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# Currency Risk Exposure of Japanese Firms with Overseas Production Bases: Theory and Evidence

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Abstract

This paper explores a new aspect on currency risk exposure of Japanese firms with overseas operations, especially focusing on the behavior of the firms that are highly dependent on overseas production. Empirical results show that in response to a Japanese yen's depreciation (appreciation), the values of the firms that are dependent on overseas production declined (rose) after controlling for the effects via the dependency on exports and imported primary materials, which is consistent with the prediction of our static version of currency risk exposure model. In conducting empirical analysis, special attention is paid to potential econometric problems such as measurement errors (errors in variables) and endogeneity (feed-back effects) of regressors. The paper further studies a dynamic currency risk exposure effect by explicitly taking account of intertemporal foreign direct investment decisions. Basically, our empirical results favor our basic dynamic model's prediction.

Key words: Currency risk exposure; *q* theory of investment; Irreversibility; Panel data; Measurement errors; Endogeneity

JEL classification: F21; F31; G12

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## I. Introduction

In 1995, the Japanese yen fluctuated significantly against the U.S. dollar. It was also reported that many of the stock price indices moved up and down in line with the exchange rate fluctuations. A firm is subject to operative (or economic) exposure[1] if the value of the firm as measured by the present discounted value of its expected future cash flows is sensitive to unexpected changes in exchange rates. Hence, this episode suggests that Japanese firms might have faced a high degree of currency risk exposure despite the fact that there are many money market instruments available for risk management.

It is probable, however, that currency risk exposure depends on attributes of the firm, particularly the degrees of dependency on exports, overseas production, and imported primary materials[2]. From this point of view, a rapid increase of overseas production by Japanese manufacturing firms in recent years[3] is a phenomenon worthy of notice. One of the main purposes for expanding overseas production is to reduce operating currency exposure[4]. Thus, if the home currency appreciates, the firm will have higher profits in terms of the home currency and its value will be higher, although the firm still might be hurt by the appreciation of the home currency.

If an expansion of overseas production would raise the profitability of a Japanese firm when the home currency appreciates, foreign direct investment can be regarded as having the same effect as an enlargement of the long position of the home currency and the short position of the foreign currencies. Hence, to some extent, the firm that conducts

[1] In the standard taxonomy of the international corporate finance literature, there are typically three categories of currency risk exposure: translation (or accounting) exposure, transaction exposure, and operating exposure. Our focus is this operating exposure. It should be noted, however, that even a firm producing wholly domestically and selling wholly domestically would face operating exposure. For more details, see Shapiro (1996), for example.
[2] For empirical studies regarding operative exposure to input prices, see Bruno and Sachs (1982).
[3] For example, the 28th *Survey of Overseas Business Activities* issued by the Ministry of International Trade and Industry (MITI) reports that overseas production ratio rose to 12.4% in FY 1997 up from about 3% in FY 1985.
[4] The other possibility is that investing in overseas production itself is a means of reducing operating currency risk exposure, which is sometimes called "natural hedge" in contrast to hedges using derivatives and other financial instruments.

foreign direct investment might have an incentive to increase the long position of the foreign currency and/or to decrease the long position of the yen to avoid currency risk.

According to the conventional portfolio balance approach to the determination of exchange rates, a surplus in the current account leads to an appreciation of the home currency, since domestic investors are obliged to increase the net long position of foreign currencies. In cases in which an expansion of overseas production raises the profitability of Japanese firms when the yen appreciates, however, it is likely that a current account surplus will not bring about the yen's appreciation as long as it flows back in the form of foreign direct investment. Taking account of the fact that foreign direct investment accounts for about one-third of the current account surplus in recent years, the effect of foreign direct investment on the exchange rate might be considerable.

Despite the important implication stated above, it is surprising that the relation between exchange rates and values of firms has not been subject to empirical research. Under such circumstances, Choi and Prasad (1995) develop a model of firm valuation to examine the exchange risk sensitivity of U.S. multinationals during 1978-89 period. In contrast to previous studies such as Bodnar and Gentry (1993) and Jorion (1990), both of which treat exports as the only source of currency risk exposure, they also take the roles of attributes other than exports such as operating profits and financial strategies into consideration. But, no attention is paid to the role of overseas production.

Concerning the case of Japanese firms, there have been even fewer studies. To our knowledge, He and Ng (1998) conduct the sole comprehensive analysis of the exposure effect on Japanese multinationals. They find that about 25 percent of 171 multinationals' stock returns experienced significant positive exposure effects. The extent of exposure is explained by the export ratio and other proxies for its hedging needs.

Based on the motivation above, in this paper, we try to analyze the currency risk exposure effects of Japanese firms, especially firms engaged in producing electric and precision machinery. The most important reason for this choice is that for these firms, the levels of dependency on exports are generally high and dependency levels on overseas production vary greatly across firms.

On the theoretical side, we first construct a static baseline model, which can explain the differences in the static effect of currency risk exposure by the differences of their three representative attributes: dependency on (a) exports, (b) overseas production, and (c) imported primary materials. Second, we explicitly introduce a firm's investment decision to capture the dynamic aspect of currency risk exposure.

On the empirical side, we are obliged to face a trade-off with regard to the sample size. One consideration is that in analyzing currency risk exposure, we need to control potential effects of various factors other than the exchange rates on the values of firms. But, in practice, it is impossible to explicitly control for all those effects. In this regard, we should choose relatively short periods during which the exchange rates changed significantly in one direction.

The use of such short periods, however, has potentially a large cost in that the estimator obtained in this way might not have desirable large-sample properties. These properties, strictly speaking, should not depend on the sample data. In reality, however, it is impossible to find estimators possessing these desirable properties in small samples. In many cases, an estimator becomes less and less biased, as the sample size becomes larger. Taking these trade-offs into consideration, we shall conduct our regression analysis in both small and large samples.

Also, most of the preceding studies ignore the potential econometric problems such as endogeneity (simultaneity) bias and/or measurement errors, which undermine the unbiasedness and consistency of the estimators. To eliminate them, we use an instrumental variables (IV) technique in a panel data setting.

The paper is organized as follows. Section II theoretically derives a basic empirical equation of currency risk exposure of the firm with overseas operations. Section III first examines the dynamic currency exposure effect by incorporating the firm's overseas investment decision. Then we explore the implication of the irreversible investment. Section IV describes the data. Section V reviews empirical issues. Section VI presents empirical results. Section VII concludes the paper.

## II. Static Currency Risk Exposure

### (i) Static Profit Maximization Problem of a Representative Firm

Let $V_t$ be the stock market value of the firm in period $t$, $\rho$ be the constant subjective discount rate in the stock market, and $D_t$ be the dividend that is paid out in period $t$. The firm makes current decisions to maximize $D_t + V_t$. Now, for simplicity, we assume the static expectations about all exogenous variables including the foreign exchange rates and the net investment is equal to zero. Under the assumption of no asset-price bubbles, we can get the relationship $V_t = D_t/\rho$, which shows that the maximization problem of the expected value of the firm reduces to the maximization of the current dividend.

Now, let us define the dividend of the firm. For simplicity, we assume that the dividend a firm pays out in a period is its current profits. Current profits are defined as the total sales less total costs, both of which must be evaluated in terms of the home currency. Thus, choice of the production location is the key to the formulation of the firm's profit maximization problem.

