Investment During the Korean Financial Crisis: the Role of Foreign Denominated Debt[1]

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Preliminary

Abstract

Without capital market imperfections, the capital structure of a firm, including the size, the maturity and the currency compostion of debts, should not matter for investment decisions. The Asian financial crises provide a good opportunity to test this hypothesis. We approach the problem in two ways: First, we apply a conventional reduced form analysis to a panel data of Korean manufacturing firms, argueing that the devaluation that occurred during the crisis provides a natural experiment in which to assess the effect of balance sheet shocks to investment. Second, we specify a structural dynamic programming problem of a firm with foreign debts and financial constraints. We solve the dynamic programming problem using a nonlinear solution method and employ indirect inference to identify structural parameters.

Both reduced-form evidence and structural parameter estimates imply an important role for finance in investment at the firm level. Our results also imply that foreign-denominated debt was not a major factor in depressing aggregate investment spending during the Korean financial crisis however. Furthermore, our results suggest that the devaluation on net improved the overall balance sheet position of firms and likely stimulated investment through the finance channel. These finding undermine support for the policy of maintaining fixed exchange rates during financial crises.

[1] **We thank seminar participants at the Board of Governors of the Federal Reserve along with participants at the BU macro lunch workshop**

1 Introduction

Without capital market imperfections, the capital structure of a firm, including the size, the maturity, and the currency composition of debts, should not matter for investment decisions. The Asian financial crises provide a good opportunity to test this hypothesis, i.e., the irrelevance of finance in investment decisions. The devaluations that occurred during these crises abruptly and massively altered the debt burdens of firms with foreign-denominated debts. Since the devaluations were exogenous events, at least from the perspectives of individual firms, the episodes make it easier to identify a distinct role for financial factors in investment decisions during the crises period.

In this paper, we test for the existence of a finance channel in the propagation of the Korean financial crisis. In addition, we provide a quantitative assessment of the effect of foreign-denominated debt on investment. This analysis provides a useful perspective on the likely benefits to fixed versus flexible exchange rates during a financial crisis. A primary argument for maintaining a fixed exchange rate is that a devaluation may adversely affect balance sheets owing to the presence of foreign denominated debt.[2] Our results imply that although foreign-denominated debt plays an important role in explaining heterogenous outcomes across firms during the crisis period, the effect of this mechanism on aggregate investment spending is likely small.

Theoretically, a devaluation can affect investment through two distinct channels: First, the devaluation increases competitiveness and raises the marginal profitability of capital of firms that export. This increase in the marginal profitability of capital stimulates investment. The benefits to production owing to this competitive devaluation are larger to the extent that a firm's production is more oriented toward the

[2]Frankel (2003) provides a recent discussion of the relative benefits of fixed versus flexible exchange rates. Aghion et al (2001) and Cepedes et al (2002) consider these issues in the context of a small open economy framework with dollar denominated debt. Gertler et al (2003) also consider the role of foreign denominated debt in the context of a GE framework explicitly calibrated to the Korean experience.

export market and less dependent on imported inputs.[3] Because these benefits of the devaluation directly affect investment opportunities in the absence of financial frictions, we consider this to be the competitiveness or fundamentals channel of the devaluation. Second, the devaluation influences the debt burden of firms – the value of debt relative to a firm's ability to repay the debt. In the presence of financial market imperfections, an increase in the debt burden causes a deterioration of the balance sheet and increases the cost of external finance. As external finance becomes more costly, firms reduce their investment. We consider this effect working through the balance sheet the finance channel of the devaluation.[4]

The effect of the devaluation on investment through the finance channel is theoretically ambiguous and depends on the extent to which a firm's debt is denominated in foreign currency and the extent to which a firm's earnings are export dependent. The devaluation raises the value of existing debt in direct proportion to the share of debt that is foreign currency denominated. Thus, foreign currency denominated debt will unambigously depress investment in the presence of financial market imperfections. For a firm that exports however, the devaluation improves its ability to pay back its debt. On net, we expect the investment spending of low export firms with high levels of foreign debt to be the most adversely affected by the devaluation.

Understanding the effect of foreign-denominated debt for investment spending requires firm-level data. In this paper, we use a newly available panel data set of Korean manufacturing firms to assess the strength of the finance channel discussed above. This data set is unique in a number of ways. It provides detailed firm-level data on non-financial variables such as sales, profits, investment and capital; it provides financial data such as debt and equity; it is comprehensive, covering all publicly-traded as well as many non-publicly traded Korean firms over the period

[3]If the production of capital uses foreign investment goods, the devaluation may also affect investment by changing the price index of investment goods. As we show below, this appears not to have been the case in the Korean episode.

[4]Another potentially important mechanism is the uncertainty which a large devaluation creates. Among others, Goldberg(1993). We do not consider this effect in this paper.

1993-2002 and thus accounts for a large fraction of overall Korean business fixed investment spending; most importantly, the data set provides detailed information on the foreign-exchange-rate exposure of the firm, both in terms of the amount of exports and in terms of the amount of foreign-denominated debt. With this data, we can effectively measure both the fundamental effect of the devaluation and the finance effect owing to the rise in the foreign debt burden on investment spending.

We begin with a reduced-form regression analysis. We view the exchange rate crisis and ensuing devaluation as a natural experiment with which we can measure the combined effect of the exchange rate devaluation on firm-level investment spending. A key point to this identification strategy is that firms should respond differently to the devaluation depending on both their level of foreign sales and their amount of foreign debt. We expect that firms with high levels of foreign sales to increase their investment relative to other firms, while firms with high levels of foreign debt will decrease their investment relative to other firms, following the devaluation. By controlling for foreign exports directly, we can cleanly identify the effect of foreign denominated debt on investment spending.

While such an analysis is informative, it does not provide a complete quantitative assessment. In the second part of the paper, we adopt a structural approach. We specify a dynamic optimization problem of a firm which produces for both domestic and foreign markets and has a composition of domestic and foreign denominated debts under a set of financial and nonfinancial constraints. We use this dynamic program to estimate the structural relationship among investment, profitability and financial conditions.

Our dynamic programming problem is flexible enough to allow the firm to choose an optimal capital structure under a financial regime which is characterized by an agency cost associated with external finance and a nonnegative dividend constraint. To solve the model, we adopt a version of Chebyshev projection methods which enable us to calculate explicitly the shadow prices associated with the occasionally binding inequality constraints (Christiano and Fisher(2000)), one for the nonnegativity constraint for dividend and the other for the irreversibility constraint for investment. To our knowledge, this is the first time that Lagrangian multipliers for the two inequality constraints are parametrically calculated together.

Structural identification proceeds in two stages. In the first stage, we derive a parametric form of the profit function and apply conventional panel-data econometric techniques to identify relevant structural parameters. In the second stage, using the estimated parameters from the profit function, we solve the dynamic program numerically and generate a complete set of panel data using our parametric policy functions. We calculate moments which summarize the actual panel data and the simulated panel data and use indirect inference to estimate the structural parameters of the model. We then use the estimated structural parameters, we evaluate the role that foreign denominated debt plays in propagating the financial crisis through investment spending.

When identifying the role of foreign debt on investment, we explicitly recognize that firms who issue foreign-denominated debt are non-representative. In particular, such firms often issue foreign debt to hedge against foreign earnings and are thus more likely to be exporters than other firms. Such firms may also be of above average quality in the credit market. To allow for such possibilities, our structural estimation explicitly accounts for firm-level heterogeneity observed in the data. In particular, our estimation strategy conditions on the underlying distribution of export composition, profitability and access to domestic and foreign markets reflected in the microeconomic data.

Several recent papers consider the role of foreign-denominated debt on firm-level investment during currency devaluations. Using a sample of Latin American firms over the 1990's, Bleakley and Cowan (2002) find that the net effect of the devaluation was likely positive for firms with high foreign denominated debt. Because these authors do not have separate information on the export status of firms, they are unable to separate balance sheet effects from competitiveness effects however. Aguiar (2004) examines the investment behavior of Mexican firms during the 1994 pesos devaluation, and finds a negative effect of foreign denominated debt that is distinct from the export mechanism. Both of these papers are reduced-form and thus make no attempt to formally quantify the effect that foreign-denominated debt exerts on the cost of finance. Pratap and Urrutia (2003). consider a stuctural model of investment with financial frictions which is calibrated to the Mexican firm-level data. This paper emphasizes the role that the devaluation played on the balance sheet during the Mexican currency crisis but makes no attempt at formal estimation however.

Our paper is also related to the extensive literature on firm level investment and capital market imperfections. [5]. Much of this literature focusses on the role of cash flow for investment spending. Although this literature finds strong evidence in favor of capital market imperfections (e.g. Fazzari, Peterson and Hubbard (1988), Kashyap, Hoshi and Scharfstein (1991) ,Schaller (1993)), these findings have been criticized for not adequately controlling for the possibility that cash flow is simply a proxy for investment opportunties or misinterpreting the relationship between investment, Q and cash flow (Kaplan and Zingales, Gomes (1999) Abel and Eberly (2002), Cooper and Ejarque (2001)).

A key question in this literature is how to identify the effect of balance sheet shocks that are independent of investment opportunties. Early work foccused on imposing structural relationships within either an Euler equation approach (Whited (1991), Bond and Meghir (1994), Hubbard et al (1995) or a Q-theoretic framework (Gilchrist and Himmelberg (1995, 1998). Another strand of the literature adopts a natural experiment approach (Blanchard et al (1994), Lamont (1997) by examining the effect of shocks to cash flow that are arguably exogenous to the firm or firm segment's investment opportunities. More recent papers achieve identification by solving and estimating the full dynamic program of a firm under capital market

[5] ubbard (199?) and Stein (2003) provide recent surveys of this literature

imperfections (Cooper and Ejarque (2003), Pratap and Rendon (2003), Hennessy and Whited (2004)). As Cooper and Ejarque (2001) document however, structural estimation alone may not be enough to rule out the alternative that investment-cash flow correlations are driven by fundamentals rather than finance.

Our contribution to this literature is three fold. First, we rely on the same type of exogenous variation exploited in the natural experiments literature to identify the effect of balance sheet shocks to investment for both the reduced-form and structural estimation. Although the reduced form estimates provide valid tests of the importance of finance for investment, they do not provide a structural interpretation of the results, and hence cannot convincingly be used for policy analysis. In addition, structural estimation without exogenous variation to identify the financial mechanism is unlikely to be robust to alternative formulations of profits, adjustment costs and investment opportunities that do not rely on financial frictions. Relatedly, both Pratap and Urrutia (2003) and Hennessy and Whited (2004) assume that, in the absence of capital market imperfections, capital accumulation is frictionless. Because capital market imperfections limit the amount of investment, these estimation procedures may not be robust to the alternative hypothesis that capital accumulation responds to profits in a data-consistent manner owing to sluggish adjustment on the real side. Our second contribution is thus to model the investment decision of the firm subject to both financial frictions and real-side frictions to the accumulation of capital. In particular, we allow for both capital adjustment costs and investment irreversibilities when modeling firm-level investment. Finally, unlike the structural estimation procedures describe above, our estimation procedure explicitly controls for microeconomic heterogeneity in access to credit markets (both domestic and foreign) and potential to export. We expect that our estimation procedure will prove useful in a variety of other contexts in which researchers conduct structural estimation at the firm-level.

The organization of the remainder of the paper is as follows. Section 2 provides summary measures of our data. Section 3 explains our reduced form strategy and reports the estimation results. Section 4 formulates the decision problem of the firm and characterizes the efficiency conditions. Section 5 estimates the theoretical profit function, simulates the model and estimates the structural parameters using indirect method. Section 5 also derives the impulse reponse functions of heterogenous firms and evaluates the role that foreign-denominated debt played in the propagation of the crisis.

2 Overview of Korean Financial Crisis

In this section, we provide an overview of the investment behavior of Korean firms during the financial crisis of 1997-1998. Figure 1 shows the impact of the crisis on our sample of manufacturing firms.[6] We plot the average ratios of investment, sales and debt relative to total assets. For comparision purposes, we also plots the annual average real exchange rate. All variables are in logs and are normalized relative to their pre-crisis (1996) values.

The results in Figure 1 are consistent with the macroeconomic effects described elsewhere (Gertler, Gilchrist and Natalucci (2003), Kruger and Yoo (2001)). Between the onset of the crisis in 1996 and the trough of economic activity that occurred sometime during 1998, sales fell 20% while investment fell nearly 100%.

Figure 1 also plots the debt-to-capital ratio for our sample of firms. Debt is valued in local currency and includes both the local-currency denominated debt and the foreign-currency denominated debt. The 70% depreciation of the currency implies a sharp rise in the value of foreign-denominated debt. As a result, the debt-to-capital ratio shows a sharp increase at the onset of the crisis, reflecting the stress on balance sheets caused by the currency depreciation. Over time, debt falls relative to assets, returning to a level somewhat below its pre-crisis value.

To the extent that the deleterious effects of the financial crisis were transmitted

[6] We defer our data description until the next section.

Figure 1: Investment, sales and debt during financial crisis.

through the exchange rate, it is worth investigating how the investment rate differed in response based on the degree of a firm's foreign exchange rate exposure. As discussed in the introduction, the exchange-rate depreciation was a positive shock to fundamentals for firms that export. It was a negative shock to the balance sheet for firms with foreign denominated debt. To investigate this heterogenous response, we divide our sample into high versus low export oriented firms, and high versus low foreign debt firms. To classify firms according to export status, we compute the pre-crisis average export to total sales ratio for each firm in our sample. We then categorize firms as high export firms if this ratio is above the pre-crisis median value. Similarly, we classify firms as high foreign debt firms based on the pre-crisis average foreign denominated debt to total debt ratio, and again classify firms as high foreign debt firms if they are above this median value. The average investment rates for high versus low foreign debt and high versus low export firms are plotted in the upper two

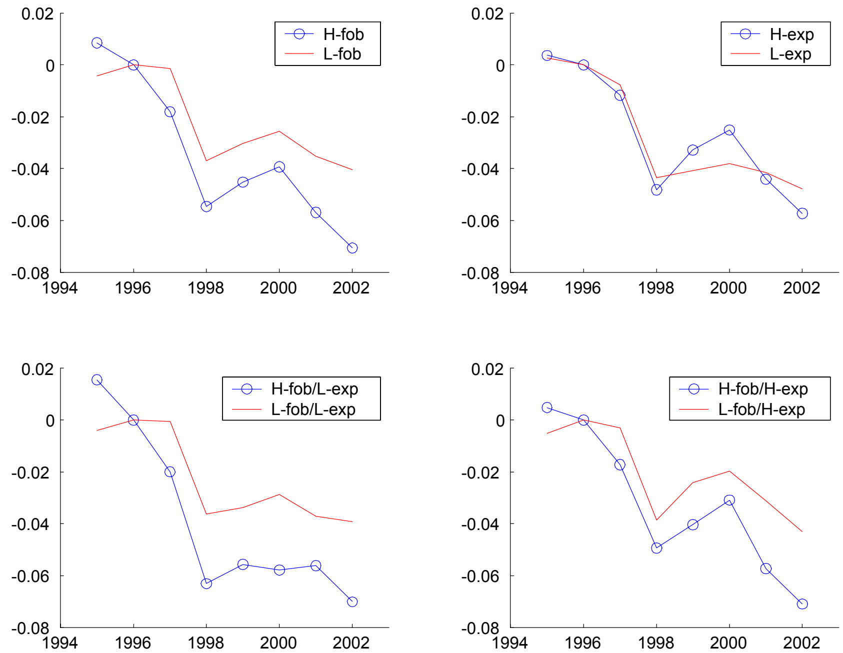

Figure 2: Investment rates.

panels of figure 2. We also consider the four way interaction obtained by classifying firms according to the median categorization of both high versus low exports and high versus low foreign debt. These four way classifications are plotted in the lower two panels of Figure 2.

