Essays In Financial And International Macroeconomics

by

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ABSTRACT

I study the importance of financial factors and real exchange rate shocks in explaining business cycle fluctuations, which have been considered important in the literature as non-technological factors in explaining business cycle fulctuations. In the first chapter, I study the implications of fluctuations in corporate credit spreads for business cycle fluctuations. Motivated by the fact that corporate credit spreads are countercyclical, I build a simple model in which difference in default probabilities on corporate debts leads to the spread in interest rates paid by firms. In the model, firms differ in the variance of the firm-level productivity, which is in turn linked to the difference in the default probability. The key mechanism is that an increase in the variance of productivity for risky firms relative to safe firms leads to reallocation of capital away from risky firms toward safe firms and decrease in aggregate output and productivity. I embed the above mechanism into an otherwise standard growth model, calibrate it and numerically solve for the equilibrium. In my benchmark case, I find that shocks to variance of productivity for risky and safe firms account for about 66% of fluctuations in output and TFP in the U.S. economy. In the second chapter, I study the importance of shocks to the price of imports relative to the price of final goods, led by the real exchange rate shocks, in accounting for fluctuations in output and TFP in the Korean economy during the Asian crisis of 1997-98. Using the Korean data, I calibrate a standard small open economy model with taxes and tariffs on imported goods, and simulate it. I find that shocks to the price of imports are an important source of fluctuations in Korea's output and TFP in the Korean crisis episode. In particular, in my benchmark case, shocks to the price of imports account for about 55% of the output deviation (from trend), one third of the TFP deviation and three quarters of the labor deviation in 1998.

# DEDICATION

I dedicate this dissertation to my family. Particularly to my wife, Joo Hee, who has put up with these many years of research, and to our precious son, Daniel, who is the joy of our lives.

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Chapter 1

CORPORATE CREDIT SPREADS AND BUSINESS CYCLES

1.1    Introduction

A key objective of business cycle research is to identify the shocks that drive output fluctuations. A recent literature emphasizes the role of uncertainty shocks where uncertainty means the variance of the firm-level productivity. (See, e.g., Bloom (2009), Bloom et al. (2009) and Arellano et al. (2010).) In this paper, I argue that shocks to heterogeneity in uncertainty across firms, as opposed to shocks to the level of uncertainty, are an important source of output fluctuations in the U.S. economy. Empirical motivation for the study of shocks to heterogeneity in uncertainty comes from the observation that corporate credit spreads fluctuate countercyclically: the quarterly yield spread between Baa and Aaa corporate bonds is negatively correlated with detrended output for the U.S. during the period 1964-2009. I build a simple model of fluctuations in the extent of heterogeneity of uncertainty across firms. I find that shocks to the extent of heterogeneity of uncertainty are an important source of fluctuations in the U.S. economy.

The key features of the model are as follows. Firms differ in the riskiness (i.e., the variance) of their idiosyncratic productivity shocks. Firms finance capital with 100% debt financing. The debt market is imperfect along several dimensions. First, repayment of debt is non-contingent except for the possibility of default. Second, the recovery rate on defaulted debt is lower than one. In this economy, as the extent of heterogeneity in riskiness increases, the credit spread increases, capital is reallocated from risky firms to safe firms, and output and productivity decrease. The induced productivity decrease in turn leads to lower labor supply, consumption and investment.

In the first section of the paper, I establish analytically how an increase in the extent of heterogeneity in riskiness leads to lower productivity in a simple static model. I also show how the recovery rate serves to amplify the size of this effect.

I then embed the static model into an otherwise standard version of the growth model, calibrate it and then use the calibrated model to study the quantitative effects of shocks to the distribution of riskiness. A critical feature of the assessment is that I use information on the fluctuations in actual default rates of corporate bonds to calibrate the size of these shocks.

In my benchmark case, shocks to the extent of heterogeneity in riskiness account for about 66% of fluctuations in output and TFP. Consistent with the analytic results in the static analysis, I find

that the recovery rate is very important: the effects of shocks to the extent of heterogeneity in riskiness on fluctuations in the credit spread, output and TFP are almost zero when the recovery rate is 100%.

There are many papers related to this paper regarding comovements in allocation of resources, credit spreads and output. Gertler and Lown (1999) studied the empirical relationship between corporate credit spreads cycles and business cycles. Khan and Thomas (2010) study the impact of financial shocks on output and aggregate TFP through the channel of reallocation of capital in an environment in which a firm's borrowing of capital via loan contracts is constrained by collateral in a way similar to Kiyotaki and Moore (1997). In this paper, I focus on assessing the implications of fluctuations in corporate credit spreads because they provide information to discipline the size of shocks that lead to fluctuations in the allocation of resources. Gomes and Schmid (2009) study the impact of aggregate productivity shocks on credit spreads in an environment in which allocation of capital is assumed to be fixed while endogenous fluctuations in allocation of capital is the key mechanism studied in this paper. Bloom (2009), Bloom et al. (2009) and Arellano et al. (2010) study the impact of uncertainty shocks on business cycles. In this paper, shocks to the extent of heterogeneity in uncertainty are the key driving force while uncertainty shocks are homogeneous across firms in those three papers. Bernanke and Gertler (1989) and Kiyotaki and Moore (1997) studied the implications of credit market imperfections for business cycles and this paper differs from them in the sense that output and TFP are highly positively correlated in my model while they are not in those two papers.

This paper is organized as follows. Section 2 sets up the static model and presents the main analytic results. Section 3 embeds the previous static model to a standard growth model. Section 4 calibrates the dynamic model and discusses the simulation results. Section 5 concludes.

## 1.2   The Basic Mechanism: A Static Analysis

In this section, I study a simple static model in order to illustrate the key economic mechanism which links increases in the extent of heterogeneity in riskiness across firms to decreases in output and productivity. I also highlight the role of financial frictions as an amplification device. In section 3, I embed this model into a dynamic setting and examine the quantitative properties of the mechanism.

### *Environment*

### Commodities

There is a final good. Capital is used in the production of the final good and can be converted to the final good one-for-one.

## Technology

There is a continuum of measure one of firms that produce the (homogeneous) final good. The stochastic production function of firm $i \in [0,1]$ is given by:

$$y(i) = z(i)[k(i)]^{\alpha}$$

where $\alpha \in (0,1)$ is the returns-to-scale parameter and $z(i)$ is the firm-level productivity.

A key feature of the model is that there is heterogeneity across firms in the extent of uncertainty that they face. For simplicity, I assume that a half of the firms face no uncertainty, i.e., $z(i) = 1, \forall i \in [0, 1/2]$, and label them as safe firms while the other half of the firms are assumed to face a positive extent of uncertainty, i.e., they draw $z(i)$ independently from an identical distribution of the mean equal to one, and I label them as risky firms. Note that two types of firms differ only in terms of the variance, but not the expected value, of the firm-level productivity. To facilitate exposition, I assume that risky firm $i$'s productivity, $z(i)$, is a random variable with two possible outcomes given by:

$$z(i) = \begin{cases} 0 & \text{w.p. } v \\ 1/[1-v] & \text{w.p. } 1-v \end{cases} , \quad \forall i \in (1/2, 1]$$

where $v \in (0,1)$ is the probability of drawing zero productivity for a risky firm. The expected productivity for a risky firm is equal to the productivity for a safe firm as mentioned earlier:

$$E[z(i)] = 1, \quad \forall i \in (1/2, 1].$$

Note that the variance of risky firm $i$'s productivity is increasing in $v$:

$$Var(z(i)) = \frac{v}{1-v}, \quad \forall i \in (1/2, 1].$$

The parameter $v$ will play a key role in this paper. I will study the consequences of an increase in the uncertainty for risky firms relative to safe firms, i.e., an increase in $v$, for allocations and prices in this economy. I will present analytical results in this section of a static model and quantify such effects in the next section of a dynamic model later.

A firm's type is assumed to be public information.

## Preferences

There is a representative household with preferences given by the expected utility function $E[u(c)]$ where $u(\cdot)$ is concave, increasing and $\mathscr{C}^2$.

The household is endowed with $\kappa > 0$ units of capital and owns all of the firms.

## Timing

The timing of events for this economy is as follows. There are two subperiods: initial and final. In the initial subperiod, the household supplies capital to firms via debt contracts. In the final subperiod, productivities for risky firms, $\{z(i)\}$, are realized, production takes place, capital is depreciated by the rate of $\delta \in (0,1)$, default/repayment decisions are made, profits are transferred to the household, confiscated output of the defaulting firms are distributed to the household, and consumption takes place.

## Debt Contracts

A firm finances its capital with 100% debt financing. By a debt contract, I mean a contractual arrangement such that firm $i$ borrows $k(i)$ units of capital and promises to pay back to the lender(s) the undepreciated capital, $[1-\delta]k(i)$, and $r(i)$ units of the final good per unit of capital:

$$r(i) = \begin{cases} r^S & ,\forall i \in [0,1/2] \\ r^R & ,\forall i \in (1/2,1] \end{cases}$$

where $r^S$ is the interest rate for a safe firm and $r^R$ is the interest rate for a risky firm.

If a firm chooses to default, then the lenders take back their undepreciated capital, and confiscate the defaulting firm's output. A defaulting firm's confiscated output is distributed to the lenders according to the share of an individual lender's capital supply to the defaulting firm. A key assumption is that the lenders lose a fraction $\tau \geq 0$ of undepreciated capital where $\tau$ represents costs of collecting back capital from a defaulting firm, e.g., court-related bankruptcy costs, losses of capital incurred by poor management during the confiscation procedures and so on.

I close this section by briefly describing the market structure of debt contracts. The debt contract market is competitive in the following sense:

1. lenders, i.e., the household, take as given the market interest rates, expected confiscated output per unit of capital, the expected probability of default for an individual firm, and can supply as much capital as they want.

2. borrowers, i.e., firms, take as given the market interest rates, and can borrow as much capital as they want.

The above two conditions essentially say that neither individual lenders nor individual firms affect the market interest rates and that individual lenders cannot affect the decision rules of firms. An

individual lender-household is assumed to be infinitesimally small such that its lending behavior cannot affect the default decision rule of an individual borrower-firm for this economy.

## A Firm's Problem

I write the ex-post profit of firm $i$ after default/repayment in the final subperiod as:

$$\pi\Big(r(i),k(i),z(i)\Big) = \max_{x\in\{0,1\}} \left\{ [1-x]\cdot\left[z(i)[k(i)]^\alpha - r(i)k(i)\right] \right\}$$

where $x$ denotes the firm's choice whether to default, $x = 1$, or not, $x = 0$.

First, it is obvious that safe firm $i$ never defaults given that the firm faces no uncertainty and that the firm would lose its output if it defaults. Therefore, safe firm $i$'s optimal decision rule of borrowing capital is given by:

$$\alpha[k(i)]^{\alpha-1} = r^S.$$

It follows that the default probability for safe firm $i$ is zero in equilibrium, which the lenders rationally expect.

Second, it is obvious that risky firm $i$ defaults and its profit is equal to zero in the event of $z(i) = 0$ for any given positive values of $r^R$ and $k(i)$. It is also obvious given that the marginal product of capital conditional on $z(i) = 1/[1-v]$ is infinite at $k(i) = 0$ that risky firm $i$ does not default in the event of $z(i) = 1/[1-v]$ and, taking it into its consideration, chooses $k(i)$ to maximize its expected profit given by:

$$\max_{k(i)} \left\{ v\cdot 0 + [1-v]\cdot\left[\frac{1}{1-v}\cdot[k(i)]^\alpha - r^R k(i)\right] \right\}$$

which implies that risky firm $i$'s optimal $k(i)$ is given such that its profit conditional on $z(i) = 1/[1-v]$ should be maximized[1]:

$$\alpha\cdot\frac{1}{1-v}\cdot[k(i)]^{\alpha-1} = r^R.$$

Lastly, it is straightforward given that only the risky firms drawing zero productivity, i.e., their output is zero, default in equilibrium that a defaulting risky firm's confiscated output per unit of capital is equal to zero in equilibrium and the default probability for risky firm $i$ is equal to $v$, the probability of zero productivity. Furthermore, by the law of large numbers, the ex-post fraction of risky firms drawing zero productivity is exactly equal to $v$, the ex-ante probability of it, and so is the default rate for risky firms.

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[1]The key here is that the firm's profit in the event of $z(i) = 0$ becomes zero by the option of default, which provides the firm with an insurance, to some extent, against the negative profit in the event of $z(i) = 0$ in the absence of such an option.

The Household's Problem

As mentioned earlier, taking as given the market interest rates, expected confiscated output per unit of capital, default probabilities and total profit, the household maximizes its expected utility subject to its budget constraint. More specifically, the household makes its decision of how much capital to supply to firms in the initial subperiod prior to realization of $\{z(i)\}$ for risky firms. In the final subperiod, when $\{z(i)\}$ for risky firms are realized, the household receives interest payments, undepreciated capital and total profit, which it uses for consumption of the final good[2].

I present formally the household's problem as follows:

$$\max_{c,\{k(i)\}} \left\{ E[u(c)] \right\}$$

$$s.t. \quad c = \pi + \int_0^{1/2} \left[1 - \delta + r^S\right] k(i) di + \int_{1/2}^1 \left[ [1 - \chi_{z(i)=0}][1 - \delta + r^R] + \chi_{z(i)=0}[1 - \delta][1 - \tau] \right] k(i) di$$

$$+ [1 - \delta] \left[ \kappa - \int_0^1 k(i) di \right],$$

$$\int_0^1 k(i) di \leq \kappa, \quad k(i) \geq 0, \forall i \in [0, 1]$$

where $\pi$ is total profit and $\chi_{z(i)=0}$ is an indicator on whether $z(i)$ is zero or not:

$$\chi_{z(i)=0} = \begin{cases} 1 & \text{if } z(i) = 0 \\ 0 & \text{otherwise} \end{cases}.$$

Recall that risky firm $i$ defaults if and only if in the event of drawing $z(i) = 0$, which is incorporated into the above household's budget constraint via the indicator function $\chi_{z(i)=0}$. In the event of $z(i) = 0$, risky firm $i$ defaults and the household loses a $\tau$ fraction of undepreciated capital as well as interests for the capital supplied to the firm.

In this economy, there is no aggregate uncertainty and hence consumption is independent of the realized gross returns to individual debts[3]. It follows that the household purchases only the debts of which expected gross returns are the highest. In order for the supply of capital to be positive for both risky and safe firms, which is the equilibrium outcome as I will show later on, the expected gross returns should be equalized between the two types of debts:

$$1 - \delta + r^S = [1 - v]\left[1 - \delta + r^R\right] + v[1 - \delta][1 - \tau]$$

[2]The household receives zero confiscated output for a defaulting risky firm in equilibrium as already discussed earlier.

[3]More formally, the equilibrium capital allocation is identical across the same type of firms as discussed earlier, which implies that the equilibrium consumption is independent of realizations of $z(i)$s for risky firms because any idiosyncratic risk is diversified away in equilibrium.

which simplifies to: $r^S = [1-v]r^R - v\tau[1-\delta]$. It is straightforward that two parameters $v$ and $\tau$ are important for the equilibrium interest rates $r^S$ and $r^R$, and hence they are also important for $r^R - r^S$, the equilibrium corporate credit spread. I will focus on the effects of increases in $v$ and/or $\tau$ on the credit spread in the comparative statics section later.

## Resource Constraint

Capital can be converted to the final good one-for-one. Taking into consideration depreciation and losses of capital in the event of default, I write the resource constraint for this economy as:

$$c = y + [1-\delta]\left[\frac{1}{2}k^S + \frac{1}{2}k^R\left[[1-v]+v[1-\tau]\right]\right] + [1-\delta]\left[\kappa - \frac{1}{2}k^S - \frac{1}{2}k^R\right]$$

where $y$ is aggregate output given by:

$$y = \frac{1}{2}[k^S]^\alpha + \frac{1}{2}\left[v \cdot 0 + [1-v] \cdot \frac{1}{1-v}\right][k^R]^\alpha$$

which simplifies to: $y = \frac{1}{2}\left[[k^S]^\alpha + [k^R]^\alpha\right]$. The resource constraint says that consumption is equal to aggregate output plus capital after depreciation and losses due to defaults.

## *Equilibrium*

Competitive equilibrium for this economy is a list of allocation $(c, y, \{k(i)\})$, interest rates $(r^S, r^R)$, expected default probability for risky firms equal to $v$, the expected confiscated output per unit of capital for a risky firm equal to zero, and total profit $\pi$ that satisfy:

1. each firm maximizes its expected profit

2. the household maximizes its expected utility subject to its budget constraint

3. the expected default probability and expected confiscated output per unit of capital for risky firms are consistent with the decision rules of risky firms

4. total profit $\pi$ is consistent with the decision rules of safe and risky firms

5. markets clear

## *Results*

In this section, I characterize the equilibrium allocation and prices of capital and then analyze the effects of an increase in the variance of productivity for risky firms relative to safe firms on aggregate output and productivity.

## A Pseudo Planner's Problem

I show that the equilibrium allocation can be obtained as the solution to the following Pseudo Planner's Problem:

$$\max_{c,k^S \geq 0, k^R \geq 0} \left\{ E[u(c)] \right\}$$

$$s.t. \quad c = \frac{1}{2}[k^S]^\alpha + \frac{1}{2}[k^R]^\alpha + \frac{1}{2}[1-\delta]k^S + \frac{1}{2}[1-\delta]k^R \left[ [1-v] + v[1-\tau] \right] + [1-\delta]\left[ \kappa - \frac{1}{2}k^S - \frac{1}{2}k^R \right],$$

$$\frac{1}{2}k^S + \frac{1}{2}k^R \leq \kappa.$$

Note that losses of capital by $\tau$ for an occurrence of $z(i) = 0$ are incorporated to the above problem so that one of the key financial frictions for this economy is maintained. Furthermore, I have already simplified the above pseudo planner's problem by imposing the obvious condition for the optimal decision rule of capital allocation such that capital allocation should be identical across the same type of firms[4]:

$$k(i) = k^S \geq 0, \forall i \in [0, 1/2], \quad k(i) = k^R \geq 0, \forall i \in (1/2, 1].$$

**Proposition 1.** *1. A unique solution to the above pseudo planner's problem exists and is identical to the equilibrium allocation*

*2. The solution is characterized by:*

$$\alpha[k^S]^{\alpha-1} = \alpha[k^R]^{\alpha-1} - v\tau[1-\delta],$$

$$\frac{1}{2}\left[ k^S + k^R \right] = \kappa.$$

*It follows that $k^S > k^R > 0$ for $\tau \in (0, 1]$ and that $k^S = k^R = \kappa$ for $\tau = 0$.*

*Proof.* See the appendix. □

A key result is that capital is allocated such that the expected gross returns are equalized across firms. The positive probability of zero productivity for a risky firm implies the positive expected losses of capital via the friction $\tau$ for a risky firm while there are no such losses for a safe firm. Given that expected output from a given amount of capital is the same between a risky firm and a safe firm, it follows that the expected gross return curve of a risky firm is below that of a safe firm. The optimality condition of capital allocation, i.e., equalization of the expected gross returns across firms, implies that

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[4]It is obvious in the sense that the same type of firms are homogeneous at the initial subperiod, when the decision for capital allocation is made.

more capital should be allocated to a safe firm than a risky firm for the case of $\tau > 0$. It is also interesting that there is no misallocation of capital for the case of $\tau = 0$.

So far, I have focused on the equilibrium allocations. I next turn to discuss the equilibrium credit spread. Lemma 1 states that credit spread is tightly related to the equilibrium capital allocation.

**Lemma 1.** *The equilibrium $r^R - r^S$, corporate credit spread, is given by:*

$$r^R - r^S = \alpha \frac{1}{1-v}[2\kappa - k^S]^{\alpha-1} - \alpha[k^S]^{\alpha-1}$$

*which is strictly positive because $k^S \geq k^R = 2\kappa - k^S > 0$ and $v \in (0,1)$.*

*Proof.* It follows from the market clearing condition and the earlier results that $\alpha \cdot [k(i)]^{\alpha-1} = r^S$ for safe firm $i$ and $\alpha \cdot 1/[1-v] \cdot [k(i')]^{\alpha-1} = r^R$ for risky firm $i'$. □

Recall that the optimality condition for the household's capital supply is simplified to:

$$r^S - [1-v]r^R = -v\tau[1-\delta]$$

which is, combined with the condition for the equilibrium capital demand of firms, simplified to:

$$\alpha[k^S]^{\alpha-1} - \alpha[2\kappa - k^S]^{\alpha-1} = -v\tau[1-\delta].$$

It follows that the two parameters $v$ and $\tau$ are important for the equilibrium capital allocation and thereby they are also important for the equilibrium interest rates and credit spread.

### Comparative Statics

The primary objective of this paper is to assess the consequences of an increase in the corporate credit spread on aggregate output. As noted above, two key parameters that influence the equilibrium corporate credit spread are $v$ and $\tau$. In this section, I present comparative statics results concerning how $v$ and $\tau$ affect equilibrium allocations and credit spread. As we will see in the next section, these effects will continue to be present in the dynamic analysis.

I show that, in the case of $\tau > 0$, in response to increases in both $v$ and $\tau$, the credit spread increases, capital is reallocated away from risky firms toward safe firms, and aggregate output decreases. Because inputs are constant in the equilibrium, it follows that TFP will also be decreasing in both $v$ and $\tau$.

This result is intuitive. In response to increases in either $v$ or $\tau$, the expected gross returns to risky debts relative to safe debts shift downward because the expected losses of capital increases. To

equalize the expected gross returns between safe and risky debts, capital should be reallocated from risky firms to safe firms. Aggregate output decreases because more capital is allocated to safe firms, which at the margin have lower (expected) productivity since $k^S > k^R$.

Proposition 2 reports the effects of an increase in $v$.

**Proposition 2.** *1. The credit spread is increasing in $v$: $d[r^R - r^S]/dv > 0$.*

*2. $k^S$ is increasing in $v$ and $k^R$ is decreasing in $v$ for $\tau \in (0,1]$:*

$$dk^S/dv > 0, \quad dk^R/dv < 0, \quad \forall \tau \in (0,1].$$

*3. Aggregate output is decreasing in $v$ for $\tau \in (0,1]$:*

$$\frac{dy}{dv} = \frac{1}{2}\left[-v\tau[1-\delta]\right]\frac{dk^S}{dv} < 0, \quad \forall \tau \in (0,1].$$

*It follows that TFP, defined as $y/\kappa$, also decreases in $v$ for $\tau \in (0,1]$.*

*Proof.* Recall that I have already derived, in the earlier discussion of the lemma 1, the equilibrium condition for the household's capital supply such that the expected gross returns are equalized between safe and risky debts:

$$\alpha[k^S]^{\alpha-1} - \alpha[2\kappa - k^S]^{\alpha-1} = -v\tau[1-\delta].$$

From the above equation, for the case of $\tau \in (0,1]$, it is obvious that $k^S$ is strictly increasing in $v$ because of $\alpha \in (0,1)$, which in turn implies that $k^R = [2\kappa - k^S]$ is strictly decreasing in $v$. It follows that $r^S$ is strictly decreasing in $v$ and $r^R$ is strictly increasing in $v$, and hence the credit spread, $r^R - r^S$, is strictly increasing in $v$. Lastly, $dy/dv = \frac{1}{2}\left[\alpha[k^S]^{\alpha-1} - \alpha[2\kappa - k^S]^{\alpha-1}\right]dk^S/dv$ is simplified to $dy/dv = \frac{1}{2}\left[-v\tau[1-\delta]\right]dk^S/dv$, which is obviously negative for $\tau > 0$ and zero for $\tau = 0$. □

The third part of the above result shows that the response of $y$ to an increase in $v$ is determined by the endogenous reallocation of capital away from risky firms toward safe firms. This reallocation effect on output is always non-positive. But, it is important to note that it is zero for the case of $\tau = 0$ and negative whenever $\tau > 0$. The reason for this is that equalization of the expected gross returns between risky and safe debts implies that the expected marginal product of capital is equalized between risky and safe firms for the case of $\tau = 0$. In this case, the marginal effect of misallocation is zero. To see this, recall the first equation in the above proof of the proposition 2:

$$\alpha[k^S]^{\alpha-1} - \alpha[2\kappa - k^S]^{\alpha-1} = -v\tau[1-\delta]$$

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which simplifies, in the case of $\tau = 0$, to: $\alpha[k^S]^{\alpha-1} - [1-v]\alpha \cdot 1/[1-v] \cdot [k^R]^{\alpha-1} = 0$, i.e., no

difference in the expected marginal product of capital between the two types of firms[5].

This result shows the importance of $\tau$ in determining the response of $y$ to an increase in $v$,

which is quite intuitive given that the larger $\tau$, the larger the current extent of misallocation and the

larger the gap in the expected productivity between safe and risky firms before an increase in $v$.

Next, proposition 3 states the results concerning the effects of an increase in $\tau$ on the

equilibrium allocations and credit spread.