Since the Plaza Accord in 1985, many Japanese firms have been re-importing relatively labor-intensive goods from the overseas production bases, while they produce only the relatively technology-incentive goods domestically. To incorporate this structural change, we assume that the firm produces the following four kinds of goods. Good 1 is produced domestically and shipped (exported) to the foreign country. Good 2 is produced and sold in the foreign country. Good 3 is produced in the foreign country and exclusively shipped (re-imported) to the home country. Goods 4 is produced and sold in the home country.

The firm produces those goods using (i) labor that must be procured in the location of production, (ii) primary materials that are traded internationally (their prices are determined in the international market in terms of the U.S. dollar), and (iii) the fixed capital stock. In the foreign country, the firm behaves as a monopoly, while in the home country, the firm takes each price as given[5] due to the existence of numerous competitors. For simplicity, we ignore the existence of tariffs, transportation costs, the joint production, and any strategic or oligopolistic interactions between firms, which sometimes preclude the continuous differentiability of the inverse functions of the demand schedules by creating kinked-demand schedules, for example[6].

Now, the firm's profit maximization problem can be written as follows[7]:

$$\begin{aligned} \underset{\{Q,L,M\}}{Max}\ D = \Pi\left[P_1^F\left(Q_1^F\right)Q_1^F + P_2^F\left(Q_2^F\right)Q_2^F\right] + P_3^H Q_3^H + P_4^H Q_4^H \\ - w^H\left(L_1^H + L_4^H\right) - \Pi w^F\left(L_2^F + L_3^F\right) - \Pi^{US} P_M\left(M_1^H + M_2^F + M_3^F + M_4^H\right) \end{aligned} \tag{1}$$

s.t $$Q_j^k = F_j^k\left(L_j^k, M_j^k, \overline{K}_j^k\right) \quad j \in 1,2,3,4 \quad k \in H,F, \tag{2}$$

where $\Pi$ (home currency/foreign currency) and $\Pi^{US}$ (home currency/US dollar) are the exchange rates, $Q_j^k$ is the output of good $j$ in the country $k$, $P_l^F\left(Q_l^F\right)$ ($l \in 1,2$) is the inverse function of the demand schedule for good $l$ in the foreign country, $P_m^H$ ($m \in 3,4$) is the price of the good $m$ in the home country, $w^k$ is the wage rate in country $k$, $L_j^k$ is the labor input, $P_M$ is the U.S. dollar-denominated price of the internationally-mobile factor

[5] The assumption of perfect competition in the home country is not really a crucial assumption to derive the static version of currency risk exposure. But, we use this assumption to keep consistency with the analysis in the next section, where we need it in order to establish equality of marginal and average q.
[6] Also, this paper will not examine the firms whose only exposure is due to competition from foreign firms that export to the home market. This emphasis on the industry structure has been at the forefront of the subject of "exchange rate pass-through". In this regard, see, for example, Dornbusch (1987), Krugman (1987), Froot and Klemperer (1989), and Marston (1996).

$M_j^k$, $\overline{K}_j^k$ is the fixed capital stock, and $F_j^k$ is the well-behaved concave production function of good $j$ in the country $k$.

Now, letting $Q_j^{k*}$, $L_j^{k*}$, $M_j^{k*}$, and $\lambda_j^*$ be the optimal values that satisfy the first-order conditions enables us to express the exposure effect on the profits of the firm as follows:

(i) in the case in which $\Pi$ changes,

$$\frac{dD^*}{d\Pi} = P_1^F\left(Q_1^{F*}\right)Q_1^{F*} + P_2^F\left(Q_2^{F*}\right)Q_2^{F*} - w^F\left(L_2^{F*} + L_3^{F*}\right)$$
$$+ \sum_{l\in 1,2}\left\{\left[\left(P_l^F\left(Q_l^{F*}\right) + \frac{dP_l^F\left(Q_l^{F*}\right)}{dQ_l^F}Q_l^{F*}\right) + \lambda_l^*\right]\frac{dQ_l^{F*}}{d\Pi}\right\} + \sum_{m\in 3,4}\left\{\left[\left(P_m^H\left(Q_m^{H*}\right) + \frac{dP_m^H\left(Q_m^{H*}\right)}{dQ_m^H}Q_m^{H*}\right) + \lambda_m^*\right]\frac{dQ_l^{H*}}{d\Pi}\right\}$$
$$+ \sum_{i\in 2,3}\left[\frac{d\lambda_i^*}{d\Pi}\left(F_i^F\left(L_i^{F*}, M_i^{F*}, \overline{K}_i^F\right) - Q_i^{F*}\right)\right] + \sum_{g\in 1,4}\left[\frac{d\lambda_g^*}{d\Pi}\left(F_g^H\left(L_g^{H*}, M_g^{H*}, \overline{K}_g^H\right) - Q_g^{H*}\right)\right], \tag{3}$$

(ii) in the case which $\Pi_{US}$ changes,

$$\frac{dD^*}{d\Pi^{US}} = P_M\left(\sum_{i\in 2,3}M_i^F + \sum_{g\in 1,4}M_g^H\right)$$
$$+ \sum_{l\in 1,2}\left\{\left[\left(P_l^F\left(Q_l^{F*}\right) + \frac{dP_l^F\left(Q_l^{F*}\right)}{dQ_l^F}Q_l^{F*}\right) + \lambda_l^*\right]\frac{dQ_l^{F*}}{d\Pi_{US}}\right\} + \sum_{m\in 3,4}\left\{\left[\left(P_m^H\left(Q_m^{H*}\right) + \frac{dP_m^H\left(Q_m^{H*}\right)}{dQ_m^H}Q_m^{H*}\right) + \lambda_m^*\right]\frac{dQ_m^{H*}}{d\Pi_{US}}\right\}$$
$$+ \sum_{i\in 2,3}\left[\frac{d\lambda_i^*}{d\Pi_{US}}\left(F_i^F\left(L_i^{F*}, M_i^{F*}, \overline{K}_i^F\right) - Q_i^{F*}\right)\right] + \sum_{g\in 1,4}\left[\frac{d\lambda_g^*}{d\Pi_{US}}\left(F_g^H\left(L_g^{H*}, M_g^{H*}, \overline{K}_g^H\right) - Q_g^{H*}\right)\right], \tag{4}$$

According to the envelope theorem, the last four terms in both equations will disappear given that the demand schedules and the production functions are continuously differentiable. This result is summarized in proposition 1.

[7] Superscript H (F) denotes the home (foreign) country. In what follows, we omit time subscript *t*.

