6</td>
</tr>
<tr>
<td>$\pi$</td>
<td>1.0</td>
</tr>
<tr>
<td>$\rho^x$</td>
<td>1.5</td>
</tr>
<tr>
<td>$\rho^y$</td>
<td>0.1</td>
</tr>
<tr>
<td>$\rho^z$</td>
<td>0.95</td>
</tr>
<tr>
<td>$\sigma^a$</td>
<td>0.125</td>
</tr>
</tbody>
</table>

Figure 2.1: Impulse response of marginal $q$ to a one-percent of standard deviation technology shock.
Figure 2.2: Impulse response of asset price to a technology shock
Figure 2.3: Impulse response of nominal variables and output.
Figure 2.4: The effects of a technology shock, where the monetary authority has stronger interest-rate smoothing; $\kappa = 3.6, \rho^n = 0.9$
CHAPTER 3

INVESTMENT, ASSET PRICES AND TECHNOLOGY SHOCKS

3.1 Introduction

The efficient asset market hypothesis indicates information related to a firm’s profit is reflected instantly to the asset price. The asset price is an index measuring a firm’s potential value. Questions arise about the efficient market hypothesis, since it appears that the asset price also responds to the information unrelated to profits. It raises a question also about the role of asset prices as an index of the value of capital stock. Some literatures, such as Blanchard, Rhee and Summers (BRS, 1993), build up proxies for fundamentals. Similarly, I use a ratio of the asset price-per-capital stock, average $q$, as a market index, and the fitted value of average $q$ on expected profits, fundamental $q$, as a proxy for fundamentals. In terms of the expected value of future profits, fundamental $q$ is also a proxy for the shadow value of the capital stock, marginal $q$. Higher average $q$ is companied with higher fundamental $q$. Average $q$, however, shows different movements from fundamental $q$ because of the speculative behavior of investors.

The asset market is connected with economic activity through investment. A firm raises investment with an increase of average $q$, as described in Tobin’s $Q$ theory.
The asset price, however, may respond to information unrelated to profits. The irrational price movements weaken bonds between average \( q \) and fundamental \( q \), and between average \( q \) and investment. This paper studies the correlation between two indices and investment spending. Previous literature studies the relationship between average \( q \) and investment at the micro level with a single equation regression model, such as Chirinko et al (1994). Blanchard, Rhee and Summers (BRS 1993) studies the macro-level data. My paper applies a vector autoregressive estimation model with the macro-level data. In addition, my paper includes a proxy for fundamentals, and I construct a proxy for fundamentals based on BRS’s procedure. BRS reports that average \( q \) is a significant factor explaining investment movements conditional on fundamental \( q \). My paper reports both indices, average \( q \) and fundamental \( q \), are complementary in explaining investment and the asset market. Average \( q \) carries additional information not observed in fundamental \( q \).

Structural vector autoregressive (SVAR) estimation in this paper assumes that a technology shock is the only source changing labor productivity in the long-run. The assumption about the long-run effects avoids controversies of instantaneous effects of a shock raised in the analysis of short-run effects. Researchers interested in the monetary policy also adopt the long-run assumptions of technology shocks and add the short-run identification assumptions for monetary shocks, such as Gali et al (2003), Fisher (2003), and Altig et al (ACEL, 2005). Research about the impacts of technology shocks on production factors reports different results. Gali (1999) conducts a bivariate long-run SVAR and reports that a positive technology shock reduces employment. On the other hand, Fisher (2003) conducts a multivariate SVAR estimation and reports that a positive technology shock raises employment. Although
both working hours and the capital stock are production factor, effects on the capital stock lasts longer; since capital is durable goods. Responses of the supply of durable production factor, investment, are the main concern of this paper.

I discuss the effects of technology shocks in terms of the extent to which the shock affects business cycles using variance a decomposition of forecast errors. Previous literatures decompose the source of business cycle into supply and demand shocks, such as Gali (1992) and Shapiro and Watson (1998). Technology and monetary shocks are the major supply and demand shocks respectively. Gali and Shapiro et al assume that monetary shocks have only the temporary impact. Technology shocks have both permanent and temporary impacts. My paper focuses on technology shocks, where the analysis is based on the long-run SVAR model, since I need additional assumptions to identify the impacts of additional shocks,.

I compare the estimation results of four settings: a basic model including only macroeconomic variables, a model adding only average $q$ to the basic, a model adding only fundamental $q$ to the basic, and a model using both average $q$ and fundamental $q$. In addition, I conduct the analysis in two ways in terms of number macro variables; one employs the minimum number of variables and the other uses the larger number of variables. The minimal scheme employs only the necessary variables to find the relationship between investment and the asset market. The larger model adds demand and monetary factors to the minimal scheme.

In all estimation settings, average $q$ shows at least 10 times larger responses to a technology shock than fundamental $q$. Fundamental $q$ filters information about future profits to dividend-price ratio and market-book value ratio. On the other hand average $q$ carries asset market information without filtering. The filtering process
implies that average $q$ has the larger volatility than fundamental $q$. In addition, when the asset market is stable, average $q$ provides sufficient information about future profits and excluding fundamental $q$ does not change the responses of investment to a technology shock significantly. On the other hand, the responses of investment and output shrink when the estimation excludes average $q$. In so far as information carried in average $q$ is reliable, using average $q$ expands economic activity. When the asset market is unstable, average $q$ carries noise along with information about the future profits. Fundamental $q$, in this case, provides useful information for investment, and excluding fundamental $q$ generates an omitted variable problem.