**Proposition 3.** *1. The credit spread is increasing in $\tau$: $d[r^R - r^S]/d\tau > 0$.*

*2. $k^S$ is increasing in $\tau \in (0,1]$ and $k^R$ is decreasing in $\tau \in (0,1]$:*

$$dk^S/d\tau > 0, \quad dk^R/d\tau < 0, \quad \forall \tau \in (0,1].$$

*3. Aggregate output is decreasing in $\tau \in (0,1]$: $dy/d\tau < 0, \quad \forall \tau \in (0,1]$.*

   *It follows that TFP, defined as $y/\kappa$, also decreases in $\tau \in (0,1]$.*

*Proof.* It is essentially the same with the proof of the proposition 2. Note again the equilibrium

condition for capital allocation:

$$\alpha[k^S]^{\alpha-1} - \alpha[2\kappa - k^S]^{\alpha-1} = -v\tau[1-\delta].$$

From the above equation, it is obvious that $k^S$ is strictly increasing in $\tau \in (0,1]$, from which all of the

other parts of the proposition 3 follow, see the proof of the proposition 2. □

The proposition 3 says that an increase in $\tau$ leads to reallocation of capital from risky firms to

safe firms and a decrease in aggregate output, which is quite similar to the effects of $v$. The key is that

an increase in $\tau$ leads to an increase in the expected losses of capital for risky debts, which is the same

as for the effect of an increase in $v$, and thereby induces a downward shift of the expected gross returns

to risky debts. It follows that, in response to an increase in $\tau$, capital is reallocated from risky firms to

safe firms, and aggregate output and productivity decrease.

Note that an increase in $\tau$ represents a decrease in the recovery rate on defaulted debt, which

could be interpreted as a negative financial shock to the collateral value of a firm as studied by Khan

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[5]Moreover, in the case of $\tau = 0$, an increase in $v$ leads to no reallocation of capital as I have already shown, in proposition 1, that allocation of capital is independent of $v$ in this case: $k^S = k^R = \kappa, \forall v \in (0,1)$ for $\tau = 0$.

and Thomas (2010). I do not explore further to compare my result to the literature because I do not focus on studying the effects of financial shocks. ( See, e.g., Khan and Thomas (2010) and references therein for this issue.)

In section 2, I illustrated the key economic mechanism which links an increase in the extent of uncertainty for risky firms relative to safe firms, which the parameter $\nu$ represents, to decreases in output and productivity. I obtained the equilibrium condition for capital allocation such that the expected gross returns should be equalized between safe and risky debts. I presented comparative statics results concerning how $\nu$, relative uncertainty across firms, and $\tau$, losses of capital in the event of default, affect equilibrium allocations and credit spread.

In short, an increase in $\nu$, again the extent of uncertainty for risky firms relative to safe firms, leads to reallocation of capital from risky firms to safe firms, an increase in the credit spread, and decreases in aggregate output and productivity. In the above result, I have shown the importance of financial frictions. First, I have shown that the effect on aggregate output of the endogenous capital reallocation, if any, induced by an increase in $\nu$ is negligible as long as there is no losses of capital in the event of default, i.e., $\tau = 0$. Second, I have also shown that an increase in $\tau$ itself leads to the result similar to an increase in $\nu$, which implies that the effects of an increase in $\nu$ are larger as long as it leads to an increase in $\tau$.

## 1.3   Dynamic Model

In this section, I embed the previous static model into an otherwise standard growth model and use the dynamic model to assess the quantitative implications of stochastic fluctuations in the extent of uncertainty for risky firms relative to safe firms.

*Environment*

Two features are added in this dynamic model. First, the household makes decisions on consumption/leisure and consumption/investment. Second, the probability of zero-productivity for a risky firm evolves stochastically so that its default probability and the credit spread fluctuate stochastically.

Technology

There is a continuum of safe firms of measure $\lambda \in (0,1)$ and a continuum of risky firms of measure $1 - \lambda$: firm $i$ is safe for $i \in [0, \lambda]$ and is risky for $i \in (\lambda, 1]$. I assume that the measure of firms is

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exogenously fixed[6].

Firm $i$'s production function is the same as in the previous static analysis except that labor services are also used in the production of the final good:

$$y_t(i) = z_t(i) \left[ [k_t(i)]^\theta [h_t(i)]^{1-\theta} \right]^\alpha, \quad \forall i \in [0,1], \quad \alpha \in (0,1), \quad \theta \in (0,1)$$

where $y_t(i)$ is the firm's output, $z_t(i)$ is an idiosyncratic productivity shock, $k_t(i)$ is capital services and $h_t(i)$ is labor services.

I assume that $z_t(i)$ is independent across $i$ as well as over time $t$. Furthermore, I assume that the per period probability distributions of $z_t(i)$ are basically the same as in the previous section. First, I maintain to assume no uncertainty for a safe firm as in the previous section[7]:

$$z_t(i) = 1, \quad \forall i \in [0,\lambda], \forall t.$$

Second, letting $v_t$ denote the zero-productivity probability for a risky firm in period $t$, I assume that $v_t$ evolves according to a first order Markov process. Let $f(\cdot|v_{t-1})$ denote the density of $v_t$ conditional on $v_{t-1}$.

Lastly, as in the previous section, a firm's type is assumed to be public information.

## Household

The representative household has preferences given by:

$$E_0 \left[ \sum_{t=0}^{\infty} \beta^t \left[ log(c_t) - \psi \frac{h_t^{1+\omega}}{1+\omega} \right] \right], \quad \beta \in (0,1)$$

where $c_t$ is consumption in period $t$, $h_t$ is labor supply and $E_0[\cdot]$ is the expectation operator in $t = 0$, and $\beta$ is the discount factor.

The household is endowed with one unit of time every period and $k_0$ units of capital in the initial period $t = 0$. The household owns all of the firms.

## Timing

The timing of events for this economy is as follows. In each period $t$, there are two subperiods, labeled initial and final, as in the earlier analysis. In the initial subperiod, $v_t$ is realized, which everyone

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[6]This assumption seems reasonable for the purpose of assessing the quantitative implications of shocks to relative uncertainty for the output fluctuations because it is well known in the literature that entering and/or exiting firms are small and thereby their effects on output are small.

[7]In this paper, I purposefully link tightly the extent of uncertainty for a firm to the firm's default probability. As we will see later on when I calibrate the model, the default rate of "safe" firms is very close to zero in mean as well as volatility.

observes, the household supplies labor to firms via (defaultable) wage contracts and capital to firms via (defaultable) debt contracts. In the final subperiod, idiosyncratic productivities for risky firms, $\{z_t(i)\}$, are realized, production takes place, firms make default decisions, profits are transferred to the household, confiscated outputs of the defaulting firms are distributed to the suppliers of labor and capital, and the household makes its consumption/investment decision.

## Debt and Wage Contracts

In this section, I describe the structure of debt and wage contracts. I maintain the key features of the debt contracts in the previous static analysis. I also maintain to assume that a firm finances its capital with 100% debt financing as in the previous section. Regarding wage contracts, I assume that wage payments to the suppliers of labor services are prone to default risk similarly to the debt contracts. Upon default of a firm's promises on wage contracts and debt contracts[8], the defaulting firm's output is confiscated and distributed to suppliers of labor services and capital. I will discuss debt and wage contracts in more detail in what follows.

A debt contract is, as standard in the literature, a one-period contract specifying lending/borrowing capital, repayment and punishment-to-default. The details of the one-period debt contracts in this section are the same as for the previous static analysis and I present key features of debt contracts rather than repeating all of the details. Firm $i$ promises to pay back to the lenders undepreciated capital, $[1-\delta]k_t(i)$, and $r_t(i)$ units of the final good per unit of capital:

$$ r_t(i) = \begin{cases} r_t^S & , \forall i \in [0, \lambda] \\ r_t^R & , \forall i \in (\lambda, 1] \end{cases} . $$

I maintain $r_t^S$ as the interest rate for a safe firm in period $t$ and $r_t^R$ as the interest rate for a risky firm.

Renegotiation is not allowed and hence the firm has two options: either fully repay or default. In the event that the firm defaults on its promises, the suppliers of capital take back the undepreciated capital and confiscate the firm's output. I will discuss the arrangement in the event of default in more detail later.

I next turn to describe wage contracts. A wage contract is a one period contract specifying a firm's uses of labor services, repayment and punishment-to-default. Firm $i$ hires $h_t(i)$ units of labor in the initial subperiod in period $t$. In return for hiring $h_t(i)$, the firm promises to pay back $w_t(i)$ units of

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[8]As we will see later on, a firm either defaults on both of the two contracts or does not default on either in equilibrium.

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the final good per unit of labor services in the final subperiod in period $t$:

$$w_t(i) = \begin{cases} w_t^S & ,\forall i \in [0,\lambda] \\ w_t^R & ,\forall i \in (\lambda,1] \end{cases}$$

where $w_t^S$ is the wage rate for a safe firm in period $t$ and $w_t^R$ is the wage rate for a risky firm. Note that wage rates differ between a safe firm and a risky firm because of the difference in default risks, just as interest rates differ for the same reason.

Similarly to debt contracts, renegotiation is not allowed for the wage contract and hence the firm has two options: either fully repay or default. In the event that the firm defaults on its promises, the suppliers of labor confiscate the firm's output.

I describe the arrangement in the event of default as follows. For simplicity, I focus on the case in which a firm defaults on both its debt and wage contracts, which suffices for my analysis because in this model a firm either defaults on both of these contracts or does not default on either. If a firm defaults on both its debt and wage contracts, then the suppliers of labor lose wages and the suppliers of capital lose interest payments, $r_t(i)k_t(i)$, and a fraction $\tau$ of undepreciated capital, $\tau[1-\delta]k_t(i)$. As mentioned earlier, the defaulting firm's output is confiscated and distributed to the suppliers of labor services and suppliers of capital. Specifically, I assume that the suppliers of labor and suppliers of capital split the confiscated output in the proportions $(1-\theta:\theta)$. Once the confiscated output is split between the suppliers of labor and suppliers of capital, individual suppliers of labor and/or capital receive the confiscated output based on their shares in labor and/or capital for the defaulting firm.

I close this section by discussing briefly the punishment for default in this economy. I have assumed that punishment is limited in the sense that a firm with a history of defaults in previous periods can still run its business and access the labor and capital markets without any penalty[9]. Alternatively, I could have assumed that a defaulting firm's access to the labor and capital markets is prohibited *permanently* and that a new entrant, of the same type as for the defaulting firm, replaces the defaulting firm immediately from the next period, which does not alter my results in this paper. More generally, I could assume that a defaulting firm must exit after liquidation by the suppliers of labor and capital and

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[9]This captures two features of reality. First, the suppliers of labor and/or capital can confiscate the defaulting firm's physical assets, i.e., output and capital, but not the know-how of the firm in running its business successfully. That is, a firm with a history of previous default(s) can always start a new business by changing the name of the firm. Second, it is difficult to maintain the cooperation of suppliers of labor and/or capital required for excluding a defaulting firm's access to labor and/or capital market in the future. A defaulting firm can start a new business with the possibility of success in its new business, which lures workers and investors to supply labor and capital services to the firm, which is the reason why I argue that it is difficult to punish a defaulting firm for multiple periods in a world of competitive markets.

that a defaulting firm's access to the labor and capital markets is prohibited for some periods in the future. I leave analysis of this for future work.

## A Firm's Problem

A firm's per-period problem is essentially the same as for the previous static analysis except that a firm, in this section, makes a decision on labor as well as capital. I summarize the results about a firm's problem and default decision rules rather than discuss them in detail.

First, firm $i$ defaults if and only if $z_t(i) = 0$, from which it immediately follows that a safe firm never defaults and that, by the law of large numbers, $v_t$ fraction of risky firms default in period $t$ the same as in the previous section. It also holds true that the (expected) confiscated output per unit of labor and per unit capital for a risky firm are equal to zero.

Second, it is obvious given that risky firm $i$'s profit in the event of $z_t(i) = 0$ is zero by the option of default that the firm's optimal quantity of labor and capital services are given such that the firm maximizes its profit conditional on $z_t(i) = 1/[1 - v_t]$. I write them in recursive form as: $\forall i \in (\lambda, 1]$,

$$\alpha\theta \frac{1}{1-v}[k(i,v,K)]^{\alpha\theta-1}[h(i,v,K)]^{\alpha[1-\theta]} = r^R(v,K),$$

$$\alpha[1-\theta]\frac{1}{1-v}[k(i,v,K)]^{\alpha\theta}[h(i,v,K)]^{\alpha[1-\theta]-1} = w^R(v,K)$$

where $r^R(v,K)$ and $w^R(v,K)$ are a risky firm's interest and wage rate functions, respectively, $k(i,v,K)$ and $h(i,v,K)$ are firm $i$'s policy functions for capital and labor, respectively, and $K$ is aggregate capital stock. $(v,K)$ is the aggregate state vector.

Similarly, safe firm $i$'s optimal quantity of labor and capital services are given by: $\forall i \in [0,\lambda]$,

$$\alpha\theta[k(i,v,K)]^{\alpha\theta-1}[h(i,v,K)]^{\alpha[1-\theta]} = r^S(v,K),$$

$$\alpha[1-\theta][k(i,v,K)]^{\alpha\theta}[h(i,v,K)]^{\alpha[1-\theta]-1} = w^S(v,K)$$

where $r^S(v,K)$ and $w^S(v,K)$ are a safe firm's interest and wage rate functions.

Lastly, it is obvious that allocations of capital and labor are identical to the same type of firms as seen in the above optimality conditions of capital and labor for risky and safe firms:

$$k(i,v,K) = \begin{cases} k^S(v,K) & \text{for } i \in [0,\lambda] \\ k^R(v,K) & \text{for } i \in (\lambda,1] \end{cases}, \quad h(i,v,K) = \begin{cases} h^S(v,K) & \text{for } i \in [0,\lambda] \\ h^R(v,K) & \text{for } i \in (\lambda,1] \end{cases}.$$

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## The Household's Problem

For simplicity, I focus on the case in which the household's supply of capital and labor are symmetric across firms of the same type. In this case, I write the household's problem in recursive form as:

$$v(k,v,K) = \max_{c,k',h^S,h^R,k^S,k^R} \left\{ \left[ log(c) - \psi \frac{h^{1+\omega}}{1+\omega} \right] + \beta \int v(k',v',K'(v,K)) f(v'|v) dv' \right\}$$

$$s.t. \quad c+k' = \pi(v,K) + \lambda \left[ w^S(v,K)h^S + [1-\delta+r^S(v,K)]k^S \right]$$

$$+[1-\lambda] \left[ [1-v] \left[ w^R(v,K)h^R + [1-\delta+r^R(v,K)]k^R \right] + v[1-\delta][1-\tau]k^R \right],$$

$$\lambda h^S + [1-\lambda]h^R = h \in [0,1], \quad \lambda k^S + [1-\lambda]k^R = k,$$

$$h^S \geq 0, h^R \geq 0, \quad k^S \geq 0, k^R \geq 0$$

where $k$ is the household's current capital.

The function $v(k,v,K)$ is the value function for the recursive problem of the household, $K'(v,K)$ is the law of motion for aggregate capital, and $\pi(v,K)$ is the aggregate profit function. Note that the household takes as given the expected default probability for a risky firm equal to $v$ and the expected confiscated output for a defaulting risky firm equal to zero, which I already incorporated into the household's budget constraint.

The above household's problem says that, taking as given price functions, default probability for risky firms, and the expected confiscated output per unit of labor and per unit of capital[10] for a risky firm in the event of default, the household makes decision on $k'$, the next period capital holdings, and $(h^S, h^R, k^S, k^R)$, supply of labor and capital to firms.

The condition for the household's optimal capital supply to safe and risky firms is that the expected gross returns should be equalized between the two types of debts as in the previous section:

$$1-\delta+r^S(v,K) = [1-v]\left[ 1-\delta+r^R(v,K) \right] + v[1-\delta][1-\tau].$$

Similarly, given total labor supply $h$, the condition for the household's optimal labor supply to safe and risky firms is that the expected wage payments per unit of labor should be equalized between the two types of wage contracts:

$$w^S(v,K) = [1-v]w^R(v,K).$$

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[10]They are zero as discussed earlier.

The resource constraint for this economy is given by:

$$c_t + k_{t+1} = y_t + [1-\delta]\left[\lambda k_t^S + [1-\lambda]\left[1 - v_t \tau\right]k_t^R\right]$$

where $y_t$ is aggregate output in period $t$ given by:

$$y_t = \lambda \left[[k_t^S]^\theta [h_t^S]^{1-\theta}\right]^\alpha + [1-\lambda]\left[[k_t^R]^\theta [h_t^R]^{1-\theta}\right]^\alpha.$$

The resource constraint says that the household's consumption plus next period capital holdings are equal to aggregate output plus undepreciated capital minus losses of capital due to defaults.

## *Equilibrium*

I study a recursive competitive equilibrium, which is a list consisting of the value function $v(k, v, K)$, policy functions $c(k, v, K), k'(k, v, K), h^S(k, v, K), h^R(k, v, K), k^S(k, v, K), k^R(k, v, K)$, interest rate functions $r^S(v, K)$ and $r^R(v, K)$, wage rate functions $w^S(v, K)$ and $w^R(v, K)$, the expected default probability for a risky firm equal to $v$, the expected confiscated output in the event of default for a risky firm equal to zero, total profit function $\pi(v, K)$ and aggregate capital transition function $K'(v, K)$ that satisfy:

1. $v(k, v, K)$ solves the Bellman equation for the household's problem earlier, and policy functions $c(k, v, K), k'(k, v, K), h^S(k, v, K), h^R(k, v, K), k^S(k, v, K)$ and $k^R(k, v, K)$ are optimal decision rules of such a problem.

2. $\forall (v, K) \in (0, 1) \times [0, \infty)$, $h^S(K, v, K)$ and $k^S(K, v, K)$ are the optimal quantity of labor and capital for safe firm $i \in [0, \lambda]$, and $h^R(K, v, K)$ and $k^R(K, v, K)$ are the optimal quantity of labor and capital for risky firm $i \in (\lambda, 1]$.

3. Markets clear: $\forall (v, K) \in (0, 1) \times [0, \infty)$,

$$c(K, v, K) + k'(K, v, K) = y(v, K) + [1-\delta]\left[\lambda k^S(K, v, K) + [1-\lambda][1 - v\tau]k^R(K, v, K)\right]$$

where output function $y(v, K)$ is defined as:

$$y(v, K) \equiv \lambda \left[[k^S(K, v, K)]^\theta [h^S(K, v, K)]^{1-\theta}\right]^\alpha + [1-\lambda]\left[[k^R(K, v, K)]^\theta [h^R(K, v, K)]^{1-\theta}\right]^\alpha.$$

4. $\pi(v, K)$ is consistent with decision rules of individual firms:

$$\pi(v, K) = [1-\alpha]y(v, K), \quad \forall (v, K) \in (0, 1) \times [0, \infty).$$

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5. $k'(k,v,K)$ and $K'(v,K)$ are consistent:

$$k'(K,v,K) = K'(v,K), \quad \forall (v,K) \in (0,1) \times [0,\infty).$$

### 1.4 Quantitative Analysis

In this section, my primary objective is to assess the quantitative consequences of shocks to $v$ to the U.S. economy during the period 1964-2009. For this purpose, I calibrate the dynamic model presented in the previous section by using NIPA data on the U.S. economy and Moody's data on corporate bond market, and I calibrate the shock process for $v$ by targeting fluctuations in the distribution of default rates of corporate bonds. I find that these shocks are an importance source of fluctuations in the U.S. economy.

*Fluctuations in The U.S. Economy And The Corporate Bond Market*

In this subsection, I document facts about fluctuations in real economic aggregates and fluctuations in the yields and default rates of corporate bonds over the period 1964-2009 as well as recovery rates for the period 1982-2009.

Data

For the U.S. economy, I use NIPA to measure output, consumption and investment, and the BLS to measure labor. I construct a series for capital by using the perpetual inventory method as in the literature based on the NIPA investment series[11]. I measure TFP as the Solow residual. Both NIPA and BLS series are for the period 1964-2009 at quarterly frequency.

I describe in more detail how I measure NIPA and BLS variables in the data. For output, I use real GDP. For consumption, I use real personal consumption expenditures on non-durables and services. For investment, I use real private investment[12]. All the above NIPA variables are measured by the chain-weighted method and are seasonally adjusted[13]. For labor, I use the BLS aggregate hours index.

For the corporate bond market, I use Moody's global corporate bond dataset[14]. Moody's uses letter grades to classify corporate bonds based on creditworthiness. This dataset provides annualized nominal yields for bonds of only two different letter grades, Aaa and Baa, at monthly frequency. I

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[11]Detailed procedure is given in the appendix.

[12]It is the NIPA item, line number 8, headed 'Gross private domestic investment: Fixed Investment'.

[13]See the appendix for more detail.

[14]See Moody's (2010).

convert the two monthly yield series to quarterly series by computing averages over the quarter, and calculate real yields by subtracting the concurrent quarterly growth rates of the BLS CPI index. I take as my credit spread index the spread in real yields between Baa and Aaa grade corporate bonds. Moody's dataset also provides annual default rates for all letter grades[15] where the default rate is measured by the ratio of the number of issuers defaulted for a year relative to the total number of issuers of the bond-cohorts[16]. As for recovery rates, Moody's uses the ratio of a bond price in the aftermath of the event of default relative to the price prior to the event of default, which is interpretable as the loss rate of a bond in the event of default[17].

In what follows, as is standard in the literature, I detrend all series using the HP-Filter: I calculate log deviation from trend for NIPA/BLS variables and credit spread.

### The U.S. Business Cycles And Credit Spread Cycles

Figure 1.1 shows fluctuations in real GDP and the Baa-Aaa corporate credit spread.
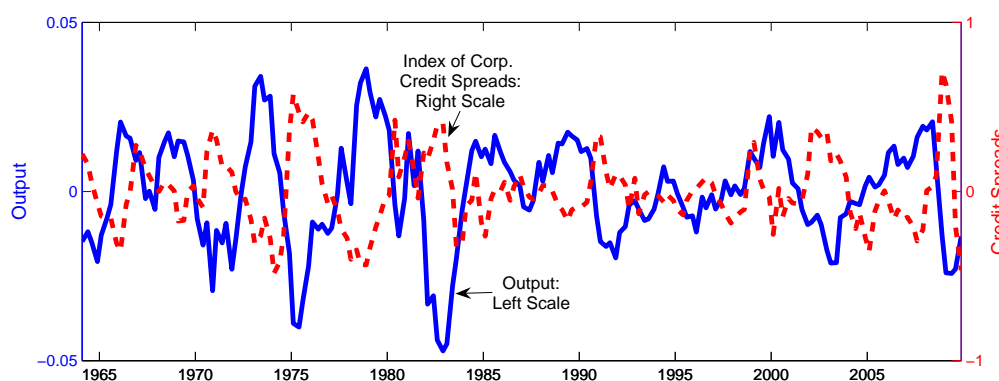


Figure 1.1: Output And An Index of Corporate Credit Spreads. Both of The Two Series Are Quarterly, Logged and HP-Filtered

The figure shows that detrended output is negatively correlated with the detrended Baa-Aaa corporate credit spread over the period 1964-2009. Table 1.1 presents descriptive statistics for aggregates of interest and the credit spread over the period 1964-2009.

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[15]Specifically, seven letter grades as follows: Aaa, Aa, A, Baa, Ba, B and Caa-C.

[16]Note that it is not a volume-weighted default rate as used by Giesecke et al. (2010) and Altman and Karlin (2010). Neither of these two papers provides default rates conditional on creditworthiness.

[17]By construction, recovery rates are measured by the issued years prior to default. For a given letter grade (unsecured) bond, Moody's provides 5 measures for the cases of 1-5 issued years prior to default: I use the sample mean of those 5 measures as my recovery rate.

| $x$ | $y$ | $h$ | $k$ | $TFP$ | $c$ | $i$ | $BAA - AAA$ |
|---|---|---|---|---|---|---|---|
| $\sigma(x)/\sigma(y)$ | 1.00 | 1.27 | 0.34 | 0.53 | 0.54 | 3.35 | 13.77 |
| $corr(x,y)$ | 1.00 | 0.88 | 0.15 | 0.45 | 0.84 | 0.91 | -0.58 |
| $corr(x,BAA-AAA)$ | -0.58 | -0.49 | 0.25 | -0.37 | -0.52 | -0.65 | 1.00 |

Table 1.1: Statistics of Aggregates of Interest and the Corporate Credit Spread. '$BAA-AAA$' Denotes the Baa-Aaa Corporate Credit Spread.

Table 1.1 presents percentage standard deviations of key aggregates and correlations with output and the Baa-Aaa corporate credit spread, where as previously mentioned all variables are log deviations of those variables from trend. The line headed '$\sigma(x)/\sigma(y)$' is the ratio of the percentage standard deviation of a variable $x$ to the percentage standard deviation of output. The percentage standard deviation of output is 1.56, which is slightly smaller than in Prescott (1986). The line headed '$corr(x,y)$' provides the correlation coefficient of a variable $x$ and output while the line headed '$corr(x,BAA-AAA)$' presents the correlation coefficient of a variable $x$ and the credit spread.