**PROPOSITION 1**: *Currency risk exposure is given by the local currency-denominated sum of sales in that local area minus the sum of inputs that are not internationally mobile used in the area (if the Japanese yen-U.S. dollar exchange rate changes, the U.S. dollar-denominated sum of primary materials determine the currency exposure of the firm).*

### (iii) Derivation of the Equation for Estimation

Multiplying both sides of Eq. (3) by $d\Pi/D^*$, taking Eq. (4) into account, yields

$$\begin{aligned}\frac{dD^*}{D^*} &= \frac{1}{D^*}\Pi P_1^F\left(Q_1^{F*}\right)Q_1^{F*}\frac{d\Pi}{\Pi} - \left[\frac{1}{D^*}(1-a)\right]\sum_{i\in 2,3}\Pi w^F L_i^{F*}\frac{d\Pi}{\Pi} \\ &\quad - \frac{1}{D^*}\Pi P_M\left(\sum_{i\in 2,3}M_i^{F*} + \sum_{g\in 1,4}M_g^{H*}\right)\frac{d\Pi^{US}}{\Pi^{US}}\end{aligned} \tag{5}$$

where $a$ is the ratio of sales except for exports from the home country to labor costs that are used in the foreign country. Now, using relationship $V_t = D_t/\rho$, Eq. (5) can be simplified as

$$\frac{dV^*}{V^*} = \frac{1}{\rho}\frac{A^F}{V^*}\frac{d\Pi}{\Pi} - \frac{(1-a)\Pi w^F}{\rho}\frac{B^F}{V^*}\frac{d\Pi}{\Pi} - \frac{1}{\rho}\frac{\left(C^H + C^F\right)}{V^*}\frac{d\Pi^{US}}{\Pi^{US}}, \tag{6}$$

where $A^F$ is the amount of exports to the foreign country from the home country, $B^F$ is the number of employees in the overseas production base, $w^F$ is the wage rate in the foreign country, and $C^H + C^F$ is the input of primary materials that are used in both home and foreign countries. Now expanding the coverage of the foreign countries where the firm operates and expressing the time and firm by subscripts $t$ and $i$ respectively yields the following equation, which yields:

$$\frac{dV_{it}^*}{V_{it-1}^*} = \alpha_0 + \alpha_1\sum_{n\in N}\frac{A_i^n}{V_{it-1}^*}\frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_2\sum_{n\in N}\frac{B_i^n}{V_{it-1}^*}\frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_3\sum_{n\in N}\frac{C_i^n}{V_{it-1}^*}\frac{d\Pi_t^{US}}{\Pi_{t-1}^{US}} + \varepsilon_{it}, \tag{7}$$

where $\alpha_1 = 1/\rho$, $\alpha_2 = -(1-a)w^F/\rho$, $\alpha_3 = -1/\rho$, $\alpha_0$ is the growth factor that is common to every firm and period, and $\varepsilon_{it}$ is the factor that is peculiar to each firm and period. Also here, $n$ denotes the name of the area (including the home country ($n = H$), $A^n$ is the amount of the exports to area $n$, $B^n$ is the number of workers in area $n$ where the firm has a production base, and $C^n$ is the input of primary materials in area $n$. Here, it should be noted that by definition, $d\Pi^H/\Pi^H = 0$, so that $B^n$ captures only the number of workers in the foreign country. Also note that we treat the term $(1-a)w^F$ as common across the foreign countries.

Now, from the discussion above, the expected signs of the parameters are $\alpha_1 > 0$, and $\alpha_3 < 0$. As for $\alpha_2$, we need a more careful consideration. If the Japanese manufacturers use production bases overseas in order to re-import the goods to Japan, $a$ might be smaller than one, that is, labor costs that are used in foreign countries might be larger than the overseas sales (except for the exports from the headquarters in Japan). So if this hypothesis is correct, $\alpha_2$ should be negative ($\alpha_2 < 0$).

## III. Dynamic Currency Risk Exposure

### (i) Dynamic Maximization Problem of a Firm with Overseas Investment[8]

Consider a firm that produces all the goods in the overseas factory, which has a linear homogeneous production function with regard to the capital stock and labor. All the goods are shipped (re-imported) to the home country. The firm is a price taker in the output market in the home country.

Also assume that the total foreign direct investment costs including adjustment costs can be specified as $\varphi(z)K^F$[9], where $\varphi(z) \geq 0$, $\varphi'(z) > 0$, $\varphi'(0) = 1$, $\varphi''(z) > 0$, $\varphi'''(z) = 0$, and $z = dK^F/K^F$. Intuitively, the more rapidly the firm adjusts its capital stock, the more costly it is. All the costs of installing the new capital stock are assumed to be denominated in the home currency, which implies that the exchange rate uncertainty falls only on the

[8] This type of investment behavior was first proposed by Uzawa (1969).
[9] $\varphi(z)$ is termed the Penrose curve. For details, see Penrose (1959).

labor costs in the foreign factory since all of the labor input is assumed to be procured locally.

For simplicity, let us assume that the firm is never demand-constrained in the output and factor markets. In this case, the firm's problem becomes as follows:

$$\underset{L^F(s), z(s), K^F(s+1)}{Max} D_t + V_t = E_t \left\{ \sum_{s=t}^{\infty} \left( \frac{1}{1+\rho} \right)^{s-t} \left[ F^F\left(L^F(s), K^F(s)\right) - \Pi w^F L^F(s) - \varphi(z(s)) K^F(s) \right] \right\} \tag{8}$$

s.t. $$K^F(s+1) = (1 + z(s)) K^F(s), \tag{9}$$

where $E_t$ is an expectation operator that is conditional on the available information at the beginning of period $t$, $L^F(s)$ is the labor input, $K^F(s)$ is the overseas capital stock in use, $w^F$ is the constant wage rate in the foreign country, $\Pi$ is the exchange rate of the home currency per local currency[10], and $\rho$ denotes the constant subjective discount rate. Ignoring the superscript $F$ and substituting Eq. (9) into Eq. (8) yields the following Lagrangian:

$$\Lambda(t) = E_t \left[ \sum_{s=t}^{\infty} \left( \frac{1}{1+\rho} \right)^{s-t} \left\{ F(K(s), L(s)) - \Pi w L(s) - \varphi(z(s)) K(s) - q(s)\left(K(s+1) - (1 + z(s)) K(s)\right) \right\} \right] \tag{10}$$

where $q(s)$ is the Lagrange multiplier. The first-order condition for labor can be written as

$$\frac{\partial \Lambda(t)}{\partial L(s)} = E_t \left[ F_L(K(s), L(s)) - \Pi w \right] = 0 \,. \tag{11}$$

Next, the first-order condition for investment-capital stock ratio $z(s)$ is

$$\frac{\partial \Lambda(t)}{\partial z(s)} = E_t \left[ -\varphi'(z(s)) K(s) + q(s) K(s) \right] = 0 \,. \tag{12}$$

Lastly, the first-order condition for the capital stock $K(s+1)$[11] is

$$\frac{\partial \Lambda(t)}{\partial K(s+1)} = E_t \left\{ -q(s) + \frac{1}{1+\rho} \left[ F_K(K(s+1), L(s+1)) - \varphi(z(s+1)) + q(s+1)(1 + z(s+1)) \right] \right\} = 0 \,. \tag{13}$$

[10] An increase in $\Pi$ means a depreciation of the home currency as before.

[11] Since in period $s$, $K(s)$ has been already predetermined, the firm's decision variable is $K(s+1)$.