In all estimation settings, I discuss the impact of technology shocks on the business cycle using variance decomposition. Only the minimal model employing average $q$ reports the similar result with Stock et al and Gali. Technology shocks account for 35 percent of output fluctuations. In case of the larger model, the portion falls to 8.3 percent. If the estimation excludes the periods when average $q$ shows a different trend, the portion rises to 68 percent. The demand and monetary variables raises output fluctuations and they reduce the role of technology shocks on the output volatility especially when average $q$ has a different trend. When the asset market is stable, the role of demand and monetary factors on output fluctuation is less significant than technology shocks.

Due to the large standard errors, Christiano, Eichenbaum and Vigfusson (CEV 2006) and Faust and Leeper (1997) raise a question about the credibility of the SVAR estimation. Especially the identification relies on the covariance matrix and also the autoregressive coefficients in the case of the long-run SVAR. The covariance matrix is estimated with a reduced form of VAR model, and the lags used in the
estimation usually are not long enough. CEV interprets the large standard error of
SVAR estimators as signs of insufficient information, and the estimator could be more
efficient with additional information and restrictions. In future work, I will discuss
the methods to improve the efficiency of the estimation.

The paper is organized as follows. In section 3.2, the data and estimation proce-
dure are presented, and section 3.3 discusses the effects of a technology shock. Section
3.4 concludes.

3.2 Estimation

This section explains the data construction and structural VAR estimation
procedure. Average productivity and working hours are major variables identifying
technology shocks. Investment, average \( q \) and fundamental \( q \) are major variables
connecting the asset market to investment and output. In addition, I consider the
inflation rate, the federal funds rate, and velocity as demand and monetary variables.

3.2.1 Data

Each data series except average \( q \) and fundamental \( q \) is taken from the Bu-
reau of Economic Analysis from 1963:01 to 2005:04. Population is measured by the
noninstitutional civilian persons over age 16. Investment is the sum of the real gross
private investment and durable good consumption. Working hours are hours of all
persons in nonfarm business sectors divided by the population. Wages are measured
by the compensation per hour in nonfarm business sector. The money stock is mea-
sured with the M2 less small time deposits plus institutional money funds. Average \( q \)
is built with data series from the Flow-of-funds released by the Board of Governors of
Federal Reserve Board. The construction of average \( q \) follows the procedure applied in von Furstenberg (1977) and BRS (1993).

Average \( q \) is defined as the ratio of market value of the capital stock to its replacement cost. Replacement costs include net non-interest bearing financial assets and tangible assets. Major components of net non-interest bearing financial assets are currency, demand deposits, and net trade credit. The market value of firms is the sum of market value of interest bearing financial assets (\( NIFL \)) and common stock. Estimation of \( NIFL \) market value follows equation (1) in Furstenberg (1977), that is,

\[
MVD = \left( \frac{\text{interest payments}}{NIFL} \right) \left( \frac{\text{interest payments}}{NIFL} \right) \left[ 1 - (1 + 0.5 \times i_{Baa})^{-2t} \right]
\]

where \( t \) is average maturity of long-term bonds, and \( i_{Baa} \) denotes the yield on Baa bonds. \( NIFL \) is measured with all liquid assets excluding demand deposits and consumer credit. Interest costs are assumed to be paid every six months, that is, the interest rates are measured as \( \frac{\text{interest payments}}{NIFL} \).

Average maturity, \( t \) in equation (3.1), is assumed to be 7 years. The Securities Industry and Financial Market Association (SIFMA) reported that the average maturities of corporate bonds were 5 to 13 years in 1990s and 2000s; average maturity was 7 to 10 years in 1990s and it was exceptionally high in 1990 as 12.8 years; average maturity was 6 to 7 years in 2000s.

The market value of equity is estimated as the dividend payments from nonfinancial nonfarm corporations divided by the dividend-price ratio of the S&P 500. The market value of a firm could be different from its fundamental value because of
asymmetric information, speculative bubbles, or irrational future expectations. Consequently, fundamental value to replacement cost ratio, $q$, could be different from average $q$.

BRS (1993) consider several candidates for fundamental values such as the profit ratio, dividend ratio, sales ratio and expected present value of profit ratio. The expected present value of profit ratio is the best candidate for fundamentals because a firm is evaluated with expected discounted profit. I construct the expected present value of profit ratio by backward recursion, assuming the profit ratio remains unchanged after the last observation. The discount rate of profit ratio, sum of the required rate of return and depreciation rate, is chosen to be 20%, which is the choice of BRS. BRS stated that varying the discount rate between 15% and 25% does not make any significant differences in the characteristics of the expected present discount value of profit ratio.

Fundamental $q$ is the fitted value of the discounted rate of profit on current and two lagged profit rate, dividend price ratio, and market-book value ratio. Fundamental $q$ displays fluctuations around one, while average $q$ dramatically increases after 1991 as reported in figure 3.1. The development of the information industry explains recent features of average $q$. The industry, developing from late 1980s, has a higher market value than the value of physical capital stock. In addition, equipment in information industry depreciates faster than any other industry. I conduct Quandt-Andrew unknown breakpoint test for average $q$. The test rejects the hypothesis of no breakpoints within trimmed data with 99.9 percent, and the most likely breakpoint is at 1991Q3, as in table 3.1.
3.2.2 Econometric Framework

Structural VAR model is based on an assumption that fluctuations of economic variables are caused by technology or nontechnology shocks. Nontechnology shocks include demand, monetary policy, and labor supply shocks. I assume that nontechnology shocks do not have permanent effects on labor productivity.