Consistent with the business cycle literature, all of the key aggregates are procyclical. The main message is that the corporate credit spread is substantially negatively correlated with output[18], TFP and labor over the period 1964-2009.

I next turn to discuss fluctuations in the default rates of corporate bonds. These fluctuations are of particular importance since I will use them to measure shocks to $v_t$ in the model. Recall that in the model the probability of default for risky firms is equal to $v_t$ and that safe firms never default. I summarize fluctuations in the default rates for safe and risky corporate bonds. I begin by discussing how to classify corporate bonds of different letter grades into safe and risky bonds, and I present statistics of the default rates for safe and risky corporate bonds.

As mentioned earlier, Moody's provides yields for only two letter grade bonds, Aaa and Baa, and I use the Baa-Aaa yield spread as my index of the corporate credit spread. Note that Aaa bonds are the safest grade according to the Moody's grade system. I use Baa letter grade as the threshold in classifying bonds into the safe and risky categories. There are three letter grades higher than Baa grade, i.e., Aaa, Aa and A, and I classify them as safe bonds. And I classify Baa, Ba and B grade bonds as

[18]See Gertler and Lown (1999) for more detailed discussion of empirical relationships between the 'High-Yield/AAA' corporate credit spread and output over the U.S. business cycles since 1980s.

risky bonds[19]. I calculate default rates[20] of safe and risky bonds by taking cross-sectional averages of corporate bonds within the categories of safe and risky bonds[21], see the table 1.2.

| Grade | Safe | Risky |
|-------|------|-------|
| Mean | 0.02% | 1.93% |
| Std. | 0.07% | 1.76% |

Table 1.2: Annual Default Rates of Corporate Bonds During the Period 1964-2009

In table 1.2, the line headed 'Mean' presents sample means of historical default rates of safe and risky bonds at annual frequency while 'Std.' does the same for sample standard deviations. The table 1.2 shows that both sample mean, 0.02%, and standard deviation, 0.07%, of historical default rates of the safe bonds are small, close to zero. For simplicity, I assume that default rates of safe bonds are zero.

*Calibration*

In this section, I describe the procedure for calibrating parameter values of the dynamic model.

Parameter Values

I calibrate several parameter values of the dynamic model by targeting long-run averages of key aggregates of the U.S. economy over the period 1964-2009 under the assumption that $v_t$ is constant and equal to its long-run average, and that the model economy is in steady state.

One period in the model corresponds to one quarter in the data. I proceed to describe in detail how I calibrate several parameter values. The benchmark parameter values are listed in table 1.3.

First, I set the steady state $v$ to the sample mean of the quarterly default rates, converted from the annual rates of 1.93% on average over the period 1964-2009, for risky corporate bonds. I choose

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[19]Note that I exclude the Moody's Caa-C grade bonds from my consideration here because default rates of Caa-C grade bonds are substantially higher than those of Baa, Ba and B grade bonds. For instance, the default rate of B grade bonds, the riskiest out of the three risky bonds, is 4.7% on average for the period 1964-2009 while the default rate of C-Caa grade bonds is 20.2% on average for the same period, which is larger by a factor of about 4 than the B grade bond default rate and by a factor of 10 than the average default rate of the three risky bonds combined. Lastly, it seems that the Caa-C grade bonds are not important for my purpose studying the implications of credit spread fluctuations on the output fluctuations because the share of the Caa-C grade bonds issuers in the corporate bond market is small, about 4% on average in 1997-2000.

[20]Moody's definition of default includes three types of events: missed or delayed repayment, bankruptcy and a distressed exchange. See Moody's (2010) p.73-74 for more detail.

[21]I use the volume-shares by letter grades as the weights and calculate weighted averages of default rates and yields of the Aaa, Aa and A grade bonds and take them as default rates and yields of safe bonds. I do the same for risky bonds based on the Baa, Ba and B grade bonds. See the appendix for more detail.

| | PARAMETER | VALUE | TARGET |
|---|---|---|---|
| $v$: | Prob. of $z(i) = 0$ for Risky Firm $i$ | .0048 | Default Rate of Risky Bonds |
| $\tau$: | Default Losses of Undepreciated Capital | .599 | Recovery Rate of Risky Bonds |
| $\lambda$: | Measure of safe firms | .289 | Volume-Share of Safe Bonds |
| $\beta$: | Discount Factor | .9909 | Real Return to Aaa Bonds |
| $\alpha$: | Returns to Scale | .95 | Benchmark |
| $\delta$: | Depreciation Rate | .015 | Benchmark |
| $\theta$: | Capital Share | .33 | Benchmark |
| $\omega$: | Curvature of Labor-Disutility | .30 | Benchmark |
| $\psi$: | Level of Labor-Disutility | 3.324 | $h_{ss} = .3333$ |

Table 1.3: Benchmark Parameter Values

$\tau = .599$ by targeting the recovery rate in the event of default for risky corporate bonds, which is about 40% on average over the period 1982-2009:

$$\frac{[1-\delta][1-\tau]}{\frac{1}{1-\delta+r^R}} = \text{recovery rate}$$

where the numerator in the LHS is the price of a defaulted risky debt, i.e., the fraction of undepreciated capital collected back, and the denominator in the LHS is the price of the same debt prior to default, i.e., the inverse of the gross returns in the event of non-default[22].

Second, I choose the value of $\lambda$ by targeting the size of newly issued safe debts relative to the size of newly issued risky debts. In the model, the size of newly issued safe debts is $\lambda k^S$ and the size of newly issued risky debts is $[1-\lambda]k^R$, and thereby the ratio of newly issued safe debts relative to the all newly issued debts is given by:

$$\frac{\lambda k^S}{\lambda k^S + [1-\lambda]k^R} = \frac{\text{size of newly issued safe debts}}{\text{size of the all newly issued debts}}$$

where its counterpart in the data is 47.7 % on average for the period 1997-2000, see the appendix for more detail. I choose the value of $\lambda$ so that in steady state the above statistic is matched to the data[23]. This results in $\lambda = 0.289$.

Third, I choose $\beta = .9909$ by targeting quarterly real returns to the Moody's Aaa grade corporate bonds, about .92% on average for the period 1964-2009, such that:

$$\frac{1}{\beta} = 1 + \text{real return to a safe debt.}$$

Fourth, I choose $\alpha = 0.95$ as my benchmark value of the returns-to-scale parameter, which is

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[22]See the appendix for more detailed discussion of the recovery rate in the data and model.

[23]Given interest rates and the values of $\alpha$ and $\theta$, I can back out capital allocation, $k^S$ and $k^R$. And I then solve for the unknown $\lambda$ that satisfies the equation : $\lambda k^S / [\lambda k^S + [1-\lambda]k^R] = 0.477$.

in the range widely used in the literature, e.g., 0.87 in Khan and Thomas (2010) and 0.975 in Arellano et al. (2010)[24].

Fifth, I choose $\delta = .015$ as my benchmark depreciation rate, which is in the range, $4\% \sim 10\%$ at annual frequency, which is typical in the literature, see, e.g., Uhlig (2007).

Sixth, as is common in the literature, I choose $\theta = .33$ as the benchmark value. This implies, in the model, about 31% non-profits capital income share in GDP and 64% labor income share in GDP, investment to GDP ratio equal to about 20% and capital to annual GDP ratio equal to 3.05, which is broadly consistent with the business cycle literature.

Lastly, I calibrate two preferences parameters: $\omega$, the curvature parameter of disutility from labor, and $\psi$, the level parameter of disutility from labor. I choose $\omega = 0.30$ as the benchmark case and choose the value of $\psi$ by targeting steady state labor supply of .3333.

<div align="center">Shock Process for <em>v</em></div>

Next, I describe the procedure used to parameterize the shock process for $v$. I assume that $f(v|v_t)$, the pdf of $v_{t+1}$ conditional on $v_t$, is a truncated normal-distribution on $(0,1)$:

$$v_{t+1} = (1-\rho)\overline{v} + \rho v_t + \sigma^\varepsilon \varepsilon_{t+1}$$

where $\varepsilon_{t+1}$ is the standard normal random variable truncated[25] at $-[(1-\rho)\overline{v} + \rho v_t]$ and $\left[1 - [(1-\rho)\overline{v} + \rho v_t]\right]\Big/ \sigma^\varepsilon$ so that $v_{t+1} \in (0,1)$, so that:

$$f(v|v_t) = exp\left(-\frac{1}{2}\left[\frac{v - [(1-\rho)\overline{v} + \rho v_t]}{\sigma^\varepsilon}\right]^2\right)\Big/ \int_0^1 exp\left(-\frac{1}{2}\left[\frac{v - [(1-\rho)\overline{v} + \rho v_t]}{\sigma^\varepsilon}\right]^2\right)dv.$$

I discretize[26] the space of $v$ and approximate the continuous stochastic process of $v$ with the Markov transition matrix by using Tauchen (1986)'s method. I need to estimate three parameters, $(\rho, \overline{v}, \sigma^\varepsilon)$, of the continuous process of $v$ specified earlier.

I choose $\rho = 0.79$ as my benchmark case and proceed to calibrate jointly the remaining two parameters, $(\overline{v}, \sigma^\varepsilon)$, i.e., location and dispersion parameters, by targeting sample mean and sample standard deviation of default rates for the risky bonds at annual frequency. I use the method of weighted

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[24]Arellano et al. (2010) take their value of returns-to-scale parameter from the estimate of Basu and Fernald (1997).

[25]Note that the error term $\varepsilon_{t+1}$ is truncated so that $v_{t+1} \in (0,1)$, which implies that $E[\varepsilon_{t+1}|v_t] \neq 0$. If there were no truncation, then the specification on the evolution of $v_{t+1}$ earlier would be the usual AR(1) process with a normally distributed error term.

[26]See the appendix for more detail.

minimum distance between the model and the data for those two target statistics[27], which results in $\overline{v} = 0.0048$ and $\sigma^{\varepsilon} = 0.0039$. Table 1.4 presents the calibration results.

| $\rho$ | $\overline{v}$ | $\sigma^{\varepsilon}$ |
|--------|--------|--------|
| 0.79 | 0.0048 | 0.0039 |

Table 1.4: Benchmark Parameter Values For the Shock Process For $v$

| Statistic | Mean | Std. | Persistence |
|-----------|------|------|-------------|
| Data | 1.9% | 1.8% | 0.32 |
| Model | 2.0% | 1.0% | 0.32 |

Table 1.5: Statistics of Default Rates For Risky Debts at Annual Frequency

Table 1.5 presents statistics of the default rates for risky debts at annual frequency. The column headed 'Mean' provides the sample mean of them and the column headed 'Std.' does the same for the sample standard deviation while the column headed 'Persistence' presents the OLS estimate of the AR(1) persistence parameter at annual frequency[28]. Statistics of the line headed 'Model' are calculated based on simulations[29].

The mean and AR(1) persistence of $v$, i.e., default rate for risky debts, at annual frequency are close to each other in the model and the data while the standard deviation of $v$ at annual frequency is somewhat smaller in the model relative to the data[30]. There are two reasons for this: in the data, default rates for risky debts are clustered around a lower extreme value, zero, and featured by a fat-tail while such features are absent in the model, see Figure 1.2.

In Figure 1.2, the top panel shows the histogram of the (unconditional) annual default rates for risky debts in the data while the bottom panel does the same, in terms of the relative frequency, for the model. Figure 1.2 shows that the calibrated shock process is missing two features of the data, the

---

[27]I use weights of (8:2) for the sample mean and sample standard deviation in assessing the distance between the model and the data in order to let the sample mean of default rates for the risky debts be as close as possible to each other in the model and the data.

[28]I mean by it the parameter $b_1$ in the following specification:

$$v_{t+1}^A = b_0 + b_1 v_t^A + \varepsilon_{t+1}^A$$

where $v_t^A$ denotes the default rate for risky debts per year in the year $t$, $b_1$ denotes the persistence parameter at annual frequency and $\varepsilon_{t+1}^A$ is an error term variable at annual frequency.

[29]The historical default rates for risky debts in the data are at annual frequency and for 46 periods, from 1964 to 2009. I do simulations, 10000 times, of drawing $v$ for $4 \times 46$ periods at quarterly frequency from the calibrated Markov transition matrix and annualize them, and estimate the above three statistics at annual frequency. I report the sample means of those statistics over the 10000 simulations.

[30]Note that it is not easy to match both mean and standard deviation of $v$: the key is that $v$ is truncated at zero.
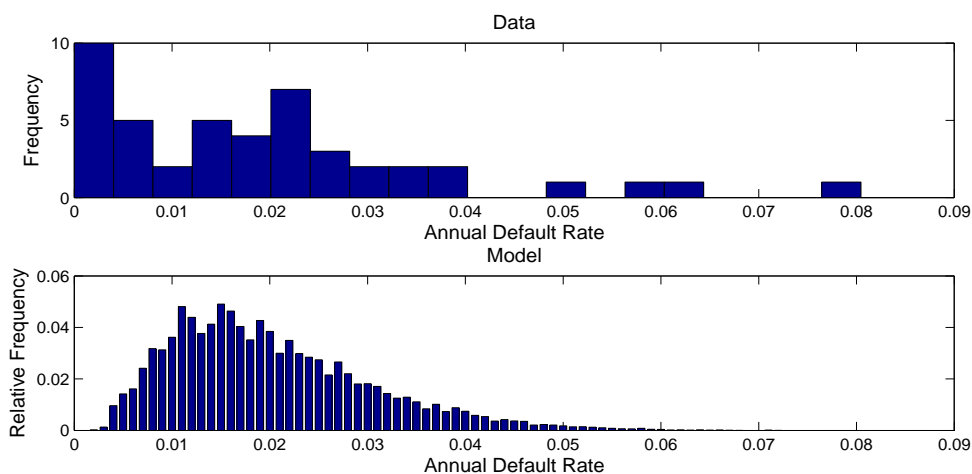
Figure 1.2: Unconditional Distribution of Default Rates for Risky Debts at Annual Frequency

clustering around zero and fat-tail. Alternatively, I could incorporate the above two features, clustering and fat-tail, to the distribution of $v$ and obtain better fit to the data of the distribution of the annual default rates for risky debts in the model, which I leave for future work.

*Simulation Method*

I feed a series of shocks to $v$ for 183 periods, which corresponds to the period 1964Q2-2009Q4, to the calibrated dynamic model where I assume that the model economy is in steady state in the initial period. I do this simulation 1,000 times.

I next turn to describe the numerical method used to solve for the equilibrium outcome. The aggregate state vector is the pair $(v, K)$ where the space of $v$ is already discretized and the space of $K$ is a continuum. I numerically solve for four policy functions by using the first order finite element method as illustrated by McGrattan (1996) where the four policy functions are consumption, interest and wage rates for safe firms, and aggregate labor supply[31]. Numerical error is about $10^{-6}$ percentage point, between the guessed and updated policy functions, uniformly over the domain. Once the policy functions are solved for, it is straightforward to calculate the allocation and price functions.

---

[31]I limit the space of $K$ to be sufficiently large, upper bound of 120% and lower bound of 80% relative to the steady state value of $K$. It turns out that the solved transition function of aggregate capital, $K'(v, K)$, never binds at those two boundaries.

*Results*

Benchmark Case

In this section, I present results for the benchmark parameter setting.

| | $\sigma(y)$ | $\sigma(x)/\sigma(y)$ | | | | | $corr(x,y)$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $x$ | $y$ | $h$ | $k$ | TFP | $c$ | $i$ | $h$ | $k$ | TFP | $c$ | $i$ |
| Data | 1.56 | 1.27 | 0.34 | 0.53 | 0.54 | 3.35 | 0.88 | 0.15 | 0.45 | 0.84 | 0.91 |
| Model | 1.04 | 0.71 | 0.52 | 0.55 | 0.37 | 4.78 | 0.92 | 0.19 | 0.95 | 0.38 | 0.95 |

Table 1.6: Statistics of Aggregates of Interest: Benchmark Case

Table 1.6 presents three statistics for standard aggregates of interest in the business cycle literature. The column headed '$\sigma(y)$' presents the percentage standard deviation of output, the column headed '$\sigma(x)/\sigma(y)$' provides the ratio of the percentage standard deviation of a variable $x$ relative to the percentage standard deviation of output while the column headed '$corr(x,y)$' presents the correlation coefficient of the variable $x$ with output[32].

Shocks to $\nu$ account for a substantial part of the output fluctuations, about 66%, and similarly for TFP[33]. This result supports my claim that relative uncertainty shocks are an important source of fluctuations in output and productivity in the U.S.

Next, correlation coefficients for aggregates of interest with output are qualitatively consistent in the model and the data.

| $x$ | $r^R - r^S$ | $w^R/w^S - 1$ | $k^S$ | $k^R$ | $h^S$ | $h^R$ |
|---|---|---|---|---|---|---|
| $\sigma(x)/\sigma(y)$ | 0.20 | 0.33 | 25.37 | 27.89 | 22.71 | 23.14 |
| $corr(x,y)$ | -0.96 | -0.96 | -0.90 | 0.99 | -0.91 | 0.98 |
| $corr(x, r^R - r^S)$ | 1.00 | 1.00 | 0.98 | -0.99 | 0.98 | -0.99 |

Table 1.7: Fluctuations in Resources-Allocation and Spreads in Interest and Wage Rates

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[32] As standard in the literature, I calculate those statistics for each simulation and take sample mean of them over simulations, which I report as the result of the model.

[33] I compute TFP as:

$$TFP_t \equiv \frac{y_t}{[K_t^{PI}]^\theta h_t^{1-\theta}}$$

where $K_t^{PI}$ is the index of capital stock constructed by the perpetual inventory method consistent with the data and given by:

$$K_{t+1}^{PI} = [1 - \widetilde{\delta}]K_t^{PI} + I_t, \quad K_0^{PI} = K_0.$$

$\widetilde{\delta}$ is the constant depreciation rate, equal to 6.60% per year, the same as what is used in constructing capital series in the data: this implies that .60% point of the annual depreciation rate is due to default-losses. See the appendix for more detail.

Table 1.7 presents statistics of simulated variables for resources-allocation and spreads in interest and wage rates. The line headed '$corr(x,y)$' presents the correlation coefficient of a variable $x$ with $y$ while the line headed $corr(x, r^R - r^S)$ does the same for $r^R - r^S$.

Note that spreads in interest and wage rates are countercyclical as predicted in the earlier static version of the model. Furthermore, we see that both capital and labor allocated to safe firms are almost perfectly correlated with output negatively and with credit spread positively.

Quantitatively, one caveat is that the magnitude of reallocation effects seems too large. For instance, in response to a 0.33% point increase in $v$, which corresponds to the one standard deviation of fluctuations in $v$, a safe firm's output increases by about 23.6 percent when aggregate output decreases by about 1.2 percent[34], i.e., a safe firm's output is countercyclical by an order of magnitude, which seems somewhat odd to an intuition. Regarding this, there are three relevant factors omitted in this paper. First, shocks to the level of aggregate productivity are absent in this paper. If there were aggregate productivity shocks, which are negatively correlated with shocks to $v$, then the negative correlation of a safe firm's output with aggregate output will be mitigated to some extent. Second, in the perspective of a firm, importantly, dynamic financing decisions, and relatedly issuing a long-term debt to smooth interest rate costs, are abstracted from. Alternatively, I could assume that a firm makes more complicated financing decision on both maturity and issuance-timing of its debts, which could affect the quantitative result of reallocation of resources. Third, if there were capital adjustment costs, then fluctuations in reallocation of resources would be mitigated[35]. I leave it for future work to examine the importance of the above three factors.

### Importance of $\tau$ in Amplifying the Effects of Shocks to $v$

In this section, I examine the importance of $\tau$, which captures a key friction in the corporate bond market. I consider an alternative parameterization in which I set $\tau$ to zero and hold the other parameters unchanged from the benchmark setting, and repeat the earlier analysis.

Table 1.8 reports the results. The bottom line presents the results for the case of $\tau = 0$. A simple comparison of standard deviations of key aggregates reveals that, as expected, there are almost no effects of shocks to $v$ for the alternative case of $\tau = 0$: standard deviations for aggregates of interest

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[34]For the purpose of illustration, I report the results of the experiment of imposing one-period shock to $v$ by .33% point to the calibrated economy holding the level of $v$ for the other periods equal to that in the calibrated economy.

[35]Of course, introducing features that mitigate fluctuations in reallocation of resources would reduce, to some extent, the response of output and productivity to one unit of increase in $v$.

| | $\sigma(y)$ | $\sigma(x)/\sigma(y)$ | | | | | $corr(x,y)$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $x$ | $y$ | $h$ | $k$ | TFP | $c$ | $i$ | $h$ | $k$ | TFP | $c$ | $i$ |
| Data | 1.56 | 1.27 | 0.34 | 0.53 | 0.54 | 3.35 | 0.88 | 0.15 | 0.45 | 0.84 | 0.91 |
| Bench | 1.04 | 0.71 | 0.52 | 0.55 | 0.37 | 4.78 | 0.92 | 0.19 | 0.95 | 0.38 | 0.95 |
| $\tau = 0$ | 0.00 | 2.84 | 9.06 | 0.09 | 4.73 | 14.44 | -1.00 | 1.00 | -1.00 | 1.00 | -1.00 |

Table 1.8: Statistics of Aggregates of Interest: Case of $\tau = 0$

are almost zero[36]. I conclude that the extent of financial frictions, represented by $\tau$, is an important amplification device for this economy. The key here is that, in the case of $\tau = 0$, there is no misallocation of resources as clarified in the previous static analysis.

<center>Case of Positive Correlation Between $\tau$ and $v$</center>

In this section, I examine the importance of the case in which $\tau$ is positively correlated with $v$ as is in the data. For simplicity, I assume that $\tau$ is perfectly positively correlated with $v$ and given by:

$$\tau(v) = 1 - \tau_0 v^{-\tau_1}, \quad \tau_0 > 0, \tau_1 > 0$$

where I take the above functional form as in Altman and Karlin (2010). I calibrate $(\tau_0, \tau_1)$ based on the data on recovery and default rates for risky bonds[37], which results in $(\tau_0 = 0.1931, \tau_1 = 0.1288)$. For the above case, I repeat the earlier analysis.

| | $\sigma(y)$ | $\sigma(x)/\sigma(y)$ | | | | | $corr(x,y)$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $x$ | $y$ | $h$ | $k$ | TFP | $c$ | $i$ | $h$ | $k$ | TFP | $c$ | $i$ |
| Data | 1.56 | 1.27 | 0.34 | 0.53 | 0.54 | 3.35 | 0.88 | 0.15 | 0.45 | 0.84 | 0.91 |
| Bench | 1.04 | 0.71 | 0.52 | 0.55 | 0.37 | 4.78 | 0.92 | 0.19 | 0.95 | 0.38 | 0.95 |
| $corr(\tau, v) = 1$ | 1.42 | 0.71 | 0.53 | 0.54 | 0.32 | 4.83 | 0.94 | 0.19 | 0.96 | 0.40 | 0.97 |

Table 1.9: Statistics of Aggregates of Interest: Case of $corr(\tau, v) = 1$

Table 1.9 reports the results. The bottom line presents the results for the case of $corr(\tau, v) = 1$. As expected, the effects of shocks to $v$ are larger, by about 40%, in the alternative parameterization in which $\tau$ is perfectly positively correlated with $v$ relative to the benchmark case.

Lastly, I close this section by discussing briefly the implications of different values of $\omega$ for the quantitative result. As is well known in the literature, the smaller $\omega$, the larger the elasticity of labor supply. It follows that the response of labor to one unit of increase in $v$ is smaller for a larger value of $\omega$ and so is the response of output because fluctuations in TFP and capital are almost independent of the value of $\omega$.

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[36]Recall that, for the case of $\tau = 0$, an increase in $v$ leads to no change in allocation of capital in the previous static model.

[37]See the appendix for more detailed discussion.

## 1.5   Conclusion

In this paper, I studied the implications of fluctuations in corporate credit spreads for business cycle fluctuations. I built a simple model in which the difference in default probabilities on corporate debts leads to the spread in interest rates paid by firms. In the model, firms differ in the extent of uncertainty, i.e., the variance of the firm-level productivity, which is in turn linked to the difference in the default probability. I found that shocks to the distribution of the extent of uncertainty across firms are an important source of fluctuations in the U.S. economy. One promising feature of the model is that the corporate credit spread is countercyclical consistent with the data. In the model, the financial frictions, in particular the recovery rate of defaulted corporate debt substantially lower than one, are an important amplification device.

The key mechanism is that an increase in the default probability, induced by an increase in the extent of uncertainty, for risky firms relative to safe firms leads to an increase in the corporate credit spread, reallocation of capital away from risky firms toward safe firms and decrease in aggregate output and productivity. I established analytically the above results in a simple static model. To quantify such effects, I embedded it into an otherwise standard growth model, calibrated it and numerically solved for the equilibrium. In my benchmark case, I found that shocks to the extent of uncertainty, which are more volatile for risky firms relative to safe firms, account for about 66% of fluctuations in both output and TFP in the U.S. economy. A critical feature of my quantitative analysis is that, in measuring such uncertainty shocks, I used the information contained in the fluctuations in actual default rates of corporate bonds in the data.