Figure 2 makes clear that, following the financial crisis, firms with high foreign debt have low rates of investment relative to firms with low foreign debt. We find little difference in the investment rate of high export versus low export firms. As we discuss further below, there is a positive correlation between foreign debt exposure and foreign sales exposure. Thus, high export firms tend to have higher foreign debt ratios which offset the beneficial effects of the exchange rate depreciation.

By considering low versus high export firms separately, the lower panels of Figure 2 help isolate the role of foreign debt on investment. For both high export and low export firms, foreign debt appears to depress the investment rate. Holding fixed the degree of exchange rate exposure through exports, we can see that the effect of foreign debt on investment is most severe for firms with the greatest mismatch between foreign sales and foreign debt exposures. Thus, the investment spending of the firms with high foreign debt but little export revenue to offset the negative consequences of the devaluation appear to be the most vulnerable during the financial crisis.

3 Regression Analysis.

We now formally assess the role of foreign denominated debt on investment spending using a panel data regression framework. As highlighted in the introduction, we view our data as providing a natural experiment in which to assess the effect of adverse shocks to the balance sheet on investment spending. In particular, although the exchange rate depreciation was common to all firms, the effect of the depreciation on the balance sheet varies across firms depending on their degree of exposure, as measured by the amount of debt that is denominated in foreign currencies. We begin by describing the empirical methodology. We then provide a description of our data set along with some descriptive statistics, after which we discuss the estimation results.

3.1 An Empirical Investment Equation

Firms in our sample differ in their foreign exchange rate exposure, both in terms of fundamentals, and in terms of the balance sheet. It is this cross-sectional heterogeneity that provides us with our identification scheme. In particular, because we can measure both, we are able to directly control for the effect of the exchange rate on fundamentals independently of its effect on the balance sheet.

To measure fundamentals, we rely on the firm's sales to capital ratio. This is consistent with the assumption that firms face monopolistic competition and that the production function is Cobb-Douglas in factor inputs. Under these assumptions the sales to capital ratio summarizes the marginal profitability of capital. If domestic and foreign sales are perfectly substitutable from the perspective of profit maximizing behavior, the overall sales to capital ratio serves as a sufficient statistic for the marginal profitability of capital. In the event that producers have market power owing to monopolistic competition, firms may set different markups in the domestic market relative to the foreign market. In this case, as we show in the appendix, the marginal profitability of capital can be decomposed into a weighted average of the domestic sales to capital ratio and the exports to capital ratio, where the relative weights depend on the degree of market power in each market. In our regression analysis, we include both of these variables separately. This effectively allows the response of investment to fundamentals to differ based on the source of profitabiltiy (foreign versus domestic).

To measure the effect of the exchange rate through the balance sheet, we exploit the fact that we observe foreign denominated debt separately from domestically denominated debt. We measure the overall balance sheet, as well as its composition using ex-ante information, We are then able to isolate the effect of the exchange rate working through the balance sheet, holding the balance sheet composition as well as the existing debt outstanding fixed.

Specifically, let b_{jt} denote the total debt of the firm at the beginning of the period, denominated in local currency terms. Let a_{jt} denote a measure of the beginning-of-period value of total assets (again denominated in local currency terms). The ratio of debt to assets (leverage) b_{jt}/a_{jt} provides a measure of the balance sheet of the firm. When leverage is high, the balance sheet is weak, which, in the presence of financial frictions would tend to depress investment.[7]

[7]Formal justification for using the debt to asset ratio as a measure of balance sheet strength can be obtained from standard model of investment with agency costs owing to costly state verification (Townsend(1979), Gale and Hellwig (199?)). Although such models are typically one period models, in more a more general framework that allows for multi-period contracting, we would also obtain the result that a measure of the value of capital in place such as total assets is a proper normalizing variable since total asset of the firm can be considered as a financial capacity, "the maximum

When measuring the effect of the exchange rate on the balance sheet, it is important to separate endogenous variation which may occur as firms re-optimize their debt composition in response to exchange rate movements, versus the exogenous variation that occurs owing purely to exchange rate movement, holding debt composition fixed. Indeed, in the model specified below, firms face an arbitrage condition which implies an endogenous rebalancing in order to maintain constant portfolio shares over time. To be consistent with our model, we measure debt composition as the pre-crisis(1994~1996) sample mean of each firm's foreign debt ratio, i.e.,

$$\hat{\omega}_j = 1/T_j^{pc} \sum \left(b_{j,t}^f / b_{j,t} \right)$$

where $b_{j,t}^f$ is the real foreign debt in domestic currency units and T_j^{pc} is the number of nonmissing observations of firm j, during the pre-crisis period. An alternative would be to use the total sample mean rather the pre-crisis sample mean. We opt to use the latter to avoid the endogeneity issues suggested above. Regression results are not sensitive to this choice however.

Given our measure of the foreign debt exposure of firm j, ω_j, the effect of an exchange rate movement on the value of debt can be measured as

$$\Omega_{jt} = 1 - \omega_j + \omega_j \left(e_t / e_{t-1} \right)$$

where e_t denotes the real exchange rate. If the real exchange rate is constant, Ω_{jt} is equal to unity for all firms. In periods when the exchange rate depreciates, e_t/e_{t-1} rises and Ω_{jt} rises with the depreciation in proportion to the firm's foreign debt share. In domestic currency terms, the value of a firm's outstanding debt, $\Omega_{jt} b_{jt}$, will

overhang of past debt they may feasibly carry" (Gertler(1992)). Also see Rogerson and Hopenhayn (??). **Footnote needs work.**

increase. Our measure of the balance sheet is then:

$$AC_{j,t} \equiv \Omega_{j,t} \left(b_{j,t}/a_{j,t} \right) \tag{1}$$

Movements in the balance sheet occur for one of two reasons, a rise in the overall level of indebtedness $b_{j,t}/a_{j,t}$ or an increase in the value of debt outstanding through changes in the exchange rate variable Ω_{jt}. Because $b_{j,t}/a_{j,t}$ is measured at the beginning of the period, within-period movements in $AC_{j,t}$ are entirely attributable to movements in the exchange rate. Because the foreign-debt ratio is firm specific, such variation has firm-specific effects, causing a greater deterioration of the balance sheet for firms who rely relatively more on foreign debt sources. Because this variation is exogenous to the firm, we effectively have a natural experiment environment in which to study the effects of exogenous shocks to the firm's balance sheet on investment.

In addition to our measures of the balance sheet and fundamentals, we control for firm and time fixed effects in our regression analysis. In addition to exchange rate effects working through either fundamentals or the balance sheet, exchange rates may influence firm-level investment through their general equilibrium effects working through output or prices. Time dummies capture this common investment component. Firm-level heterogeneity may occur if the mean level of investment differs systematically by firm, either because the mean level of fundamentals differ, or the cost of investing differs across firms in some systematic way. For instance, if firms who access foreign debt markets are on average higher quality, we would expect them to have a lower average cost of capital and a higher capital intensity. By allowing for firm fixed effects, we control for such firm-level heterogeneity when assessing the effect of exchange rates on investment.

Finally, we also allow for serial correlation in the investment process by including lagged investment on the right hand side of the regression. The lagged dependent variable on the right hand side can be justified if there is a distinction between measured and actual investment because of timing distinctions between reported and actual expenditures. Alternatively, serial correlation in unobservable investment cost shocks would also justify the use of a lagged dependent variable. In the empirical section, we consider regressions with and without the lagged dependent variable. Although it is significant, the regressions with and without the lagged dependent variable provide similar implications regarding the role of fundamentals and the balance sheet variable for investment.

Our empirical investment equation is then

$$(i/k)_{j,t} = c + c_j + \rho(i/k)_{j,t-1} + \boldsymbol{\alpha}'(\mathbf{s}/\mathbf{k})_{j,t} + \beta(\hat{\Omega}b/a)_{j,t} + \delta_t + \epsilon_{j,t} \tag{2}$$

where $(i/k)_{j,t}$ is investment normalized by the tangible capital stock, $(\mathbf{s}/\mathbf{k})_{j,t}$ is a vector of domestic and foreign sales normalized by the tangible capital stock, $[(s^d/k)_{jt}$ $(s^f/k)_{jt}]$, $\boldsymbol{\alpha}$ =$[\alpha^d \ \alpha^f]$ is a vector of coefficients measuring the effect of fundamentals on investment, δ_t is a time dummy and c_j is the firm-specific fixed-effect.

As a robustness check, we also estimate another version of the empirical investment equation where we separate out the effects of the devaluation given the average foreign debt ratio and the overall beginning of period leverage ratio:

$$(i/k)_{j,t} = c + c_j + \rho(i/k)_{j,t-1} + \boldsymbol{\alpha}'(\mathbf{s}/\mathbf{k})_{j,t} + \beta\hat{\omega}_j(e_t/e_{t-1}) + \gamma(b/a)_{j,t} + \delta_t + \epsilon_{j,t} \tag{3}$$

In this regression, we effectively isolate the heterogenous effect that the exchange rate has on firm-level investment owing to differences in firms' foreign debt exposure ω_j.

In the absence of capital market imperfections, standard adjustment cost theory predicts that $\beta = \gamma = 0$ under the assumption that $\mathbf{s}/\mathbf{k}_{jt}$ properly measures fundamentals. In general, current sales to capital ratios are not necessarily a sufficient statistic for fundamentals, since it is the entire present discounted value of future profit streams that determine profit streams. If $\mathbf{s}/\mathbf{k}_{jt}$ follows an AR1 process, then the present value $\mathbf{s}/\mathbf{k}_{jt}$ is proportional to the current value $\mathbf{s}/\mathbf{k}_{jt}$ and we properly measure fundamentals. If $\mathbf{s}/\mathbf{k}_{jt}$ follows a richer stochastic process, then we have introduced measurement error into the equation however.

A frequent concern in the investment literature is that balance sheet measures may enter investment equations significantly because the regression does not properly measure fundamentals. This is often the case with regressions that measure fundamentals using Tobin's Q and measure the balance sheet using profitabiltiy or cash flow. Tobin's Q is known to have weak explanatory power for investment. The positive cash flow effect then at least in part captures some component of fundamentals. In this situation, cash flow may be spuriously correlated with investment because it provides information about fundamentals.

In our framework, it is unlikely that the balance sheet term $\hat{\omega}_j(e_t/e_{t-1})$ is spuriously correlated with fundamentals however, after controlling for the firm fixed-effect. Firms in our data set that hold greater levels of foreign debt have, on average, higher ratios of exports to total sales. In effect, these firms are partially hedging the exchange rate risk associated with foreign earnings by issueing foreign debt. In the absence of financial frictions, an exchange rate depreciation is therefore more likely to be a positive shock to fundamentals for high foreign debt firms than low foreign-debt firms. This implies that, in the event that we measure fundamentals with error, we are likely to observe an upward bias on the coefficients β and γ. Indeed, with no financial frictions, one would expect these coefficients to be positive rather than negative if fundamentals are measured with error. Hence, our estimation procedure is biased against finding a negative effect of the balance sheet working through the exchange rate mechanism on investment.[8]

[8] To further investigate the role of fundamamentals in our investment specification, we also considered a regression approach in the spirit of Gilchrist and Himmelberg (1998) where fundamentals are measured as the present discounted value of the future stream of marginal profits $\mathbf{s}/\mathbf{k}_{jt}$. This present discouted value is computed using a panel-data VAR framework analagous to Gilchrist and Himmelberg (1998). The results from these regressions provide very similar implications to the basic regression described above regarding the influence of the exchange rate working through the foreign denominated debt. Although we did not include these results in the current paper, they are available upon request.

3.2 Econometric Methodology

To estimate (2) and (3), we consider two estimators: an IV version of a fixed effect estimator and a panel-data GMM estimator. Our use of instrumental variables is to control for the endogeneity that may exist between current sales and current investment. As we have argued above, the exchange rate movements interacted with the firm's foreign debt exposure is exogenous. If time to build for investment is less than one year however, we may reasonably expect current sales and current investment to suffer from simultaneity bias. By adopting an IV estimator with lagged values of sales as instruments we control for this possibility.

The fixed effect IV estimator is a standard 2SLS estimator that controls for fixed effects by removing group means. We adopt this estimator in part for its simplicity. It controls for firm-level heterogeneity and provides a reasonable summary of the data without applying complicated instruments sets or weighting matrices. This estimator thus has the virtue that it is easy to apply when estimating the structural model through indirect inference below. As we discuss in more detail below, our structural estimation chooses structural parameter values such that model regressions match the coefficients obtained from this estimator using indirect inference.

The fixed effect IV estimator has some limitations for pure regression analysis however. In particular, in the presence of lagged dependent variables, such estimators are inconsistent. We therefore also consider the more general GMM panel-data estimation procedure proposed by Arellano and Bond (1991). This estimator uses first differences to eliminate the fixed effect. This introduces serial correlation in the error term which can be controlled for through the appropriate instrument choice in our panel data framework.