**(ii) Dynamics of the System**

Eqs. (11)-(13) characterize the firm's dynamic behavior. In the steady state, it follows that $E[dq] \equiv E_t[q(t+1)] - q(t) = 0$. By setting $s = t$, Eq. (13) can be rewritten as

$$q(t) = \varphi'(z(t)) = E_t\left[\frac{F_K(K(s+1), L(s+1)) - \varphi(z(t+1))}{\rho - z(t+1)}\right]. \tag{14}$$

Figures A and B present the determination of the optimal value of $z$. Let A be the point $(\rho, F_K)$. Then the value of $q$ can be shown by the slope of the line connecting the points A and B on the Penrose curve, where the capital stock grows at a constant rate of $z$. Note that at the point B, the following transversality condition holds:

$$\lim_{T\to\infty} E_t\left[\left(\frac{1}{1+\rho}\right)^T q(t+T)K(t+T)\right] = 0. \tag{15}$$

**(iii) Dynamic Currency Risk Exposure**

The baseline case assumes that the firm starts with the point O in Figure, where conditions $F_K = \rho$ and $F_L = \Pi w$ hold, so $z = dK/K = 0$ and $q = 1$ follow. Now let us approximate $\varphi(z)$ up to the second-order in the neighborhood of the point O such that

$$\varphi(z) = \varphi(0) + \varphi'(0)z + \frac{1}{2}\varphi'' z^2 = z + \frac{1}{2}\varphi'' z^2. \tag{16}$$

Suppose that an unexpected change in $\Pi$ shifts the expected value of the marginal productivity of the capital stock $E_t[F_K(t+1)]$ from $\rho$ to $\rho + dF_K$. Eq. (14) becomes,

$$q(t) = \varphi'(z(t)) = 1 + \varphi'' E_t[z(t+1)] = \frac{\rho + dF_K - E_t\left[z(t+1) + \frac{1}{2}\varphi'' z(t+1)^2\right]}{\rho - E_t[z(t+1)]}. \tag{17}$$

We can solve this quadratic equation as[12]

$$E_t[z(t+1)] = E_t[dz] = \frac{\rho\varphi'' - \sqrt{(\rho\varphi'')^2 - 2\varphi'' dF_K}}{\varphi''} = \rho - \sqrt{\rho^2 - \frac{2}{\varphi''}dF_K}. \tag{18}$$

Thus, we can express the response of $q$ to an unexpected change in $\Pi$ as

$$\frac{dq}{d\Pi} = \varphi'' E_t \left[ \frac{dz}{dF_K} \frac{dF_K}{d\Pi} \right]. \tag{19}$$

Eq. (19) states that there are two sources from which an asymmetric effect can occur in currency risk exposure between depreciation and appreciation shocks. One possible source is the relative magnitude in $E_t[dz]$ between depreciation and appreciation shocks due to the presence of the radical term of the functional form of $E_t[dz]$. It can be easily shown that if we consider this source only, the following relation holds:

$$\left.\frac{dq}{d\Pi}\right|_{d\Pi>0} < \left.\frac{dq}{d\Pi}\right|_{d\Pi<0}, \qquad \text{if} \quad \left.\frac{dF_K}{d\Pi}\right|_{d\Pi>0} = \left.\frac{dF_K}{d\Pi}\right|_{d\Pi<0}. \tag{20}$$

Another possibility of the asymmetry stems from the shape of the Penrose curve. Suppose, for instance, the situation in which it is more costly for the firm to reduce the capital stock than to increase it. This situation corresponds to the so-called irreversibility of investment[13]. In this case, $\varphi''|_{dK/K<0} > \varphi''|_{dK/K>0}$ should hold, which implies that the following relationship is possible if and only if the irreversibility effect is larger than the effect shown in Eq. (19)[14], that is

$$\left.\frac{dq}{d\Pi}\right|_{d\Pi>0} > \left.\frac{dq}{d\Pi}\right|_{d\Pi<0}, \qquad \text{if} \quad \left.\frac{dF_K}{d\Pi}\right|_{d\Pi>0} = \left.\frac{dF_K}{d\Pi}\right|_{d\Pi<0}. \tag{21}$$

The discussion so far presumes that the firm is initially at the (neutral) point O[15]. In reality, however, depending on the initial level (not the direction) of the exchange rate $\Pi$, the firm might be always in the process of expanding or withdrawing from the overseas production particularly during a relatively short period. In the context of the foreign direct investment, Japanese manufacturers have been seeking to expand their overseas production base since 1985 in response to the steady appreciation of the yen, so that they have been much more likely to be always in expanding phase than in

[12] We disregard another solution because it violates the transversality condition.
[13] Bernanke (1983) is an important early work on irreversibility.
[14] Here, I implicitly assume that the effect of the asymmetric value of $\varphi''$ on $E_t[dz]$ is small enough.
[15] Strictly speaking, the above result holds as long as the exchange rate shock changes the phase expansion to withdrawal or vice versa.

withdrawing (or neutral) phase in this period. Thus, the irreversibility effect on currency risk exposure might not have a role in determining the relative magnitude in the response of $q$ of the Japanese manufacturers between appreciation and depreciation shocks.

**(iii) The Stock Market Value of the Firm and Marginal q**

Linear homogeneity of production and the Penrose functions inplies

$$q(t)K(t+1) = E_t\left[\sum_{s=t+1}^{\infty}\left(\frac{1}{1+\rho}\right)^{s-t}\left[F(K(s), L(s)) - \Pi wL(s) - \varphi(z(s))K(s)\right]\right] \equiv V(t), \tag{22}$$

given that the transversality condition holds. Thus, the equality of marginal and average $q$ is shown, as established by Hayashi (1982), which implies that the argument so far about marginal $q$ is valid in terms of the stock market value of the firm that is used in empirical analysis later.

Now let us evaluate currency risk exposure in terms of the current number of employees. Similarly in the last section, we can use the envelope theorem to evaluate the change in the value of the firm in response to an unexpected exchange rate shock. In the case in which the firm is always in expanding or withdrawing phase, it follows that

$$\frac{dV^*(t)}{d\Pi} = -E_t\left[\sum_{s=t+1}^{\infty}\left(\frac{1}{1+\rho}\right)^{s-t} L^*(s)w\right] = -w\overline{L}\left[\sum_{s=t+1}^{\infty}\left(\frac{1+z^*}{1+\rho}\right)^{s-t}\right], \tag{23}$$

where $\overline{L}$ denotes the initial number of workers before the shock and superscript * denotes the optimal value after the shock. Here, it should be noted that the rate of adjustment in labor input is the same as that in the capital stock due to the linear homogeneity of the production function. In terms of the elasticity, Eq. (23) can be written as

$$\frac{dV^*(t)}{V^*(t)} = -\frac{\Pi w\overline{L}}{V^*(t)}\left[\sum_{s=t+1}^{\infty}\left(\frac{1+z^*}{1+\rho}\right)^{s-t}\right]\frac{d\Pi}{\Pi}, \tag{24}$$

where $E_t[z^*]_{d\Pi>0} < E_t[z^*]_{d\Pi<0}$ holds if we measure it from the same initial level of $\Pi$.

On the other hand, if the firm is initially at the point O,

$$\frac{dV^*(t)}{V^*(t)} = -\frac{\Pi\bar{L}}{V^*(t)}\left[w + \frac{1}{2}\varphi'' z^{*2}\left(\frac{w\Pi}{1-\alpha}\right)^{1/\alpha}\right]\left[\sum_{s=t+1}^{\infty}\left(\frac{1+z^*}{1+\rho}\right)^{s-t}\right]\frac{d\Pi}{\Pi}, \tag{25}$$

where we use the Cobb-Douglas functional form $Q = L^{\alpha}K^{1-\alpha}$ to evaluate $K^*$ as a function of $L$ and other parameters. These equations show a dynamic currency risk exposure effect, whose impact depends upon the number of the overseas workers in the initial state.