In this paper, firms are restricted to finance their capital via only short-term non-contingent debt contracts. I leave it for future work to investigate how the results would change if the above corporate financing restriction is relaxed more realistically.

Chapter 2

THE PRICE OF IMPORTS AND AGGREGATE TFP: THEORY AND APPLICATION TO THE

KOREAN CRISIS OF 1997-98

2.1    Introduction

During the Asian crisis of 1997-98, Korea's output was below trend by about 7.7 percentage point. Two

years later, it was above trend. This 7.7 percent deviation from trend in Korea's output is unusual in the

sense that Korea's output deviation from trend is typically about 2 percentage point during non-crisis

periods in the late 1990s and early 2000s. The objective of this paper is to understand what factors gave

rise to this sharp negative decline in output.

Studies that apply the business cycle accounting framework of Chari et al. (2007) to the

Korean crisis episode find that TFP shocks, measured by the Solow Residual, can account for most of

Korea's output deviation in 1998. (See Otsu (2008).) Key to the results of this exercise is that there was

a very large negative deviation of TFP from trend for Korea in 1998, by about 5.7%. If one assumes that

there was a negative technology shock of this size, it is easy to understand the large contractions in

labor and output. However, if one is not willing to assume an exogenous temporary productivity shock

of this size, one is led to ask why TFP deteriorated so much. This motivates me to look for

non-technology shocks.

As is typical in other episodes of financial and/or currency crises, the Korean crisis was

characterized by financial shocks and real exchange rate shocks. In this paper, I focus on real exchange

rate shocks. I assume that real exchange rate shocks lead to similar shocks to the price of imports and

exports relative to final goods, which closely describes the case of the Korean crisis. (See Burstein et al.

(2005).) I proceed to study the impact of exogenous changes in the price of imports on business cycles

of a small open economy.

Specifically, I assess the importance of shocks to the price of imports relative to the price of

final goods in accounting for deviations in Korea's output, TFP and labor in 1998. I calibrate a DSGE

small open economy model by using the Korean data, and simulate it to assess the consequences of

shocks to the price of imports to the Korean economy in 1998.

The main result of the simulation exercise is that, in the benchmark case, shocks to the price of

imports account for about 55% of the output deviation, one third of the TFP deviation and three quarters

of the labor deviation in the Korean economy in 1998. One of promising features of my results is that a

large part, 60%, of the negative deviation of the real wage rate is also accounted for by the import-price shocks. The model features two key mechanisms. First, shocks to the price of imports lead to a reduction of the real wage rate, which leads to contractions of labor and output. Second, TFP deteriorates in response to an increase in the price of imports via the reduction in the share of imports used in production, and thereby output also decreases. As I explain in the analysis, this result is dependent on the fact that the Korean economy has a substantial wedge that distorts the effective price that final good producers pay for the imported good relative to the "at-the-dock" price of imports[1].

There are many papers related with this paper regarding comovements of the price of imports and output. There are several papers studying the impact of shocks to the terms of trade on real output and TFP in the international business cycle literature, see, e.g., Mendoza (1995) and Kehoe and Ruhl (2008). Differently from them, I show that it is shocks to the price of imports relative to the final good rather than shocks to the terms of trade that determines, up to a first order approximation, changes in TFP in a standard small open economy framework. Burstein et al. (2005) document the fact about the tight relationship between real exchange rate and the price of imports and exports relative to the final good while I focus on the consequences of fluctuations in the price of imports relative to the final good in a general equilibrium framework. Regarding the Korean crisis of 1997-98, there are several papers, to name a few, Benjamin and Meza (2009), Gertler et al. (2007) and Otsu (2008). This paper differs from those papers in shocks and propagation mechanisms studied: they focus on financial shocks and financial frictions while I focus on real exchange rate shocks and distortions on the use of imported goods.

This paper is organized as follows. Section 2 sets up the model, section 3 defines the way to measure real output and TFP, and section 4 presents the main analytic results. Section 5 embeds the previous static model into an otherwise standard growth model. Section 6 calibrates the dynamic model and discusses the simulation results. Section 7 concludes.

## 2.2    Model

In order to facilitate exposition of the key economic mechanism, in this section I consider a static model of a small open economy. Section 5 extends the analysis to a dynamic setting.

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[1]This result is mechanically similar to the results in Kehoe and Ruhl (2008) for the case of shocks to the terms of trade in the presence of the tariff distortion.

Basically, in this model, I generalize the static model considered by Kehoe and Ruhl (2008) by breaking the equivalence between the terms of trade and the price of imports relative to the price of final goods. For this purpose, I introduce a foreign demand function of exported goods and the real exchange rate into a standard small open economy framework as in Gertler et al. (2007).

This extension is conceptually important even though it does not alter the mechanics of the standard small open economy model. In the quantitative analysis carried out later in this paper, it is important to correctly measure changes in the price of imports relative to the final good price. The key point here is that, in general, changes in the price of imports relative to the price of final goods are not equal to changes in the terms of trade.

Prices of exports and imports will be specified relative to the final good price, which will result in the determination of the terms of trade. This will allow the price of imports relative to the final good price to differ from the terms of trade.

## Technology

There are four goods: an imported good($m$), an export good($x$), a domestic final good($y$) and a foreign final good($y^F$). The domestic final good is produced domestically and the imported good is used as an intermediate good in the production of the domestic final good. This final good can be consumed and/or used as an intermediate input in the production of the export good. The export good is demanded by the rest of the world. The foreign final good is consumed by the rest of the world.

The production function of the domestic final good is given by:

$$y = F(m,h)$$

where $h$ is labor services.

The production function displays CRS, is increasing, concave, of class $C^2$, and satisfies:

$$\lim_{m \to 0} \frac{\partial F(m,\cdot)}{\partial m} = \infty, \lim_{m \to \infty} \frac{\partial F(m,\cdot)}{\partial m} = 0$$

$$and \quad \frac{\partial^2 F(m,\cdot)}{\partial m^2} < 0, \frac{\partial^2 F(\cdot,h)}{\partial h^2} < 0, \quad \forall (m,h) \in R_{++}^2.$$

The first two limiting conditions are the usual Inada conditions and the last two conditions imply decreasing marginal product of imported intermediate input and labor services respectively.

Since the production function satisfies CRS, without loss of generality, I assume that there is a single firm in the final good sector.

The production function of the export good is given by:

$$x = A \cdot e$$

where $A$ is the productivity in the export good sector and $e$ is the final good used in the production of the export good. I assume that a single monopolist produces the export good[2]. I will refer to this firm as the export firm.

The foreign final good is consumed by the rest of the world as mentioned earlier. I label the rest of the world as 'the foreign country' and the small open economy of interest as 'the home country'. The imported and export goods for the home country are the export and imported goods for the foreign country, respectively. I abstract from the technology of the rest of the world because I focus on the home country, which is a small open economy.

## Household

There is a representative (domestic) household with preferences over the domestic final good consumption( $c$ ), represented by the utility function $u(c)$ assumed to be increasing and concave.

The household is endowed with one unit of time, which is supplied inelastically[3]. The household owns all shares of every firm.

I use the domestic final good as numeraire and its price is normalized to one. The household's budget constraint is given by:

$$c = wh + \pi + T$$

where $h$ is labor supply, $w$ is the real wage rate, $\pi$ is total profit, and $T$ is a lump-sum transfer from the government.

## Demand For Exports

As in the literature, see, e.g., Gertler et al. (2007), I assume that the export firm takes as given the foreign demand function for the export good, $Q(\bar{p}^F)$, where $\bar{p}^F$ is the price of the export good relative

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[2]I assume a single exporter for simplicity. Alternatively, I could assume a continuum of exporters each of whom produces a distinct variety and behaves as a monopolistic competitor, which does not change my results.

[3]Because my focus here is on the response of aggregate TFP to changes in the price of imported good, abstracting from endogenous labor supply is without loss of generality. In the quantitative analysis later on, I allow for an endogenous labor supply decision.

to the *foreign* final good and $Q(\bar{p}^F)$ is the foreign demand of the export good as a function of $\bar{p}^F$.

Letting $s$ denote the real exchange rate, defined as the price of the foreign final good relative to the domestic final good, I write the export firm's profit maximization problem as:

$$\pi = \max_{\bar{p}^F} \{[s\bar{p}^F - 1/A]Q(\bar{p}^F)\}$$

where $\pi$ and $1/A$ are the profit and the constant marginal cost, respectively, of the export firm in terms of the domestic final good.

To facilitate exposition, I assume that $Q(\bar{p}^F)$ is linear[4]:

$$Q(\bar{p}^F) = -a\bar{p}^F + b, \quad a > 0, b > 0$$

where $a$ and $b$ are the slope and intercept term, respectively, of the function $Q(\bar{p}^F)$.

I denote by $\widetilde{p}$ the price of the export good relative to the *domestic* final good and write it as: $\widetilde{p} = s\bar{p}^F$ where $s$ denotes again the real exchange rate. It is obvious that the export good firm's decision rule with respect to $\bar{p}^F$ is a function of $s$ and $(a,b)$, and it follows that $\widetilde{p}$ is also a function of $s$ and $(a,b)$. I will study later the effects of changes in $(s,a,b)$ on aggregate TFP via the effects on the price and quantity of the export good.

## Prices And Wedges

First, I assume that the real exchange rate, $s$, is exogenous to this economy, which is reasonable because the home country is a small open economy.

Second, I describe how the price of the imported good is determined. Letting $\widetilde{p}^F$ denote the price of the imported good relative to the *foreign* final good, which is exogenous to this economy, I write the "at-the-dock" price of the imported good relative to the *domestic* final good, denoted by $\bar{p}$, as:

$$\bar{p} = s\widetilde{p}^F.$$

Note that $\bar{p}$ is exogenous to this economy and increases proportionately in response to an increase in $s$, which captures the case of large devaluations, see Burstein et al. (2005).

A key feature of my analysis is that the effective price that the final good firm pays for the imported good is higher than the "at-the-dock" price of the imported good. This may be due to such factors as tariffs or taxes. I write the price that the final good firm pays for the imported good as:

$$p = (1 + \tau^m)\bar{p}$$

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[4]This specification guarantees the existence of a unique interior solution to the export firm's profit maximization problem, and also serves to simplify the analytics.

and will refer to $\tau^m$ as the import wedge. This wedge will play a key role in the subsequent analysis.

Symmetrically to the import wedge, I assume that there is also a labor wedge that makes the price of labor services faced by the final good firm different from the market wage rate that workers receive. I denote the labor wedge by $\tau^h$. This labor wedge captures payroll taxes and any non-price factors that distort the labor market[5]. It follows that the final good firm pays $(1 + \tau^h)w$ units of the final good per unit of labor services, where $w$ is the market wage rate received by the workers. While the labor wedge will not play a role in the subsequent analysis, the key point is that I do not require any asymmetry between imported goods and labor services in terms of the existence of wedges[6].

I abstract from the final good wedge, which makes the final good price faced by the household and export firm different from the price that the final good firm receives, because it is equivalent to a combination of the import and labor wedges.

### Government

In what follows, I assume that the government receives all wedge receipts, i.e., that taxes are the only source of wedges. Given my focus on aggregate TFP, this assumption is without loss of generality. Alternative assumptions, such as assuming the wedge represents a markup, would affect the household's decisions only by changing the household's income level. In a more general model this may affect labor supply, but, as noted earlier, aggregate TFP is independent of labor supply.

As in the literature, e.g., Kehoe and Ruhl (2008), I assume that all tax revenues are used to finance a lump-sum transfer($T$) to the household, subject to a balanced budget condition:

$$T = \tau^m \bar{p}m \, + \, \tau^h wh.$$

### Resource Constraint

The resource constraint is given by:

$$c = [y - e] + [\widetilde{p}x - \bar{p}m]$$

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[5]More generally, if I interpret labor services as a domestic intermediate good, then the labor wedge in my model can capture taxes levied on domestic intermediate goods. That is, I could assume that the production function of the domestic intermediate good is linear in labor with labor productivity normalized to one. In this case, taxes levied on domestic intermediate goods will be equivalent to the labor wedge in my original setup.

[6]In contrast, this asymmetry is one of the key ingredients in the model studied by Mendoza and Yue (2008) who study the impact of interest rate shocks to a small open economy's TFP. They assume that working capital is needed for imported goods but not domestically produced goods. It is an open question if the assumption of asymmetry between imported goods and domestic goods is empirically compelling.

where the terms inside the first and second brackets of the RHS of the equation represent consumption of domestically produced final goods and consumption of the (domestic) final goods transferred from the rest of the world as a payment to net exports of this economy, respectively.

I briefly discuss the above resource constraint. If trade is balanced, then $c = [y - e]$, which says that domestically produced (domestic) final goods net what is used for exports is consumed. In general, trade is not balanced for this economy, i.e. $[\widetilde{p}x - \bar{p}m] \neq 0$, where $[\widetilde{p}x - \bar{p}m]$ represents net exports or the trade surplus of this economy. Note that the trade surplus is consumed immediately[7] according to the resource constraint specification.

*Equilibrium*

I focus on the equilibrium for this economy, which is defined as an allocation ($c = [y - e] + [\widetilde{p}x - \bar{p}m]$, $m, h, x, e$), a real wage rate $w$, the export good price $\widetilde{p} = s\bar{p}^F$, a government transfer $T$, and total profit $\pi$ that satisfies the following conditions:

1. Taking the price of imports($\bar{p}$) and real wage rate($w$) as given, the final good firm maximizes its profit

2. Taking the foreign demand function as given, the export firm maximizes its profit

3. Taking $(w, T, \pi)$ as given, the household maximizes its utility subject to its budget constraint

4. Markets clear

5. The government's budget is balanced

## 2.3   Measuring Output and TFP

My objective is to analyze changes in real output and aggregate TFP in the model in response to changes in the price of imports and/or exports, which are in turn caused by either changes in real exchange rate or shifts of the foreign demand function. That is, I consider how equilibrium varies as we

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[7]That is, the (domestic) final good as much as net exports is transferred to this small open economy from the rest of the world, where this trade of the final good is not recorded as imports but as capital transfer according to NIPA. For this economy, by the definition of the imported good, the trade of imported goods only is recorded as imports according to NIPA.

More generally, in a dynamic setting, I could assume that the trade surplus is not consumed today but invested, for tomorrow consumption, in holding foreign assets, e.g., foreign currency, which would show up as an increase in the country's net savings position in the international capital markets. The key point is that consumption/investment decision is irrelevant to the effect on aggregate TFP of changes in primitives for this economy.

change $(\widetilde{p}^F, s, a, b)$. Specifically, I consider a pair of values for $(\bar{p} = s\widetilde{p}^F, s, a, b)$:

$$((\bar{p}_0 = s_0\widetilde{p}_0^F, s_0, a_0, b_0), \ (\bar{p}_1 = s_1\widetilde{p}_1^F, s_1, a_1, b_1))$$

where the subscript $t = 0$ and $t = 1$ represent the previous and current periods, respectively.

Next, I describe how to measure changes in real output and aggregate TFP from period 0 to period 1. I measure real output in the model economy in the same way that real GDP is calculated in NIPA. That is, I first measure current price GDP as the sum of value added and adjust it to account for changes in relative prices, which means the set of prices of different goods and wage rate relative to the domestic final good price. As discussed by Kehoe and Ruhl (2008), there are two methods to measure real GDP: the base period price method and Fisher chain-weighted method. In this paper, I focus on the Fisher chain-weighted method[8], and measure real GDP by deflating current price GDP by the Fisher chain-weighted price index to account for changes in the relative prices.

First, current price GDP, which is again the sum of value added, is given by:

$$GDP_t \equiv [F(m_t, h_t) - p_t m_t] + [\widetilde{p}_t x_t - e_t] + \tau^m \bar{p}_t m_t$$

$$= [F(m_t, h_t) - \bar{p}_t m_t] + [\widetilde{p}_t - 1/A]x_t$$

where $GDP_t$ is current price GDP. The terms inside the first and second brackets of the RHS of the GDP equation on the first line are value added in the final good sector and export good sector, respectively. Lastly, $\tau^m \bar{p}_t m_t$ is the government's import tax revenue. The second line follows by using $p_t = [1 + \tau^m]\bar{p}_t$, $e_t = x_t/A$ and rearranging terms.

A key issue is what price to use in measuring the value of one unit of imported goods. As in the above second line, and as in Kehoe and Ruhl (2008), it is the at-the-dock price of imports, $\bar{p}_t$, because $\tau^m \bar{p}_t m_t$ is included separately in GDP. If $\tau^m \bar{p}_t m_t$ were not included separately in GDP, then it would be inconsistent with NIPA procedures[9].

Second, I measure real GDP by deflating current price GDP by the Fisher chain-weighted price index($P_t$):

$$RGDP_t \equiv \frac{GDP_t}{P_t} = \frac{y_t - \bar{p}_t m_t + [\widetilde{p}_t - 1/A]x_t}{P_t}, \quad \forall t \in \{0, 1\}$$

[8]The results for the case of measuring real GDP using the base period price method is provided in the appendix.

[9]For instance, if $\tau^m$ actually represents the rate of markups levied by monopolistic import and wholesale traders, then $\tau^m \bar{p}_t m_t$ is recorded as sum of profits of those monopolistic import and wholesale traders, which is included in GDP in NIPA.

where $P_t \in \{P_1, P_0\}$ is given by:

$$P_1 = \left(\frac{y_1 - \bar{p}_1 m_1 + [\tilde{p}_1 - 1/A]x_1}{y_1 - \bar{p}_0 m_1 + [\tilde{p}_0 - 1/A]x_1}\right)^{1/2} \left(\frac{y_0 - \bar{p}_1 m_0 + [\tilde{p}_1 - 1/A]x_0}{y_0 - \bar{p}_0 m_0 + [\tilde{p}_0 - 1/A]x_0}\right)^{1/2}, \quad P_0 = 1.$$

Note that without loss of generality the Fisher chain-weighted price index in the previous period, $P_0$, is normalized to one. In the case of $\tilde{p}_t = 1/A$, the above formula for chain-weighted real GDP becomes identical to that in Kehoe and Ruhl (2008).

Lastly, I describe how to measure aggregate TFP. Note that labor services are the only non-intermediate input factor in the model economy. As in Kehoe and Ruhl (2008), I measure aggregate TFP for this economy as the NIPA measure of output per unit of labor services:

$$TFP_t = RGDP_t / h_t, \quad \forall t \in \{0, 1\}.$$

Since labor supply is always equal to one in the equilibrium, it follows that aggregate TFP for this economy is equal to real GDP.

## 2.4   Results

In this section, I present analytical results about the effect of an increase in the price of imports and/or exports on measured aggregate TFP. In particular, I focus on the differences between the effect of an increase in the price of imports and the effect of an increase in the terms of trade. Before presenting a detailed discussion of results, I summarize the main results as follows.

First, TFP decreases, up to a first order approximation, in response to an increase in the price of imports if $\tau^m > 0$, but is constant with respect to the price of imports if $\tau^m = 0$. This result basically follows from the fact that the gross output based measure of productivity differs from the value added based measure of productivity. In particular, the two measures of productivity differ for each other in their responses to an increase in the price of imports in the case of $\tau^m > 0$, i.e., the case in which there are distortions on the use of imported goods. On the one hand, by construction, gross output based productivity[10] is independent of an increase in the price of imports: $y_t / F(m_t, h_t) = 1, \forall \bar{p}_t > 0$. On the other hand, value added based productivity[11] responds negatively to an increase in the price of imports in the case of $\tau^m > 0$ because the marginal contribution of imported goods to gross output is greater than the marginal cost of the imported goods because of the existence of distortions $\tau^m > 0$. TFP

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[10]It is measured by gross output per input, which is the composite good of imported goods and labor services.

[11]It is measured by the sum of value added (: real GDP) per unit of labor services

belongs to value added based productivity measure. It follows that TFP responds negatively to an increase in the price of imports in the case of $\tau^m > 0$.

Second, an increase in the price of imports relative to the domestic final good differs from an increase in the terms of trade. It follows that, in the case of $\tau^m > 0$, TFP declines in response to increases in both the price of imports and exports relative to the final good even if the terms of trade increases little or even decreases. It is the price of imports relative to the price of the final good rather than relative to the price of exports that determines the level of TFP, holding all else constant.

I next present these results formally.

**Proposition 1.** *There is a negative first order effect on $TFP_1$ of an increase in $\bar{p}_1$ if $\tau^m > 0$, and there is a first order effect of changes in $(s_1, a_1, b_1)$ on $TFP_1$ if $[\widetilde{p}_0 - 1/A] > 0$:*

$$log(TFP_1) - log(TFP_0)$$

$$= \left[\frac{\tau^m \bar{p}_0}{TFP_0}\right] \left( \left[\frac{dm_1}{d\bar{p}_1}\right] \left[\bar{p}_1 - \bar{p}_0\right] \right) + \left[\frac{\widetilde{p}_0 - \frac{1}{A}}{TFP_0}\right] \left( \left[\frac{\partial x_1}{\partial s_1}\right] \left[s_1 - s_0\right] + \left[\frac{\partial x_1}{\partial a_1}\right] \left[a_1 - a_0\right] + \left[\frac{\partial x_1}{\partial b_1}\right] \left[b_1 - b_0\right] \right)$$

$$+ o(\bar{p}_1 - \bar{p}_0) + o(s_1 - s_0) + o(a_1 - a_0) + o(b_1 - b_0) \qquad where \lim_{z \to 0} \frac{o(z)}{z} = 0$$

*and derivatives are evaluated at $(\bar{p}_1 = \bar{p}_0, s_1 = s_0, a_1 = a_0, b_1 = b_0)$.*

*Proof.* Given in the mathematical appendix. □

Note that an increase in the real exchange rate parameter, $s_1$, appears in terms inside the first parenthesis, through $\bar{p}_t = s_t \widetilde{p}_t^F$ by definition, as well as the second.

Proposition 1 says that there is a negative first order effect of an increase in the price of imports, $\bar{p}_1$, on $TFP_1$ in the case of $\tau^m > 0$, and no such effect in the case of $\tau^m = 0$. This result is similar to results in Kehoe and Ruhl (2008) for the case of an increase in the terms of trade in the presence of tariffs distortions. In particular, I show in the appendix that $TFP_1$ is independent of $\bar{p}_1$ for the special case in which $\tau^m = 0$ and $\widetilde{p}_0 = 1/A$ as in the setup of Kehoe and Ruhl (2008). This result is stronger than results in Kehoe and Ruhl (2008): their result is up to a first order approximation while my result is obtained without approximation for this case.

Second, there is a first order effect of changes in $(s_1, a_1, b_1)$ on $TFP_1$ in the case of $\widetilde{p}_0 - 1/A > 0$, and no such effect in the case of $\widetilde{p}_0 - 1/A = 0$. I focus on the case of $\widetilde{p}_0 - 1/A > 0$, in

which there are positive profits in the export sector[12]. It follows that, in the case of $\widetilde{p}_0 - 1/A > 0$, a decrease in the quantity of exports, $x_1$, show up as contractions in real profits in the export good sector, which makes TFP decrease. On the other hand, if it were the case that $\widetilde{p}_0 = 1/A$, then there would be no first order effects of decreases in $x_1$ on real profits and $TFP_1$.

I consider the case of changes in $(s_1, a_1, b_1)$ such that the equilibrium price of exports, $\widetilde{p}_1$, is induced to increase. In this case, it is indeterminate if $x_1$ would increase or decrease since it depends on specific changes in $(s_1, a_1, b_1)$. This implies that, for the case of $\widetilde{p}_0 > 1/A$, the first order effect of an increase in $\widetilde{p}_1$ on $TFP_1$ is negative if the equilibrium $x_1$ decreases, and is positive if $x_1$ increases.

In short, if $\widetilde{p}_0 - 1/A > 0$, then there is a first order effect of an increase in the price of exports, $\widetilde{p}_1$, on $TFP_1$ via changes in $x_1$: this effect is negative in the case that $x_1$ decreases, and it is positive in the opposite case.

Lastly, I discuss the different effects on $TFP_1$ between an increase in the price of imports and an increase in the terms of trade. In the case of $\tau^m > 0$, there is a first order effect of increases in both the price of imports, $\bar{p}_1$, and the price of exports, $\widetilde{p}_1$, on $TFP_1$ even if there is no increase in the terms of trade. This result is simply a combination of the two above results. The key point here is that it is each of changes in the price of imports and shifts of the foreign demand function of the export good rather than changes in the terms of trade that determines, up to a first order approximation, changes in TFP. An increase in the price of imports, $\bar{p}_1$, induces a decrease in the quantity of imports, which results in a decrease of $TFP_1$ in the case of $\tau^m > 0$ and constancy of $TFP_1$ in the case of $\tau^m = 0$. Leftward shift of the foreign demand function of the export good, e.g., a decrease in $b_1$, induces a decrease in $x_1$, which results in a decrease of $TFP_1$ in the case of $\widetilde{p}_0 - 1/A > 0$ and constancy of $TFP_1$ in the case of $\widetilde{p}_0 - 1/A = 0$.