After taking first differences to remove fixed effects, equation 2 may be expressed as

$$\begin{aligned}\Delta(i/k)_{j,t} &= \rho\Delta(i/k)_{j,t-1} + \boldsymbol{\alpha}'\Delta(\mathbf{s}/\mathbf{k})_{j,t} + \beta\Delta(\hat{\Omega}b/a)_{j,t} + \delta_t + v_{j,t} \qquad (4)\\ v_{j,t} &= \epsilon_{j,t} - \epsilon_{j,t-1}\end{aligned}$$

Since the sales variables are treated as endogenous and the lagged dependent variable, $\Delta(i/k)_{j,t-1}$ is correlated with the error term, $v_{j,t} = \epsilon_{j,t} - \epsilon_{j,t-1}$, by construction, $(i/k)_{j,t-s}$ and $(\mathbf{s}/\mathbf{k})_{j,t-s}$ are valid instruments for $s \geq 2$. The balance-sheet variable is treated as a predetermined variable and therefore, $(\hat{\Omega}b/a)_{j,t-s}$ are valid instruments for $s \geq 1$. We use the two-step version of Arellano and Bond(1991) GMM estimator where the residuals of the first-step estimation are used to construct the optimal weighting matrix for the second-step estimator. We also provide the results of overidentifying restriction tests in the tables. For the fixed-effect IV estimator, we use $(\mathbf{s}/\mathbf{k})_{j,t-s}$ for $s \geq 1$ and $(\hat{\Omega}b/a)_{j,t-s}$ for $s \geq 1$ as instruments. When estimating equation 3 which considers the separate effects of $\hat{\Omega}_{jt}$ and $b/a_{j,t-s}$, we use lags of $\hat{\Omega}_{j,t-s}$ and $b/a_{j,t-s}$ as separate instruments in both the IV fixed-effect estimator and the GMM estimator.

3.3 Data

Our data set is a unique, proprietary data set of Korean manufacturing firms. The data set is provided by KIS (Korea Information System). It provides income-statement and balance sheet data for all listed manufacturing companies over the period 1993 to 2002. The data is comparable to Compustat, the standard data set used for U.S. firm-level investment studies, in terms of the information provided. Unlike Compustat however, our data set covers both publicly traded and non-publicly traded firms. Unlike Compustat data, it also provides distinct information on the value of foreign versus domestically denominated debt, and foreign versus domestic sales.

Table 1 provides summary statistics, constructed for the full sample, and before and after the onset of the crisis. The mean rate of investment fell from 23 percent

Table 1: Summary Statistics

	Full Sample Mean	Full Sample Std. Dev.	Pre-Crisis Mean	Post-Crisis Mean
$(i/k)_{j,t}$	0.169	0.244	0.230	0.136
$(s/k)_{j,t}$	3.756	3.195	3.939	3.657
$(\pi/k)_{j,t}$	0.764	0.866	0.785	0.753
$(b/a)_{j,t}$	0.371	0.211	0.392	0.363
$(b/k)_{j,t}$	1.459	1.385	1.702	1.387
$\left(s^f/s\right)_{j,t}$	0.284	0.279	0.251	0.307
$\left(b^f/b\right)_{j,t}$	0.140	0.189	0.140	0.140
$corr\left(s^e/s, b^e/b\right)$	0.1669		0.251	0.120

Table 2: Quantile Distribution of Pre-Crisis Firm-Level Means

	0%	25%	50%	75%	100%	mean
$(b/a)_j$	0.000	0.261	0.399	0.504	1.632	0.391
$\left(s^f/s\right)_j$	0.000	0.034	0.158	0.419	0.983	0.255
$\left(b^f/b\right)_j$	0.000	0.024	0.081	0.185	1.000	0.141

pre-crisis to 13.6 percent post-crisis. Exports as a fraction of total sales rose form 25 percent pre-crisis to 30.7 percent post-crisis while overall profitability and overall sales fell slightly during the post-crisis period. These numbers are consistent with the figures displayed above. The last row of table 1 provides information on the correlation between foreign exchange earnings and foreign-denominated debt. The correlation is 0.17 over the entire sample period, and substantially higher than that, pre-crisis (0.25). Thus, firms who access foreign debt markets are more likely to be export-oriented firms.

Table 2 provides information on the quantile distribution of firms's pre-crisis averages of export-sales ratios, leverage-ratios and foreign-debt ratios. This information is explicitly used to calculate a distribution of firm types that may be embedded in our structural estimation described below. The median firm in our sample has export/sales ratio of 15 percent while nearly 25% of the firms have almost no exports. Likewise, the median firm in our sample has a foreign-debt to total debt ratio of eight percent. Importantly, there is considerable variation in the foreign-debt ratio, the key variable measuring the heterogeneity in the balance sheet effect of the devaluation across firms.

3.4 Estimation Results

We now turn to our estimation results. We begin with a simple pooled OLS regression of the investment rate on fundamentals – the domestic sales- and foreign sales-to-capital ratios, and our measure of the balance sheet $(\hat{\Omega} b/a)_{j,t}$. These results are reported in table 3. The first column of table 3 reports results for the full sample whereas the second column restricts the data to a balanced panel.[9] All variables are highly statistically significant. For both data sets, the balance sheet has a strong neg-

[9] In our structural estimation reported in the next section, for computational reasons, we confine our attention to the balanced panel. It is therefore important to establish the comparability between the two data sets.

Table 3: Investment Equation: Pooled OLS

	Unbalanced Panel $(i/k)_{j,t}$	Balanced Panel $(i/k)_{j,t}$
$(s^d/k)_{j,t}$	0.015	0.014
	(0.000)	(0.000)
$(s^e/k)_{j,t}$	0.015	0.017
	(0.000)	(0.000)
$(\hat{\Omega}b/a)_{j,t}$	-0.134	-0.109
	(0.000)	(0.000)
No of Obs.	3094	1620
F	40.00	21.62
Prob>F	0.000	0.000

ative effect on investment, consistent with the notion that the exchange rate caused a reduction in investment through a balance-sheet channel. The fundamentals as measured by the sales-to-capital ratios are also statistically significant although the coefficients are relatively small. We find little difference between the estimates for the unbalanced and the balanced panel – the coefficient on the balance-sheet variable is slightly smaller for the balanced panel, which is consistent with the notion that selection induced by the balanced-panel biases our estimates towards higher quality firms with less severe financial frictions.

We now turn to the fixed-effects IV estimation results. These are reported in table 4. Again, we consider both the unbalanced and balanced panel for comparison purposes. The first set of estimates reported in Table 3 again include the sales-to-capital ratios (both domestic and foreign) along with the balance sheet variable $(\hat{\Omega}b/a)_{j,t}$. Again, we find a statistically significant effect of the fundamentals on investment. Using fixed effects and IV estimation increases the coefficients on the fundamentals by a factor of four or more relative to the OLS regression reported above. This is

Table 4: Investment Equation: IV Fixed Effects

	Unbalanced Panel		Balanced Panel	
	$(i/k)_{j,t}$	$(i/k)_{j,t}$	$(i/k)_{j,t}$	$(i/k)_{j,t}$
$(s^d/k)_{j,t}$	0.069	0.069	0.113	0.111
	(0.000)	(0.000)	(0.000)	(0.000)
$(s^e/k)_{j,t}$	0.047	0.047	0.030	0.030
	(0.000)	(0.000)	(0.029)	(0.000)
$(\hat{\Omega}b/a)_{j,t}$	-0.208		-0.207	
	(0.000)		(0.000)	
$(b/a)_{j,t}$		-0.195		-0.182
		(0.000)		(0.000)
$\hat{\omega}_j e_t$		-0.502		-.509
		(0.000)		(0.000)
No. of Obs.	2490	2490	1440	1440
No. of Inds.	419	419	180	180
χ^2	2118	2143	1372	1403
$Prob > \chi^2$	0.000	0.000	0.000	0.000

consistent with the argument that there may be simultaneity bias between investment and fundamentals that is corrected for using instrumental variables. As in the OLS regression, the coefficient on the balance-sheet variable is again negative and highly statistically significant. In the second and fourth columns of table 3, we decompose the balance-sheet effect into two terms – the beginning-of-period debt-level $(b/a)_{j,t}$ and the exchange rate interacted with the pre-sample foreign-debt ratio $\hat{\omega}_j e_t$. Because the regression includes a full set of time dummies, the coefficient on $\hat{\omega}_j e_t$ directly measures the heterogenous effect of the exchange rate on investment owing to the fact that firms face different degrees of foreign-debt exposure at the onset of the crisis. Again, both balance sheet variables are negative, statistically significant and quantitatively large. At the mean value of the foreign-debt to total-debt ratio ($\omega_j = 0.14$), the estimated coefficients on $\omega_j e_t$ imply that the 70% devaluation would reduce the investment rate by 5% (a fifty percent reduction relative to the mean investment rate of 30%)

Table 5 reports analagous estimation results to table 4, this time using the GMM estimation methodology described above. Here we have included the lagged dependent variable for robustness. The estimation is performed using a first-differenced and an appropriate choice of instruments. Again, we find a statistically signifant role for both fundamentals as measured by the ratios of domestic sales and foreign sales to capital ratios. The coefficient estimates on the balance sheet variables are again negative, quantitatively large and statistically significant. When the balance sheet is broken out into its two components, beginning of period debt and the term $\omega_j \Delta e_t$ we again find an independant effect of the exchange rate interacted with the pre-sample foreign debt ratio. This coefficient is somewhat smaller in magnitude than the coefficient obtained in the previous IV fixed effects estimator but is still larger than the coefficient on the debt-to-asset ratio. In all regressions, the coefficient on the lagged dependent variable is statistically significant though relatively small in magnitude. As with the IV fixed effects estimator, results do not differ substantially between the

Table 5: Investment Equation: First Differenced GMM

	Unbalanced Panel		Balanced Panel	
	$\Delta(i/k)_{j,t}$	$\Delta(i/k)_{j,t}$	$\Delta(i/k)_{j,t}$	$\Delta(i/k)_{j,t}$
$\Delta(s^d/k)_{j,t}$	0.038	0.032	0.042	0.052
	(0.000)	(0.000)	(0.000)	(0.000)
$\Delta(s^e/k)_{j,t}$	0.042	0.050	0.070	0.055
	(0.000)	(0.000)	(0.000)	(0.000)
$\Delta(\hat{\Omega}b/a)_{j,t}$	-0.179		-0.227	
	(0.002)		(0.002)	
$\Delta(b/a)_{j,t}$		-0.131		-0.176
		(0.016)		(0.000)
$\hat{\omega}_j \Delta e_t$		-0.167		-0.180
		(0.050)		(0.000)
$\Delta(i/k)_{j,t-1}$	0.222	0.186	0.321	0.280
	(0.000)	(0.000)	(0.000)	(0.000)
No. of Obs.	1990	1990	1260	1260
No of Inds.	412	412	180	180
Sargan	47.54	87.28	25.795	102.42
	(0.958)	(0.382)	(0.917)	(0.237)
m2	-0.16	-0.39	-1.07	-1.22
	(0.869)	(0.698)	(0.284)	(0.223)

Table 6: Investment Equation: First Differenced GMM by sub-groups I

	H-fob	L-fob	L-exp	H-exp
	$\Delta(i/k)_{j,t}$	$\Delta(i/k)_{j,t}$	$\Delta(i/k)_{j,t}$	$\Delta(i/k)_{j,t}$
$\Delta(s^d/k)_{j,t}$	0.056	0.043	0.033	0.047
	(0.000)	(0.000)	(0.000)	(0.000)
$\Delta(s^e/k)_{j,t}$	0.029	0.077	0.038	0.087
	(0.008)	(0.000)	(0.000)	(0.000)
$\Delta(\hat{\Omega}b/a)_{j,t}$	-0.331	-0.079	-0.328	0.046
	(0.002)	(0.176)	(0.001)	(0.358)
$\Delta(i/k)_{j,t-1}$	0.190	0.202	0.188	0.204
	(0.000)	(0.000)	(0.000)	(0.000)
No of Obs.	989	1001	1035	955
No of Inds.	207	205	206	206
Sargan	46.95	38.65	41.96	38.87
	(0.516)	(0.830)	(0.717)	(0.812)
m2	-0.79	0.39	0.36	-0.87
	(0.431)	(0.694)	(0.722)	(0.385)

balanced and unbalanced panels.

In tables six and seve, we consider the possibility that the effect of the devaluation has non-linear effects which depend on the overall export and foreign debt position. To do so, we divide our sample between high export and low export firms and high foreign debt vs low foreign debt firms. These classifications are again based on the median pre-crisis averages of export to total sales and foreign debt to total debt ratios. Table five reports the regressions for the samples split separately by each category – export status and foreign debt status, while table six reports the regressions for the four way categorization.

According to table six, the investment spending of firms with high foreign debt responds negatively to the balance sheet variable. The effect is economically large

Table 7: Investment Equation: First Differenced GMM by sub-groups II

	H-fob/L Exp $\Delta(i/k)_{j,t}$	H-fob/H-exp $\Delta(i/k)_{j,t}$	L-Fob/L-exp $\Delta(i/k)_{j,t}$	L-Fob/H-exp $\Delta(i/k)_{j,t}$
$\Delta(s^d/k)_{j,t}$	0.055	0.070	0.040	0.059
	(0.000)	(0.000)	(0.000)	(0.000)
$\Delta(s^e/k)_{j,t}$	0.028	0.071	0.227	0.044
	(0.000)	(0.000)	(0.000)	(0.001)
$\Delta(\hat{\Omega}b/a)_{j,t}$	-0.568	-0.174	-0.237	0.100
	(0.000)	(0.050)	(0.012)	(0.000)
$\Delta(i/k)_{j,t-1}$	0.148	0.145	0.165	0.209
	(0.000)	(0.000)	(0.000)	(0.000)
No of Obs.	349	640	686	315
No of Inds.	70	137	136	69
Sargan	42.31	46.98	46.95	49.54
	(0.829)	(0.671)	(0.672)	(0.571)
m2	-0.42	-0.99	0.60	-0.40
	(0.673)	(0.325)	(0.550)	(0.689)

and statistically significant. There is no significant effect of the balance sheet for firms with low foreign debt however. When comparing firms by export category, consistent with theory, firms with low exports exhibit a strong negative response of investment to the balance sheet. Firms with high exports, for whom the exchange rate depreciation represents a positive shock to fundamentals, show no sensitivity to the balance sheet variable.

Table seven provides further confirmation of these patterns. Firms who are likely to be most vulnerable to the exchange rate shock – firms with low exports and high foreign debt – exhibit the most sensitivity of investment to the balance sheet variable. The coefficient on the balance sheet is -0.56 and highly significant. Firms who are least vulnerable – firms with high exports and low foreign debt actually exhibit a small positive response of investment to the balance sheet – the coefficient is 0.1. As expected, the other two categories, low foreign debt/high exports and high foreign debt/low exports exhibit responses that are between these extremes.

In summary, the reduced form analysis presented in this section confirms that Korean firm-level investment responded to the exchange rate devaluation during the Korean financial crisis in a manner that is consistent with the notion that credit frictions working through the balance sheet were a determining factor in the overall investment response. Consistent with theory, the evidence implies that the devaluation depressed investment for firms who whose financial position was most exposed to exchange rate shocks. It also implies that the extent of the currency mismatch between export exposure and debt exposure is an important determinant of the strength of the balance sheet mechanims working through exchange rates.