Eq. (25) tells us that if the irreversibility effect denoted $\varphi''|_{dK/K<0} > \varphi''|_{dK/K>0}$ is large enough, there is a possibility that the exposure effect is larger in magnitude in the case of depreciation than in the case of appreciation despite the fact that $E_t[z^*]_{d\Pi>0} < E_t[z^*]_{d\Pi<0}$. Remember, however, that this argument is also valid if the initial state coincides the point O, but the exchange rate shock changes the phase from expansion to withdrawal, or vice versa. The discussion above can be summarized in the following proposition:

**PROPOSITION 2**: *The level (not the direction) of the exchange rate determines whether the firm should be expanding or withdrawing from overseas production. If the firm is initially at the point where foreign direct investment is zero, or the exchange rate shock is large enough to change the phase between expansion and withdrawal, then the degree of irreversibility has a role in determining the relative magnitude in currency risk exposure between appreciation and depreciation shocks. If the firm is always in expanding or withdrawing phase in sample periods, however, the irreversibility does not have any role in it.*

## IV. The Data

As sample firms, we choose the firms classified in electric and precision machinery listed on the Tokyo Stock Exchange. This is because they are generally highly dependent on international operations such as exports, imports of primary materials, and overseas production. The number of the sample firms turned out to be 84, of which 74 firms belong to the electric machinery industry and the remaining 10 firms belong to the precision machinery industry.

**(i) The Value of the Firm**

The value of the firm is calculated as the estimated sum of the market value of net liabilities and capital. Each component is computed as follows.

**A. Method for Computing the Market Value of Net Liabilities**

Since circulating assets other than inventory and circulating liabilities have a property of high turnover in a relatively short period, we regard their book values as their market values. On the other hand, concerning the fixed liabilities accompanying interest payments such as borrowing and corporate bonds, we compute their market values by discounting the total interest payments by appropriate interest rates.

**B. Method for Computing the Market Value of Capital**

Some existing studies adopt the method of discounting the dividend by the interest rate to compute the market value of the capital per unit of the stock[16]. But, in this paper, in order to capture daily market values of the capital, we use the method of multiplying the stock price by the number of outstanding shares[17].

**C. Data Sources**

Financial Data : Annual Financial Report

Stock Price : *Nihonkeizai Shimbun* (Nikkei News Paper), various daily issues

Number of Existing Shares: *Kigyo Zaimu Karute* (Chart of Corporate Financial Affaires),

[16] For example, Tobin and Brainard (1977) use this method.

edition of FY1994, Toyo Keizai Inc, Tokyo, Japan

Interest Rates : Annual Report on Economic Statistics (Bank of Japan)

**(ii) Independent Variables**

**A. The Degree of Dependency on Exports**

To construct this variable, we first aggregate the exports of each firm into three large regions (American continent, European continent, and Asian, Oceanic and African region). Second, we multiply the aggregated exports by the corresponding rates of change in the effective exchange rate of the Japanese yen. Third, dividing the results for each region by the value of the firm and summing up over the three regions yield our index of degree of the dependency on exports.

We calculate the effective exchange rates of the yen[18]by taking a weighted average of daily nominal exchange rates change of 6 currencies in the case of the American continent, 16 currencies in the case of the European continent, and 14 currencies in the case of the Asian, Oceanic, and African region.

**B. The Degree of Dependency on Overseas Production**

First, we calculate the number of workers in the foreign production base as the number of employees (unit =1000) times the capital (equity) ratio of the firm in its subsidiary[19]. Second, multiplying the level of the overseas production by the rate of change in the effective exchange rate of the yen and dividing it by the value of the firm yields our measure of the degree of dependency on overseas production by region.

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[17] Stock prices are adjusted for temporary declines due to write-offs, which occur when a firm increases its capital.

[18] For details on the currencies and weights used to calculate the effective exchange rate by region, see the Appendix. We use the amount of the exports of electric machinery from Japan to each county as the weight.

[19] The data source of the number of employees of overseas subsidiaries and the capital ratios is "General Survey of Companies with Overseas Operations" (*Kaigai Shinshutsu Kigyou Soran*: Toyo Keizai Inc, Tokyo Japan).

**C. The Degree of Dependency on Imported Primary Materials**

In most cases, the headquarters in Japan purchase this kind of factor collectively for use in their overseas subsidiaries, so we can focus on the headquarters' data. Since imported primary materials are not listed explicitly in the annual corporate financial report, we are obliged to regard the sum of material and fuel under the category of primary materials[20] times the nominal yen-dollar exchange rate divided by the value of the firm as our measure of the degree of dependency on imported materials.

## V. Empirical Issues

**(i) Two Types of the Dependent Variable**

We use the following two types of the dependent variables:

$$\left.\frac{d\Omega_{it}^{*}}{\Omega_{it-1}^{*}}\right|_{g}=\frac{dV_{it}^{*}}{V_{it-1}^{*}}-Const_{i}-\sum_{j\in R}\theta_{j}Day_{j}\ , \tag{26}$$

and

$$\left.\frac{d\Omega_{it}^{*}}{\Omega_{it-1}^{*}}\right|_{n}=\frac{dV_{it}^{*}}{V_{it-1}^{*}}-Const_{i}-\sum_{j\in R}\theta_{j}Day_{j}-\beta_{i}\frac{dV_{mt}}{V_{mt-1}}\ . \tag{27}$$

Here, $V_m$ denotes the value of the sum of all the firms listed in the Tokyo Stock Exchange, which corresponds to the market portfolio in the Capital Assets Pricing Model (CAPM), and so $\beta_i$ provides a measure of market-risk sensitivity of each firm. $Day_j$ is a dummy variable that takes 1 if the day is *j* and takes 0 otherwise, so $\theta_j$ denotes the coefficient of the day-of-the-week effect[21].

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[20] We define the material that is not processed at all or undergoes a minimum processing necessary for trading (copper plate, steel, etc) as the primary materials transacted internationally. Further, we calculate the sum of material and fuel as its quantity times their prices reported in annual financial report. In so doing, the firms that report the price information in the form of an index rather than in terms of absolute values are excluded from the sample firms.

[21] A number of studies have uncovered evidence that refutes the belief that the expected daily returns on stocks are the same for all days of the week. For early evidence on NYSE-listed securities, see French (1980) and Gibbons and Hess (1981).

In other words, we employ the two-step procedure in which first, the components that exclude the influences of the day-of-the-week effect and market portfolio are estimated using the whole sample, and then each exposure coefficient is estimated[22]. The measure (26) is meant to capture the "gross" effect of currency risk exposure. On the other hand, the measure (27) captures the "net" effect.

### (ii) Econometric Methodology

### A. Fundamental Estimation Methods

Generally, a panel data model can be expressed as

$$y_{it} = \alpha_i + \beta x_{it} + \mu_i + v_{it} . \tag{28}$$

In this setting, if we assume that $\alpha_i = \alpha$ and $\mu_i s$ are fixed for all *i*, Eq. (28) can be viewed as the pooling (OLS) model.

Next, if the $\mu_i$ s are assumed to be fixed parameters and the disturbance $v_{it}$ to be stochastic distributed $iid(0, \sigma_v^2)$, the model becomes the fixed effects model. Note that the $x_{it}$ s are assumed to be independent of the $v_{it}$ s.