In short, $TFP_1$ decreases, up to a first order approximation, in response to an increase in the price of imports, $\bar{p}_1$, in the case of $\tau^m > 0$ and in response to a decrease in $x_1$ in the case of $\widetilde{p}_0 - 1/A > 0$ rather than $TFP_1$ responds to changes in the terms of trade, i.e., the ratio of $\bar{p}_1$ relative to $\widetilde{p}_1$.

**Proposition 2.** $w_1$ *is strictly decreasing in* $(1 + \tau^m)\bar{p}_1$.

*Proof.* Given in the mathematical appendix. □

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[12]It can be interpreted as the case in which there are taxes levied on the export sector, e.g., sales taxes. In this case, $\widetilde{p}_0 - 1/A > 0$ still holds true even for the case of the infinitely elastic foreign demand function that implies zero profit in the export sector, and all the subsequent analysis results hold true, too.

The above proposition[13] essentially says that $w_1$ declines in response to an increase in $\bar{p}_1$ holding $\tau^m$ and $\tau^h$ constant. That is, the real wage rate, which is in terms of the (domestic) final good, is decreasing in the level of the 'at-the-dock' price of imports. This result has an important implication for aggregate labor market outcomes. Note that in a standard real business cycle model, labor supply responds negatively to temporary declines in the real wage. This implies that a temporary rise in the price of imports results in a contraction of aggregate labor supply. This effect will be important in the quantitative analysis later in the paper.

I close this section by discussing the non-relevance of the labor wedge, $\tau^h$, with respect to effects of changes in $\bar{p}_1$ and/or $(s_1, a_1, b_1)$ on $TFP_1$ and $w_1$. From the formula presented in proposition 1, it is obvious that first order change in log of $TFP_1$, i.e., percent change in $TFP_1$, in response to changes in $\bar{p}_1$ and/or $(s_1, a_1, b_1)$ are independent of the level of $\tau^h$. In addition, I show in the appendix that the percentage change in the real wage rate, $w_1$, in response to one percentage increase in $\bar{p}_1$ is also independent of $\tau^h$. Based on this non-relevance of $\tau^h$ with respect to effects of changes in $\bar{p}_1$ and/or $(s_1, a_1, b_1)$ on $TFP_1$ and $w_1$, I will abstract from the labor wedge, more broadly wedges on domestic intermediate goods, in the section of application to the Korean crisis.

## 2.5   Dynamic Model

In this section, I extend the previous analysis by embedding the static model into an otherwise standard growth model. I will use this dynamic model to study the behavior of the Korean economy during the Asian crisis of 1997-98. This episode is interesting since the price of imports, aggregate TFP, output and labor, all experienced large temporary deviations from trend. I use this dynamic model to assess the importance of shocks to the price of imports relative to the final good in accounting for the movements in output, labor and TFP.

*Environment*

Essentially two features are newly added in this extension. First, the household makes decisions about leisure and saving in addition to consumption. Second, capital services are also used in production of the final good.

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[13]Kehoe and Ruhl (2008) consider this result conditionally on $F_{12}(m_1, h_1)$, the second-order cross derivative, whereas I do not need that condition.

<div align="center">Technology</div>

I parameterize the final good production function as CES:

$$Y_t = F(M_t, K_t^\theta [A_t h_t]^{1-\theta}) = \begin{cases} \left[ \alpha \cdot M_t^{(\rho-1)/\rho} + (1-\alpha) \cdot [K_t^\theta [A_t h_t]^{1-\theta}]^{(\rho-1)/\rho} \right]^{\rho/(\rho-1)} & \text{if } \rho \neq 1 \\ M_t^\alpha \cdot [K_t^\theta [A_t h_t]^{1-\theta}]^{1-\alpha} & \text{if } \rho = 1 \end{cases}$$

where $Y_t$ is the (domestic) final good output, $M_t$ is the imported good, $K_t$ is capital services, $A_t$ is labor-augmenting technological change, $\rho$ is the elasticity of substitution between the imported goods and the composite good of the capital and labor services[14], and $\alpha$ is the weight parameter associated with the imported goods.

I assume that $A_t$ grows at a constant rate $\gamma$:

$$A_t = [1+\gamma]^t, \quad t = 0, 1, 2, \ldots.$$

The production function of the export good is given by:

$$X_t = E_t$$

where $E_t$ is the final good used for the production of the export good $X_t$.

<div align="center">Household</div>

There is an infinitely lived representative household with preferences given by:

$$E_0 \left[ \sum_{t=0}^\infty \beta^t U(C_t, h_t) \right]$$

where $E_0$ is the expectation operator at the initial period, $C_t$ and $h_t$ are final good consumption and labor supply in period $t$, respectively.

For the functional form of $U(C_t, h_t)$, I consider two cases as in Otsu (2008): Cobb-Douglas preferences and GHH preferences[15]. First, Cobb-Douglas preferences, a special case of unitary intertemporal elasticity of substitution, are given by[16]:

$$U(C_t, h_t) = log(C_t) + \phi log(1 - h_t)$$

---

[14]Once again, the composite good can be interpreted as a domestic intermediate good.

[15]It is named after Greenwood et al. (1988).

[16]Note that this *log-log* preference specification is a standard one widely used in the business cycle literature, see, e.g., Prescott (1986).

which I use as a benchmark case.

Second, GHH preferences are given by:

$$U(C_t, h_t) = log\left(C_t - [1+\gamma]^t \chi \frac{1}{v+1}[h_t]^{v+1}\right), \quad v > 0$$

where $v+1$ represents the curvature of disutility function of labor and $\gamma$ is again the constant growth rate of labor-augmenting technology. For more detailed discussion about these two different specifications of preferences, see Otsu (2008).

The case of GHH preferences makes the model generated consumption variation larger compared to the benchmark case of Cobb-Douglas preferences by getting rid of the income effect on labor supply[17].

The household is endowed with one unit of time in each period and $K_0$ units of capital at the initial period $t = 0$. The household receives the sequence of government lump-sum transfer $\{\mathscr{T}_t\}$ independently of its choices.

I again normalize the price of the (domestic) final good to one for every period. Then, the household's period budget constraint is given by:

$$C_t + I_t = \omega_t h_t + r_t K_t + \Pi_t + \mathscr{T}_t, \quad \forall t = 0, 1, 2, \ldots,$$

$$I_t = K_{t+1} - [1 - \delta]K_t,$$

$$h_t \in [0, 1], \quad C_t \geq 0, K_{t+1} \geq 0$$

where $\omega_t$ and $r_t$ are (real) wage rate and capital rental price, respectively, $I_t$ is investment, $\Pi_t$ is total profit, and $\delta$ denotes the depreciation rate of capital.

### The Price of Imports

The price of imports, $\bar{p}_t$, which is in terms of the (domestic) final good, is a random variable that takes values in the set $\{\bar{p}^1, \bar{p}^2, \ldots, \bar{p}^i, \ldots, \bar{p}^N\}$ where $\bar{p}^i$ is the $i$th, in an ascending order, outcome in the sample space of $\bar{p}_t$.

The history-dependent probability distribution of $\bar{p}_t$ is represented by a first order Markov process, which is given by:

$$Prob[\bar{p}_{t+1} = \bar{p}^i | \bar{p}_t = \bar{p}^j] = \lambda(i, j), \quad 1 \leq i, j \leq N$$

---

[17]Note that the percentage standard deviation of consumption is larger than that of output for many emerging economies, true for the Korean case, which substantially differs from the case of most of developed economies that Cobb-Douglas preferences suit well, see for example Neumeyer and Perri (2005).

where $\lambda(i,j)$ is the $i$th row and $j$th column member of the Markov transition matrix $\Lambda$.

## The Price of Exports

In this model, I abstract from changes in the price of exports in order to focus on the effect of shocks to the price of imports relative to the (domestic) final good. This leads me to assume that the price of exports relative to the (domestic) final good is always equal to one:

$$\widetilde{p}_t = 1, \quad \forall t.$$

In the previous static analysis, we learned that the effect of increases in the price of exports on TFP is limited to the extent that the previous period price of exports exceeds the average cost of exports, i.e., $\widetilde{p}_{t-1} \gtreqqless 1$ for this economy. It is an open question if the extent of profits[18] in the export sector is large in the data. My assumption of zero profit[19] is without loss of generality for the purpose of studying the effects of shocks to the price of imports because the price of imports does not affect the level of profits in the export good sector for this economy.

In order to assess the effect of shocks to the price of imports without changes in terms of trade, I will consider later on, in the section of application to the Korean crisis episode, an alternative case in which $\widetilde{p}_t$ is always equal to $\bar{p}_t$:

$$\widetilde{p}_t = \bar{p}_t, \quad \forall t$$

which captures the case in which shocks to the real exchange rate drive fluctuations in both $\bar{p}_t$ and $\widetilde{p}_t$.

## Wedges

As in the earlier model, the final good firm pays $p_t = [1 + \tau^m]\bar{p}_t$ units of final good per imported good, and the import wedge is modeled as an ad-valorem tax levied on imported goods by the government.

I abstract from wedges on domestic factors, i.e., capital and labor wedges, because of the non-relevance of them regarding the responses of aggregate TFP, capital rental price and real wage rate to changes in $\bar{p}_t$ as long as those wedges are constant[20].

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[18]More precisely, I mean before-tax profits here. For this economy, before-tax profits are equal to after-tax profits because it is assumed that there are no sales taxes and no taxes on the use of the final good. In general, even if after-tax profits are zero, before-tax profits would be positive in the presence of positive sales taxes.

[19]Recall that it is already assumed that one unit of the final good can be used as one unit of the export good with no taxes levied on the final goods and that the final good price is normalized to one.

[20]Recall that the non-relevance of labor wedge has been already clarified in the previous static analysis. It is straightforward to derive these non-relevance results of domestic factor wedges in this extended model.

Government

The government collects taxes on imported goods and uses this tax revenue to finance a lump-sum transfer to the household. I maintain the assumption of balanced budget for the government for every period.

Balanced Trade and Closed Capital Market

As is standard in the literature, for simplicity, I assume that trade is balanced[21]:

$$X_t = \overline{p}_t M_t, \quad \forall t.$$

In the alternative case of $\widetilde{p}_t = \overline{p}_t$, the balanced trade condition is given by:

$$X_t = M_t, \quad \forall t.$$

Related to the above assumption of balanced trade, I abstract from international borrowing/lending, of which effects have been extensively studied in the literature, see, e.g., Gertler et al. (2007) and Otsu (2008) for its application to the Korean crisis case. I assume that this economy is closed with respect to the trade of capital: savings are always equal to investment, and the capital services market is closed in the sense that the household's capital supply is always equal to the domestic, the final good firm's, demand of capital in the equilibrium.

I briefly discuss if this is a good description of Korea. In accounting for the output contraction for Korea in 1998, as will be shown later, the deviation of capital from trend was not important: capital was *above* trend in 1998. It follows that my abstraction from international capital trade does not hurt the generality of my results according to the objective in this paper to account for negative deviations in TFP, output and labor for Korea in 1998. In short, international capital trade seems important in accounting for the consumption contraction but not so much for the output contraction, see the discussion in Otsu (2008) about this issue.

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[21]See, for example, Kehoe and Ruhl (2008) and Atkeson and Burstein (2009). More generally, I could model the unbalanced trade case by allowing for the household in this economy to borrow from the international capital market. I abstract from this international borrowing/lending problem because it has been extensively studied in the literature: for about this issue applied to the Korean crisis case, see, e.g., Gertler et al. (2007) and Otsu (2008).

## Resource Constraint

The resource constraint for this economy is given by:

$$C_t + I_t + E_t = Y_t$$

where $E_t$ is again the quantity of the final good used in exports.

### *Notation*

In order to make the analysis stationary, from now on, I rewrite all the variables, except for $(h_t, r_t, \bar{p}_t, \widetilde{p}_t = 1)$, relative to labor-augmenting technology parameter $A_t$:

$$c_t \equiv \frac{C_t}{A_t}, i_t \equiv \frac{I_t}{A_t}, k_t \equiv \frac{K_t}{A_t}, w_t \equiv \frac{\omega_t}{A_t}, y_t \equiv \frac{Y_t}{A_t}, m_t \equiv \frac{M_t}{A_t}, x_t \equiv \frac{X_t}{A_t}, e_t \equiv \frac{E_t}{A_t}, \pi_t \equiv \frac{\Pi_t}{A_t}, T_t \equiv \frac{\mathcal{T}_t}{A_t}.$$

I denote steady state variables by using asterisk, e.g., $k^*$ denotes the steady state value of $k_t$, and I use a hatted variable to denote the log deviation of that variable from the steady state value. For example, the log deviation of $k_t$ from the steady state is given by:

$$\widehat{k_t} \equiv log(k_t) - log(k^*).$$

### *Equilibrium*

I study a recursive competitive equilibrium, which is a list consisting of a value function $v(k, \bar{p}, K)$, policy functions $c(k, \bar{p}, K), h(k, \bar{p}, K), k'(k, \bar{p}, K), m(\bar{p}, K)$, price functions $w(\bar{p}, K)$ and $r(\bar{p}, K)$, (degenerate) total profit function $\pi(\bar{p}, K) = 0$, transfer function $T(\bar{p}, K)$ and aggregate capital transition function $K'(\bar{p}, K)$ that satisfy:

1. $v(k, \bar{p}, K)$ solves the following Bellman equation:

$$v(k, \bar{p}, K) = \max_{c, h, k'} \left\{ U(c, h) + \beta \sum_{i=1}^{N} \lambda(\bar{p}^i, \bar{p}) v(k', \bar{p}^i, K'(\bar{p}, K)) \right\}$$

$$s.t. \quad c + [1 + \gamma]k' - [1 - \delta]k = w(\bar{p}, K)h + r(\bar{p}, K)k + \pi(\bar{p}, K) + T(\bar{p}, K),$$

$$h \in [0, 1], \quad c \geq 0, k' \geq 0$$

and policy functions $c(k, \bar{p}, K), h(k, \bar{p}, K)$ and $k'(k, \bar{p}, K)$ are the optimal decision rules of the problem above.

2. $\forall K > 0, \bar{p} \in \{\bar{p}^1, \dots, \bar{p}^N\}$, the following decision rules $m^D = m(\bar{p}, K), k^D = K, h^D = h(K, \bar{p}, K)$

solve the final good firm's profit maximization problem given by:

$$\max_{m^D, k^D, h^D} \left\{ F(m^D, [k^D]^\theta [h^D]^{1-\theta}) - [1 + \tau^m]\bar{p}m^D - w(\bar{p}, K)h^D - r(\bar{p}, K)k^D \right\}.$$

3. Markets clear:   $\forall K > 0, \bar{p} \in \{\bar{p}^1, \dots, \bar{p}^N\}$,

$$c(K, \bar{p}, K) + [1 + \gamma]k'(K, \bar{p}, K) - [1 - \delta]K = F(m(\bar{p}, K), K^\theta [h(K, \bar{p}, K)]^{1-\theta}) - \bar{p}m(\bar{p}, K).$$

4. Balanced budget for the government:

$$T(\bar{p}, K) = \tau^m \bar{p}m(\bar{p}, K), \quad \forall K > 0, \bar{p} \in \{\bar{p}^1, \dots, \bar{p}^N\}.$$

5. $k'(k, \bar{p}, K)$ and $K'(\bar{p}, K)$ are consistent:

$$k'(K, \bar{p}, K) = K'(\bar{p}, K), \quad \forall K > 0, \bar{p} \in \{\bar{p}^1, \dots, \bar{p}^N\}.$$

As discussed earlier, this economy is assumed to be closed with respect to the trade of capital, which is already implicitly reflected to the fact that capital rental price function $r(\bar{p}, K)$ is endogenous and the implicitly incorporated market clearing condition of capital services, $k = K$.

### Measuring Output and TFP

As before, I use the Fisher chain-weighted method to measure real output. First, current price GDP is given by:

$$GDP_t \equiv y_t - \bar{p}_t m_t + [\widetilde{p}_t - 1]x_t$$

$$= y_t - \bar{p}_t m_t$$

where the first line follows from the same definition of current price GDP as for the previous static analysis, and the second line follows from the assumption $\widetilde{p}_t = 1$.

In the alternative case of $\widetilde{p}_t = \bar{p}_t$, current price GDP is given by:

$$GDP_t \equiv y_t - \bar{p}_t m_t + [\bar{p}_t - 1]x_t$$

$$= y_t - m_t$$

where the second line follows from the balanced trade assumption, $x_t = m_t$, in this case.

The way to construct the Fisher chain-weighted price index is the same as for the previous static analysis. It is straightforward to measure real GDP then. Letting $RGDP_t$ stand for this measure of output at period $t$, TFP is given by:

$$TFP_t \equiv RGDP_t / [k_t^\theta h_t^{1-\theta}], \quad \forall t.$$

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Up to a first order approximation, the current period log deviation of TFP, $\widehat{TFP_t}$, is increasing in the current period log deviation of the ratio of imported to domestic composite goods, $[\widehat{m_t} - \theta\widehat{k_t} - (1-\theta)\widehat{h_t}]$, and is decreasing in the log deviation of the previous period price of imports, $\widehat{p_{t-1}}$:

$$\widehat{TFP_t} \approx \left[\frac{\overline{p}^* m^*}{F(m^*, d^*) - \overline{p}^* m^*}\right]\left[\tau^m\left[\widehat{m_t} - \widehat{d_t}\right] - \widehat{p_{t-1}}\right]$$

$$where \ d_t \equiv [k_t]^\theta [h_t]^{1-\theta}, \quad \widehat{d_t} = \theta\widehat{k_t} + (1-\theta)\widehat{h_t}$$

and the symbol "$\approx$" indicates that this relationship holds up to a first order approximation.

*Proof.* Given in the mathematical appendix. ☐

From now on, I mean log deviation when I refer to 'percentage deviation' in the sense of first order approximation. The above result says that the impact of shocks to the price of imports on the percentage deviation in aggregate TFP is proportional to the percentage deviation in imported goods minus the percentage deviation in domestic composite goods, $[\widehat{m_t} - \widehat{d_t}]$. This tight relationship between $\widehat{TFP_t}$ and $[\widehat{m_t} - \widehat{d_t}]$ will be useful in checking the consistency between model's prediction and the data in the next section of application to the Korean crisis episode.

## 2.6   Application to The Korean Crisis of 1997-98

In this section, I describe the data and the quantitative method, and then I assess the importance of shocks to the price of imports relative to final good prices in accounting for the movements in output, labor and TFP in Korea over the period 1994-2002, in particular, deviations of those variables in 1998. I find that import price shocks can account for a substantial part of fluctuations in output, labor and TFP.

### *Korean Economy*

I document facts about changes in economic aggregates of the Korean economy during the Asian Crisis of 1997-98. I focus on deviations from trend.

### Data

The dataset I use is basically the National Accounts provided by the Korean Statistical Information Service. Data on population, hours worked, prices and an index of the quantity of imported goods is

also provided by the Korean Statistical Information Service.

The dataset covers the period 1994-2002, and is annual. Throughout this paper, following the convention of the literature, I calculate log deviation from trend of any variable by estimating the OLS linear trend of the log of that variable[22]. From now on, I mean this log deviation when I refer to 'deviation'.

I describe how I measure variables in the data. For output, I use the chain-weighted real GDP per adult of ages between 15-64 years old. For labor, I use total hours worked, the product of the per adult number of people employed and the weekly hours worked per worker. For capital, I use the perpetual inventory method[23] of a constant depreciation rate to construct capital series based on investment data. For consumption, I use private consumption expenditures on non-durables and services as in Otsu (2008). Lastly, for the quantity of imports, I use the total value of all imported goods and services measured in chain-weighted prices. All the quantity variables are measured by the chain-weighted method, and then converted to units per adult.

Next, I describe how I measure prices of imported and final goods. For the prices of imported goods and prices of final goods and services, I use the Import Price Index (: IPI) and Consumer Price Index (: CPI), respectively, for all goods and services. Then, I take the ratio of IPI relative to CPI as the price of imports relative to the price of final goods. From now on, I mean the price of imports relative to the price of final goods when I refer to 'the price of imports'.

Lastly, I describe how I measure real wage rate. Using the Survey on Wages & Working Hours at Establishments dataset collected by the Korean MINISTRY OF EMPLOYMENT and LABOR[24] over the period 1994-2002, I first measure a nominal wage rate by dividing the annual average total wage payments by the annual average total hours worked. I construct the real wage rate index by dividing the nominal wage rate by CPI used earlier.

Korean Crisis

First, I show fluctuations in Korea's key aggregate variables in Figure 2.1.

In the picture, we see that output was below trend by about 7.7 percentage point in 1998. To

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[22]Given the short length of my time-series, the HP filter is less desirable than a linear trend.

[23]Detailed procedure is given in the appendix.

[24]This dataset covers wages and working hours of all employees at establishments with 5 permanent employees or more by industry over the period 1993-1998 and with 10 permanent employees or more by industry over the period since 1999 through 2007.

Figure 2.1: Korea's Business Cycle Fluctuations During the Period 1994-2002

explore the source of this output drop, I look at deviations of three factors: labor, capital and TFP. The picture shows that labor and TFP were below trend by about 6.7 percentage point and 5.7 percentage point, respectively, whereas capital was above trend by about 5 percentage point. Therefore, I conclude that both labor contraction and TFP deterioration are important in accounting for the negative deviation in Korea's output in 1998. A key question is what would have depressed both labor and TFP in 1998 so significantly.

Second, I summarize the descriptive statistics of the data. Given the short horizon of the dataset, which is over the period 1994-2002, these descriptive statistics are illustrative for the particular period of interest, but are not intended to characterize the general business cycles properties of the Korean economy.

| $z$ | $\bar{p}$ | $y$ | $h$ | $k$ | TFP | $c$ | $i$ | $m$ | $m/[k^\theta h^{1-\theta}]$ |
|---|---|---|---|---|---|---|---|---|---|
| $\sigma(z)$ | 6.4 | 3.5 | 3.5 | 3.5 | 2.3 | 4.5 | 9.4 | 10.9 | 9.5 |
| $\sigma^{NC}(z)$ | 3.9 | 2.1 | 2.5 | 1.0 | 3.2 | 3.2 | 7.3 | 7.4 | 6.0 |
| $corr(z,y)$ | -0.84 | 1.00 | 0.95 | -0.31 | 0.85 | 0.97 | 0.97 | 0.96 | 0.94 |
| $corr(z,\bar{p})$ | 1.00 | -0.84 | -0.80 | 0.55 | -0.89 | -0.86 | -0.78 | -0.75 | -0.77 |

Table 2.1: Descriptive Statistics of Korea's Key Aggregates During the Period 1994-2002

Table 2.1 provides percentage standard deviation, correlation coefficients with output and correlation coefficients with the price of imports for Korea's aggregate variables of interest. $\bar{p}$, $y$, $h$, $k$, $c$, $i$, $m$ and $m/[k^\theta h^{1-\theta}]$ denote deviations of the price of imports, output, labor, capital, consumption, investment, imports and the ratio of imports to the domestic composite good, respectively, as the notation used in the dynamic model.

The line headed $\sigma(z)$ provides percentage standard deviation of a variable $z$ over the entire period 1994-2002 while the line headed $\sigma^{NC}(z)$ does the same over the non-crisis periods, 1994-1997 and 1999-2002. In non-crisis periods, Korea's output is not substantially more volatile than is the U.S. output. It is also interesting that both quantity($m$) and price($\bar{p}$) of imports are more volatile than output, by a factor of about 3 and 2, respectively. Lastly, consumption is also more volatile than output, as noted by Neumeyer and Perri (2005).

The line headed $corr(z,y)$ provides the correlation coefficient of a variable $z$ and output. As is the case for the U.S., all the variables except for capital and the price of imports are procyclical.

The line headed $corr(z,\bar{p})$ provides the correlation coefficient of a variable $z$ and the price of imports. It is noteworthy that output, labor and TFP are all highly negatively correlated with the price of imports. In particular, the imported to domestic composite good ratio, the last column, is negatively correlated with the price of imports.

Third, I provide deviations of Korea's aggregates of interest in 1998, see table 2.2.

| $z$ | $\bar{p}$ | $y$ | $h$ | $k$ | TFP | $c$ | $i$ | $m$ | $m/[k^\theta h^{1-\theta}]$ |
|---|---|---|---|---|---|---|---|---|---|
| $\widehat{z}_{1998}$ | 14.2 | -7.7 | -6.7 | 5.0 | -5.7 | -9.0 | -17.3 | -22.5 | -20.4 |
| $\widehat{z}_{1998}/\sigma^{NC}(z)$ | 3.7 | -3.7 | -2.6 | 1.6 | -5.6 | -2.8 | -2.4 | -3.0 | -3.4 |

Table 2.2: Deviations of Korea's Key Aggregates In 1998

The line headed $\widehat{z}_{1998}$ provides the percentage deviation of $z$ in 1998 while the line headed $\widehat{z}_{1998}/\sigma^{NC}(z)$ provides the ratio of $\widehat{z}_{1998}$ relative to $\sigma^{NC}(z)$. The main message is that deviations of the price of imports, output, labor and TFP are significantly larger, by a factor of larger than or equal to 2.6, in 1998 than on average in non-crisis periods. The significant deviation of TFP in 1998, by more than 5 times the typical deviation in non-crisis periods, suggests that this deviation is not likely to be entirely driven by true technology shocks. And the unusually large significant deviation of the price of imports, by 3.7 times the typical deviation in non-crisis periods, is particularly noteworthy. Based on these facts, it is of interest to explore whether shocks to the price of imports are important in explaining significant deviations in Korea's output, labor and TFP in 1998.