4 Quantitative Model

4.1 The Theoretical Set-Up

In this section we present the structural model of investment that we estimate. The model is a standard convex-adjustment cost model of investment augmented to include financial market imperfections. The model explicitly incorporates the effect of exchange rates on investment working through the two distinct channels outlined above: the effect of exchange rates on fundamentals, and the effect of exchange rates on the firm's balance sheet. The model is solved numerically and estimated using indirect-inference.

The firm maximizes the expected present value of dividends. The investor is assumed to be risk-neutral. We assume that firms are heterogenous with respect to a vector of individual characteristics h_j. The individual characteristics vector includes the steady state export ratio, ζ_j, foreign debt ratio, ω_j and the steady state leverage ratio, Γ_j, which is determined by the individual specific discount factor β_j. We will provide a justification for the heterogeneity of the discount factor after discussing the optimization problem.

The state variables of the firm are the current level of capital k_j, the level of one period discount bonds in domestic currency units, b_j, the index of technology z_j which we assume follows a first-order markov process, and the real exchange rate e,which also follows a first order markov process.[10]

We express the maximization problem in a recursive form of dynamic programming

[10] As shown in the Bellman equation, the states include the one period lagged value of the real exchange rate. This is due to the fact that the dividend, d_j, is a function of the lagged real exchange rate as well as the current value of real exchange rate when the firm carries foreign debt. In other words, the lagged real exchange rate is neede to ensure that the effect of devaluations are reflected in the current value of the firm.

with a set of state variables

$$
\begin{aligned}
w(\mathbf{s}_j;\mathbf{h}_j) &= \max_{k'_j,b'_j}\{d_j+\beta_j\int_{dz'_j}\int_{de'} w(\mathbf{s}'_j;\mathbf{h}_j)dF(dz'_j,z)dG(de',e)\} \qquad (5)\\
\mathbf{s}_j &= [k_j,b_j,z_j,e,e_{-1}]\\
\mathbf{h}_j &= [\zeta_j,\omega_j,\Gamma_j]
\end{aligned}
$$

where the subscript j is an index for the individual, j.

The real exchange rate is the only macroeconomic state variable which we control for in this framework. Theoretically, the state space may include other macroeconomic variables such as aggregate incomes in the domestic and the world economy and real factor prices. We do not model these explicitly however. Instead, we rely on fixed time dummies to sweep such effects out of the data. When estimating the model using indirect inference we then use the same approach to remove time effects from simulated data produced by our model.[11]

Dividends are defined as

$$
\begin{aligned}
d(k_j,b_j,k'_j,b'_j,z_j,e,e_{-1};\mathbf{h}_j) \equiv\; & \pi(k_j,z_j,e;\mathbf{h}_j)-p^i(e)i_j-c(i_j,k_j)\\
& -b_j+b'_j/R(k_j,b_j,z_j,e,e_{-1};\mathbf{h}_j) \qquad (6)
\end{aligned}
$$

where $\pi(\ ;\mathbf{h}_j)$ is the firm's profit after maximizing over variable inputs, $p^i(e)$ is the price of the investment goods, which is allowed to depend on the real exchange rate since the production technology can use imported capital goods. $c(i_j,k_j)$ is the capital adjustment cost which is assumed to be convex. $R(k_j,b_j,z_j,e,e_{-1};\mathbf{h}_j)$ is the gross interest rate on external finance which is also assumed to be convex.[12]

[11] This procedure may not be robust if other macroeconomic shocks contribute to model dynamics in a highly non-linear way. While it is possible that this is the case, our essential identification strategy works off of the interaction between the exchange rate and the degree of foreign debt exposure. Both of these are included as state variables in our model.

[12] Some authors, for instance, Cooper and Ejarque(2003) specified a linear borrowing cost function and tested the existence of the capital market firictions. We will provide the reason why we think that the convexity is better choice theoretically and empirically in the numerical analysis.

We assume that the profit function is strictly concave in capital with the curvature of the profit function determined by the degree of market power.[13] The firm is assumed to produce for both domestic and foreign markets using both domestic and imported variable inputs, and therefore, the profit is a function of the real exchange rate. The profit function may be either increasing or decreasing in the real exchange rate depending on the composition of the output markets and the production technology.

The borrowing cost is a function of all state variables. In particular, it is a convex function of the balance sheet position of the firm which, roughly speaking, is measured as debt outstanding relative to the value of assets in place. While we do not formally justify the borrowing cost, it may be motivated by assuming the existence of information asymmetries in capital market and the nature of the resulting optimal contract between the lender and the borrower(See Bernanke and Gertler(1988) and Bernanke, Gertler and Gilchrist(1999)). We specify the functional form for the borrowing costs below. The concavity of the profit function and the convexities of the capital adjustment cost and the borrowing cost makes the momentary gain function, $d(\ ;\mathbf{h}_j)$ itself concave and well behaved.

The borrowing cost also depends on the individual characteristics denoted by the argument $\mathbf{h}_j$. Among all the individual characteristics, the most important one in the current analysis is the foreign debt ratio of the firm. The decision of the monetary authority to abandon the fixed exchange rate directly affects the debt burden of the firm if the firm carries foreign-denominated debt. Furthermore, when the firm carries foreign debts, the effective rate of borrowing cost is affected by the lagged exchange rate and the dividend is also a function of the lagged real exchange rate. If there are no financial frictions in the capital market, an exogenous increase in the debt burden will not affect investment however. By parameterizing our debt cost function we nest this possibility in our estimation strategy.

[13] Cooper and Ejarque(2001, 2003) argues that the market power alone can generate enough cash-flow sensitivity of the investment spending without any financial frictions. Later, in the numerical analysis, we will check the validity of this hypothesis.

The heterogeneity of the discount factor is a device introduced to account for the observed degree of heterogeneity in leverage across firms. This device has been previously employed by Krusell and Smith (1998) and Carlstrom and Fuerst (2000).[14] The discount factor for firm j, β_j is composed of two components, a common discount factor β and the firm specific discount factor μ_j. In the appendix, we show that the steady-state leverage ratio is a monotone decreasing function of this additional discount factor under standard assumptions for the functional forms.

Finally we assume that the firm faces two occasionally binding inequality constraints. namely, one for nonnegativity of dividends and the other for irreversibility of physical investment.

$$d(k_j, b_j, k'_j, b'_j, z_j, e, e_{-1}; \mathbf{h}_j) \geq 0 \tag{7}$$

$$i_j = k'_j - (1-\delta)k_j \geq 0$$

The first constraint is equivalent to the assumption that the firm cannot issue new equities. It implies that once the inequality constraint is binding, the firm should satisfy the dividend constraint either by issueing new debt or by reducing investment.

In our model, the financial frictions are imposed by a pricing function, $R(k_j, b_j, z_j, e, e_{-1}; \mathbf{h}_j)$. The firm can issue any amount of debt it wants to choose as long as it is willing to incur the increase in borrowing costs associated with increased debt issuance. In the absence of a non-negativity constraint on dividends, the firm can avoid this borrowing cost by issueing more equity, i.e. taking a negative dividend and thereby avoiding any form of financial constraints. In this case, investment would respond exactly as in the neoclassical model absent capital market frictions. With the dividend constraint in place, the firm must take into account the effect of investment on increased borrowing today. Even if the dividend constraint does not bind today, the fact that it may

[14]As pointed put by Krusell and Smith(1998), idiosyncratic shocks have difficulty producing a meaningful degree of heterogeneity in wealth distribution among agents unless the shock process has an unrealistically large variance or persistency.

bind in the future will still constrain the response of investment and make investment sensitive to the firm's balance sheet position.[15]

4.2 The Efficiency Conditions

We summarize the maximization problem expressed in (1)$\sim$(4) as a constrained value maximization problem

$$
\begin{aligned}
Z_j &= (1+\lambda_{d,j})d_j + \lambda_{k,j}\left[k'_j - (1-\delta)k_j\right] \\
&\quad + \beta_j \int_{dz'_j}\int_{de'} v(\mathbf{s}'_j;\mathbf{h}_j)dF(dz'_j,z_j)dG(de',e)
\end{aligned}
$$

where $v(\ ;\mathbf{h}_j)$ is a constrained value function and $\lambda_{d,j}$ and $\lambda_{j,k}$ are two Lagrangian multipliers for the nonnegativity constraint for dividend and the irreversibility of investment. The FOC for the debt policy(or dividend policy) is given by

$$
(1+\lambda_{d,j}) + \beta_j R_j \int_{dz'_j}\int_{de'} \frac{\partial v}{\partial b'_j}(\mathbf{s}'_j;\mathbf{h}_j)dF(dz'_j,z_j)dG(de',e) = 0
$$

where $\mathbf{s}_j$ is a vector which includes natural logs of all state variables. Using the envelope condition,

$$
\frac{\partial v}{\partial b_j}(\mathbf{s}_j;\mathbf{h}_j) = -(1+\lambda_{d,j})\left[1 + \frac{b'_j}{R_j^2}\frac{\partial R_j}{\partial b_j}\right]
$$

and updating the condition one period, we can write

$$
1+\lambda_{d,j} = \beta_j R_j \int_{dz'_j}\int_{de'} \left(1+\lambda'_{d,j}\right)\left[1 + \frac{b''_j}{R_j'^2}\frac{\partial R'_j}{\partial b'_j}\right] dF(dz'_j,z_j)dG(de',e)
$$

[15] Another issue to consider when modeling financial frictions is whether or not to allow an exit option for the firm. To keep the model simple enough for structural estimation, we do not consider this aspect here.

This expression is a no-arbitrage condition. It differs in two ways from conventional no-arbitrage conditions. First of all, it depends on financial variables of individual firms. Second of all, it has a time varying discount factor, $(1+\lambda'_{dj})/(1+\lambda_{dj})$ which measures the shadow value of the internally generated funds today relative to tomorrow. The Lagrangian multiplier is a function of all state variables and individual characteristics. Since it measures the shadow value of the internal funds, it will have similar time series characteristics to the borrowing cost $R(\mathbf{s}_j;\mathbf{h}_j)$, a result which may be easily verified.

The FOC for investment is given by

$$p^i(e) + \frac{\partial c(i_j,k_j)}{\partial i} - \lambda_{k,j} + \beta_j \int_{dz'_j}\int_{de'} \frac{\partial v}{\partial k'_j}(\mathbf{s}'_j;\mathbf{h}_j)dF(dz'_j,z_j)dG(de',e) = 0 \qquad (8)$$

After invoking the envelope condition[16] and updating the condition one period, we can obtain the following recursive relationship

$$\begin{aligned} q(i_j,k_j) - \frac{\lambda_{k,j}}{1+\lambda_{d,j}} &= \beta_j \int_{dz'_j}\int_{de'} \frac{1+\lambda'_{d,j}}{1+\lambda_{d,j}} \left\{ \frac{\partial d'_j}{\partial k'_j} - \frac{\lambda'_{k,j}}{1+\lambda'_{d,j}} \right. \\ &\left. +(1-\delta)\left[q(i'_j,k'_j) - \frac{\lambda'_{k,j}}{1+\lambda'_{d,j}} \right] \right\} dF(dz'_j,z_j)dG(de',e) \end{aligned} \qquad (9)$$

where

$$q(i_j,k_j) \equiv p^i(e) + \partial c(i_j,k_j)/\partial i.$$

[16]The envelope condition for the capital stock is given by

$$\begin{aligned} \frac{\partial v}{\partial k'_j}(\mathbf{s}'_j;\mathbf{h}_j) &= (1+\lambda'_{d,j})\frac{\partial d'_j}{\partial k'_j} - (1-\delta)\lambda'_{k,j} + \beta_j(1-\delta) \\ &\times \int_{dz''_j}\int_{de''} \frac{v}{k''_j}(\mathbf{s}''_j;\mathbf{h}_j)dF(dz''_j,z'_j)dG(de'',e') \\ &= (1+\lambda'_d)\left\{ \frac{\partial d'_j}{\partial k'_j} - \frac{\lambda'_{k,j}}{1+\lambda'_{d,j}} + (1-\delta)\left[q(i',k') - \frac{\lambda'_{k,j}}{1+\lambda'_{d,j}} \right] \right\} \end{aligned}$$

This envelope condition is different from standard one due to the presence of two Lagrangian multipliers. If none of the constraints are binding, then the envelope condition is identical to traditional one.

Except for the additional Lagrange multipliers associated with the dividend constraint, this is an otherwise standard FOC with respect to investment. Again the time varying discount factor plays an active role. If the constraint is binding today, but has a lower probability of binding tomorrow[17], $(1+\lambda_j')/(1+\lambda_j)$ takes a value lower than 1 and the firm discounts the future more aggressively thereby making the investment decision more sensitive to the current movement of the fundamental and financial variables. Finally, the efficiency conditions includes the following Khun-Tucker conditions

$$\lambda_{d,j} \geq 0, \quad d(\mathbf{s}_j, k_j', b_j'; \mathbf{h}_j) \geq 0, \quad \lambda_{d,j} d(\mathbf{s}_j, k_j', b_j'; \mathbf{h}_j) = 0 \tag{10}$$

$$\lambda_{k,j} \geq 0, \quad k_j' - (1-\delta)k_j \geq 0 \quad \lambda_{d,j}\left[k_j' - (1-\delta)k_j\right] = 0$$

4.3 Numerical Strategy

The model cannot be solved analytically, we therefore use numerical methods to obtain an approximation to the solution. In particular, we adopt a version of Chebyshev projection methods (Judd(1992)) to approximate the solution of the model. Due to the presence of occasionally binding constraints, approximating policy variables directly has less chances of numerical success. Hence we approximate the conditional expectations of the model first and then reconstruct the policy and the multiplier variables using the approximated conditional expectations following Wright and Williams(1982, 1984), den Han and Marcet(1988) and Christiano and Fisher(1999).[18]

[17] The expected value of tomorrow's shadow value is positive as long as there is nonzero probability of binding situation.

[18] Our method can be called Chebyshev PEA(Parameterized Expectation Approach) method following Christiano and Fisher(1999). The Chebyshev PEA method is different from the conventional PEA method proposed by den Han and Marcet(1988) in a number of points. First, it uses Chebyshev polynomials which provides orthogonal and smooth basis functions. This provides much more

4.4 Functional Assumptions

We now consider the explicit functional form assumptions underlying the profit function and the agency cost. We start by parameterizing the profit function, after which we consider our specification of the agency cost.