VAR estimation uses combination of nine variables: seven major macroeconomic variables, average $q$ and fundamental $q$. The seven variables are labor productivity growth rate, working hours, the marginal cost of production, investment-to-output ratio, federal funds rate, inflation rate, and velocity. A vector $X_t$ is defined with the eight variables.

\[
X_t = \begin{bmatrix}
\Delta \ln (GDP/H) \\
\Delta \ln GDP
deflator \\
\Delta \ln H \\
\Delta \ln (GDP/H) - \Delta \ln (Wage/GDP
deflator) \\
\ln (investment/GDP) \\
Federal
dFundsRate \\
ln GDP + \ln GDP
deflator - \ln M2 \\
q, \ q^*, \text{or } (q \text{ and } q^*)
\end{bmatrix}
\]  

where $q$ denotes average $q$, and $q^*$ is fundamental $q$.

Suppose the structural model has the following form,

\[
A_0 X_t = A (L) X_{t-1} + \varepsilon_t
\]

where $L$ is the lag operator defined as $AL^kX_t = AX_{t-k}$ and $A (L)$ is a p-th order polynomial with $L$ such that $A (L) = A_1 + A_2L^1 + ... + A_{p+1}L^p$. A vector of shocks $\varepsilon_t$ is assumed to be independent and identical over time, and elements of $\varepsilon_t$ are independent each other.

The reduced form VAR representation is written with coefficient matrices $B$.  

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\[ X_t = B(L)X_{t-1} + u_t, \]
\[ Eu_t u_t' = V \]

where \( B(L) \) is a \( p \)-th order polynomial. A vector of exogenous economic shocks \( u_t \) is interpreted as a linear transformation of underlying orthogonal shocks \( \varepsilon_t \),

\[ u_t = C\varepsilon_t, E\varepsilon_t\varepsilon_t' = I \tag{3.3} \]

where \( C \) is a square matrix and \( I \) is the identity matrix. The relation between the structural VAR and reduced form VAR is determined such that,

\[ C = A_0^{-1}, B(L) = A_0^{-1}A(L) \]

The matrix \( C \) can be recovered with a relation supported by theory or appropriate assumptions. My identification of technology shocks is that only innovations to technology have a permanent effect on labor productivity. This is also used the one used in Fisher (2003), Gali (1992, 1999), and ACEL (2005).

The long-run effects of a shock are represented with a matrix \( U \) such as,

\[ U = (I - A_0^{-1}A(1))A_0^{-1} \tag{3.4} \]
\[ = [I - B(1)]^{-1}C \]

where a polynomial \( A(1) \) with order \( p \) gives \( A(1) = A_1 + A_2 + ... + A_p \). The assumption that only technology shocks can alter productivity permanently implies that first row elements in \( U \) are zero except the first element.
\[ U = \begin{bmatrix} u_{11} & 0_{1 \times 7} \\ u_{21} & u_{22} \end{bmatrix} \] \tag{3.5}

Fundamental shocks are orthogonal, and the covariance matrix of the reduced form is denoted with \( \Lambda \). The long-run variance-covariance matrix of \( Y_t \) can be written as,

\begin{align*}
[I - B(1)]^{-1} V [I - B(1)]^{-1} \\
= [I - A_0^{-1} A(1)] A_0^{-1} (A_0^{-1})' [I - A_0^{-1} A(1)]'
\end{align*}

\tag{3.6}

The variance-covariance matrix in equation (3.6) is identical to \( UU' \) in equation (3.4). The matrix \( UU' \) has a cholesky decomposition matrix \( P \). The matrix \( P \) replaces \( U \) for computational convenience, and it satisfies the assumption that neither demand or monetary shock has long-run effects on labor productivity.

The replacement, however, imposes more assumptions such that working hours cannot change labor productivity nor inflation in the long-run. As the paper focuses on technology shocks only, the additional assumption does not influence my results. Technology shock effects are observed with \( u_{11} \) and \( u_{21} \) of equation 3.5. The order of variables corresponding to \( u_{21} \) does not change impulse responses nor the variance of forecast errors caused by technology shocks.

Let \( \Psi_s \) be a coefficient matrix of the moving average(MA) representation, \( X_t = \sum_{s=0}^{t} \Psi_s u_{t-s} \). The variance of \( s \)-period ahead forecast errors is written as follows:

\[ Var \left( X_{t+s} | \Omega_t \right) = V + \Psi_1 V \Psi_1 + ... + \Psi_{s-1} V \Psi_{s-1} \]

where \( \Omega_t \) is an information set available at time \( t \), and \( Var \left( X_{t+s} | \Omega_t \right) \) is the conditional variance conditioned on current information.
3.3 Responses to Technology Shocks

This section presents the long-run SVAR estimation results. I conduct an estimation with two settings; one is the minimum number of variables and the other adds the demand and monetary variables to the minimal model. I estimate the large system over the sub-sample period (1963Q1-1991Q3) and over the full-sample period (1963Q1-2005Q4). Average \( q \) shows a different trend after 1991Q3, and the sub-sample estimation excludes the period when average \( q \) rises above one.