I close this section by summarizing fluctuations in Korea's real wage rate, see table 2.3.

| $corr(w,y)$ | $corr(w,\bar{p})$ | $\sigma(w)$ | $\sigma^{NC}(w)$ | $\widehat{w}_{1998}$ |
|---|---|---|---|---|
| 0.86 | -0.74 | 4.1% | 3.8% | -5.2% |

Table 2.3: Descriptive Statitics of Korea's Real Wage Rate

The first four columns of the above table presents the correlation coefficient between the real wage rate, $w$, and output, correlation coefficient between $w$ and the price of imports, standard deviation of $w$ over the period 1994-2002 and standard deviation of $w$ over the non-crisis periods. The column headed '$\widehat{w}_{1998}$' is the log deviation of $w$ in 1998.

The main message is that the real wage rate is highly negatively correlated with the price of imports over the period 1994-2002, consistent to the theory. This relationship was strongly held in 1998: the real wage rate was below trend significantly, by 5.2%, while the price of imports was above trend significantly. It is important to account for the real wage deviation in 1998 because the reduction of the real wage in response to an increase in the price of imports is closely related with correctly accounting for contractions in labor and output. I will confront fluctuations in the model generated real wage rate to the data later in discussing the simulation results.

*Calibration*

In this section, I describe how I calibrate parameter values of the dynamic model.

Level of the Import Wedge

The import wedge measures the extent of distortion on the use of imported goods. In principle, the *aggregate* import wedge is, to first order approximation, simply equal to the sum of all the individual wedges distorting the use of imported goods. I label these as *individual* import wedges. I classify a factor as an individual import wedge if it satisfies both of the following conditions:

1. It increases the price of imported goods actually charged to the final good producer relative to the at the dock prices of imported goods

2. It does not represent domestic intermediate goods or services used in the production of the final goods

First, payments to labor and capital services do not belong to individual import wedges because they do not satisfy either the first or the second condition. Second, transportation costs do not satisfy the second condition as long as they are expenditures on transportation services because transportation services is one of the domestic intermediate goods and services used in the production of the final goods.

Third, it is obvious that taxes and tariffs levied on imported goods are classified as individual import wedges. Note that importing foreign goods costs more than taxes, tariffs and transportation costs: there are custom clearance fees, i.e., inspection cost, documentation fees and so on. I assume that such custom services are not intermediate inputs in the production of the final goods, and hence I classify "ad-valorem" custom clearance fees as an individual import wedge.

Lastly, I consider "ad-valorem" markups levied on imported goods by any rent-seekers, i.e., import and/or wholesale traders of monopolistic power, which I label as the rent-seekers' markups. In general, there could be rent-seekers in distributing imported goods from the dock to the final good firm. I assume that these rent-seekers provide no labor services used as intermediate inputs in the production of the final goods. It immediately follows from this assumption that rent-seekers' markups are equivalent to taxes in satisfying the two conditions for an individual import wedge: the two differ only in who are owners of such taxes and/or markups receipts.

In summary, there are four individual import wedges: taxes, tariffs, custom clearance fees and rent-seekers' markups. I have estimates of the first three but no estimate of the last one. In the benchmark case, I set the last one, the rent-seekers' markups, equal to zero in order to be conservative. In the sensitivity analysis, I consider the case in which it is positive.

I next describe how to calculate the benchmark (aggregate) import wedge $\tau^m$ based on estimates of taxes, tariffs and custom clearance fees. Tariffs rates in 1998 are estimated to be 9.8% and 13.2% based on weighted and unweighted averages, respectively, where the averages are taken over the cross-section of the 6-digit level tariffs rates dataset provided by WTO[25]. The weighted one is likely to be downward-biased while the unweighted is likely to be upward-biased[26]. I take 11.5%, the midpoint of the two estimates, as the benchmark value and provide sensitivity analysis results for the two cases of weighted and unweighted averages as lower and upper bound of tariff rates, respectively.

According to the website *Export.gov (2009)*[27], there are value added taxes of 10% for the sum of the at-the-dock prices of imported goods and tariffs. I set the ad-valorem customs clearance fees to

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[25]Each time series of the two cross-sectional average tariffs rates exhibits decreasing trend over time. The sample mean of each of the two time-series for the period 1994-2002 is similar to the tariffs rates in 1998.

[26]A brief discussion is provided by WTO website about this issue.

[27]This is one of federal agencies managed by the U.S. Department of Commerce's International Trade Administration: http://www.export.gov/logistics/eg_main_018142.asp
See the item titled "South Korea".

8% based on the estimate by Lee et al. (2008)[28].

Combining these tariffs, taxes and customs clearance fees, I calculate $\tau^m = .32$ as:

$$1 + \tau^m = (1 + \text{tariff rate})(1 + \text{VAT})(1 + \text{customs clearance fees})$$

$$= (1 + 0.115)(1 + 0.10)(1 + 0.08), \quad \therefore \tau^m = 0.3248$$

where VAT denotes the value added tax rate.

### Other Parameter Values

As in Otsu (2008), I assume that the Korean economy is growing along a balanced growth path over the period 1994-2002. That is, the Korean economy would have been on the steady state balanced growth path over that period if there were no shocks to the price of imports. Given the calibrated value of $\tau^m$, I calibrate other parameter values by targeting averages of Korea's statistics in the data. Once again, the data is for the period 1994-2002. The benchmark parameter values are listed in table 2.4.

| | PARAMETER | VALUE | TARGET |
|---|---|---|---|
| $\tau^m$: | Import Wedge | .3248 | Tariff, Taxes and Customs Clearance Fees |
| $\bar{p}_0$: | Price of Imports | 1 | Normalization |
| $\rho$: | Elasticity of Substitution | 1 | Benchmark |
| $\alpha$: | Imported Goods Weight | .2898 | Import/GDP |
| $\gamma$: | Growth Rate of Labor Augmenting Tech. | .0507 | Growth Rate of per adult GDP |
| $\beta$: | Discount Factor | .9838 | Real Rate of Return |
| $\delta$: | Depreciation Rate | .064 | Estimate |
| $\theta$: | Capital Share | .40 | Investment/GDP |
| $\phi$: | Benchmark Preference | 1.721 | $h_{ss} = .3166$ |
| $v$: | GHH Preference: Curvature | .34 | Otsu(2008) |
| $\chi$: | GHH Preference: Level | .37 | $h_{ss} = .3166$ |

Table 2.4: Benchmark Parameter Values

First, I normalize $\bar{p}_0$, the steady state 'at-the-dock' price of imports, to one. Second, I set the elasticity of substitution parameter $\rho$ to one, the case of a Cobb-Douglas production function. This value is in the range, $[.5, 3.0]$, of the elasticity of substitution parameter between home goods and foreign goods widely used in the international business cycle literature. Third, I choose $\alpha = 0.289$ by targeting the average import to GDP ratio, which is about 28%:

$$\frac{\bar{p}^* m^*}{(m^*)^\alpha ([k^*]^\theta [h^*]^{1-\theta})^{1-\alpha} - \bar{p}^* m^*} = \frac{\alpha/(1 + \tau^m)}{1 - \alpha/(1 + \tau^m)}$$

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[28]See the row "G: Handling fees for customs clearance" of the table in the footnote 1 of Lee et al. (2008).

where the numerator and denominator of the LHS of the equation is the steady state imports and real GDP, respectively. Given the average import to GDP ratio, I solve for $\alpha$.

The constant growth rate of labor augmenting technology, $\gamma$, is set to 5.07%, the average growth rate of per adult real GDP. I choose $\beta = .9838$ to match the average annual real interest rate[29] of 6.8%, by using the steady state Euler equation:

$$(1+\gamma) = \beta[1 + \text{ real rate of return }].$$

I set $\delta = 0.064$ based on the average depreciation rate of capital in the data. I choose $\theta = .40$ to match the average investment to GDP ratio, about 34%. In the model, this implies about 32% investment to GDP ratio, which is consistent with the data given the 2% population growth rate in the data. Moreover, the model implied capital to GDP ratio is 2.76, which is also close to the capital to GDP ratio equal to 2.78 in the data based on the estimates provided by Pyo et al. (2006). For the benchmark preference parameter $\phi$, I target the average labor supply[30] of .3166. For the GHH preference parameters $\chi$ and $\nu$, I first choose $\nu = .34$ so that $\nu + 1 = 1.34$ as done by Otsu (2008), and then I choose $\chi = .37$ by targeting the average labor supply.

## State Space and Evolution of $\bar{p}$

I discretize the state space of log deviation of $\bar{p}$ and calibrate its Markov transition matrix by following Tauchen (1986)'s method[31]. The first-order serial correlation coefficient of log deviation of $\bar{p}$ is estimated to be slightly negative and insignificant. I choose the case of zero serial correlation, i.e., i.i.d. process, as the benchmark case. The results in the case of the estimated slightly negative serial correlation are almost identical to the benchmark setting[32].

Figure 2.2 shows the resulting discretized time-series of log deviation of $\bar{p}$ where a solid line is the original series in the data and a dashed one is the discretized one. They look almost identical to each other.

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[29]This is equal to the average nominal annual yield of 6-month maturity CD, about 11 percentage point, minus the average annual inflation rate measured by CPI growth rate, about 4.2 percentage point.

[30]I convert the data on total hours worked, which is the employment per adult times weekly hours worked per worker, to the one comparable to the model by dividing the data by $17 \times 6$ hours, which is the weekly hours available to a worker, i.e., 17 hours per day and 6 days per week.

[31]For a more detailed discussion about this procedure, see the appendix.

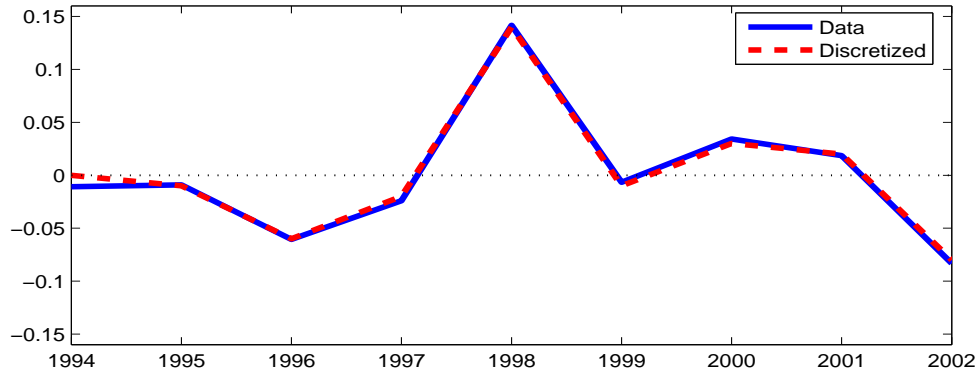[32]See the table in the appendix for the results of this case.

Figure 2.2: Shocks to the Price of Imports

*Simulation Method*

As an initial condition, I assume that the Korean economy is on the balanced growth path as of 1994, and then consider temporary fluctuations in $\bar{p}$ over the period 1995-2002. That is, the initial state, in calendar year 1994, is the steady state, and I feed in the observed $\bar{p}$ series over the period 1995-2002. In other words, I assume that the realizations of the stochastic process are the same as observed in the data.

The aggregate state vector is a pair $(\bar{p}, K)$. I limit the space of $K$ such that the upper bound is above the steady state value of $K$ by 20% and the lower bound is below it by 20%[33]. Note that the space of $K$ is a continuum. I numerically solve for two policy functions, consumption and labor supply, by using the first order finite element method as illustrated by McGrattan (1996). Numerical error is about $10^{-7}$ percentage point, between the guessed and updated policy functions, uniformly over the domain. Once the policy functions are solved for, it is straightforward to calculate the allocation and price functions.

*Results*

I compare statistics of the simulated variables and counterparts in the data. Recall that any variable in the data is already detrended: log deviation from linear trend. In order to be consistent with the data, I also convert simulated variables to log deviations[34].

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[33]It turns out that solved policy functions never bind at those two limit points for capital within the range of 10 percentage point above and below the steady state value of $K$.

[34]Noting that shocks to $\bar{p}$ are already detrended, I calculate log deviation of a simulated variable by subtracting log of the steady state value from the log of the simulated variable.

First, I discuss how the model predicted series are correlated with each other. I find that, in each of the two different preference cases, all aggregate variables of interest except for capital and the price of imports are highly positively correlated with output and highly negatively correlated with the price of imports, consistent with the data. I present the results only for the standard preference specification, which is my benchmark preference case[35], see table 2.5.

| $z$ | $\bar{p}$ | $y$ | $h$ | $k$ | TFP | $c$ | $i$ | $m$ | $\frac{m}{k^\theta h^{1-\theta}}$ | $w$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $corr(z,y)$ | | | | | | | | | | |
| Data | -0.84 | 1.00 | 0.95 | -0.31 | 0.85 | 0.97 | 0.97 | 0.96 | 0.94 | 0.86 |
| Model | -0.99 | 1.00 | 0.98 | -0.32 | 0.99 | 0.75 | 0.97 | 0.99 | 0.99 | 0.99 |
| $corr(z,\bar{p})$ | | | | | | | | | | |
| Data | 1.00 | -0.84 | -0.80 | 0.55 | -0.89 | -0.86 | -0.78 | -0.75 | -0.77 | -0.74 |
| Model | 1.00 | -0.99 | -1.00 | 0.46 | -1.00 | -0.64 | -0.99 | -1.00 | -1.00 | -0.95 |

Table 2.5: Descriptive Statistics of Korea's Key Aggregates During the Period 1994-2002. Model Results Are For The Benchmark Preference Case

Signs of correlation coefficients are perfectly matched between the model and the data. Furthermore, the absolute values of correlation coefficients seem also close between the model and the data.

Next, focusing on the contraction in 1998, I discuss how much of the deviation in aggregate variables in 1998 can be accounted for by shocks to the price of imports for each of the benchmark and GHH preference cases.

### The Benchmark Preference Case

Table 2.6 provides deviations in the model, for the benchmark preference specification, and those in the data for output, labor, capital, TFP, consumption, investment, imports, the ratio of imports to the domestic composite good and real wage rate.

| | $y$ | $h$ | $k$ | TFP | $c$ | $i$ | $m$ | $\frac{m}{k^\theta h^{1-\theta}}$ | $w$ |
|---|---|---|---|---|---|---|---|---|---|
| Data | -7.7 | -6.7 | 5.0 | -5.7 | -9.0 | -17.3 | -22.5 | -20.4 | -5.2 |
| Model | -4.2 | -5.1 | 1.5 | -1.8 | -0.8 | -52.2 | -22.2 | -19.7 | -3.1 |
| Model/Data | 55.1 | 76.4 | 29.5 | 30.9 | 8.7 | 302.6 | 98.8 | 96.4 | 59.2 |

Table 2.6: Deviations of Korea's Key Aggregates In1998: Benchmark Preference Case

First, shocks to the price of imports account for about one third of the deviation in TFP. The column headed '$\frac{m}{k^\theta h^{1-\theta}}$' says that the deviation in the ratio of imports to the domestic composite good is almost the same in the model and the data. This means that my benchmark choice of unitary elasticity

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[35]Results for the GHH preference case are similar to those for the benchmark preference case.

of substitution between imported and domestic composite goods, $\rho = 1$, is good at fitting the substitutability between the two goods in the data. I plot the simulated results for TFP and the import to domestic composite good ratio, $\frac{m}{k^\theta h^{1-\theta}}$, in Figure 2.3 and 2.4, respectively.
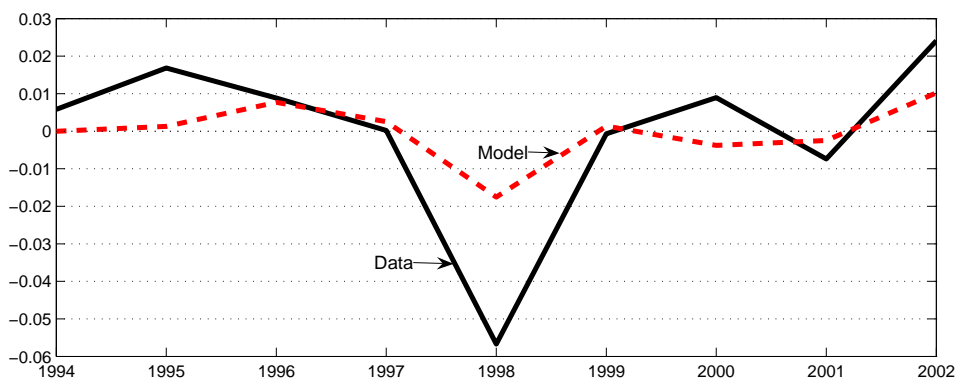


Figure 2.3: TFP
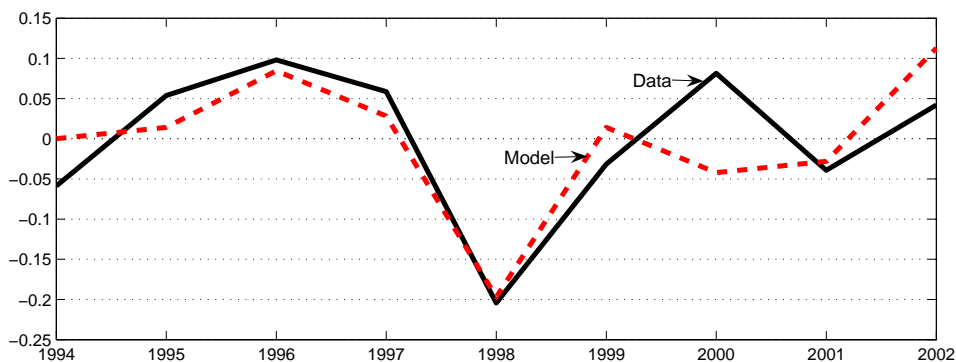


Figure 2.4: Import to Domestic Composite Good Ratio

Second, shocks to the price of imports account for about 55% of the deviation in output and three quarters of the deviation in labor. The last column says that the effect of shocks to the price of imports on the real wage rate is sizable, about 60% relative to the data, which explains the large deviation of labor. Note that shocks to the price of imports account for little, about 9%, of the consumption deviation. This result about the consumption deviation is quite different in the GHH preference case, which I will discuss in the next section. I plot the simulated results in the benchmark preference case, see Figure 2.5.

In short, shocks to the price of imports account for one third of the deviation in TFP, and a greater share of deviations in output and labor in 1998. For consumption, shocks to the price of imports

Figure 2.5: Allocation For the Benchmark Preference Case

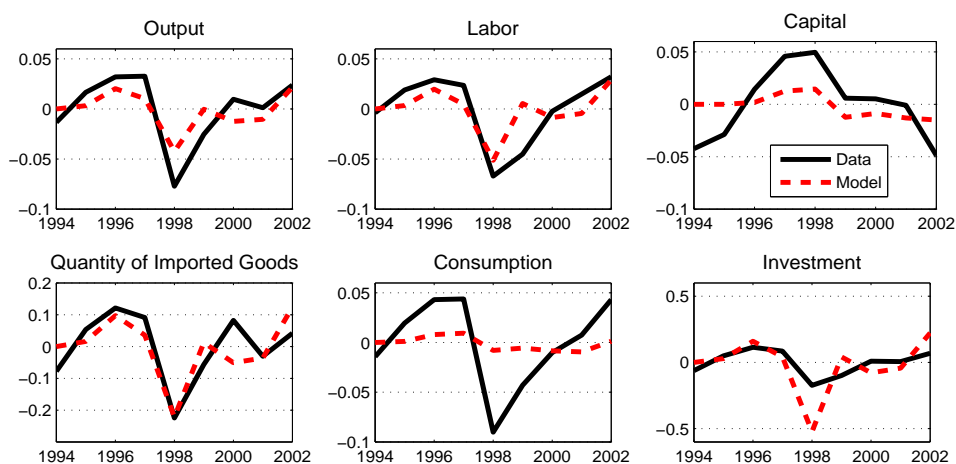account for little of the consumption deviation in the benchmark preference case.

I close this section by discussing the challenge of accounting for the significant deviation in the real wage rate. I apply the business cycle accounting procedure of Chari et al. (2007) to the stand-in firm's optimality condition with respect to hiring labor services and calculate the implied real wage rate, i.e., the marginal product of labor. That is, I calculate the real wage rate implied by the standard growth model when it is engineered to match output and labor perfectly as in the data, which I denote by $w^{BCA}$: $w^{BCA} \equiv (1-\theta)Y/H$ where $Y$ and $H$ are real GDP and labor supply in the data, respectively. Table 2.7 presents log deviation of Korea's real wage rate in 1998 for the data, the model in the benchmark preference specification and $w^{BCA}$, the one implied by the business cycle accounting framework.

| Data | Model | BCA |
|------|-------|------|
| -5.2 | -3.1 | -1.0 |

Table 2.7: Deviation of Korea's Real Wage Rate In 1998: Benchmark Preference Case

The last column says that technology shocks account for about 20% of the deviation in the real wage rate given output and labor as in the data: the real wage rate decreases in response to negative technology shocks in the standard growth model. This result implies that it is a challenge to account for the real wage deviation, and related to this point, it is an open question if financial shocks in the absence of labor market frictions can account for the significant reduction in the real wage rate. Note that the effect of shocks to the price of imports on the real wage rate is significantly large, about 60% to the data: see the column headed 'Model'. In short, it is a challenge to account for the real wage deviation in 1998, with respect to which technology shocks do not seem of a first order importance but shocks to the

price of imports are important.

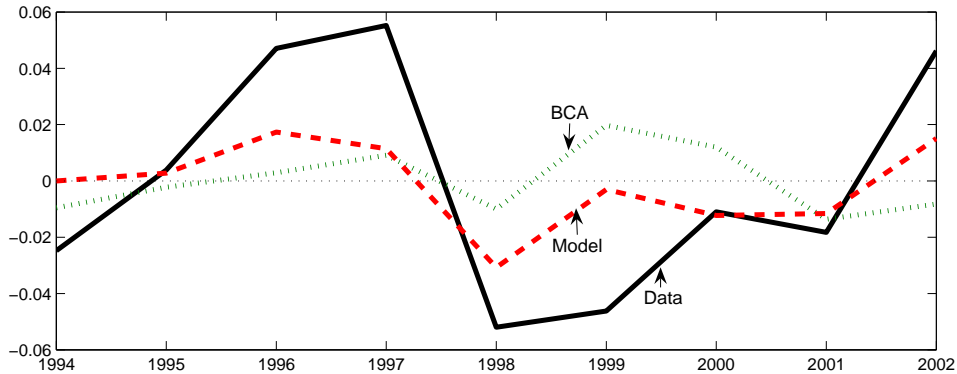I plot the time series for the real wage rate in Figure 2.6.



Figure 2.6: Real Wage Rate For the Benchmark Preference Case

From the picture, we see that fluctuations in the real wage rate implied by the business cycle accounting framework, $w^{BCA}$, is not so much close to the data while the model generated real wage series for the benchmark preference specification mimic well the series in the data.

The GHH Preference Case

Table 2.8 presents deviations in the model, for the GHH preference case, and those in the data for output, labor, capital, TFP, consumption, investment, imports, the ratio of imports to the domestic composite good and real wage rate.

|            | $y$   | $h$   | $k$  | TFP  | $c$  | $i$   | $m$   | $\frac{m}{k^\theta h^{1-\theta}}$ | $w$  |
|------------|-------|-------|------|------|------|-------|-------|------|------|
| Data       | -7.7  | -6.7  | 5.0  | -5.7 | -9.0 | -17.3 | -22.5 | -20.4 | -5.2 |
| Model      | -5.5  | -7.1  | 1.2  | -1.8 | -5.8 | -34.1 | -23.5 | -19.7 | -2.4 |
| Model/Data | 71.3  | 105.2 | 24.8 | 30.9 | 64.0 | 197.4 | 104.3 | 96.4  | 46.1 |

Table 2.8: Deviations of Korea's Key Aggregates In1998: GHH Preference Case

Note first that the results for TFP and the ratio of imports to the domestic composite good are the same as for the benchmark preference case, and the real wage rate deviation is slightly smaller, about 46% to the data, than in the benchmark preference specification, which is about 60% to the data.