4.4.1 Production Technology and Market Structure

Firm j produces $y_t(j)$, a 2×1 vector composed of two differentiated goods, $y_{d,t}(j)$ and $y_{f,t}(j)$ with a CRS Cobb-Douglas technology. Although the firm produces two differentiated goods, it employs only one type of capital, $k_t(j)$ and the production processes of both goods are subject to the same idiosyncratic shock, $a_t(j)$ which follows AR(1) process. The product differentiation technology is captured in the different uses of variable inputs. More specifically, we assume the following form for the production process

$$y_t(j) = \begin{bmatrix} y_{d,t}(j) \\ y_{f,t}(j) \end{bmatrix} = \exp\left[a_t(j)\right] k_t(j)^{\alpha} \begin{bmatrix} (m_{d,t}(j)^{\sigma} n_{d,t}(j)^{1-\sigma})^{1-\alpha} \\ (m_{f,t}(j)^{\sigma} n_{f,t}(j)^{1-\sigma})^{1-\alpha} \end{bmatrix} \tag{11}$$

where $m_{d,t}(j)$, $n_{d,t}(j)$ are imported intermediate materials and labor inputs employed for the production of the domestic goods, and $m_{f,t}(j)$ and $n_{f,t}(j)$ are imported intermediate materials and labor inputs employed for the production of the foreign goods. Finally, α is the income share of the capital, $\sigma(1-\alpha)$ is the income share for the imported materials and $(1-\sigma)(1-\alpha)$ is the income share of labor.

In this framework, a firm with a given level of technology a and capital k must choose how to allocate variable inputs across the domestic and foreign markest to

efficient and accurate solutions. Second, the calculation of conditional expectation is based on quadrature method rather than on Monte-Carlo method. Third, the conventional PEA uses a successive approximation technique to find functional fixed points. This method is not even locally convergent sometimes even when implemented with 'homotopy'(See Gaspar and Judd(2000)). In Chebyshev PEA approach, the successive approximation method is replaced by a numerical equation solver based on Newton's method.

maximize profits. The firm faces monopolistic competition in both markets. In particular, we assume an iso-elastic demand curve and allow the elasticities to differ across the domestic and foreign markets, ε_i for $i = d, f$:

$$y_{i,t}(j) = \theta_i(j)\,[p_{i,t}(j)]^{-\varepsilon_i}\, Z_{i,t} \quad \text{for} \quad i = d, f \tag{12}$$

where $y_{i,t}(j)$ is the demand for the firm j's output in market i, $p_{i,t}(j)$ is the real prices of the product in market i, $Z_{i,t}$ is aggregate shock or aggregate shifter common to all firms in the market i. The term $\theta_i(j)$ can be interpreted as a firm-specific constant term in the estimation of the log-linear demand function of firm j in market i. It is closely related with the firm's market share in the sense that when all price variables and exogenous variables are set at their steady state values, the size of market demand is proportional to this parameter. We do not assume a long- run relationship between the firm size and the aggregate shock. In other words, the firm size is determined by firm-specific elements which we summarize using $\theta_i(j)$. However, in the short-run, we allow for both idiosyncratic and aggregate shocks to market demands with the aggregate shocks being determined by exchange rate dynamics. The values of the aggregate shocks are normalized to one in the steady state.[19]

4.4.2 Profit Function

Under the assumptions set out in the previous subsection, the closed-form profit function of a firm can be written as

$$\begin{aligned} \pi_t(j) &= \sum_{i=d,f} \Gamma_i s_{i,t}(j) \\ &= \sum_{i=d,f} \Gamma_i \theta_i(j)^{\varsigma_i} \Xi_{i,t} \exp\left[a_t(j)\right]^{\vartheta_i} e_t^{\xi_i} k_t(j)^{\gamma_i} \end{aligned} \tag{13}$$

[19] In empirical estimation, two income variables enter as log deviations from their steady state values.

where the mark-up ratios in each market are given by

$$\Gamma_i = 1 - \chi_i (1 - \alpha) \tag{14}$$

Note that the mark-up ratios for both markets are constants determined by two important parameters, i.e., inverse of market power, χ_i and the production share of capital, α. $\Xi_{i,t}$ is a function of aggregate state variables, more specifically, a decreasing function of variable factor prices and an increasing function of aggregate income shock (For an algebraic derivation for this function, see the appendix).

The elasticities need special mentioning. They are given by

$$\varsigma_i = \frac{1 - \chi_i}{1 - \chi_i(1 - \alpha)} \tag{15}$$

$$\vartheta_i = \frac{\chi_i}{1 - \chi_i(1 - \alpha)} \tag{16}$$

$$\gamma_i = \frac{\chi_i \alpha}{1 - \chi_i(1 - \alpha)} \tag{17}$$

$$\xi_i = \mathbf{1}(i = f) + \frac{\chi_i \left[\mathbf{1}(i = f) - \sigma\right]}{1 - \chi_i(1 - \alpha)} \tag{18}$$

for $i = d, f$. $\mathbf{1}(i = f)$ is an indicator function which takes unity when $i = f$ and zero otherwise. The first thing to note is that the elasticity with respect to capital is greater than zero but less than unity because of the market power($\chi_i < 1$). Second, the elasticity with respect to the real exchange rate is negative for domestic market due to the assumption of dependence of production on imported materials. Third, the elasticity for the foreign market is positive and bounded by $(1 + \chi_i \alpha) / [1 - \chi_i(1 - \alpha)]$, which is the case of an imported input ratio, $\sigma = 0$.

The profit function can be rewritten as a weighted average of the two profit sources, i.e.,

$$\pi_t(j) \equiv \theta(j) \sum_{i=d,f} \zeta_i(j) \left[\Gamma_i \Xi_t \exp\left[a_t(j)\right]^{\vartheta_i} e_t^{\xi_i} k_t(j)^{\gamma_i}\right] \tag{19}$$

where the weight function, $\zeta_i(j)$ and the firm specific constant term, $\zeta_i(j)$ are defined as

$$
\begin{aligned}
\zeta_i(j) &\equiv \theta_i(j)^{\varsigma_i} / \textstyle\sum_{i=d,f} \theta_i(j)^{\varsigma_i} \\
\theta(j) &\equiv \textstyle\sum_{i=d,f} \theta_i(j)^{\varsigma_i}
\end{aligned}
$$

The weighting function is closely related with the steady state export sales ratio of the firm. To see this, note that the steady state export sales ratio is given by

$$
\frac{s_{f,ss}}{s_{d,ss}+s_{f,ss}} = \frac{\theta_f(j)\left[p_{f,ss}(j)\right]^{1-\varepsilon_f} Z_{f,ss}}{\sum_{i=d,f} e_{ss}^{\mathbf{1}(i=f)} \theta_i(j)\left[p_{i,ss}(j)\right]^{1-\varepsilon_i} Z_{i,ss}}
$$

Since $e_{ss} = p_{f,ss}(j) = p_{d,ss}(j) = Z_{f,ss} = Z_{d,ss} = 1$ in the steady state, the ratio collapses to

$$
\varpi_f(j) \equiv \theta_f(j) / \textstyle\sum_{i=d,f} \theta_i(j)
$$

This last expression provides a good approximation to the true weight function, $\zeta_i(j)$ if the parameters, ς_i are close to 1. In the numerical dynamic programming, we use an empirical estimate of $\varpi_f(j)$ rather than $\zeta_i(j)$. In other words, the profit function is defined as a weighted average of two profit sources and the weight is given by an empirical estimate of the steady-state export sales ratio, $\hat{\varpi}_f(j)$.

4.4.3 Borrowing Cost

For the borrowing cost, we assume, following Gilchrist and Himmelberg(1998), that the total cost is composed of two parts, a risk free rate r and the external finance premium or agency cost, η :

$$
R(\mathbf{s}_t; \mathbf{h}_j) = (1+r_t)\left[1+\eta(\mathbf{s}_t; \mathbf{h}_j)\right] \tag{20}
$$

We assume that the risk free rate is fixed over time $r_t = r_f = 1/\beta - 1$. Traditionally, the agency cost or the credit risk premium has been modeled as an increasing function of the leverage ratio (See Miller and Modigliani(195x) and Hayashi(198x) and recently Blundell, Bond and Schiantarelli(1992)). We also follow this tradition. However, since we keep track of the debt stock variable in local currency units, we need to take into account the interaction between the total debt amount in local currency unit and the effect of a depreciation on the value of foreign debt.

For that purpose, we define a firm-specific depreciation function as

$$\Omega_j(e_t, e_{t-1}) \equiv 1 - \omega(j) + \omega(j)\left(e_t/e_{t-1}\right)$$

This function captures the change in valuation of the debt stock between two time periods, the time when the debt is issued and the time when the debt is redeemed. Using this function, the effective total debt is defined as $\Omega_j(e_t, e_{t-1})b_t(j)$. In the steady state when the real exchange rate takes its long run value, 1, the foreign debt ratio does not affect the total amount of effective debt. However, in the short-run, the effective total debt is increasing in depreciation rate, e_t/e_{t-1}. The implicit assumption behind this formulation is that each firm has a preferred foreign debt ratio and does not deviate from it in the short run. We do not try to explain why different firms have different foreign debt ratios in the long run. We do allow for such heterogeneity among firms in our empirical exercise. The reason why firms do not change the foreign debt ratios in the short run is motivated by a no-arbitrage condition.

The total effective leverage ratio is defined as

$$x(\mathbf{s}_t; \mathbf{h}_j) \equiv \frac{\Omega_j(e_t, e_{t-1})b_t(j)}{\Pi_j(e_t, z_t(j))k_t(j)}$$

where $\Pi_j(s_t, z_t(j)) \equiv \sum_{i=d,f} \Gamma_i \theta_i(j)^{\varsigma_i} \Xi_{i,t} \exp\left[a_t(j)\right]^{\vartheta_i} e_t^{\xi_i}$ and measures the profitability of installed capital. The denominator approximates the firm's collateral value, or total asset value. We multiply the profitability measure by the capital stock in order to capture the effect of changes in firm's profitability on the collateral value and therefore the agency cost.

The agency cost is specified as a monotonically increasing convex function of this effective leverage ratio. We choose the following functional form[20]

$$\eta(\mathbf{s}_t;\mathbf{h}_j) \equiv \eta\left[x(\mathbf{s}_t;\mathbf{h}_j)\right] = \frac{\kappa}{\phi}\left\{\exp\left[\phi x(\mathbf{s}_t;\mathbf{h}_j)\right] - 1\right\} \tag{21}$$

This function has a number of nice properties. First, the function is convex, i.e., $\eta'(x) > 0$, $\eta''(x) > 0$. Second, the agency cost is nondecreasing in the parameter, ϕ. In other words, $\eta(x;\phi_1) \geq \eta(x;\phi_2)$ if $\phi_1 > \phi_2$. Third, the curvature of the agency cost is increasing in the level of the argument, x and the parameter, ϕ. The curvature of the agency cost for any given leverage ratio, x is $x\eta''(x)/\eta'(x) = x\left[\kappa\phi\exp(\phi x)\right]/\left[\kappa\exp(\phi x)\right] = \phi x$. It is in this sense that the parameter, ϕ measures the severity of the financial constraint. A higher ϕ results in a higher curvature of the agency cost as well as a higher level of agency cost. For a given ϕ, the parameter κ can be used for testing the null hypothesis of no capital market imperfection. Lastly, if $\phi = 0$, the agency cost function is equivalent to a linear function, $\kappa x(\mathbf{s}_t;\mathbf{h}_j)$.

4.4.4 Price of Investment Goods

Production in a typical small open economy is substantially dependent on imported capital goods. This suggests that the capital goods price $p^i(e_t)$ should be modeled as an explicit function of the exchange rate. In practice however, the exchange rate devaluation influenced domestic prices and foreign prices in such a way as to not have had a significant effect on the overall relative price of investment goods. Figure 5 depicts the domestic and imported relative price indices for investment goods, where

[20] One natural choice for this functional form is a power function form in the leverage ratio, i.e.

$$\frac{\kappa}{1+\phi}x(\mathbf{s}_t;\mathbf{h}_j)^{1+\phi}$$

This functional form has been actually used in empirical analysis, for instance, Blundell, Bond and Schiantarelli(1992), Bond and Meghir(1994), and Jaramillo, Schiantarelli and Weiss(1996). This functional form provides an analytically convenient formula and also a constant elasticity. However, this functional form is not satisfactory in that the value of the function is not monotonic in the curvature parameter, ϕ

all prices are normalized by the producer price index for manufacturing.

Figure 5 shows that the relative prices of investment goods have a downward time trend. This is a general feature of industrialized countries. Although the price index of imported investment goods increased during the crisis, the weighted average price index for all type of investment goods remained close to the overall time trend during the crisis. In fact, a close look reveals that the relative price was lower than the time trend in the crisis year, 1998.[21] Despite the price hikes in imported investment goods, the total relative price of investment goods declined relative to the time trend because the prices of investment goods produced domestically fell faster than the time trend during the crisis, presumably due to a sudden drop in investment demand.

These results suggest that modeling the price hikes in imported investment goods without accounting for the price decreases in domestic investment goods would provide a misleading description of price dynamics during the crisis. Because the relative prices of investment goods were arguably neutral or slightly favorable to investment during the crisis and therefore unlikely to provide a major source of investment dynamics during this period, we simplify our analysis by assuming a constant relative price of investment, setting $p^i(e_t) = 1$.

5 Structural Estimation

To estimate the structural parameters of the model, we employ the indirect inference method of Gourieroux, Monfort and Renault(1993) and Smith(1993). To minimize our computational burden, we proceed in two steps. In the first step, we estimate the profit function using standard regression techniques. In the second step, we apply the indirect method to the investment equation using the actual panel data and the simulated data obtained from our model. The indirect method allows us to identify the structural parameters related to the investment decision – adjustment and agency

[21] The weights were calculated according to Input-Output Table published by Bank of Korea(1995).

costs.

5.1 Identification of the Profit Function

Since the profit function and the sales function are identical up to a scaler, Γ_i, the structural parameters of the profit function can be identified by estimating either the profit function or the sales function. Separate accounting data are not available for domestic and foreign profits. However separate sales data are available and therefore can be used to identify the domestic and foreign profit functions. The sales function for market i is given by

$$s_{i,t}(j) = \theta_i(j)^{\varsigma_i} \Xi_{i,t} \exp\left[a_t(j)\right]^{\vartheta_i} e_t^{\xi_i} k_t(j)^{\gamma_i} \quad \text{for } i = d, f$$

By taking logs, we then have the following form of a fixed-effect panel data regression with AR(1) error term, developed by Baltagi and Wu(1999) and Baltagi(2000),

$$\begin{aligned} \log s_{i,t}(j) &= \varsigma_i \log \theta_i(j) + \xi_i \log e_t + \gamma_i \log k_t(j) + \log \Xi_{i,t} + v_{i,t} \\ v_{i,t}(j) &= \rho_v v_{i,t}(j) + u_t(j), \quad u_t(j) \sim iidN(0, \sigma_u^2) \\ v_{i,t}(j) &\equiv \vartheta_i a_t(j) \end{aligned} \tag{22}$$

for $i = d, f$. Note that there is no endogeneity problem, i.e., the regressors are either strictly exogenous or predetermined. All variables are real quantity values deflated by appropriate price index (see the previous section). In this estimation, we control for the influences of aggregate shocks using log-differenced real GDP of domestic market and world market. For the index of world income series, we used the WEO data base obtained from the IMF.