Here, the loss of degrees of freedom can be avoided if $\mu_i$ is assumed to be random. In this case, $\mu_i \sim iid(0, \sigma_\mu^2)$, $v_{it} \sim iid(0, \sigma_v^2)$ and the $\mu_i$ s are independent of the $v_{it}$ s for all *i* and *t*. Now the model can be stated as $y_{it} = \alpha + \beta x_{it} + \mu_i + v_{it}$ . This is the random effects model.

[22] This procedure is used by Bartov and Bodnar (1994). In contrast, Jorion (1990) and Bodnar and Gentry (1993) use a one-step approach with raw returns on the left-hand side and the market portfolio and other variables on the right-hand side of the regression. Christie, Kennelley, King, and Schaeffer (1984) argue that the two-step method can result in downward biased *t*-statistics.

## B. Basic Specification Tests

### (a) Pooling (OLS) Estimator vs. Fixed Effects Estimator

The hypothesis that fixed effects are jointly zero is tested by an $F$-test such that

$$F(n-1, nT-n-K) = \frac{\left(R^2_{FIXED} - R^2_{POOL}\right)/(n-1)}{\left(1-R^2_{FIXED}\right)/(nT-n-K)}, \tag{29}$$

where $R^2$ denotes the coefficient of determination. $n$ is the number of the units, $T$ is the number of time periods, and $K$ is the number of regressors of the OLS.

### (b) Pooling (OLS) Estimator vs. Random Effects Model Estimator

Breush and Pagan (1980) proposed a Lagrange Multiplier (LM) test specified as

$$LM = \frac{nT}{2(T-1)}\left[\left\{\sum_{i=1}^{N}\left(\sum_{t=1}^{T}\varepsilon_{it}\right)^2 \Big/ \sum_{i=1}^{N}\sum_{t=1}^{T}\varepsilon_{it}^2\right\} - 1\right]^2, \tag{30}$$

where $\varepsilon_{it}$ is the pooling model residual. Under the null hypothesis of $\sigma^2_{\mu} = 0$, $LM$ is distributed as chi-squared with one degree of freedom

### (c) Random Effects Estimator vs. Fixed Effects Estimator

Hausman (1978) devised the following chi-squared statistic for testing whether the random effects estimator is an appropriate alternative to the fixed effects estimator:

$$H = \frac{\left(\hat{\beta}_{FIXED} - \hat{\beta}_{RANDOM}\right)^2}{Var\left(\hat{\beta}_{FIXED}\right) - Var\left(\hat{\beta}_{RANDOM}\right)}. \tag{31}$$

## C. Potential Econometric Problems and Procedures for Eliminating them

### (a) Endogeneity of Regressors

Performance in the stock market might feed back into the exchange rates markets. The exchange rates might be a function of, for example, money supply and/or the interest rates. They, in turn, might be a function of the overall performance in the stock market (probably, causality runs in both directions) as long as the arbitrage between those markets works. Since the overall performance in the stock market is endogenous, so too are exchange rates. In fact, our "gross" measure of firm values, which includes the overall stock market trend, might contain a higher degree of such feedback effects than the "net" measure of firm values, which captures only the so-called "abnormal" returns.

To explain the endogeneity problem in a panel data setting, let us assume the simplest form of estimation equation with a single regressor and no constant term as follows:

$$y_{it} = \beta x_{it} + \varepsilon_{it} \qquad (\varepsilon_{it} = \mu_i + v_{it}). \tag{32}$$

In this model, endogeneity manifest itself through $Cov(\varepsilon_{it}, x_{it}) \neq 0$. $Cov(\mu_i, x_{it}) \neq 0$ can be tested using the Hausman test statistic (31). Under the null hypothesis of $Cov(\mu_i, x_{it}) = 0$, the fixed and random effects estimators should be equivalent. In the case in which the null hypothesis is rejected, the use of a fixed effects model can eliminate the bias.

It should be emphasized, however, that the estimated coefficients still might be biased as a consequence of $Cov(v_{it}, x_{it}) \neq 0$. So we need a more powerful test procedure to detect it. To this end, the following test procedure is devised by Spencer and Berk (1981).

Suppose that $w_{it}$ is an instrumental variable that is correlated with the regressor $x_{it}$, but not with the disturbance $v_{it}$. To perform the test, estimate the following equation:

$$y_{it} = \beta_1 x_{it} + (\beta_2 - \beta_1)\hat{e}_{it} + \varepsilon_{it}, \tag{33}$$

where $x_{it} = \hat{x}_{it} + \hat{e}_{it}$ and $\hat{x}_{it} = \hat{b} w_{it}$. Under the null hypothesis of no endogeneity, $\beta_1 = \beta_2$ holds, so that the coefficient on $\hat{e}_{it}$ should be zero. This test can be performed by a *t* test in the case in which we are concerned with the endogeneity of one variable, and an *F* test in the case of more than one variable[23]. The discussion above implies that the bias that stems from $Cov(v_{it}, x_{it}) \neq 0$ can be eliminated by using the instrumental variables (IV).

[23] Note that the test just described is one variant of a Hausman specification test.

**(b) Measurement Errors (Errors in Variables)**

As we mentioned in the data section, it is highly probable that some variables, especially the dependency on imported primary materials be seriously subject to measurement errors. Now suppose that the observed $y_{it}^*$ and $x_{it}^*$ contain errors of measurement such that

$$y_{it}^* = y_{it} + \tau_{it} \text{ with } \tau \sim N(0, \sigma_\tau), \text{ and } x_{it}^* = x_{it} + \upsilon_{it} \text{ with } \upsilon \sim N(0, \sigma_\upsilon). \tag{34}$$

Assume further that $\tau_{it}$ and $\upsilon_{it}$ are independent of each other as well as with $x_{it}$, and each process involves no serial correlation. The estimated regression equation will be the form:

$$y_{it}^* = \beta x_{it}^* + (\tau_{it} - \beta \upsilon_{it}) = \beta x_{it}^* + \varepsilon_{it}^*. \tag{35}$$

Eq. (35) suggests that the presence of measurement errors will lead to an underestimate of the true regression parameter if the OLS is used. Notice that measurement error of the dependent variable $\tau_{it}$ does not any impact on the estimated coefficient $\hat{\beta}$. It turns out that also in this case, the use of the instrumental variables is the key to eliminating this bias and thus, testing measure for the presence of measurement errors is essentially the same as in the case of endogeneity.

**(c) Choice of Instrumental Variables**

First, it is possible to use as instrumental variables the lagged values of the independent variables. They are likely to be contemporaneously correlated with the original independent variables, but, once lagged, they might not be correlated with the disturbance term.

Second, given the high correlation between the exchange rates and interest rates, lagged values of the 10-year government bond rate can be a good candidate of instrumental variables[24].

## VI. Empirical Results

### (i) Choice of Sample Periods

We pick up sample periods of (i) 30 business days, (ii) 60 business days, and (iii) 90 business days during which the rates of change in the yen-dollar exchange rate were the largest, as well as the whole sample, which covers January 18 to December 29 in 1995.