Second, however, the effects of shocks to the price of imports on output, labor and consumption are substantially larger in the GHH preference case than in the benchmark preference specification. This is similar to the results of Otsu (2008) regarding the impact of technology shocks. In my results for the GHH preference case, shocks to the price of imports account for about three quarters

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of the deviation in output and 105% of the deviation in labor. Note that the effects are particularly large for the consumption deviation, about two thirds of the data. In contrast, the effect on the consumption deviation is almost zero in the benchmark preference case. Figure 2.7 shows the simulated results in the GHH preference case.
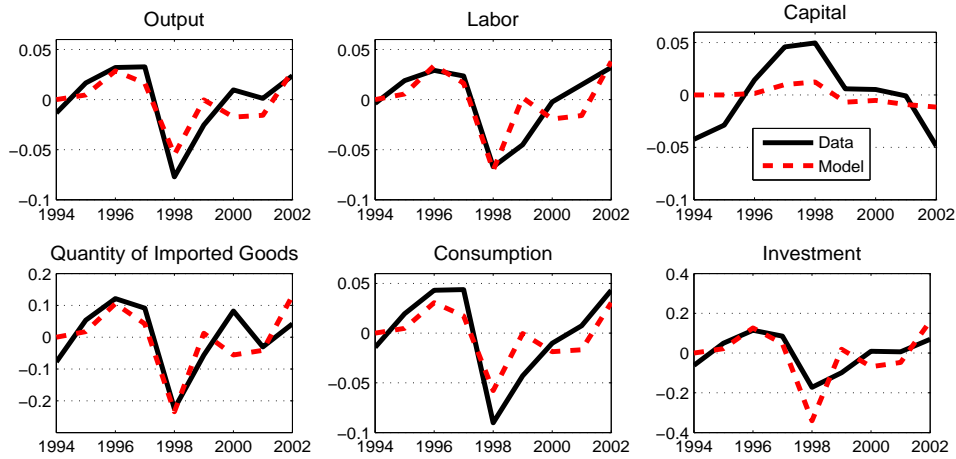


Figure 2.7: Allocation For the GHH Preference Case

As is well known in the literature, there is no income effect in the response of labor to a temporary change in real wage rate for GHH preferences, which is the key to the larger deviation in labor supply predicted by the model in this case relative to the benchmark preference specification. Note that the labor deviation in the GHH preference case is almost the same as in the data, which is also similar to the results of Otsu (2008).

In short, in the GHH preference case, shocks to the price of imports account for one third of the TFP deviation in 1998 and a greater share of deviations in output and labor in 1998: 105% of the deviation in labor and about three quarters of the deviation in output. The effects on TFP in the GHH preference case are the same as in the benchmark preference specification while those effects on output, labor and consumption are significantly larger in the GHH preference case relative to the benchmark preference specification. Those effects are particularly larger for the consumption deviation: shocks to the price of imports account for about two thirds of the consumption deviation while they do little, about 9%, in the benchmark preference case.

To close this section, I provide a brief discussion about how the results in this paper are related to those in Otsu (2008). He obtains the results that a standard small open economy model combined with capital utilization and capital adjustment costs can explain virtually all of deviations in TFP,

output, labor and consumption in 1998 when technology shocks with variation equal to one third the variation in the data are fed in. That is, variable capital utilization rates can account for about two thirds[36] of TFP variation in the data[37]. In my results, in the absence of variable capital utilization rates, shocks to the price of imports account for about one third of the TFP deviation in 1998 in the benchmark parameter setting. Otsu (2008) does not attempt to explain the source of the large exogenous drop in TFP that drives aggregate outcomes in 1998. My model suggests that changes in the relative price of imports can generate the size of technology shocks that his model requires.

Sensitivity Analysis

I carry out the sensitivity analysis to see if the previous results for the setting of benchmark parameter values are robust to different values of $\tau^m$. I provide results only for the GHH preference case[38], see table 2.9.

| | Data | Model: GHH Preference | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $\tau^m$ | - | 0.0 | 0.23 | 0.30 | 0.32 | 0.35 | 0.39 | 0.46 |
| Output | -7.7 | -3.0 | -4.7 | -5.3 | -5.5 | -5.7 | -6.0 | -6.6 |
| | | (38.5) | (61.2) | (69.3) | (71.3) | (73.3) | (78.2) | (85.3) |
| TFP | -5.7 | 0.0 | -1.2 | -1.6 | -1.8 | -1.9 | -2.2 | -2.6 |
| | | (-0.7) | (20.7) | (28.8) | (30.9) | (33.1) | (38.2) | (45.7) |
| Labor | -6.7 | -5.2 | -6.5 | -6.9 | -7.1 | -7.2 | -7.5 | -7.9 |
| | | (77.0) | (96.5) | (103.5) | (105.2) | (107.0) | (111.1) | (117.3) |
| Real Wage | -5.2 | -1.8 | -2.2 | -2.4 | -2.4 | -2.4 | -2.5 | -2.7 |
| | | (33.7) | (42.3) | (45.3) | (46.1) | (46.9) | (48.7) | (51.3) |

Table 2.9: Deviations of Korea's Key Aggregates In1998: Sensitivity Analysis. Numbers Inside Parenthesis Are The Percentage Ratios of The Model Deviations Relative To The Data

The table displays deviations in 1998 of Korea's aggregates in the data and in the model, in the GHH preference case, for different values of $\tau^m$. The numbers inside parenthesis are the percentage ratios of the model generated deviations relative to the data. I consider seven different values of $\tau^m$, and I describe what is the case for each of these seven different values of $\tau^m$. First, I consider an extreme case of $\tau^m = 0$ to clarify the effects of shocks to the price of imports on labor and TFP. Second, to be conservative, I consider only two individual import wedges, taxes and tariffs: using benchmark parameter values of these two individual import wedges, I calculate $\tau^m = 0.23$ in this case. Third,

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[36]Of course, this effect depends on the elasticity of depreciation rate of capital to the utilization rate of capital.

[37]In Otsu (2008), unusually significantly large technology shocks in 1998 are still required, which is larger than the typical technology shocks in non-crisis periods by a factor of 5. The key point here is that variable capital utilization rates reduce the required *absolute* extent of impulse, i.e., technology shocks, for every period in 1994-2002, but do *not* reduce the extent of impulse in 1998 *relative to* that in non-crisis periods. In contrast, my results are obtained in the absence of technology shocks.

[38]See the table in the appendix for results in the benchmark preference specification.

$\tau^m = 0.30$ and $\tau^m = 0.35$ are cases in which I set the tariff rate to weighted and unweighted averages, respectively. Finally, $\tau^m = 0.39$ and $\tau^m = 0.46$ are cases in which the "ad-valorem" rent-seekers' markups is 5% and 10%, respectively: it is zero in the benchmark parameter setting.

The main results are that shocks to the price of imports account for a greater share of deviations in TFP, labor and output for higher value of $\tau^m$, consistent to the theory. In particular, the effect of shocks to the price of imports on the TFP deviation, relative to the data, increases dramatically from almost zero to 44% as $\tau^m$ increases from zero to 0.46. It is also noteworthy that, even in an extreme case of $\tau^m = 0$, shocks to the price of imports still account for a substantial part of deviations in labor and output. This indicates that shocks to the price of imports are still important in affecting labor supply and output even in the case that there is no friction to trade.

It is interesting whether the relationships between the responses in the above aggregates and the level of the import wedge parameter are close to linear or convex or concave. I plot the responses of TFP, output, labor and real wage presented in the table 2.9 against the level of $\tau^m$, see Figure 2.8.
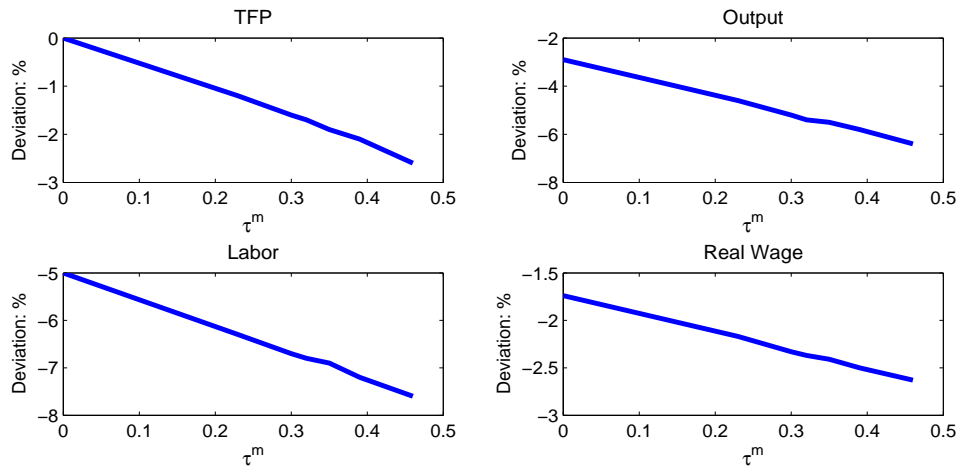


Figure 2.8: The Level of the Import Wedge, $\tau^m$, and Responses in Aggregates of Interest to an Increase in the Price of Imports in 1998

From the picture, we can see that these relationships are close to linear. Roughly speaking, the responses in aggregates of interest to increases in the price of imports are increasing, with constant rates, in the level of $\tau^m$.

Next, the effect of shocks to the price of imports on labor supply also increases substantially as $\tau^m$ increases even though this increase does not look as striking as for the effect on TFP. Recall that the key mechanism in propagating shocks to the price of imports to labor supply is that those shocks induce

the real wage rate to fall. In other words, the effect of shocks to the price of imports on labor supply is increasing in the level of $\tau^m$ because the negative response of real wage rate to those shocks is increasing in the level of $\tau^m$, see the bottom line headed 'Real Wage' in the table 2.9. Therefore, it follows that the effect of shocks to the price of imports on output is also larger for higher level of $\tau^m$ given that the effects on both TFP and labor supply of those shocks are increasing in $\tau^m$.

I close this section by emphasizing that the sensitivity of the results to the level of $\tau^m$ does not indicate that the results for the benchmark parameter values should be discredited. Recall that there was an issue about which is the correct level of tariff rates between the weighted and unweighted tariff rates. The results in cases of both tariff rates, i.e., $\tau^m = 0.30$ and $\tau^m = 0.35$, are not different substantially from the benchmark case of $\tau^m = 0.32$: differences are about two percentage point for all of deviations in TFP, output and labor in terms of the percentage ratios of the model generated deviations to the data. The only remaining issue here is what is the correct value of the ad-valorem rent-seekers' markups. I do not have any estimates of this, which is why I set the benchmark value of this parameter to zero in order to let the benchmark case as conservative as possible. If this parameter value is positive, then the theory predicts, as illustrated by cases of $\tau^m = 0.39$ and $\tau^m = 0.46$, that the importance of the shocks to the price of imports in accounting for deviations in TFP, output and labor is higher than is in the benchmark result. That is, the benchmark results are lower bound of the effects of shocks to the price of imports.

Alternative Case of $\bar{p}_t = \widetilde{p}_t$: No Shocks to the Terms of Trade

I carry out the same experiment for the alternative case[39] in which $\bar{p}_t = \widetilde{p}_t$ so that there is no shocks to terms of trade even in the presence of shocks to $\bar{p}_t$, see table 2.10 for the results.

| | | | | | GHH Preference | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | $y$ | $h$ | $k$ | TFP | $c$ | $i$ | $m$ | $m/[k^\theta h^{1-\theta}]$ | $w$ |
| Data | | -7.7 | -6.7 | 5.0 | -5.7 | -9.0 | -17.3 | -22.5 | -20.4 | -5.2 |
| Model | BCHMK | -5.5 | -7.1 | 1.2 | -1.8 | -5.8 | -34.1 | -23.5 | -19.7 | -2.4 |
| | NOTOT | -6.5 | -7.5 | 0.4 | -2.1 | -6.0 | -13.3 | -24.1 | -19.7 | -2.5 |
| Model/Data | BCHMK | 71.3 | 105.2 | 24.8 | 30.9 | 64.0 | 197.4 | 104.3 | 96.4 | 46.1 |
| | NOTOT | 83.7 | 111.9 | 8.4 | 37.4 | 66.8 | 77.1 | 107.0 | 96.4 | 48.9 |

Table 2.10: Deviations of Korea's Key Aggregates In1998: Alternative Case of $\bar{p}_t = \widetilde{p}_t$

The line headed 'Model' provides deviations of aggregates of interest for the GHH preference specification: 'BCHMK' headed line does for the benchmark case of $\widetilde{p}_t = 1$ and 'NOTOT' headed line

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[39]For this experiment, I do not need to change any benchmark parameter values because of the normalization $\bar{p}_{ss} = 1$ taken in the benchmark calibration setting. Note that $\widetilde{p}_t = 1$ in the benchmark case whereas $\widetilde{p}_t = \bar{p}_t$ in this alternative case, which implies that $\bar{p}_{ss} = 1$ in the steady state for both the two cases.

does for the alternative case of $\widetilde{p}_t = \bar{p}_t$. The line headed 'Model/Data' provides the percentage ratios of the model generated deviations relative to those in the data.

The main result is that the effects of shocks to the price of imports are significantly larger in the alternative case of no shocks to terms of trade than for the benchmark case. In this alternative case, shocks to the price of imports and shocks to the price of exports account for about 6.5 percentage point more of deviations of labor and TFP, and about 12 percentage point more of the output deviation relative to the benchmark case. This indicates that increases in the price of exports and decreases in the quantity of exports are also significantly important in accounting for deviations in Korea's output, labor and TFP in 1998.

Korea's net exports increased slightly in 1998 in the data while the model posits that net exports are constant and equal to zero. Note that contractions of the quantity of imports in the model are almost the same as in the data. It follows that Korea's quantity of exports was not likely to be contracted in 1998 in the data as much as in the model. This implies that the effects of increases in the price of exports on TFP are likely to be less than the results in the alternative case. That is, the true effect on the TFP deviation in 1998 of shocks to the price of imports and shocks to the price of exports is likely between the two results of the benchmark case of $\widetilde{p}_t = 1$ and the alternative case of $\widetilde{p}_t = \bar{p}_t$, i.e., it is between -1.8 percentage point and -2.1 percentage point, which corresponds to between 30.9% and 37.4% relative to the data.

## 2.7   Conclusion

The Korean crisis was featured by the fact that both output and TFP were below trend and the price of imports relative to the price of final goods was above trend in 1998, and that those three deviations are significantly larger than the typical deviations in non-crisis period. Motivated by these facts, in this paper, I studied the importance of shocks to the price of imports in accounting for fluctuations in output and TFP in a standard small open economy model, and applied the analysis to the Korean crisis episode. I find that, in the benchmark case, shocks to the price of imports account for about 55% of the output deviation (from trend), one third of the TFP deviation, and three quarters of the labor deviation in the Korean economy in 1998. One of promising features of my results is that a large part, 60%, of the negative deviation of the real wage rate is also accounted for by the import-price shocks.

The main mechanism of the model is twofold. First, shocks to the price of imports induce a reduction of the real wage rate, which leads to contractions of labor and output. Second, TFP deteriorates in response to an increase in the price of imports if and only if the import wedge, which

measures the extent of distortions on the use of imported goods, is positive. One of the key findings is that it is the changes in the price of imports relative to the price of final goods, rather than the changes in the terms of trade, that determines, up to a first order approximation, the changes in measured TFP in a standard small open economy framework.

# REFERENCES

Altman , E. I. and B. J. Karlin (2010), "Defaults and Returns in the High-Yield Bond and Distressed Debt Market: The Year 2009 in Review and Outlook", manuscript, New York University Salomon Center.

Arellano, C., Y. Bai and P. Kehoe (2010), "Financial Markets and Fluctuations in Uncertainty", Research Department Staff Report, Federal Reserve Bank of Minneapolis.

Atkeson, A. and A. Burstein (2009), "Innovation, Firm Dynamics, and International Trade", manuscript, University of California at Los Angeles.

Basu, S. and J. G. Fernald (1997), "Returns to Scale in U.S. Production: Estimates and Implications, Journal of Political Economy, 105(2): 249-83.

Benjamin, D. and F. Meza (2009) , "Total Factor Productivity and Labor Reallocation: The Case of the Korean 1997 Crisis", B.E. Journal of Macroeconomics, 9(1): Article 31.

Bernanke, B. and M. Gertler (1989), "Agency costs, net worth, and business fluctuations", American Economic Review, 79(1): 14-31.

Bloom, N. (2009), "The Impact of Uncertainty Shocks", Econometrica, 77(3): 623-685.

Bloom, N., M. Floetotto and N. Jaimovich (2009), "Really Uncertain Business Cycles", manuscript, Stanford University.

Burstein, A. T., M. Eichenbaum and S. Rebelo (2005), "Large Devaluations and the Real Exchange Rate", Journal of Political Economy, 113(4): 742-784.

Chari, V., P. Kehoe and E. McGrattan (2007), "Business Cycle Accounting", Econometrica, 75(3): 781-836.

Correia, I., J. C. Neves and S. Rebelo (1995), "Business cycles in a small open economy", European Economic Review, 39(6): 1089-1113.

Dubey, P. and J. Geanakoplos (2002), "Competitive Pooling: Rothschild-Stiglitz Reconsidered", Quarterly Journal of Economics, 117(4): 1529-1570.

Export.gov (2009), http://www.export.gov/logistics/eg_main_018142.asp

Gertler, M. and C. S. Lown (1999), "The information in the high-yield bond spread for the business cycle: evidence and some implications", Oxford Review of Economic Policy, 15(3): 132-150.

Gertler, M., S. Gilchrist and F. M. Natalucci (2007), "External Constraints on Monetary Policy and the Financial Accelerator", Journal of Money, Credit and Banking, 39(2-3): 295330.

Giesecke, K., F. A. Longstaff, S. Schaefer and I. Strebulaev (2010), "Corporate Bond Default Risk : A 150-Year Perspective", manuscript, Stanford University.

Gomes, J. and L. Schmid (2009), "Equilibrium Credit Spreads and the Macroeconomy", manuscript, University of Pennsylvania.

Greenwood, J., Z. Hercowitz and G. W. Huffman (1988), "Investment, Capacity Utilization, and the Real Business Cycle", American Economic Review, 78(3): 402-417.

Hamilton, D. T. (2001), "Default and Recovery Rates of Corporate Bond Issuers : 2000", Moody's Investors Service, Global Credit Research, Special Comment.

Kehoe, T. J. and K. J. Ruhl (2008), "Are Shocks to the Terms of Trade Shocks to Productivity?", Review of Economic Dynamics, 11(4): 804-819.

Kiyotaki, N. and J. Moore (1997), "Credit cycles", Journal of Political Economy, 105(2): 211-248.

Khan, A. and J. K. Thomas (2010), "Credit Shocks and Aggregate Fluctuations in an Economy with Production Heterogeneity", manuscript, Ohio State University.

Lee, Y., P. L. Kennedy and H. Brian (2008), "Import Demand System Analysis of the South Korean Wine Market with the Source Differentiated AIDS Model", manuscript, presented at the American Agricultural Economics Association Annual Meeting, Orlando, FL, July 27-29, 2008.

McGrattan, E. (1996), "Solving the stochastic growth model with a finite element method", Journal of Economic Dynamics and Control, 20(1-3): 19-42.

Mendoza, E. G. (1995), "The Terms of Trade, the Real Exchange Rate, and Economic Fluctuations", International Economic Review, 36(1): 101-137.

Mendoza, E. G. and V. G. Yue (2008), "A Solution to the Default Risk-Business Cycle Disconnect", manuscript, University of Maryland.

Moody's (2010), "Corporate Default and Recovery Rates, 1920-2009", Moody's Investors Service, Special Comment.

Neumeyer, P. A. and F. Perri (2005), "Business cycles in emerging economies: the role of interest rates", Journal of Monetary Economics, 52(2): 345-380.

Otsu, K. (2008), "A neoclassical analysis of the Korean crisis", Review of Economic Dynamics, 11(2): 449-471.

Prescott, E. C. (1986), "Theory ahead of business cycle measurement", Federal Reserve Bank of Minneapolis Quarterly Review, Fall: 9-22.

Pyo,H. K., G. Rhee and B. Ha (2006), "Growth Accounting and Producivity Analysis by 33 Industrial Sectors in Korea(1984-2002)", manuscript, Hitotsubashi University.

Tauchen, G. (1986), "Finite state Markov-chain approximations to univariate and vector autoregressions", Economics Letters, 20(2): 177-181.

Uhlig, H. (2007), "Explaining asset prices with external habits and wage rigidities in a DSGE model", American Economic Review, 97(2): 239-43.

Appendix A

APPENDIX FOR CHAPTER 1

In this section, I prove proposition 1.

1. I prove the existence and uniqueness of the solution to the pseudo planner's problem. The first order condition of the pseudo planner's problem is given by:

$$1 - \delta + \alpha [k^S]^{\alpha-1} = [1-v]\left[1 - \delta + \alpha \frac{1}{1-v}[k^R]^{\alpha-1}\right] + v\left[[1-\delta][1-\tau]\right],$$

$$\frac{1}{2}\left[k^S + k^R\right] = \kappa.$$

The first equation is the optimality condition of capital allocation, which says that the expected gross returns to capital should be equalized across firms, and the second equation corresponds to the resource constraint to capital. These two equations simplify to:

$$\alpha[k^S]^{\alpha-1} = [1-v]\alpha \frac{1}{1-v}[k^R]^{\alpha-1} - v\tau[1-\delta],$$

$$k^R = 2\kappa - k^S.$$

I plug $k^R = 2\kappa - k^S$ into the optimality condition of capital allocation, i.e., equalization of the expected gross returns, and derive one equation with one unknown as follows:

$$\alpha[k^S]^{\alpha-1} - \alpha[2\kappa - k^S]^{\alpha-1} = -v\tau[1-\delta]$$

where the LSH of the above equation is strictly decreasing in $k^S$ and the RHS of the above equation is constant in $k^S$.

Note that $\alpha \in (0,1)$, and it follows that the LHS explodes to negative infinity as $k^S \to 2\kappa$ while it explodes to positive infinity as $k^S \to 0$. The LHS is continuous with respect to $k^S$, and thereby existence of the solution $k^S \in (0, 2\kappa)$ to the above equation follows from the intermediate value theorem. And the uniqueness of such a solution immediately follows from the strict monotonicity mentioned earlier. Finally, it is obvious that $k^S > k^R$ for the case of $\tau \in (0,1]$ because the RHS is negative in this case, and $k^S = k^R = \kappa$ for the case of $\tau = 0$.

2. I prove the equivalence between the planner's solution and the equilibrium allocation. Using the decision rules of firms discussed earlier, I have derived, see the lemma 1, capital demanded by the two types of firms as:

$$\alpha[k^S]^{\alpha-1} = r^S \quad and \quad \alpha \frac{1}{1-v}[k^R]^{\alpha-1} = r^R$$

which shows that allocation of capital and interest rates are in a tight relationship.

Recall that the optimality condition of the household's problem is given by:

$$r^S = [1 - v]r^R - v\tau[1 - \delta].$$

Plugging the earlier condtion $\alpha[k^S]^{\alpha-1} = r^S, \alpha \cdot 1/[1-v] \cdot [k^R]^{\alpha-1} = r^R$ and market clearing condition $[1/2][k^S + k^R] = \kappa$ into the above optimality condition of the household's problem, I simplify the characterization of the equilibrium allocation as:

$$\alpha[k^S]^{\alpha-1} = \alpha[2\kappa - k^S]^{\alpha-1} - v\tau[1 - \delta]$$

which is identical to the earlier optimality condition of the pseudo planner's problem.

## A.2 DATA

First, I describe NIPA variables. I basically use the 'Table 1.1.3. Real Gross Domestic Product, Quantity Indexes' of NIPA, which provides quantity indexes for output, consumption and investment where the index for each item is seasonally adjusted and relative to the quarterly average over the year 2005. Then I convert the quantity index to the variables in terms of billions of chained 2005 dollars by using the quarterly average over the year 2005 based on 'Table 1.1.6. Real Gross Domestic Product, Chained Dollars'.

Second, I report default and recovery rates for seven grade bonds provided by Moody's dataset on corporate bonds. Table A.1 present statistics, sample mean and standard deviation, of annual percentage default rates of corporate bonds according to the Moody's grade system.

| Grade | Aaa | Aa | A | Baa | Ba | B | Caa-C |
|-------|-----|------|------|------|------|------|-------|
| Mean  | 0.00 | 0.03 | 0.03 | 0.16 | 1.00 | 4.72 | 20.24 |
| Std.  | 0.00 | 0.12 | 0.08 | 0.28 | 1.18 | 4.34 | 20.78 |

Table A.1: Annual Percentage Default Rates of Corporate Bonds Over the Period 1964-2009

I next present the number-of-issuers shares of corporate bonds by bond grades, see table A.2.

| Aaa | Aa | A | Baa | Ba | B | Caa-C |
|-----|------|------|------|------|------|-------|
| 3.3 | 13.2 | 25.4 | 21.9 | 13.7 | 18.5 | 4.0 |

Table A.2: Percentage Shares of Corporate Bonds For the Period 1997-2000: Measured By Number of Issuers

Lastly, I present the recovery rates of corporate bonds by bond grades, see table A.3.

| Aaa | Aa | A | Baa | Ba | B | Caa-C |
|-------|-------|-------|--------|-------|-------|-------|
| 61.96 | 44.37 | 41.44 | 43.794 | 42.36 | 37.53 | 34.85 |

Table A.3: Sample Mean of Percentage Recovery Rates of Corporate Bonds For the Period 1982-2009: Averages of Recovery Rates By the Year Prior To Defaults

Recovery rate of a corporate bond is measured by the ratio of the post-default price of that corporate bond relative to the price of the corporate bond in some years prior to default. The recovery rates reported in the above table are averages of them measured in 1, 2, 3, 4, and 5 years prior to default. See Moody's (2010) for discussion in more detail.