For each estimation setting, I compare the impulse responses of four cases: i) excluding both average \( q \) and fundamental \( q \); ii) including only average \( q \); iii) including only fundamental \( q \); iv) including both average and fundamental \( q \).

3.3.1 Models with The Minimum Number of Variables

I need two variables, productivity growth and working hours, for the one-technology-shock identification scheme (Gali, 1999). To discuss the asset market and investment, I need investment and the asset market indices. I build up a benchmark model which including both average \( q \) and fundamental \( q \) along with the productivity growth, working hours and investment. Other minimal models exclude fundamental \( q \) or average \( q \) from the benchmark model.

I discuss the interactions between average \( q \), fundamental \( q \) and investment through comparison of impulse responses of each model. In the minimal model, excluding average \( q \) reduces the responses of output and investment, while excluding fundamental \( q \) does not change the responses significantly. Average \( q \) delivers asset market information, and the good news encourages economic activity. Fundamental \( q \) provides the expectation for the future profits. In the early periods the expectation fails to
incorporate the sudden changes in productivity, and output increases even without fundamental $q$.

Figure 3.2 displays the responses of output in the four cases of the minimal model. Output, in the basic model, rises 2.5 basis points in the first quarter and increases to 6 basis points by the sixth quarter, as in figure 3.2(a). When I add average $q$ to the basic model, the initial responses of output rises 5 basis points and increases to 9 basis points by the sixth quarter, as in figure 3.2(b). Instead of average $q$ I include fundamental $q$. In this case output rises 2 basis points in the first quarter, and then increases to 6 basis points by the six quarter, as in figure 3.2(c). When I include both average $q$ and fundamental $q$ in estimation, output rises four basis points and then rises to 10 basis points by the sixth quarter, as in figure 3.2(d). The size of initial response, the peak size, and the decreasing speed after the peak are similar between (a) and (c), and between (b) and (d). The four cases display that output jumps up and rises for four quarters and then slowly converges to zero. Whether I include fundamental $q$, features of the output response do not change significantly. On the other hand, average $q$ amplifies the output responses such that the responses of output in the case (b) and the case (d) are larger than the responses of output in the case (a) and the case (c). Average $q$ expands the effects of a shock on output, while fundamental $q$ has no effect on the output responses.

I present the responses of investment in the four cases to a technology shock in figure 3.4. In the basic model, figure 3.4(a), investment falls one percent. Although it increases for six quarters, it is still below the steady-state value. Adding average $q$ to the basic model, figure 3.4(b), raises investment very slightly. Investment increases to approximately two percent, and then decreases. Figure 3.4(c) displays the responses
of investment where I add fundamental $q$ instead of average $q$. Investment falls approximately one percent, increases to 8 basis points and then gradually decreases. Investment in the case (c) shows similar responses to the case (a), in terms of the initial responses, the peak size and the speed of changes. The estimation including both average $q$ and fundamental $q$, the case (d), generates larger investment when a positive shock is realized. Investment rises slightly in the first quarter, and increases to 2 percent by the sixth quarter. Investment shows the positive responses only when the estimation includes average $q$.

I present the responses of the asset market indices in figure 3.6. I reports three estimation results: a model using average $q$, but not fundamental $q$: a model using fundamental $q$, but not average $q$: and the benchmark model. I have two average $q$s, one is from the model excluding fundamental $q$, in the figure 3.6(a), and the other is from the benchmark model in the figure 3.6(c). I have also two fundamental $q$s, one is from model excluding average $q$, in the figure 3.6(b), and the other is from the benchmark model, in the figure 3.6(d).

Average $q$, in the figure 3.6(a), has the short-run fluctuations around zero in the early periods, and then increases from the fifth quarter. On the other hand fundamental $q$, in the figure 3.6(b), falls 40 basis points, slowly increases to 3 basis points by the third quarter and then decreases. Fundamental $q$ falls below the steady-state value when a positive technology shock is realized. A positive shock commonly raises the future profits, but the fundamental $q$ indicates that the profit expectation fall. Again, the response of fundamental $q$ raises a question of the model identification problem.
Figure 3.6 (c) and (d) draw the responses of average $q$ and fundamental $q$ respectively, where the estimation employs both indices. Average $q$ rises 2.6 percent, displays short-run fluctuations for ten quarters, and then gradually increases. Fundamental $q$ rises 20 basis points, continuously increases for three quarters, and then decreases for ten quarters. Adding fundamental $q$ boosts the response of average $q$ over all periods. Average $q$ in the benchmark model, figure (c) has the larger initial increase and the higher increasing trend compared to average $q$ that excluding fundamental $q$, figure (a). Average $q$ also shifts up the responses of fundamental $q$ over all periods. Fundamental $q$ rises above the steady-state value only when the estimation uses average $q$, and it is consistent with BLS (1993) in that fundamental $q$ is a significant factor explaining investment with a condition on average $q$.

Next I discuss about the role of technology shocks as a source of business cycle with variance decomposition of forecast error. Many previous papers do not report the confidence intervals for variance decomposition because of the large standard errors. Lutkepohl (1990) and Runkle (1987) emphasize the importance of confidence intervals for estimators. Lutkepohl derives the asymptotic distribution, and Runkle reports the confidence intervals calculated by both bootstrapping and normal intervals derived from to asymptotic covariance. This paper reports the confidence intervals calculated by bootstrapping since the discussion of asymptotic distribution is beyond the scope of this research.