Table 1. shows the results from estimating this equation. Several things need to be noted. First, the estimated elasticity for foreign sales with respect to the real exchange rate is much smaller than predicted by theory. Theoretically it must be greater

than 1, as shown by the theoretical coefficient, $1+\chi_i\,(1-\sigma)\,/\,[1-\chi_i(1-\alpha)]>1$. This might be the result of abstracting from pass-through phenomena or pricing to market behavior in our theoretical model. Second, the estimated coefficients for capital suggest a substantial degree of market power in both the domestic and foreign market. Third, the market power implied by the capital coefficients is stronger in the domestic market than in the foreign market, i.e.,

$$1.642=\frac{1}{\hat{\chi}_d}=\frac{\alpha+\hat{\gamma}_d(1-\alpha)}{\hat{\gamma}_d}>\frac{\alpha+\hat{\gamma}_f(1-\alpha)}{\hat{\gamma}_f}=\frac{1}{\hat{\chi}_f}=1.376$$

where the capital share in the production function, α is calibrated as 0.45 according to recent Bank of Korea(1995) estimates.

Lastly, the estimated exchange rate coefficients imply a threshold value, 0.25, above which a firm's profit is increasing in the real exchange rate. In other words, if a firm's steady state export-sales ratio is greater than 0.25, then profits are increasing in the real exchange rate. To understand this point, consider the weighted-average form of the profit function. If we approximate this arithmetic average using a geometric average, then the real exchange rate elasticity can be written as

$$\begin{aligned}\xi(j) &= \zeta_f(j)\xi_f+\zeta_d(j)\xi_d\\ &= \left(\xi_f-\xi_d\right)\zeta_f(j)+\xi_d\end{aligned}$$

where the last equality was from $\zeta_d(j)=1-\zeta_f(j)$. If we interpret the firm specific weight, $\zeta_f(j)$ as a steady state export- sales ratio of firm j, then the last expression suggests that firm j's profit is increasing in the real exchange rate only if the steady state export sales ratio is greater than the ratio

$$-\hat{\xi}_d/\left(\hat{\xi}_f-\hat{\xi}_d\right)=0.25$$

Table 8. Identification of Profit Function Coefficients

	$\log s_{f,t}$	$\log s_{d,t}$
$\log e_t$	$\mathbf{0.360}$	$-\mathbf{0.120}$
	(0.000)	(0.000)
$\log k_{j,t}$	$\mathbf{0.545}$	$\mathbf{0.412}$
	(0.000)	(0.000)
$\log \Xi_{d,t}$		$\mathbf{1.479}$
		(0.000)
$\log \Xi_{f,t}$	$\mathbf{5.355}$	
	(0.002)	
ρ_v	$\mathbf{0.325}$	$\mathbf{0.223}$
c	$\mathbf{0.915}$	$\mathbf{2.851}$
	(0.000)	(0.000)
N. of Obs.	2544	2847
N. of Inds.	416	441
F	106.76	145.18
$Prob > F$	(0.000)	(0.000)
R^2	0.4103	0.6230

This threshold value is a bit greater than the median export sales ratio(0.203) and a bit smaller than the mean export sales ratio(0.284) in the sample. This suggests that when the real exchange rate is depreciating, the overall level of profits for the average firm in the economy is likely unaffected by movements in the real exchange rate. This leads us to question the conventional wisdom, especially emphasized by Bleakly and Cowan(2002), that the real exchange rate devaluation during the Asian crisis increased the competitivenesses of firms in these export-oriented countries and thereby substantially improved the profitability or the cash flows of the firms.

5.2 Identification of agency and adjustment costs

5.2.1 Methodology

In this subsection, we estimate two structural parameters of the model, one for capital adjustment cost and the other for agency cost, κ. Another important parameter value is ϕ, which measures the curvature of the agency cost. However, to reduce the computational burden, we fixed this parameter value at 2 through out the estimation process. In that sense, the estimation could be classified as a conditional one. Our main goal in this exercise is to provide an explicit test of the relevance of capital market frictions for investment during the crisis. Remember that we specified the agency cost function as

$$\frac{\kappa}{\phi}\left[\exp\left(\phi x\right)-1\right]$$

where x is a measure for the firm's financial burden properly normalized by firm's asset, namely the leverage ratio. Under the null hypothesis of no financial market frictions, the estmated value of κ should be close to zero.

Our estimation strategy is based upon the principles of indirect inference method proposed by Gourieroux, Monfort and Renault(1993), Smith(1993) and Gallant and Tauchen(1996). The idea of indirect inference is to use a criterion function derived from an auxiliary statistical model which may be estimated in both the data and from simulated data obtained from the structural model. We then choose the structural parameters such that the auxilliary model's parameter estimates obtained from the simulated data are close to the parameter estimates obtained from the actual data.

The main steps of the estimation procedure are: First, specify an auxiliary model and parameters. Second, estimate the parameters of the auxiliary model from the real data. Third, for a given set of structural parameters, solve and simulate the model and estimate the parameters of the auxiliary model using this simulated data. Finally, the true structural parameters are chosen so that the estimated auxiliary parameters for the real data and the simulated data are matched as closely as possible.

Denote the criterion function for the auxiliary model applied to the real data by Q. Then the estimate of the auxiliary model can be defined as

$$\hat{\beta} = \arg\max_{\beta} Q_T(\mathbf{x}_T;\beta) \tag{23}$$

where $\mathbf{x}_T$ is a data matrix and T is the number of observations. In the case of panel data, T implies the product of the number of time observations and the number of individuals. Now, according to Gourieroux et al(1993), define the so-called binding function, $\beta = b(\theta)$ as a simulated counterpart of $\hat{\beta}$, i.e., a solution to $E_\theta \left[\partial Q(\mathbf{x}; b(\theta))/\partial b(\theta)\right] = 0$. In actual estimation, the binding function is replaced by an empirical counterpart,

$$\hat{b}_S(\theta) = \frac{1}{S}\sum_{s=1}^{S}\hat{\beta}_T^{(s)}(\theta)$$

where S is the number of simulations. The minimum distance estimator of the structural parameter vector, θ is defined as

$$\hat{\theta}_{MD}^{S} = \arg\min \left[\hat{\beta} - \hat{b}_S(\theta)\right]' \Omega \left[\hat{\beta} - \hat{b}_S(\theta)\right] \tag{24}$$

where Ω is a positive definite matrix. As the sample size goes to infinity, the indirect inference estimator $\hat{\theta}_{MD}^{S}$ is consistent and asymtotically normal for any fixed S. The asymptotic optimal weighting matrix is

$$\Omega_0 = A_0 B_0^{-1} A_0$$

where $A_0 = \lim_{T\longrightarrow\infty} E\{\partial^2 Q(\mathbf{x};\beta)/\partial\beta_0\partial\beta_0'\}$ and $I_0 = \lim_{T\longrightarrow\infty} var\{\sqrt{T}\partial Q(\mathbf{x};\partial\beta)/\partial\beta_0 - E[\sqrt{T}\partial Q(\mathbf{x};\partial\beta)/\partial\beta_0|\mathbf{x}]\}$. With this choice of the weighting matrix, the indirect inference estimator follows an asymptotic distribution

$$\sqrt{T}(\hat{\theta}^S_{MD} - \theta_0) \xrightarrow{d} N(0, avar(\hat{\theta}^S_{MD}))$$

where $avar(\hat{\theta}^S_{MD}) = (1 + 1/S)[\partial b(\theta_0)/\partial\theta\Omega_0\partial b(\theta_0)/\partial\theta']^{-1}$

Several things are worthwhile mentioning. First, the asymptotic efficiency of the estimator crucially depends on how well the auxiliary model captures the properties of the original structural model. In our case, the auxiliary model should reflect two fundamental aspects, namely the influences on investment of the fundamental and the financial frictions, controlling for important individual characteristics. We believe that the reduced form regression used in section 2,

$$(i/k)_{j,t} = c_j + \beta^d(s^d/k)_{j,t} + \beta^e(s^e/k)_{j,t} + \beta^f(\hat{\Omega}b/x)_{j,t} + \delta_t + \varepsilon_{j,t}$$

is well suited for these requirements. It controls seperately the influences of marginal profitability of capital and the financial conditions in a parsmonious way. It also controls for the heterogeneities among different firms owing to their foreign sales ratio and foreign debt ratios.

Second, we wish to control for firm-level heterogeneity in a model consistent manner. Recent researchers using indirect inference to estimate structural investment models with financial frictions have applied indirect inference to a few researchers to firm-level panel data., (Cooper and Ejarque(2004) and Whited and Hennessy(2004)). The models used in these studies do not allow for individual firm characteristics however. To match to the data, the approach taken is to estimated an auxiliary regression model in the data that includes a fixed-effect constant term in it. This fixed effect constant term controls for all important heterogeneities in the data. Finally, the fixed-effect estimates from the real data set are compared with OLS estimates from simulated data set with iid firms.

We chose a different approach. We explicitly include in our theoretical model all important individual characteristics of the real data since we are doubtful a fixed effect constant term applied to the real data but not the model would appropriately capture the heterogenous response of firms depending on their foreign sales exposure, their foreign debt position or their overall debt position.

The heterogeneities we control for are three dimensional objects, $\mathbf{h}_j$: the firm-specific steady-state values of the leverage ratio, the foreign debt ratio and the foreign sales ratio. We estimate these ratios as pre-crisis sample means from the individual firm data. The dynamic programming problem of each individual in the simulation stage is a function of this individual characteristics vector, $\mathbf{h}_j$, hence the notation, $v(\mathbf{s}_j; \mathbf{h}_j)$ for the firm value. The optimized short-run policies can deviate from these long-run ratios. However, we set up the dynamic programming so that after certain number of periods, these ratios return to their long run values in the absence of innovations to exogenous state variables.

With this structure in place, we then apply the same auxilliary regression for both the real and the simulated data. We employed an IV Fixed Effect estimator for the real data in the section 2 and the result is reported in the first column of table 1. We employ the same estimator with the same set of instrument variables for the simulated panel data.[22]

Third, when a researcher generates random iid sample, it is important to create a long time series and drop a certain number of initial observations. Since we are not generating a random iid sample, the initial value problem is not so serious. We assume that all individual characteristics were set at their long-run values. However, the distributions of these individual characteristics are nondegenerate and chosen to replicate the distributions observed in the data prior to the onset of the financial crisis. For the real exchange rate, we use the actual realizations in the simulations. The

[22] Since we do not have macroeconomic state variables other than the real exchange rate in the theoretical model, we need to get rid of any influences on firm level investment rate from the real data set. This can be done by a time dummy variables in the estimation for real data.

simulated panel data has the same number of time observations for each individuals. Since we do not model exit behavior, the panel is balanced although we use unbalanced panel in the estimation of the auxiliary parameters for the real data. This should not be a problem since the estimated auxiliary parameters are almost identical for both unbalanced and balanced data(See table 1). For variance reduction, 100 was chosen for simulation number, S. In other words, $\hat{b}_S(\theta)$ is an average of 100 IV Fixed Effect estimates.

Fourth, it would be a computationally formidable task if we want to generate a panel data with the same number of individuals in the data. To see this problem, suppose that there are 400 individuals in the real data. Since analytical forms of the solution to the minimization of criterion function are not available, the actual minimization is done numerically. For one set of trial structural parameters, the minimization program has to solve the dynamic programming 400 hundred times.

To reduce the computational burden, we create a simulated panel with a smaller number of individuals, but which replicates the distributions of individual characteristics in the data. This is done in a following way: i) Estimate the empirical distribution functions for the three individual characteristics describe above. The quartiles of this distribution are reported in the table 2 . ii) Using this empirical distribution, calculate a joint distribution of the three individual characteristics. Since we rely on the quartile distribution, this procedure generates a panel with $4^3 = 64$ individuals. iii) Finally, 64 time series are generated in each simulation and a weighted average version of an IV Fixed Effect estimator is applied to the model simulated data. The weights are determined by the empirical probability of observing each of the 64 types.

Effectively, we are assuming that the data is well approximated by 64 individual types characterized by the individual characteristics described above. By relying on the joint empirical distribution to weight these types, we effectively control for the fact that a firm who is a high foreign-debt type is also more likely to be a high export type in our estimation stragegy.

Using this procedure, we estimate two structural parameters using three moments, namely, $\hat{\beta}^d - \hat{b}^d_S(\theta)$, $\hat{\beta}^e - \hat{b}^e_S(\theta)$, and $\hat{\beta}^f - \hat{b}^f_S(\theta)$. In other words, the system is overidentified. Practically, this implies two things. The choice of the weighting matrix matters and the minimized distance follows a chi-square distribution with the degree of freedom 1 and therefore provides a Sargan test statistic of overidentifying restrictions. For the optimal weighting matrix, we choose the inverse of variance-covariance matrix of the auxiliary parameter estimates in the real data, i.e. $\hat{\Omega} = [T\hat{V}(\hat{\beta})]^{-1}$. For the Sargan statistics, we use the following statistics

$$J(\hat{\theta}) = \frac{TS}{1+S}\left[\hat{\beta} - \hat{b}_S(\hat{\theta})\right]' \hat{\Omega} \left[\hat{\beta} - \hat{b}_S(\hat{\theta})\right] \sim \chi^2(1)$$

Finally, for the structural parameters related with profit function, we use the estimates identified in the first state estimation of profit function. These include, two capital elasticities of domestic and export profit functions, two persistence parameters of idiosyncratic shocks, one for domestic and the other for export profit, and finally two real exchange rate elasticities of domestic and foreign profits. For the real exchange rate persistence, we estimated an ARIMA(1,0,0) model for the time periods from 1966 to 1996.[23]

5.2.2 Structural Estimation Results

Tables 9 and 10 summarize our estimation results. We consider three alternative estimates. Each estimate differs somewhat in the measure the normalization used to

[23] The persistence was estimated as 0.801. In case we include after crisis sample in the estimation of real exchange rate persistence, the parameter was estimated as 0.596 which can be considered as too low as relative to pre-crisis estimate. This is primarily due to the fact that after the huge shock of devaluation in 1998, the real exchange rate appreciated back substantially in the next year. If we use a dummy variable for 1998 year, then the parameter was estimated as 0.897, which can be too high as relative to pre-crisis estimate. We think that there are substantial uncertianties about true value of persistence leve after the crisis and it is too early to make a conclusion about whether there was a permanent shift in persistence level. Currently, one conservative choice will be to use pre-crisis estimate.