### (ii) Empirical Results

First, we look at the regression results for the whole period (Table 1)[25]. According to the specification test results, the fixed effects model is rejected in terms of the $F$ and the Hausman tests. On the other hand, $LM$ test result is in favor of the random effects model against the pooling model. Thus, if endogeneity and/or measurement errors problems are not present, the random effects model ought to be the best one to refer to. Endogeneity (or measurement errors) test results, however, suggest the significant rejection of the null hypothesis of $Cov(\varepsilon_{it}, x_{it}) = 0$, which reveals that the random effects model does not yield a consistent estimator. Since the $F$ statistic for the significance of the fixed effects have already rejected the fixed effects model, the pooling IV model should be the right choice.

All the coefficients estimated by the pooling IV model rejects the null hypothesis of no currency exposure, highly significantly satisfying the sign required by our theory except for the coefficient on the dependency on imported primary materials in the case in which the net measure is used. Especially, the coefficient on the dependency on overseas

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[24] We use up-to-five-day lags. As for the long-term interest rate, we use the first difference form.

production is significantly found to be negative, which suggests that the major aim to establish overseas production bases is to re-import goods to Japan. Comparing the results between the gross and net measures of the value of the firm, each coefficient is larger in magnitude in the case of the gross measure than in the case of the net measure. This is an easily expected result, since the gross measure of the value of the firm fully reflects the overall stock market performance, which is thought to be more closely correlated with the macroeconomic variables, including exchange rates than the (abnormal) net measure of the value of the firm.

Now take a look at Table 2, which reports regression results on the asymmetric dynamic currency exposure effect. The results of the pooling IV model tell us that when we use the gross measure, the coefficient dummy variable (which equals one when the yen depreciates against the U.S. dollar, and zero, otherwise) on the dependency on overseas production takes a significantly positive value, suggesting that the dynamic currency risk exposure effect in the case in which the firm is in expanding phase is present. In the case of the net measure, however, it takes a positive value, but not significant.

Table 3 reports the regression results for various short sub-periods. An overall impression is that especially in the appreciation periods, the performance of the regression is much poorer than when we use the overall sample. If we look at the results in the depreciation period, however, we can get much better results than in the appreciation periods. For example, in the case of the 30-day period, all the coefficients obtained by the pooling IV model significantly satisfy the expected sign regardless of which measure of the value of the firm is used. One of the most conceivable reasons for this difference in the performance between the appreciation and depreciation periods is that investors in the stock market were sure that the rapid appreciation of the yen was not permanent. If that is

[25] We use White's (1980) method for correcting the heteroscedasticity of the disturbance term.

the case, they might prefer to wait and see for some time until their uncertainty of the exchange rates will be clear.

The last thing to note is that the coefficients of determination $R^2$ in the regressions are extremely small in most of the cases. Thus, it might be safer to further examine the overall fit of each model. As one way to do that, we computed the $F$ statistics under the null hypothesis that all the slope coefficients are jointly zero. It turns out that except for a few exceptions, pooling estimators significantly rejects the null hypothesis, while the fixed effects estimators cannot significantly reject it. As shown by the specification test for testing fixed effects, overall performance of fixed effects is so poor that the larger number of degrees of freedom lost undermines the significance level of the $F$-statistics.

Now, it might be a good idea to evaluate the estimated coefficients in terms of the economic significance. Using the coefficients of the pooling IV model reported in Table 2 yields the following simulation result in terms of the gross measure of the value of the firm. First, when the Japanese yen depreciates (appreciates) 10% uniformly against all the currencies, the value of the firm that exports 10 billion yen will instantaneously rise (decline) by 3.7 billion yen. Second, the value of the firm that employs 1,000 workers abroad will instantaneously decline (rise) by 2.4 (3.7) billion yen when the Japanese yen uniformly depreciates (appreciates) by 10%.  Lastly, the value of the firm that imports 10 billion yen of primary materials will rise (decline) 10.2 billion yen when the Japanese yen depreciates (appreciates) against the U.S. dollar by 10 %.

If we assume that these results hold for all Japanese manufacturing firms, we can simulate a macro-economic impact as follows. First, using the fact that the total value of exports of goods by Japanese firms in the fiscal year 1995 is about 41,000 billion yen[26], we can estimate that a 10% depreciation (appreciation) of the yen will cause the total

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[26] This data is taken from "Balance of Payments, Monthly," Bank of Japan.

value of all Japanese manufacturing firms to rise (decline) by about 15,100 billion yen, which corresponds to about 1.3 times the level of current profits[27] of all the manufacturing firms in the fiscal year 1995. Similarly, from the fact that the total number of overseas employees of all Japanese manufacturing firms is about 2,119,000[28], we can show that a 10% depreciation (appreciation) of the yen will cause the total value of all Japanese manufacturing firms to decline (rise) by about 5,100 (7,800) billion yen, which approximately corresponds to about 40% of the level of current profits. Third, since the total value of imports of primary materials[29] in 1995 is about 15,000 billion yen, a 10% depreciation (appreciation) of the yen will decline (raise) the total value of all the Japanese manufacturing firms by about 15,200 billion yen, which is about 1.3 times of the current profits.

## VII. Concluding Remarks

This paper explores a new aspect on currency risk exposure of the firms with overseas production bases. Empirical results generally confirm the predictions by our model, although it is highly simplified. We hope that this direction of research will enrich our understanding of currency risk exposure.

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[27] The data source is "Financial Statements Statistics of Corporations by Industry," Ministry of Finance.

[28] The data source is "*Kaigai Shinshutsu Kigyou Soran*" (General Survey of Companies with Overseas Operations): *Toyo Keizai* Inc, Tokyo Japan). The survey of this literature was conducted in October, 1995.

[29] We calculated this figure as the sum of imports of foods, raw materials, metal materials and products, and nonmetal materials and products. This data is taken from "Trade Statistics", Ministry of Finance.

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## Table 1: Regression Results for the Whole Period

(January 18-December 29 Number of Observations=20,160)

(a) Gross Measure: $$\left.\frac{d\Omega_{it}^*}{\Omega_{it-1}^*}\right|_g = \alpha_i + \alpha_1 \sum_{n\in N} \frac{A_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_2 \sum_{n\in N} \frac{B_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_3 \sum_{n\in N} \frac{C_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^{US}}{\Pi_{t-1}^{US}} + \varepsilon_{it}$$

[Specification Tests]

| | Null Hypothesis | Test Statistic |
|---|---|---|
| *F* Test (Pooling vs. Fixed Effects) | $H_0$: $\alpha_i$=0 for all *i* | 0.01 |
| *LM* Test (Pooling vs. Random Effects) | $H_0$: $\sigma_u^2$=0 | 41.17*** |
| Hausman Test (Fixed Effects vs. Random Effects) | $H_0$: Cov($u_i$, $x_{it}$)=0 | 0.00 |
| *F* Test (Endogeneity & Measurement Errors) | $H_0$: Cov($e_{it}$, $x_{it}$)=0 | 25.21*** |