The impacts of technology shocks on output volatility increase when the estimation includes average $q$. In the basic model, technology shocks account for 20.3 percent of the output volatility at the business cycle horizon (Table 3.2). Adding only average $q$ to the estimation, the share rises to 40.9 percents. Adding both average $q$ and
fundamental $q$ raises the share up to 34.6 percent. On the other hand fundamental $q$ lowers the extent to which technology shocks explain the business cycle. Compared to the basic model, the first column, the share falls from 20.3 percent to 14.4 percent when the estimation adds fundamental $q$ to the basic model, third column. Compared to the estimation employing average $q$, the second column, employing both indices, reduces the share of technology shocks from 40.9 percent to 34.6 percent of output volatility. The model which includes both fundamental $q$ and average $q$ is compatible with Shapiro and Watson (1998), which reported that technology shocks account for 37 percents of output fluctuations at the business cycle horizon.

3.3.2 The Large-scale, Sub-sample Estimation

This section reports the large-scale estimation results. The large system consists of variables used in the minimal model, and the inflation rate, marginal cost of labor, federal funds rates, and velocity. I divide the sample periods at the break-point of the average $q$ series. I conduct estimation over sub-sample period (1963Q1 - 1991Q3) and also full sample period (1963Q1 - 2005Q4). Sub-sample estimation excludes the periods when average $q$ has an upward trend.

The standard errors of the large-scale model are large and they increase so quickly over time, especially for output. Faust and Leeper (1997) points out efficiency problems in the long-run SVAR, and I face the same problem in the large-scale estimation. I will postpone this issue for the future study, and focus on the relationship of asset market indices and economic activity.

The responses of output in the four cases are quite similar each other, due to the large confidence intervals, as in figure 3.8. I draw a magnified graph of the output
responses by erasing the confidence intervals, figure 3.9. Output, in the basic model, rises 14 basis points, falls to its trough negative three basis point at the third quarter and gradually rises. Output displays medium-term fluctuations over 10 years, such that it has a peak at the 12th quarter and another peak in 10 years. On the other hand, adding one asset market index, average $q$, draws the responses of output having long-run fluctuations. Output rises 15 basis points, displays short-run fluctuations for 10 quarters and then gradually falls over periods. Like the minimal model, adding average $q$ changes the output movements more significantly than adding fundamental $q$. Adding fundamental $q$ to the basic model slightly reduces the output responses such that output rises 13 basis points, falls to its trough negative five basis point at the fourth quarter at the third quarter, and then rises over 3 years. It also displays medium-term fluctuations along with the basic model. When I add average $q$ to the model along with fundamental $q$, output shows similar responses to the model without fundamental $q$. When the economy is stable, the expectation of the future fails to incorporate the sudden changes in the economy. On the other hand, the asset market responds instantly to any news affecting profits.

The standard error of investment is large, and the standard error of the estimation using average $q$ rises faster than the basic model, as in figure 3.10. Like the output movements, adding average $q$ to the estimation changes the cycle of investment fluctuations, as in figure 3.11. Investment, in the basic model, draws medium-term fluctuations such that it rises for 10 quarters, falls gradually over 10 quarters to its trough at negative 1.1 percent. Adding average $q$ to the basic model generates the long-run fluctuations of investment, where one cycle is over 50 years. The model having fundamental $q$ but not average $q$ has the similar responses of investment to
the basic model, as in figure 3.10(a) and (c), and figure 3.11. Adding fundamental $q$ reduces slightly the investment movements. On the other hand investment in the benchmark model moves along with the investment of the average $q$ model, such that it draws long-run fluctuations.

Figures 3.12 and 3.13 display the responses of average $q$ and fundamental $q$ to one percent change in technology shocks. Advanced productivity raises production of goods, profits increase and also the market value of firms rises. Both average $q$ and fundamental $q$ rise when a positive technology shock is realized in all estimation cases. Average $q$ has larger standard errors than fundamental $q$, since the asset market is more volatile than the expectation. Average $q$ enlarges the responses of fundamental $q$, while fundamental $q$ reduces the responses of average $q$.

The variance decomposition of the forecast error explains the extent to which technology shocks explain economic fluctuations. I perform forecast error decomposition for the four estimation settings. Table 3.3 reports decomposition results of two estimations, one excludes both average $q$ and fundamental $q$, and the other excludes fundamental $q$. Table 3.4 reports the results of two estimations, one excludes average $q$, and the other includes both average $q$ and fundamental $q$. The effects of technology shocks in the large system are estimated substantially larger than those in the minimal models. Technology shocks are a major source of average $q$ fluctuations through the business cycle horizon.

Table 3.3 indicates that the shocks account for 53 percent of the average $q$ volatility in the second quarter and for 72.8 percent in the eighth year. Estimation, excluding both average $q$ and fundamental $q$, shows that the shocks explain a significant portion of output and hour. The shocks account for approximately 26 and 61.6 percent of
output fluctuations in the second and eighth year respectively; approximately 9.4 and 25.2 percent of hour fluctuations in the second and eighth year respectively. Adding average \( q \) to the estimation amplifies the effects of the shocks on both output and hours. The shocks account for approximately 29 and 70 percent of output fluctuations in the second and eighth year respectively; approximately 25.4 and 47.56 percent of hour fluctuations in the same period.

While the shocks account for a significant portion of average \( q \) volatility, they account for a small portion of fundamental \( q \) volatility. Estimation which excludes average \( q \) reports that the shocks account for less than 12 percent of fundamental \( q \) fluctuations. The portion increases to 23 percent when average \( q \) is added to estimation, but it is much less than the portions of average \( q \) volatility (Table 3.4).