In addition to the persistence of shocks, we also condition on appropriate choices of the variance of shocks.

measure the balance sheet, both in the data and in the model specification. In the first set of estimates, we normalize debt using the book value of capital, in the second set, we normalize debt using the book value of total assets, while in the third set of estimates, we normalize debt using sales. We view the latter normalization as most appropriate for our model since it allows our measure of the balance sheet to depend explicitly on current profit conditions as well as the existing capital stock. Thus, for firms with high exports, this measure will capture the notion that the balance sheet will improve as profitability owing to increased exports increases.

Overall the model succeeds in matching the auxilliary coefficients obtained from the IV fixed effect regression in the data. For either normalization, we come close to matching the parameterers on both the foreign and domestic sales coefficients. When using either total assets or total sales as our normalizing factor when measuring the balance sheet, we also succeed in matching the coefficient on the balance sheet variable as well (-0.2). When using the book value of capital, we find some downward bias on this coefficient in our model (-0.1 vs 0.2) suggesting that this variable may indeed be constructed with error in this case.[24]

Table 9. Estimates of Auxiliary Parameters in Simulation and Data

	$(s^d/k)_{j,t}$	$(s^e/k)_{j,t}$	$(\hat{\Omega}b/x)_{j,t}$
Auxiliary Model 1$(x = a)$			
Simulated Moments(1)	0.075	0.038	− 0.101
Simulated Moments(2)	0.067	0.050	− 0.203
Data Moments	0.068	0.042	− 0.200
Auxiliary Model 2$(x = s)$			
Simulated Moments	0.066	0.042	− 0.200
Data Moments	0.061	0.043	− 0.202

[24]Using capital as a normalizing factor misses the variation obtained from the exchange rate that is naturally included in the sales data. We suspect that because total assets includes inventories and financial as well as non-financial assets, it also capture such variation in a natural fashion.

Table 10 reports the structural parameters obtained from this estimation procedure, along with the test of over-identifying restrictions. For all three regressions, the structural coefficients are fairly close to each other and estimated with a high degree of precision. The adjustment costs are somewhat high but in the ball park of previous estimates obtained in the literature (and much lower than those obtained using a Tobin's Q style framework). The coefficient measuring agency costs, κ, is estimated to be 0.1 and highly significant. The model clearly rejects the null hypothesis of no financial market imperfections. The over-identifying restrictions for the model are not rejected when using either total assets or sales as the normalizing factor. They are rejected when using the book value of capital, providing further confirmation that this variable is inappropriate as a normalizing factor.

Table 10. Estimates of Structural Parameters

	$\hat{\gamma}$	$\hat{\kappa}$	$\hat{J}$
Auxiliary Model 1($x = a$)			
Estimates(1)	**3.765**	**0.116**	**5.219**
p-values	(0.000)	(0.000)	(0.012)
Estimates(2)	**3.858**	**0.135**	**0.421**
p-values	(0.000)	(0.000)	(0.516)
Auxiliary Model 2($x = s$)			
Estimates	**3.859**	**0.126**	**0.332**
p-values	(0.000)	(0.000)	(0.564)

5.3 Model simulations

We now consider the implications of our model estimates for investment. We first compute the implied effect of the exchange rate depreciation on average investment. We take the actual path of the exchange rate and compute the simulated path of investment for each of our 64 firm types. We then compute the weighted average of

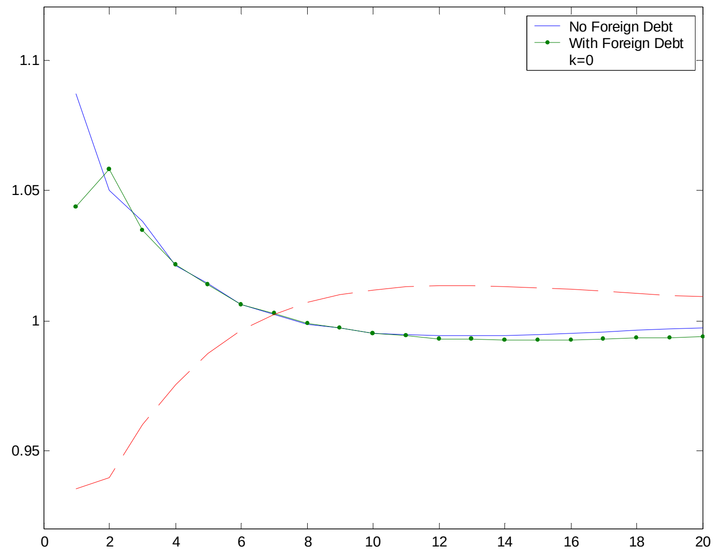

Figure 3: Average Investment following the exchange rate devaluation.

this response, using the empirical distribution to compute the weights.[25] We then conduct two counterfactual experiments. First, we assume that foreign denominate debt is zero. Second, we assume that $k = 0$, so that financial frictions play no role in the dynamics.

These results are shown in figure 3. In the absence of foreign debt, investment responds positively to the depreciation, rising by 9% relative to its baseline. Foreign debt depresses investment as is expected. The effect occurs in the first year, where investment is now only 6% above baseline. The aggregate investment rate fell 100% during the crisis. Our results imply that the exchange rate only accounts for a small fraction of this drop – for most firms in our sample, the devaluation does not represent a large increase in fundamentals. Our estimates also imply that the 4% reduction

[25] We have also computed a value weighted response in a similar manner. These estimates imply similar conclusions regarding the role of foreign denominated debt and the role of the balance sheet operating through the exchange rate.

in investment owing to the presence of foreign-denominated debt accounts for only a small fraction of the total drop in investment. On net, foreign-denominated debt does not seem to have played a strong roll in determining investment dynamics during the crisis.

Figure 3 also plots the effect of setting $k = 0$. We interpret this as the case of no financial frictions.[26] Interestingly, our parameter estimates imply that financial frictions had a non-trivial effect on investment through the exchange rate depreciation, but that the effect was positive. In our model, financial frictions depend on the value of debt relative to profitability. As the devaluation occurs, profitability increases by a sufficient amount to more than offset the reduction in the balance sheet owing to the presence of foreign denominated debt.

6 Conclusion:

In this paper we find that the presence of foreign denominated debt exerted a strong influence on investment at the micro-level. This is found to be true in both reduced-form regressions and structural parameter estimates obtained from a model of firm-level investment with both real and financial frictions. Our structural parameter estimates allow us to conduct counterfactual exercises. These exercises imply that foreign-denominated debt had only a small influence on aggregate investment spending. These results also suggest that the net effect of the devaluation working through the balance sheet was positive – because profits rose more than commensurate with foreign denominated debt, the overall rate of investment is likely to have been stimulated by the effect of the devaluation working through the balance sheet.

These results come with the caveat that they are partial equilibrium estimates computing the direct effect of the exchange rate on investment spending, holding over

[26] When setting $k = 0$, we do not set $\beta_j = 1/(1 + r)$ however. Thus these estimates should be interpreted as reflecting the average discount factor applied by our firms. We plan to redo this exercise assuming that all firms face the same common discount factor.

macro-economic factors fixed. It is difficult to see how our main result finding, that foreign denominated debt played a neglible role in determining aggregate investment dynamics would be overturned by general equilibrium considerations however.

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Wright and Williams 1982

Wright and Williams 1984

Appendix A: Derivation of the Profit Function.

In this appendix we derive the closed-form solution for the profit function specified in section 4. The profit function is defined as

$$\begin{aligned}\pi_t(j) &= p_{d,t}y_{d,t}(j) + e_t p_{f,t} y_{f,t}(j) \\ &\quad - w_{n,t}(n_{d,t}(j) + n_{f,t}(j)) - e_t w_{m,t}(m_{d,t}(j) + m_{f,t}(j))\end{aligned}$$

Using the definition of market demands, it can be rewritten as

$$\begin{aligned}\pi_t(j) &= \left[\theta_d\left(j\right) Z_{d,t}\right]^{1-\chi_d} y_{d,t}(j)^{\chi_d} + e_t \left[\theta_f\left(j\right) Z_{f,t}\right]^{1-\chi_f} y_{f,t}(j)^{\chi_f} \\ &\quad - w_{n,t}\left(n_{d,t}(j) + n_{f,t}(j)\right) - e_t w_{m,t}(m_{d,t}(j) + m_{f,t}(j))\end{aligned}$$

where $\chi_i \equiv \left(\varepsilon_i - 1\right)/\varepsilon_i$. Static profit maximization with respect to variable inputs, $m_{i,t}(j)$ and $n_{i,t}(j)$ for $i = d, f$ leads to the following conditional demand functions

$$\begin{aligned}e_t w_{m,t} m_{i,t}(j) &= (1-\alpha)\sigma\chi_i \left[\theta_i\left(j\right) Z_{i,t}\right]^{1-\chi_i} e_t^{\mathbf{1}(i=f)} y_{i,t}(j)^{\chi_i} \\ w_{n,t} n_{i,t}(j) &= (1-\alpha)(1-\sigma)\chi_i \left[\theta_i\left(j\right) Z_{i,t}\right]^{1-\chi_i} e_t^{\mathbf{1}(i=f)} y_{i,t}(j)^{\chi_i}\end{aligned}$$

where $\mathbf{1}(i = f)$ is an indicator function which takes one if $i = f$, and zero otherwise. Subsituting these conditional demand functions in the profit results in the following profit function

$$\pi_t(j) = \sum_{i=d,f} \Gamma_i s_{i,t}(j)$$

where the mark-up ratios and the sales for each market are given by

$$\begin{aligned}\Gamma_{i,t} &= 1 - \chi_i\left(1-\alpha\right) \\ s_{i,t}(j) &= e_t^{\mathbf{1}(i=f)} y_{i,t}(j)^{\chi_i} \left[\theta_i\left(j\right) Z_{i,t}\right]^{1-\chi_i}\end{aligned}$$

Note that the mark-up ratios are constants for both markets. If the firm has the same market power in both markets, the mark-up ratios in both markets are equalized in the steady state since $e_{ss} = 1$. To get the closed form of profit function, we substitute the conditional demand functions in the sales functions to get

$$s_{i,t}(j) = \theta_i(j)^{\varsigma_i} \Xi_{i,t} \exp\left[a_t(j)\right]^{\vartheta_i} e_t^{\xi_i} k_t(j)^{\gamma_i} \quad \text{for } i = d, f$$

where the elasticities of sales functions with respect to state variables are the same as described in the text. $\Xi_{i,t}$ is a complicated function of aggregate state variables. It is a decreasing function of variable factor prices and a increasing function of aggregate income shocks.

Appendix B: Data Construction.

We construct standard ratios for investment and sales relative to capital. All variables are deflated by the appropriate price indices. Investment spending is deflated by the capital goods price index from the producer price index; domestic sales, total debt and total assets are deflated by the producer price index for manufacturing; and foreign sales are deflated by the export price index. Investment data are constructed as the difference between the *Increase in Tangible Asset* and the *Decrease in Tangible Asset* variables from the Cash Flow Statement. All other variables in the regression are extracted from either the Balance Sheet or Income Statement.

The real capital stock data is constructed according to the perpetual inventory method, i.e.,

$$k_{j,t+1} = (1-\delta)k_{j,t} + \frac{I_{j,t}}{P_{k,t}} \tag{25}$$

where $I_{j,t}$ is nominal investment spending of firm j and $P_{k,t}$ is the capital goods price index. This way of constructing of the real capital stock requires an information for initial value, $k_{j,0} \equiv K_{j,0}/\tilde{P}_{k,0}$ where $\tilde{P}_{k,0}$ is the price index for installed capital at time 0. Since this price level is not available, we deflate the initial nominal capital stock by the capital price index, $P_{k,0}$.

To exclude the influences of extreme observations, our sample is constructed using a cut-off rule which drops outliers defined as observations in the lowest and the highest 0.5% of the sample.

Appendix C: Numerical Solution Method:

In general, the algorithm tries to approximate the conditional expectation associated with efficiency conditions of dynamic models. In generic terms, the approximation can be described as

$$\exp(\mathbf{h}[\log(\mathbf{x},\mathbf{k})]) \simeq \int_{d\mathbf{x}'} g(\mathbf{x},\mathbf{x}',\mathbf{c},\mathbf{c}',\mathbf{k},\mathbf{k}',\boldsymbol{\lambda},\boldsymbol{\lambda}')d\Theta(d\mathbf{x}',\mathbf{x}) \tag{26}$$

where the RHS is the conditional expectation typically included in Euler equations of dynamic models and the LHS is the approximating function of that conditional expectation. $\mathbf{h}[\ ]$ are Chebyshev polynomials, $\mathbf{x}$ is a exogenous state vector, $\mathbf{k}$ is a endogenous state vector, $\mathbf{c}$ is a control vector, $\boldsymbol{\lambda}'$ is a Lagrangian multiplier vector associated with the occasionally binding inequality constraints and Θ is a joint distribution of exogenous states. The integrand, $g(\ )$ function contains economic informations which summarizes the dynamics of the model.

The reason why this method is a fixed point algorithm is that all policy variables, endogenous state variables and the multipliers can be shown to be functions of this approximated conditional expectation function, $\exp(\mathbf{h}[\log(\ ,\ )])$. The solutions of the model are the fixed points to the functional equations

$$\exp(\mathbf{h}[\log(\mathbf{x},\mathbf{k})]) = T\exp(\mathbf{h}[\log(\mathbf{x},\mathbf{k})]) \tag{27}$$

where the operater T is defined as the RHS of eq. (17), $\int_{\mathbf{x}'} g[\ \ ]d\Theta(d\mathbf{x}',\mathbf{x})$.[27]

To apply this method to our model, we need to transform FOCs of the model into more convenient forms, more specifically we need to make the LHS of FOCs invertible

[27]In fact, the calculation of integral in the conditional expectation is replaced by quadrature method in actual computation.

to the policy variables. To that end, we rewrite the FOCs as

$$\frac{1+\lambda_{d,j}}{b'_j} = \beta_j \int_{dz'_j} \int_{de'} \frac{1+\lambda'_{d,j}}{b''_j} \frac{b''_j/R'_j}{b'_j/R_j} \times \left[R'_j + \frac{\partial R'_j}{\partial b'_j} \frac{b''_j}{R'_j} \right] dF(dz'_j, z) dG(de', e) \tag{28}$$

$$q(i_j, k_j) \frac{1+\lambda_{d,j}}{b'_j} - \frac{\lambda_{k,j}}{b'_j} = \beta_j \int_{dz'_j} \int_{de'} \frac{1+\lambda'_{d,j}}{b''_j} \frac{b''_j}{b'_j} \left\{ \frac{\partial d'_j}{\partial k'_j} - \frac{\lambda'_{k,j}}{1+\lambda'_{d,j}} + (1-\delta) \left[q(i'_j, k'_j) - \frac{\lambda'_{k,j}}{1+\lambda'_{d,j}} \right] \right\} dF(dz'_j, z) dG(de', e) \tag{29}$$

Now we approximate the conditional expectations of the FOCs as

$$\exp(h_{j,b}(\mathbf{s}_j)) \simeq \int_{dz'_j} \int_{de'} \frac{1+\lambda'_{d,j}}{b''_j} \frac{b''_j/R'_j}{b'_j/R_j} \times \left[R'_j + \frac{\partial R'_j}{\partial b'_j} \frac{b''_j}{R'_j} \right] dF(dz'_j, z) dG(ds', s) \tag{30}$$

$$\exp(h_{j,k}(\mathbf{s}_j)) \simeq \int_{dz'_j} \int_{de'} \frac{1+\lambda'_{d,j}}{b''_j} \frac{b''_j}{b'_j} \left\{ \frac{\partial d'_j}{\partial k'_j} - \frac{\lambda'_{k,j}}{1+\lambda'_{d,j}} + (1-\delta) \left[q(i'_j, k'_j) - \frac{\lambda'_{k,j}}{1+\lambda'_{d,j}} \right] \right\} dF(dz'_j, z) dG(de', e) \tag{31}$$

where $\exp(h_{j,b}(\mathbf{s}_j))$ and $\exp(h_{j,k}(\mathbf{s}_j))$ are parameterized expectations, $h_b(\ )$ and $h_b(\ )$ are Chebyshev polynomias and $\mathbf{s}_j$ is a vector of log transformed state variables, i.e. $\mathbf{s}_j \equiv [\log k_j \ \log b_j \ \log z_j \ \log e \ \log e_{-1}]$. Note that the approximated conditional expectations are indexed by subscript, j since the functional forms are determined by individual characteristics, $\mathbf{h}_j$.