## A.3    CALIBRATION AND SIMULATION RESULTS

In this section, I discuss how to calibrate parameter values and the procedure to measure aggregate capital stock in the simulation results.

Recovery rate is again defined as the ratio of the price of a defaulted bond relative to the bond price prior to default. I begin by describing the procedure for calculating the recovery rate for risky corporate bonds in the data. I calculate recovery rates for the risky corporate bonds by a weighted average of recovery rates for Baa, Ba and B grade bonds, which results in about 41.3% on average over the period 1982-2009. Taking into consideration the Caa-C grade bonds omitted, of which recovery rates are about 34% on average for the same period, I adjust the above 41.3% recovery rate slightly downward to 40% and take it as my estimate of the recovery rates of the risky corporate bonds.

In turn, I describe how to measure the recovery rate in the model economy consistently with the data. First, in the model, one unit of defaulted risky debt returns $[1-\delta][1-\tau]$ units of undepreciated capital where the price of capital in the final subperiod in terms of the final good is equal to one. Next, I measure the price of a risky debt prior to default, i.e., in the initial subperiod, in terms of the final good in the final subperiod as the inverse of gross returns to the debt in the event of non-default as in the literature: $1/[1-\delta+r^R]$. Therefore, the ratio of the price of a defaulted risky debt relative to the price of the debt prior to default is the ratio of $[1-\delta][1-\tau]$ relative to $1/[1-\delta+r^R]$:

$$\frac{[1-\delta][1-\tau]}{\frac{1}{1-\delta+r^R}} = \text{recovery rate.}$$

Next, I describe the procedure for calculating the volume share of safe bonds which consist of Aaa, Aa and A grade bonds, or the investment-grade excluding Baa grade bonds.

Note that the volume share of the speculative-grade bonds in the U.S. newly-issued, per year, corporate bond market is about 27.5% on average for the period 1993-2009 according to Altman and Karlin (2010). Therefore, the volume share of the investment-grade bonds is about 72.5% on average for the same period because corporate bonds are categorized as either investment-grade or speculative-grade. The Baa grade corporate bonds account for about 34.25%, on average, of the number of outstanding investment-grade bond-issuers for the period 1997-2000 according to Hamilton (2001). I assume that volume shares are proportional to the number-of-issuers shares for the investment-grade bonds and I calculate the volume-share of safe bonds in corporate bond market, which results in about 47.7% as:

$0.725 \times [1 - .3425] = .4767$.

Now, I describe the procedure to discretize the space of $v$. I partition it, the interval $(0,1)$, by equal distance of 0.00025 except that I set the last bin to a wide interval of $[0.03975, 1.00)$ by setting the maximum discrete level of $v$ to 0.04, which is sufficiently large in the following sense: the maximum level of default rates for risky debts at annual frequency is 16% in the calibrated economy where it is 8% in the data.

For the case in which $\tau$ is perfectly positively correlated with $v$, I consider the following specification:

$$\tau(v) = 1 - \tau_0 v^{-\tau_1}, \quad \tau_0 > 0, \tau_1 > 0$$

which posits $\tau$ as a function of $v$. Recall that $1 - \tau$ and $v$ are interpreted as recovery rate and default rate for risky debts, respectively. The data on recovery rates are available for the period 1982-2008 and 2009.

I calibrate $\tau_0$ and $\tau_1$ by targeting the sample mean of recovery rates and curvature of the recovery rate function of the default rate for risky debts, respectively.

I estimate $\tau_1$ by using the NLS method by regressing the historical recovery rates against the historical default rates. I then calibrate $\tau_0$ so that the expected value of $\tau(v)$ based on the already calibrated benchmark shock process for $v$ should be equal to the benchmark value of $\tau = 0.599$. This results in $(\tau_0 = 0.1931, \tau_1 = 0.1288)$.

Lastly, I describe the procedure to construct capital stock by using the perpetual inventory method as in the literature. I denote by $K_t^{PI}$ such a constructed capital stock in period $t$, which is given by:

$$K_{t+1}^{PI} = [1 - \widetilde{\delta}]K_t^{PI} + I_t, \quad K_0^{PI} = K_0.$$

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$\widetilde{\delta}$ is the constant depreciation rate the same as what I used in constructing capital series in the data. I restrict $\widetilde{\delta}$ such that $K_t^{PI}$ is the same with the correctly measured capital stock, $K_t$, in the deterministic steady state in which $v$ is constant equal to the sample mean of default rates for risky debts in the data. This results in $\widetilde{\delta} = .0165$, which implies that capital is depreciated by 6.60% per year on average: 0.60% depreciation is due to losses for occurrences of defaults and the remaining 6.0% depreciation is due to non-defaults, e.g., physical and economical depreciation.

APPENDIX FOR CHAPTER 2

## B.1  MATHEMATICAL APPENDIX

Claim: In the equilibrium, $m_t/h_t$ is strictly decreasing in $(1+\tau^m)\bar{p}_t$ and is independent of $\tau^h, \forall t \in \{0,1\}$.

*Proof.* The equilibrium allocation and prices must satisfy the first order condition w.r.t. $m$ for the final good producer's profit maximization problem, which is given by:

$$F_1(m_t, h_t) = (1+\tau^m)\bar{p}_t$$

where $F_1(\cdot,\cdot)$ is the first order partial derivative of $F(\cdot,\cdot)$ with respect to the first arguement. I rewrite this equation using the property that $F_1(m_t, h_t)$ is homogeneous of degree zero:

$$F_1(m_t/h_t, 1) = (1+\tau^m)\bar{p}_t.$$

Note that $\tau^m$ and $\bar{p}_t$ are exogenously given and that $F_1(m_t/h_t, 1)$ is strictly decreasing in $m_t/h_t$. It follows that $m_t/h_t$, in equilibrium, is strictly decreasing in $(1+\tau^m)\bar{p}_t$ and independent of $\tau^h$. $\quad\square$

First, I present proof of proposition 1.

*Proof.* I prove the result for the case in which $\tau^m = 0$ and $\tilde{p}_0 = 1/A$. And I then prove the result for the case of $\tau^m > 0$ and/or $\tilde{p}_0 > 1/A$.

- In the case of $\tau^m = 0$ and $\tilde{p}_0 = 1/A$, current price GDP is given by $GDP_t = w_t h_t$, which basically follows from the fact that $F(m_t, h_t) = \bar{p}_t m_t + w_t h_t$ in this case. Plugging $F(m_t, h_t) - \bar{p}_t m_t = w_t h_t$ into the formula of current price GDP, i.e., $GDP_t = F(m_t, h_t) - \bar{p}_t m_t$, I obtain: $GDP_t = w_t h_t$.

  Using the above expression for current price GDP, I derive the chain-weighted real GDP and TFP. The chain-weighted real GDP is given by:

  $$RGDP_1 = \frac{GDP_1}{P_1}, \quad P_1 = \left[\frac{w_1 h_1}{w_0 h_1}\right]^{1/2}\left[\frac{w_1 h_0}{w_0 h_0}\right]^{1/2} = \frac{w_1}{w_0}.$$

  Plugging $P_1 = w_1/w_0$ into the earlier equation of $RGDP_1$, I obtain:

  $$RGDP_1 = \frac{w_1 h_1}{w_1/w_0} = w_0 h_1.$$

  Next, I calculate TFP as:

  $$TFP_1 = RGDP_1/h_1 = w_0$$

  from which it follows that $TFP_1$ is independent of $\bar{p}_1$.

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- In the case of $\tau^m > 0$ and $\widetilde{p}_0 \geq 1/A$, recall that chain-weighted real GDP is given by:

$$RGDP_t \equiv \frac{GDP_t}{P_t} = \frac{y_t - \bar{p}_t m_t + [\widetilde{p}_t - 1/A]x_t}{P_t}, \quad \forall t \in \{0,1\}$$

where $P_t \in \{P_1, P_0\}$ is given by:

$$P_1 = \left(\frac{y_1 - \bar{p}_1 m_1 + [\widetilde{p}_1 - 1/A]x_1}{y_1 - \bar{p}_0 m_1 + [\widetilde{p}_0 - 1/A]x_1}\right)^{1/2} \left(\frac{y_0 - \bar{p}_1 m_0 + [\widetilde{p}_1 - 1/A]x_0}{y_0 - \bar{p}_0 m_0 + [\widetilde{p}_0 - 1/A]x_0}\right)^{1/2}, \quad P_0 = 1.$$

It follows that the log of $RGDP_1$ is given by:

$$log(RGDP_1) = \frac{1}{2} log\left(F(m_1,1) - \bar{p}_1 m_1 + [\widetilde{p}_1 - \frac{1}{A}]x_1\right) + \frac{1}{2} log\left(F(m_1,1) - \bar{p}_0 m_1 + [\widetilde{p}_0 - \frac{1}{A}]x_1\right)$$

$$- \frac{1}{2} log\left(F(m_0,1) - \bar{p}_1 m_0 + [\widetilde{p}_1 - \frac{1}{A}]x_0\right) + \frac{1}{2} log\left(F(m_0,1) - \bar{p}_0 m_0 + [\widetilde{p}_0 - \frac{1}{A}]x_0\right)$$

which I approximate around $\bar{p}_0$ and $(s_0, a_0, b_0)$ as:

$$log(RGDP_1) = log(RGDP_0) + \left[\frac{F_1(m_0,1) - \bar{p}_0}{RGDP_0}\right]\left(\left[\frac{dm_1}{d\bar{p}_1}\right]\left[\bar{p}_1 - \bar{p}_0\right]\right)$$

$$+ \left[\frac{\widetilde{p}_0 - \frac{1}{A}}{RGDP_0}\right]\left(\left[\frac{\partial x_1}{\partial s_1}\right]\left[s_1 - s_0\right] + \left[\frac{\partial x_1}{\partial a_1}\right]\left[a_1 - a_0\right] + \left[\frac{\partial x_1}{\partial b_1}\right]\left[b_1 - b_0\right]\right)$$

$$+ o(\bar{p}_1 - \bar{p}_0) + o(s_1 - s_0) + o(a_1 - a_0) + o(b_1 - b_0) \quad where \lim_{z \to 0} \frac{o(z)}{z} = 0.$$

Note that changes in the quantity of export, $x_1$, are decomposed into three parts, which are induced by changes in $(s_1, a_1, b_1)$ because the quantity of export, $x_t$, is a function of $(s_t, a_t, b_t)$ as mentioned earlier.

Given that $TFP_t = RGDP_t, \forall t \in \{0,1\}$ due to $h_t = 1, \forall t \in \{0,1\}$, I finish proving the result by using the equilibrium condition that $F_1(m_0, 1) = [1 + \tau^m]\bar{p}_0$.

$\square$

Second, I present proof of proposition 2.

*Proof.* The equilibrium allocation and prices must satisfy the first order condition w.r.t. $h_t$ for the final good producer's profit maximization problem, which is given by:

$$F_2\left(1, \frac{h_t}{m_t}\right) = (1 + \tau^h)w_t$$

where $F_2(\cdot, \cdot)$ is the first order partial derivative of $F(\cdot, \cdot)$ with respect to the second arguement. It is straightforward to derive the result from the above equation given that $m_t/h_t$ is strictly decreasing in $(1 + \tau^m)\bar{p}_t$ and the assumed property $[\partial^2 F(\cdot, h)/\partial h^2] < 0$. $\square$

From the earlier proof of proposition 2, it immediately follows that $dlog(w_1)/dlog(\bar{p}_1)$ is constant with respect to $\tau^h$:

$$\frac{dlog(w_1)}{dlog(\bar{p}_1)} = \bar{p}_1 \frac{F_{22}(1,h_1/m_1)}{F_2(1,h_1/m_1)} \left[ d\left[\frac{1}{m_1/h_1}\right] \middle/ d\bar{p}_1 \right]$$

where the RHS of the above equation is constant with respect to $\tau^h$ because $m_1/h_1$ is indepedent of $\tau^h$ as discussed earlier. This result states that the percentage change in $w_1$ in response to one percentage increase in $\bar{p}_1$ is independent of $\tau^h$.

Third, I present proof of the analytic results for dynamic model.

*Proof.* Log of TFP for this economy is given by:

$$log(TFP_t) = log(RGDP_t/d_t)$$

$$= \frac{1}{2}log\left(F\left(\frac{m_t}{d_t},1\right) - \bar{p}_t\frac{m_t}{d_t}\right) + \frac{1}{2}log\left(F\left(\frac{m_t}{d_t},1\right) - \bar{p}_{t-1}\frac{m_t}{d_t}\right)$$

$$- \frac{1}{2}log\left(F\left(\frac{m_{t-1}}{d_{t-1}},1\right) - \bar{p}_t\frac{m_{t-1}}{d_{t-1}}\right) + \frac{1}{2}log\left(F\left(\frac{m_{t-1}}{d_{t-1}},1\right) - \bar{p}_{t-1}\frac{m_{t-1}}{d_{t-1}}\right).$$

I derive the log deviation of $TFP_t$ from the steady state and simplify it as:

$$\widehat{TFP_t} \equiv log(TFP_t) - log(TFP^*)$$

$$\approx \left[\frac{m^*}{d^*}\right] \frac{\left[F_1\left(\frac{m^*}{d^*},1\right) - \bar{p}^*\right]\left(\widehat{\frac{m_t}{d_t}}\right) - \bar{p}^*\widehat{\bar{p}_{t-1}}}{F\left(\frac{m^*}{d^*},1\right) - \bar{p}^*\frac{m^*}{d^*}}$$

where $F_1(m,\cdot) \equiv \partial F(m,\cdot)/\partial m$ denotes the first order partial derivative of $F(m,\cdot)$ with respect to the first argument $m$. Using the equilibrium property that $F_1(m^*/d^*,1) = [1+\tau^m]\bar{p}^*$, i.e., the optimality condition for imported goods, I simplify $\widehat{TFP_t}$:

$$\widehat{TFP_t} \approx \bar{p}^*m^* \frac{\left[[1+\tau^m]-1\right]\left[\widehat{m_t}-\widehat{d_t}\right] - \widehat{\bar{p}_{t-1}}}{F(m^*,d^*) - \bar{p}^*m^*}$$

where I used the property that $F(m,d)$ is homogeneous of degree one and the obvious result that $\widehat{[m_t/d_t]} = \widehat{m_t} - \widehat{d_t}$. Rearranging terms, I conclude that:

$$\widehat{TFP_t} \approx \left[\frac{\bar{p}^*m^*}{F(m^*,d^*) - \bar{p}^*m^*}\right]\left[\tau^m\left[\widehat{m_t}-\widehat{d_t}\right] - \widehat{\bar{p}_{t-1}}\right].$$

□

Finally, I present the results for the case in which I measure output, i.e., real GDP, by using the base period price method. Differently from the chain-weighted method, the base

period price method, by construction, does not involve adjusting changes in prices because prices used in measuring real GDP are fixed to those for a reference period. As in Kehoe and Ruhl(2008), I choose $t = 0$ as the base period and focus on the case that $\widetilde{p}_t = 1/A, \forall t \in \{0, 1\}$. In this case, (measured) output is given by:

$$RGDP_t^B = y_t - \overline{p}_0 m_t$$

where $\overline{p}_0$ is the at-the-dock price of imports in the base period. TFP is defined as the output per labor the same as in the earlier analysis and given by:

$$TFP_t^B \equiv RGDP_t^B / h_t$$

which is again the same with $RGDP_t^B$ because $h_t = 1$ in the equilibrium.

In this case, I obtain an odd result that TFP is maximized at the base period. Note that the choice of a base period is arbitrary and thereby the change in $TFP$ from previous period to the current period is arbitrary. I present a formal result for this.

Claim: If $\tau^m = 0$, then $TFP^1 < TFP^0, \forall \overline{p}_1 \neq \overline{p}_0$ where $t = 0$ is the base period.

*Proof.* Let $m_t^*$ denote the optimal choice of the final good firm for the quantity of imported good at period $t \in \{0, 1\}$ and $h_t^*$ similarly for the labor input. In the perspective of the final good firm, the optimality of $m_0^*$ implies:

$$F(m_0^*, h_0^*) - \overline{p}_0 m_0^* - w_0 h_0^* \geq F(m, h_0^*) - \overline{p}_0 m - w_0 h_0^*, \quad \forall m > 0$$

which simplifies to

$$F(m_0^*, h_0^*) - \overline{p}_0 m_0^* \geq F(m, h_0^*) - \overline{p}_0 m, \quad \forall m > 0.$$

Furthermore, the LHS of the above inequality is strictly larger than the RHS for the case in which $m_0^* \neq m$ because $F_{11}(m, \cdot)$ is strictly monotone for all $m > 0$.

It immediately follows that:

$$TFP_0 = F(m_0^*, 1) - \overline{p}_0 m_0^* > F(m_1^*, 1) - \overline{p}_0 m_1^* = TFP_1, \quad \forall \overline{p}_1 \neq \overline{p}_0$$

where I used the equilibrium condition of $h_0^* = 1$ and $m_1^* \neq m_0^*$ for $\overline{p}_1 \neq \overline{p}_0$. $\qquad \square$

Note that, for the case in which the current period, $t = 1$, is the base period, we have exactly opposite sign in comparing $TFP_0$ and $TFP_1$ such that:

$$TFP_0 = F(m_0^*, 1) - \overline{p}_1 m_0^* < F(m_1^*, 1) - \overline{p}_1 m_1^* = TFP_1, \quad \forall \overline{p}_1 \neq \overline{p}_0.$$

Next, I turn to discuss the result for the case in which $\tau^m > 0$ and $\widetilde{p}_t = 1/A, \forall t \in \{0, 1\}$. I focus on the case in which $t = 0$ is the base period for simplicity. In this case, $TFP_1$ becomes of the maximum level in the case of $\overline{p}_1 = \overline{p}_0/[1 + \tau^m]$. This implies that $[TFP_1 - TFP_0]$ depends on the ratio of $\overline{p}_1$ relative to $\overline{p}_0$:

$$\text{If } \tau^m > 0, \text{ then } \exists \delta^* > \delta_* > 0 \ s.t. \ \left[ TFP_1 > TFP_0, \forall \frac{\overline{p}_1}{\overline{p}_0} \in (\delta_*, \delta^*) \right.$$

$$\text{and} \quad TFP_1 \le TFP_0, \forall \frac{\overline{p}_1}{\overline{p}_0} \in (0, \delta_*] \cup [\delta^*, \infty) \Big].$$

*Proof.* It is obvious from the fact that, in equilibrium, $TFP_1 = [F(m_1^*, 1) - \overline{p}_0 m_1^*]$ is maximized at $\overline{p}_1 = \overline{p}_0/[1 + \tau^m]$ given that $[F(m, 1) - \overline{p}_0 m]$ is strictly concave in $m > 0$. $\qquad \square$

## B.2 DATA

I describe data sources of various statistics used in the data analysis.

1. Output, consumption, investment and imports:

   National Accounts provided by the Korean Statistical Information Service. See the table 11, "Expenditures on GDP".

   a) Capital: it is constructed by the *perpetual inventory* method under the assumption that Korea was on the steady state growth path in the year 1960. For various initial levels of the capital stock, constructed capital stock sereies converge very closely to each other within 10 years.

   b) Depreciation rate: Pyo et. al (2006) present their estimate of the depreciation rate series for the Korean economy.

2. Labor:

   see the table "Employed persons by hours worked" provided by the Korean Statistical Information Service. I calculate the weekly total hours worked by the product of "Total employment" and "Average hour by week" in the table.

3. CPI and Import Price Index(: IPI):

   available at the Korean Statistical Information Service, *http://www.kosis.kr/eng/index.htm*

   a) CPI: 'Price' → 'Consumer price index(2005=100)' → 'CPI by Basic Groups'

   b) IPI: 'Price' → 'Export price index & import price index(2005=100)' → 'IPI(Basic Groups)'

## B.3   NUMERICAL METHODS AND SIMULATION RESULTS

First, I describe the procedure to discretize the state space of $\bar{p}$ and to calibrate its transition matrix. I set $N = 37$, and discretize the state space of log deviation of $\bar{p}$. More specifically, I discretize the state space of $\widehat{\bar{p}} \equiv log(\bar{p}) - log(\bar{p}^*) = log(\bar{p})$ by partitioning the interval $[-0.18, 0.18]$: I set an equal distance of .01 between two end points for each partition. I then calibrate the Markov transition matrix by following Tauchen (1986).

Next, I discuss several robustness check results.

In the table B.1, I provide the results for the case in which the transition matrix is different from the bechmark parameter setting. In this case, $\widehat{\bar{p}}$ has a negative serial correlation coefficient, -0.1389 as estimated in the data even if it is insignificant, while $\widehat{\bar{p}}$ is i.i.d. over time, i.e., zero serial correlation, in the benchmark parameter setting. For this purpose, I recalibrate the transition matrix of $\widehat{\bar{p}}$ by targeting the serial correlation coefficient equal to -0.1389 and then I repeat the earlier analysis. I present the results for this case in the table B.1 where '$\check{\rho}$' denotes the serial correlation coefficient of $\widehat{\bar{p}}$.

| | $y$ | $h$ | $k$ | TFP | $c$ | $i$ | $m$ | $m/[k^{\theta}h^{1-\theta}]$ | $w$ |
|---|---|---|---|---|---|---|---|---|---|
| Data | -7.7 | -6.7 | 5.0 | -5.7 | -9.0 | -17.3 | -22.5 | -20.4 | -5.2 |
| Model: Benchmark Preference | | | | | | | | | |
| BCHMK : $\check{\rho} = 0.00$ | -4.2 | -5.1 | 1.5 | -1.8 | -0.8 | -52.2 | -22.2 | -19.7 | -3.1 |
| $\check{\rho} = -0.1389$ | -4.2 | -5.0 | 1.4 | -1.8 | -0.9 | -51.3 | -22.2 | -19.7 | -3.1 |
| Model: GHH Preference | | | | | | | | | |
| BCHMK : $\check{\rho} = 0.00$ | -5.5 | -7.1 | 1.2 | -1.8 | -5.8 | -34.1 | -23.5 | -19.7 | -2.4 |
| $\check{\rho} = -0.1389$ | -5.5 | -7.1 | 1.2 | -1.8 | -5.8 | -33.9 | -23.5 | -19.7 | -2.4 |

Table B.1: Deviations of Key Aggregates In1998: Case of an Alternative Transition Matrix

The line headed 'BCHMK : $\check{\rho} = 0.00$' provides the results for the benchmark case, i.e., $\check{\rho} = 0.00$, and the line headed '$\check{\rho} = -0.1389$' does for the case of $\check{\rho} = -0.1389$ for each of the benchmark preference specification and GHH preference specification. Basically, the results are almost the same between the two cases of $\check{\rho} = 0.00$ and $\check{\rho} = -0.1389$ for both the two preference specifications.

Lastly, I provide the sensitivity analysis results with respect to $\tau^m$ for the benchmark preference specification, see the table B.2.

Table B.2 presents deviations in 1998 of Korea's aggregates in the data and the model generated series for different values of $\tau^m$ for the case of the benchmark preference

|  | Data | Model: Benchmark Preference | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $\tau^m$ | - | 0.0 | 0.23 | 0.30 | 0.32 | 0.35 | 0.39 | 0.46 |
| Output | -7.7 | -1.9 | -3.5 | -4.1 | -4.2 | -4.4 | -4.8 | -5.3 |
| | | (24.8) | (45.6) | (53.1) | (55.1) | (57.0) | (61.7) | (68.4) |
| TFP | -5.7 | 0.0 | -1.2 | -1.6 | -1.8 | -1.9 | -2.2 | -2.6 |
| | | (-0.7) | (20.7) | (28.8) | (30.9) | (33.1) | (38.2) | (45.7) |
| Labor | -6.7 | -3.7 | -4.7 | -5.0 | -5.1 | -5.2 | -5.5 | -5.8 |
| | | (54.5) | (69.5) | (75.0) | (76.4) | (77.9) | (81.3) | (86.2) |
| Real Wage | -5.2 | -2.2 | -2.8 | -3.0 | -3.1 | -3.1 | -3.3 | -3.4 |
| | | (42.7) | (54.0) | (58.1) | (59.2) | (60.2) | (62.7) | (66.3) |

Table B.2: Deviations of Korea's Key Aggregates In1998: Sensitivity Analysis for the Benchmark Preference Specification.

specification. The numbers inside parenthesis are the percentage ratios of the model generated

deviations relative to the data.

# BIOGRAPHICAL SKETCH

Seon Tae Kim was born in Goksung, Republic of Korea, on April 27, 1978. In 1997, he entered the Seoul National University, Seoul, Republic of Korea, majoring in Economics. He temporarily left school for military duty for the period 2000-2003. Upon graduation in 2004, he joined the master program at the School of Economics, Seoul National University in Seoul. In 2005, he entered the W. P. Carey School of Business at Arizona State University to pursue a doctorate in Economics.