The impacts of technology shocks on output volatility are not different significantly depending upon the estimation specification. On the other hand, the impacts on investment and hour increase significantly when average \( q \) is added to estimation. Excluding both average \( q \) and fundamental \( q \) from estimation has the same result with including only fundamental \( q \). Including both average \( q \) and fundamental \( q \) in estimation has the same result with including only average \( q \).

### 3.3.3 The Large-scale, Full-sample Estimation

This section reports the estimation results over the full-sample period (1991Q4-2005Q4) which encompasses periods when average \( q \) rises drastically. The large-scale estimation has the large standard error. Even for the short-run the standard error
rises very quickly, it is hard to detect the responses of variables. I magnify the movements of each variable by erasing the confidence intervals and draw long-run graphs of each variable.

I present the responses of output generated from the four estimation settings in figure 3.14 and 3.15. In the basic model, output rises 23 basis points, and its standard error is 28 basis points, figure 3.14(a). Adding average $q$ to the estimation, the case (b), and raises increasing speed of standard error. Output rises 15 basis points and its standard error is 27 basis points. The standard error, in the case (a), increases to 5 percent for 15 quarters and it continuously rises to 20 percent for another 10 quarters. On the other hand, the standard error of the case (b) increases to 6 percent for 15 quarters and it increases exponentially to 123 percents for another 10 quarters. Including fundamental $q$ does not change the output responses significantly in the early periods, as in the case (c). Output rises 10 basis points and its standard error is 27 basis points. The standard error rises to 5.4 percent for 15 quarters and it rises to 16 percent for another 10 quarters. Standard errors in the benchmark model, case (d), increases exponentially even faster than the case (b). The standard error rises from 28 basis points to 18 percent for 15 quarters.

Erasing the confidence intervals makes available to detect the output movements in detail, as in figure 3.15. Both average $q$ and fundamental $q$ generate cycles of output when a technology shock triggers the movements in economic activity. In the basic model output has a hump-shaped response where its peak is located at the fourth year. On the other hand, output in the case (b) has a cycle in the long-run. Adding average $q$ to the estimation enlarges the effects of a technology on output in terms of size of the effects and also in terms of the length of periods. In the case (c),
output draws a long-term cycle, but it is smaller than the case \((b)\) in terms of size of a peak and of the length of a cycle. A peak of the first cycle of the case \((c)\) is even smaller than the basic model. In the benchmark, output draws business cycles where one cycle is shorter than the case \((b)\) and \((c)\), while it has a increasing trend.

The four estimation models draw the impulse responses of investment with confidence intervals, figure 3.16, and without confidence intervals, figure 3.17. Investment in all cases shows similar features of output including standard errors, and the long-run cycles. The basic model \((a)\) and the fundamental \(q\) model \((c)\) shows similar responses in the early periods. For the first 15 quarters, the two cases show similar standard errors of investment. The standard error for average \(q\) model \((b)\) increases exponentially, and in the benchmark model, it rises even faster than case \((b)\). The basic model draws a hump-shaped response, and its peak locates at the fourth year. The case \((b)\) draws similar but smaller responses to the basic model for 5 years, and then it starts a long-run cycle. Overall periods case \((b)\) shows the smaller responses than case \((a)\) and \((c)\), but one cycle is longer than other cases. The benchmark also has cycles, and its peak of the first cycle is smaller than the basic model, and also smaller than the case \((c)\). Cycle decreases over periods but it stabilizes at 5 basis points. A technology shock has permanent effects on investment in the benchmark case, while it is temporary in case \((a)\).

Figure 3.18 and 3.19 present the responses of two asset market indices. The standard errors of two indices in the benchmark model increase exponentially, and the standard errors of average \(q\) rise faster than fundamental \(q\) in the benchmark model. A pair of figures \((a)\) and \((c)\), and another pair \((b)\) and \((d)\) indicate that additional variable raises standard errors. Especially the additional variable is not
stable, standard error of other variables increases exponentially. Figure 3.19 shows that average $q$ has much larger responses than fundamental $q$. Although the size of response is different, two indices in the benchmark has similar features of business cycle in terms of the length of a cycle. Cycles of both indices decrease over time, and they stabilize at zero. Fundamental $q$ draws a similar response curve with investment, and average $q$ jumps up when a shock is realized, and then falls continuously. The benchmark and fundamental $q$ have similar movements to investment.

Table 3.5 summarizes the impacts of technology shocks on volatility of major macro variables. Using full sample, technology shocks account for much smaller portions of fluctuations of average $q$ than the subsample estimations. The shocks account for 6.59 percent and almost 3 percent of average $q$ fluctuations in the 8th and 32nd quarter respectively, while the shocks account for more than 50 percent of average $q$ fluctuations for overall periods in the subsample estimation.

Significant differences in the variance decomposition of forecast errors between full sample and subsample estimations are observed in output. Table 3.5 indicates that technology shocks explain around 26 percent and 21 percent of output fluctuations in the 2nd and 32nd quarter respectively, which are very close to the findings of Gali (1992).