We can now express the system of equations in the model using these approximation functions. Substituting for the two parameterized expectations in the transformed FOCs, and dividing the resulting first FOC by the second FOC, we can have

$$q(k'_j, k_j) - \frac{\lambda_{k,j}}{1+\lambda_{d,j}} = \frac{\exp(h_{j,k}(\mathbf{s}_j))}{\exp(h_{j,b}(\mathbf{s}_j))} \tag{32}$$

This can be used to construct the policy function for new capital. To that end, suppose that the irreversibility constraint is not currently binding, i.e. $\lambda_{j,k} = 0$. If, given the level of current capital, q is monotonically related with the level of tomorrow's capital, then there exists an invertible relationship between them, i.e[28].

$$k'_j = q^{-1}\left[\frac{\exp(h_{j,k}(\mathbf{s}_j))}{\exp(h_{j,b}(\mathbf{s}_j))}\right] \tag{33}$$

However this policy is valid only if the irreversibility constraint is non-binding in the current period. Therefore, the actual policy sould be expressed as

$$k'_j(\mathbf{s}_j) = \begin{cases} q^{-1}\left[\frac{\exp(h_{j,k}(\mathbf{s}_j))}{\exp(h_{j,b}(\mathbf{s}_j))}\right] & \text{if} \quad q^{-1}\left[\frac{\exp(h_{j,k}(\mathbf{s}_j))}{\exp(h_{j,b}(\mathbf{s}_j))}\right] \geq (1-\delta)k_j \\ (1-\delta)k_j & \text{if} \quad q^{-1}\left[\frac{\exp(h_{j,k}(\mathbf{s}_j))}{\exp(h_{j,b}(\mathbf{s}_j))}\right] < (1-\delta)k_j \end{cases} \tag{34}$$

or more simply

$$k'_j(\mathbf{s}_j) = \max\left\{(1-\delta)k_j, q^{-1}\left[\frac{\exp(h_{j,k}(\mathbf{s}_j))}{\exp(h_{j,b}(\mathbf{s}_j))}\right]\right\} \tag{35}$$

Therefore the investment policy should be

$$i_j(\mathbf{s}_j) = \max\left\{0, q^{-1}\left[\frac{\exp(h_{j,k}(\mathbf{s}_j))}{\exp(h_{j,b}(\mathbf{s}_j))}\right] - (1-\delta)k_j\right\} \tag{36}$$

[28] If we assume a quadratic form for the capital adjustment cost, for instance, $c(i_j, k_j) = \frac{\gamma}{2}\left(\frac{i_j}{k_j} - \delta\right)^2 k_j$, q can be expressed as $q_j = 1 + \gamma\left(\frac{i_j}{k_j} - \delta\right) \simeq \frac{\exp(h_{j,k}(\mathbf{s}_j))}{\exp(h_{j,b}(\mathbf{s}_j))}$. Then we can solve this expression for investment or new level of capital,

$$i_j = \left\{\frac{1}{\gamma}\left[\frac{\exp(h_{j,k}(\mathbf{s}_j))}{\exp(h_{j,b}(\mathbf{s}_j))} - 1\right] + \delta\right\} k_j$$

Note that the investment is linearly increasing in q value and in the steady state($q_j = 1$), $i_j = \delta k_j$.

Note that the level of new capital and investment can be determined without knowing whether the nonnegative dividend constraint is binding. Based upon this knowledge of tomorrow's capital level, we can express the optimal debt policy as

$$b_j'(\mathbf{s}_j) = \begin{cases} \left[\beta_j \exp(h_{j,b}(\mathbf{s}_j))\right]^{-1} & \text{if} \quad \left[\beta_j \exp(h_{j,b}(\mathbf{s}_j))\right]^{-1} \geq \Phi_j(\mathbf{s}_j) \\ \Phi_j(\mathbf{s}_j) & \text{if} \quad \left[\beta_j \exp(h_{j,b}(\mathbf{s}_j))\right]^{-1} < \Phi_j(\mathbf{s}_j) \end{cases} \tag{37}$$

or more simply

$$b_j'(\mathbf{s}_j) = \max\{\Phi_j(\mathbf{s}_j), \left[\beta_j \exp(h_{j,b}(\mathbf{s}_j))\right]^{-1}\} \tag{38}$$

where Φ is defined as minimum level of debt finance satisfying the financial constraint

$$\Phi_j(\mathbf{s}_j) \equiv R(\mathbf{s}_j; \mathbf{h}_j)b_j + p^i(e)i_j + c(i_j, k_j) - \pi_j(k_j, z_j, e) \tag{39}$$

The dividend policy is determined by the definition. The dividend policy is always nonnegative by construction.

$$d_j(\mathbf{s}_j, k_j', b_j'; \mathbf{h}_j) = \pi_j(k_j, z_j, e) - p^i(e)i_j(\mathbf{s}_j) - c(i_j(\mathbf{s}_j), k_j) - R(\mathbf{s}_j, \mathbf{h}_j)b_j + b_j'(\mathbf{s}_j) \tag{40}$$

Since we have determined all policy variables, we can pin down the levels of the Lagrangian multipliers as

$$\lambda_{j,d}(\mathbf{s}_j) = \frac{b_j'(\mathbf{s}_j)}{\left[\beta_j \exp(h_{j,b}(\mathbf{s}_j))\right]^{-1}} - 1$$

$$\lambda_{j,k}(\mathbf{s}_j) = (1 + \lambda_{j,d}(\mathbf{s}_j)) \left[q(k_j'(\mathbf{s}_j), k_j')) - \frac{\exp(h_{j,k}(\mathbf{s}_j))}{\exp(h_{j,b}(\mathbf{s}_j))} \right] \tag{41}$$

Note that since the multipliers are nonnegative, the constrained policy b_j' cannot be smaller than the unconstrained(or unbinded) policy, $[\exp(h_b(\mathbf{x}))]^{-1}$ and for the same reason, the constrained Tobin's q cannot be smaller than the unconstrained Tobin's q, $\exp(h_{j,k}(\mathbf{x}))/\exp(h_{j,b}(\mathbf{x}))$. The rest of the system can be derived exactly in the same way.

$$k''_j(\mathbf{s}'_j) = \max\left\{(1-\delta)k'_j(\mathbf{s}_j), q^{-1}\left[\frac{\exp(h_{j,k}(\mathbf{s}'_j))}{\exp(h_{j,b}(\mathbf{s}'_j))}\right]\right\} \tag{42}$$

$$i'_j(\mathbf{s}'_j) = \max\left\{0, q^{-1}\left[\frac{\exp(h_{j,k}(\mathbf{s}'_j))}{\exp(h_{j,b}(\mathbf{s}'_j))}\right] - (1-\delta)k'_j(\mathbf{s}_j)\right\} \tag{43}$$

$$b''(\mathbf{s}'_j) = \max\{\Phi_j(\mathbf{s}'_j), \left[\beta_j \exp(h_{j,b}(\mathbf{s}'_j))\right]^{-1}\}$$

$$\lambda'_{j,d}(\mathbf{s}'_j) = \frac{b''(\mathbf{s}'_j)}{\left[\beta_j \exp(h_{j,b}(\mathbf{s}'_j))\right]^{-1}} - 1 \tag{44}$$

$$\lambda'_{j,k}(\mathbf{s}'_j) = \left(1 + \lambda'_{j,d}(\mathbf{s}'_j)\right)\left[q(k''(\mathbf{s}'_j), k'(\mathbf{s}_j)) - \frac{\exp(h_{j,k}(\mathbf{s}'_j))}{\exp(h_{j,b}(\mathbf{s}'_j))}\right] \tag{45}$$

$$\begin{aligned} d_j(\mathbf{s}'_j, k''_j, b''_j; \mathbf{h}_j) \quad &= \quad \pi_j(k'_j, z'_j, e') - p^i(e')i_j(\mathbf{s}'_j) \\ &\quad -c(i_j(\mathbf{s}'), k'_j) - R(\mathbf{s}'_j, \mathbf{h}_j)b'_j + b''_j(\mathbf{s}'_j) \end{aligned} \tag{46}$$

Finally, after parameterized policies and multiplier functions are substituted in the RHSs of the conditional expectations, the functional fixed points of the model can be written as the solutions to the following system[29]

[29] There could be other transformations to enable us to identify the policy variable. However, some of them do not satisfy the Kuhn-Tucker condition. For instance, a possible invertible form might be

$$b'_j\left(1+\lambda_{j,d}\right) = \beta_j \int_{dz'}\int_{de'} b''_j\left(1+\lambda'_{j,d}\right)\frac{b'_j}{b''_j}\left[R_j + \frac{\partial R_j}{\partial b'_j}b'\right] dF(dz'_j, z_j)dG(de', e)$$

In this case we parameterize the conditional exectation to get

$$b'_j\left(1+\lambda_{j,d}\right) = \beta_j \exp(h_{j,b}(\mathbf{s}_j))$$

If the constraint is nonbinding, the debt policy is given by $b'_j = \beta_j \exp(h_{j,b}(\mathbf{s}_j))$. If the constraint is binding the policy is given by $b'_j = R_j b_j + i + c(i_j, k_j) - \pi(k_j, z_j, e)$. Finally the Lagrangian multiplier is calculated as

$$\lambda_d = \frac{\beta_j \exp(h_{j,b}(\mathbf{s}))}{b'_j} - 1$$

If the constraint is nonbinding, this formula correctly gives $\lambda_{j,d} = 0$. However, if the constraint is binding where the unconstrained policy is lower than the constrained policy, this formula returns a negative value for the multiplier.

$$
\begin{aligned}
\exp(h_{j,b}(\mathbf{s}_j)) \simeq \beta_j \int_{dz'_j} \int_{ds'} & \exp(h_{j,b}(\mathbf{s}'_j)) \left[\frac{b''_j(\mathbf{s}'_j)/R(\mathbf{s}'_j;\mathbf{h}_j)}{b'_j(\mathbf{s}_j)/R(\mathbf{s}_j;\mathbf{h}_j)} \right] \\
& \times \left[R(\mathbf{s}'_j;\mathbf{h}_j) + \frac{\partial R(\mathbf{s}'_j;\mathbf{h}_j)}{\partial b'_j} \frac{b''_j(\mathbf{s}'_j)}{R(\mathbf{s}'_j;\mathbf{h}_j)} \right] dF(dz'_j, z) dG(ds', s)
\end{aligned}
$$

$$
\begin{aligned}
\exp(h_{j,k}(\mathbf{s}_j)) \simeq \beta_j \int_{dz'_j} \int_{ds'} & \exp(h_{j,b}(\mathbf{s}'_j)) \left[\frac{b''_j(\mathbf{s}'_j)}{b'_j(\mathbf{s}_j)} \right] \left\{ \frac{\partial d}{\partial k'_j}(\mathbf{s}'_j, k''_j, b''_j; \mathbf{h}_j) \right. \\
& \left. - \frac{\lambda_{j,k}(\mathbf{s}'_j)}{1+\lambda_{j,d}(\mathbf{s}'_j)} + (1-\delta) \left[\frac{\exp(h_{j,k}(\mathbf{s}'_j))}{\exp(h_{j,b}(\mathbf{s}'_j))} \right] \right\} dF(dz'_j, z) dG(ds', s)
\end{aligned}
$$

for $j = 1, \cdots, N$

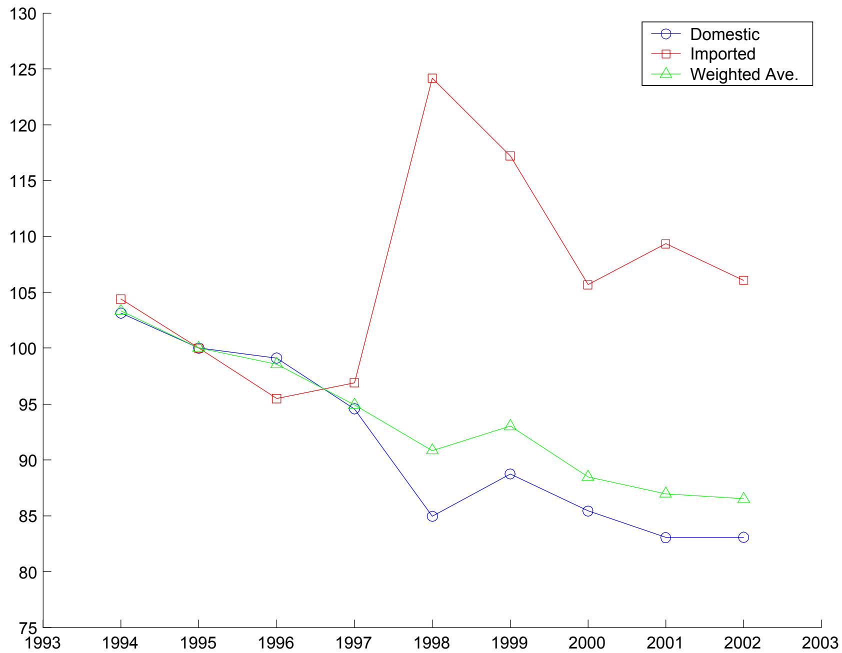

Figure 4: Relative Price of Investment Goods