It is noteworthy that technology shocks account for much smaller portions of working hour and inflation variances in the 32nd quarter such as 2.5 percent of working hour fluctuations and 11.3 percent of inflation fluctuations; and corresponding portions are 48 percent and 60 percent in the sub-sample estimation. Along with output
variances, working hour and inflation variances in full sample estimation are consistent with results of previous literatures, which reported that non-technology shocks explain significant portions of working hours and inflation variances.

When average $q$ is excluded in full sample estimation, the shocks account for 3.2 percent and 7.9 percent of output variances, and 44.2 percent and 62.6 percent of investment variances in the 2nd and 32nd quarter.

When fundamental $q$ replaces average $q$, technology shocks become a less significant factor explaining business cycle fluctuations. The shocks account for 0.5 and 4.6 percent of fundamental $q$ fluctuations and 13 percent and 22 percent of output fluctuations in the 2nd and 32nd quarter.

Even when average $q$ is included, technology shocks are not a significant factor explaining output fluctuations, such that the shocks account for 12.4 and 8.3 percent of the fluctuations in the 2nd and 32nd quarter. The shocks, however, become a significant factor explaining the investment variances. The shocks account for 23.4 and 58.7 percent of the variances in the 2nd and 32nd quarter, and they account for 4.2 and 3.3 percent of the investment variances for the corresponding periods.

When average $q$ is stable at one, technology shocks are a significant factor explaining business cycles, as observed in the sub-sample estimation. When average $q$ deviates from one, technology shocks measured with labor productivity become less significant, as observed in full sample estimation.

**Impulse Responses of other variables**

Figures 3.20 through 3.22 display the responses of working hours and monetary policy variables. The responses of inflation rates and working hours are very similar
in three cases. Nominal interest rates and velocity show different features depending upon whether average $q$ or fundamental $q$ is included.

Working hours rise with positive technology shocks and the inflation rate shows negative response initially and it converges over time. Nominal interest rates show negative responses in two cases, in which average $q$ or fundamental $q$ is used separately. Real interest rates rise in three cases as the inflation responses are larger than nominal interest rate responses.

Velocity decreases over time when average $q$ and fundamental $q$ are used at the same time. Velocity is measured with nominal GDP and the money stock. Decreasing velocity indicates that negative inflation is larger than output increase or that the money stock increases faster than nominal GDP. Velocity rises when fundamental $q$ is used; it decreases for the first 5 quarters and rises after that time, when average $q$ is used in estimation.

3.4 Conclusion

I apply the structural VAR estimation where effects of a technology shock are identified with an assumption on long-run effects. The assumption excludes all shocks except technology from changing labor productivity in the long-run. I do not assume restrictions on short-run effects of any shock.

Average $q$ shows at least 10 times larger responses than fundamental $q$. Adding average $q$ in estimation raises the responses of output and investment, when the estimation excludes monetary variables or excludes the periods when the asset market has a rising trend. When the estimation includes monetary variables using full-sample periods, fundamental $q$ boosts up further the responses of output and investment.
Adding monetary variables to estimation reduces the extent to which technology shocks explain business cycle from 35 to 8 percent. On the other hand, excluding periods when average $q$ has a different trend raises the extent.

Average $q$ signals information relating future profits, and fundamental $q$ filters information carried in average $q$. When the asset market is stable, less noise is mixed up with profit information carried in average $q$. Under such an environment, filtering average $q$ is not very helpful, and economic activity conditional on fundamental $q$ is only slightly changed. On the other hand, when there is more noise in profit information carried in average $q$, filtering is helpful deciding economic decision. In such a circumstance, fundamental $q$ boosts economic activity further.

This section concludes that average $q$ and fundamental $q$ are complementary to each other, especially when the asset market is not stable. The estimation excluding average $q$ faces an omitted variable problem. When the asset market is not stable, excluding fundamental $q$ generates an omitted variable problem too.
Figure 3.1: Average $q$ and fundamental $q$ (1963Q2-2005Q4)
<table>
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<th>Prob</th>
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<tr>
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<td>Max Wald F-Stat(1991Q3)</td>
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<td>Exp Wald F-stat</td>
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Note: The test is based on estimation of $q_t=0.027+0.98q_{t-1}$, and it tests "no breakpoints within data". Quandt-Andrew test conducts a single Chow breakpoint test at every observation between two dates, between $\tau_1$ and $\tau_2$. The maximum statistic is the maximum of the individual Chow F-statistics, such as $\text{Max } F = \max_{\tau_1<\tau<\tau_2} (F(\tau))$. The Exp statistic takes the form, $\text{Exp } F = \ln \left( \frac{1}{\kappa} \sum_{\tau=\tau_1}^{\tau_2} \exp \left( \frac{1}{2} F(\tau) \right) \right)$.

Table 3.1: Quandt-Andrews Test for Breakpoint of Average Q

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Note: $q$ and $q^*$ denotes average $q$ and fundamental $q$ respectively. Numbers in parenthesis are standard errors.

Table 3.2: The minimal model: fraction of output explained by technology shocks
Figure 3.2: The minimal model: short-run response of output to a technology shock with 90 percent confidence intervals.
Figure 3.3: The minimal model: responses of output
Figure 3.4: The minimal model: short-run response of investment to a technology shock with 90 percent confidence intervals
Figure 3.5: The minimal model: responses of investment
Figure 3.6: The minimal model: short-run response of the asset market indexes to a technology shock with 90 percent confidence intervals.
Figure 3.7: The minimal model: responses of the asset market indexes
Figure 3.8: The large-scale, sub-sample model: short-run response of output with 90 percent confidence intervals.
Figure 3.9: The large-scale, sup-sample model: responses of output
Figure 3.10: The large-scale, sub-sample model: short-run responses of investment with 90 percent confidence intervals
Figure 3.11: The large-scale, sub-sample model: responses of investment
Figure 3.12: The large scale, sub-sample model: short-run responses of the asset market indexes with 90 percent confidence intervals
Figure 3.13: The large-scale, sup-sample model: responses of the asset market indexes
### Table 3.3: The large-scale, sub-sample estimation: the variance decomposition of the forecast error using average q

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### ii. VAR without average q (excluding both average and fundamental q)

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Note: q – ratio indicates average q. Sample period is 1963Q1-1991Q3. Numbers in parenthesis are standard errors.
Figure 3.14: The large-scale, full-sample model: short-run responses of output with 90 percent confidence intervals
Table 3.4: The large-scale, sub-sample estimation: the variance decomposition of the forecast error using fundamental q

### i. VAR with fundamental q (excluding average q)

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### ii. VAR with average q and fundamental q

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Note - Numbers in parenthesis are standard errors. q-ratio and q*-ratio indicate average q and fundamental q respectively. Sample period is 1963Q1-1991Q3
Figure 3.15: The large-scale, full-sample model: responses of output
Figure 3.16: The large-scale, full-sample model: short-run responses of investment with 90% confidence intervals
Figure 3.17: The large-scale, full-sample model: responses of investment
Figure 3.18: The large-scale, full-sample model: short-run responses of the asset market indexes with 90 percent confidence intervals
Figure 3.19: The large-scale, full-sample model: responses of the asset market indexes
Table 3.5: The large-scale, full-sample estimation: the variance decomposition of the forecast error using average q
Figure 3.20: Short-run responses to a technology shock with 90% confidence intervals. VAR estimation includes average $q$. 
Table 3.6: The large-scale, full-sample estimation: the variance decomposition of the forecast error using fundamental q

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Note - $q$ – ratio and $q^*$ – ratio indicate average q and fundamental q. Numbers in parenthesis are standard errors. Sample period is 1963Q1-2005Q4
Figure 3.21: Short-run impulse responses to a technology shock with 90% confidence intervals. VAR estimation includes fundamental $q$.
Figure 3.22: Short-run impulse responses to a technology shock with 90% confidence intervals in the benchmark model
CHAPTER 4

CONCLUDING REMARKS

In this dissertation I study the specification of the investment technology, and conduct empirical research on economic activity conditional on the asset market indices.

In chapter 2, I expound factors determining the asset price, especially the capital installation function. Depending upon the function, investment has various dynamics and it affects output and asset price dynamics. In addition, the efforts to make the capital installation more efficient have different impact on the asset price directly. It is not just a size of the foregone capital stock during the capital installation process, as Basu (1987) discussed, but the function itself. Christiano et al (2005) also considers an alternative installation function, but their research reports only that larger costs generate smaller output movements. There is no doubt that larger costs generates smaller output volatility. This section, however, explains that various capital installation technology generates different impacts on the economy even with the same size of adjustment costs.

I compare two investment technologies; the capital installation is more efficient with the larger capital stock, the \((i-k)\) case, and the other case indicates that the installation is more efficient with a constant investment growth, the \(\Delta i\) case. The
asset price shows a larger fluctuations in the $\Delta i$ case than the $(i - k)$ case. The $\Delta i$ case has smaller costs of investment than the $(i - k)$ case. The net costs of investment are the difference between purchasing price and the value of the created capital stock. In the $(i - k)$ case, initial purchasing costs are much larger than the value of created capital stock, since a firm accumulates more capital stock in the early periods when adjustment costs are highest. Due to large adjustment costs, the value of created capital stock is smaller than the costs. In the later periods, the adjustment costs falls in the accelerated speed, and investment spending also falls. In the $\Delta i$ case, a firm does not raise investment drastically, and changes investment gradually. Such investment management lowers adjustment costs and raises the value of created capital stock. The smaller net costs of the $\Delta i$ case raise asset price more than the $(i - k)$ case.

In chapter 3, I estimate economic activity conditional on two asset market indices, average $q$ and fundamental $q$. VAR estimation shows that output and investment rises when a positive technology shock is realized, and average $q$ boosts up output and investment. Fundamental $q$ is the profit forecasts and it filters information carried in average $q$, and it reduces the impacts of average $q$ on output and investment. When the asset market is stable over time, filtering information is not significant in an economy. In such environment the role of fundamental $q$ is not critical such that excluding fundamental $q$ generates the slightly smaller responses of output and investment. It is meaningful to study the role of asset market indices in economic activity at macro level. In addition, I use a long-run assumption to identify the effect of technology shocks. The method excludes debates about instantaneous effects of a
shock. Although some people argue about whether a technology shock is exogenous, it is at least more exogenous than a monetary shock.

In summary, this dissertation makes a contribution on better understanding the asset price behavior and understanding the role of capital installation in determining asset prices. In addition, a VAR estimation excluding the asset market index, especially average $q$, has omitted variable problem. When the asset market is not stable, excluding fundamental $q$ also generates an omitted variable problem. Average $q$ has at least 10 times larger responses to a technology shock in all estimation settings. Adding monetary variables in estimation reduces the extent at which technology shocks explain output volatility from 35 to 8 percents. On the other hand, excluding the periods when the asset market experiences turbulence raises the extent to 68 percent.
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