[Regression Results]

| | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | *F* (all α's=0) | $R^2$ |
|---|---|---|---|---|---|---|
| A. Pooling Model | | | | | | |
| (i) OLS | 0.970E-04 | 0.318 | -1.322 | -0.303E-01 | 14.55*** | 0.002 |
| | ( 0.668) | ( 6.415)*** | (-4.132)*** | (-0.102) | | |
| (ii) Instrumental Variables | 0.162E-04 | 3.856 | -30.220 | -9.895 | ---------- | ---------- |
| | ( 0.092) | ( 5.615)*** | (-7.131)*** | (-1.710)* | | |
| B. Fixed Effects Model | | | | | | |
| (i) OLS | --------- | 0.318 | -1.324 | -0.306E-01 | 0.52 | 0.002 |
| | ( --------- ) | ( 4.723)*** | (-3.397)*** | (-0.062) | | |
| (ii) Instrumental Variables | --------- | 4.210 | -33.224 | -13.153 | ---------- | ---------- |
| | ( --------- ) | ( 5.246)*** | (-6.920)*** | (-1.697)* | | |
| C. Random Effects Model | 0.9704E-04 | 0.317 | -1.322 | -0.303E-01 | ---------- | ---------- |
| | ( 0.662) | ( 6.402)*** | (-4.124)*** | (-0.102) | | |

(b) Net Measure: $$\left.\frac{d\Omega_{it}^*}{\Omega_{it-1}^*}\right|_n = \alpha_i + \alpha_1 \sum_{n\in N} \frac{A_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_2 \sum_{n\in N} \frac{B_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_3 \sum_{n\in N} \frac{C_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^{US}}{\Pi_{t-1}^{US}} + \varepsilon_{it}$$

[Specification Tests]

| | Null Hypothesis | Test Statistic |
|---|---|---|
| *F* Test (Pooling vs. Fixed Effects) | $H_0$: $\alpha_i$=0 for all *i* | 0.01 |
| *LM* Test (Pooling vs. Random Effects) | $H_0$: $\sigma_u^2$=0 | 41.02*** |
| Hausman Test (Fixed Effects vs. Random Effects) | $H_0$: Cov($u_i$, $x_{it}$)=0 | 0.00 |
| *F* Test (Endogeneity & Measurement Errors) | $H_0$: Cov($e_{it}$, $x_{it}$)=0 | 5.75*** |

[Regression Results]

| | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | *F* (all α's=0) | $R^2$ |
|---|---|---|---|---|---|---|
| A. Pooling Model | | | | | | |
| (i) OLS | 0.147E-04 | 0.107 | -0.826 | -0.544 | 3.88*** | 0.001 |
| | ( 0.113) | ( 2.398)** | (-2.867)*** | (-2.036)** | | |
| (ii) Instrumental Variables | 0.283E-04 | 1.699 | -12.888 | -5.532 | ---------- | ---------- |
| | ( 0.204) | ( 3.288)*** | (-3.862)*** | (-1.214) | | |
| B. Fixed Effects Model | | | | | | |
| (i) OLS | --------- | 0.107 | -0.828 | -0.545 | 0.15 | 0.001 |
| | ( --------- ) | ( 1.837)* | (-2.407)** | (-1.188) | | |
| (ii) Instrumental Variables | --------- | 1.958 | -14.295 | -7.198 | ---------- | ---------- |
| | ( --------- ) | ( 2.655)*** | (-3.232)*** | (-0.993) | | |
| C. Random Effects Model | 0.147E-04 | 0.107 | -0.826 | -0.544 | ---------- | ---------- |
| | ( 0.112) | ( 2.393)** | (-2.861)*** | (-2.032)** | | |

*Notes*: 1. We use a linear combination of (up to 5-day) lagged 10-year government bond yield (first difference form) and each regressor as instrumental variables.
2. Figures in parentheses are *t*-values in two-tail tests.
(*: significant at 10% level **: significant at 5% level ***: significant at 1% level)
3. The *t*-values are computed based on heteroscedasticity–corrected standard error estimators obtained by the method proposed by White (1980).

**Table 2: Regression Results on the Asymmetric Dynamic Currency Risk Exposure**

(January 18-December 29 Number of Observations=20,160)

(a) Gross Measure: $\left.\frac{d\Omega_{it}^{*}}{\Omega_{it-1}^{*}}\right|_{g} = \alpha_i + \alpha_1 \sum_{n\in N} \frac{A_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^n}{\Pi_{t-1}^n} + \left(\alpha_2 + \alpha_2^d * Dum\right) \sum_{n\in N} \frac{B_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_3 \sum_{n\in N} \frac{C_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^{US}}{\Pi_{t-1}^{US}} + \varepsilon_{it}$

[Specification Tests]

| | Null Hypothesis | Test Statistic |
|---|---|---|
| *F* Test (Pooling vs. Fixed Effects) | $H_0$: $\alpha_i$=0 for all *i* | 0.01 |
| *LM* Test (Pooling vs. Random Effects) | $H_0$: $\sigma_u^2$=0 | 41.17*** |
| Hausman Test (Fixed Effects vs. Random Effects) | $H_0$: Cov($u_i$, $x_{it}$)=0 | 0.01 |
| *F* Test (Endogeneity & Measurement Errors) | $H_0$: Cov($e_{it}$, $x_{it}$)=0 | 20.86*** |

[Regression Results]

| | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_2^d$*Dum | $\alpha_3$ | *F* (all $\alpha$'s=0) | $R^2$ |
|---|---|---|---|---|---|---|---|
| A. Pooling Model | | | | | | | |
| (i) OLS | 0.111E-03 | 0.318 | -1.219 | -0.203 | -0.301E-01 | 10.96*** | 0.002 |
| | ( 0.744) | ( 6.414)*** | (-3.042)*** | (-0.428) | (-0.102) | | |
| (ii) Instrumental Variables | -0.105E-04 | 3.677 | -36.499 | 12.108 | -10.215 | ---------- | ---------- |
| | (-0.058) | ( 5.523)*** | (-7.086)*** | ( 2.212)** | (-1.740)* | | |
| B. Fixed Effects Model | | | | | | | |
| (i) OLS | --------- | 0.318 | -1.186 | -0.274 | -0.303E-01 | 0.51 | 0.002 |
| | ( --------- ) | ( 4.718)*** | (-1.745)* | (-0.163) | (-0.061) | | |
| (ii) Instrumental Variables | --------- | 4.200 | -39.243 | 11.829 | -13.544 | ---------- | ---------- |
| | ( --------- ) | ( 5.227)*** | (-7.315)*** | ( 2.195)** | (-1.745)* | | |
| C. Random Effects Model | 0.1114E-03 | 0.318 | -1.219 | -0.204 | -0.301E-01 | ---------- | ---------- |
| | ( 0.738) | ( 6.401)*** | (-3.033)*** | (-0.427) | (-0.101) | | |

(b) Net Measure: $\left.\frac{d\Omega_{it}^{*}}{\Omega_{it-1}^{*}}\right|_{n} = \alpha_i + \alpha_1 \sum_{n\in N} \frac{A_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^n}{\Pi_{t-1}^n} + \left(\alpha_2 + \alpha_2^d * Dum\right) \sum_{n\in N} \frac{B_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_3 \sum_{n\in N} \frac{C_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^{US}}{\Pi_{t-1}^{US}} + \varepsilon_{it}$

[Specification Tests]

| | Null Hypothesis | Test Statistic |
|---|---|---|
| *F* Test (Pooling vs. Fixed Effects) | $H_0$: $\alpha_i$=0 for all *i* | 0.03 |
| *LM* Test (Pooling vs. Random Effects) | $H_0$: $\sigma_u^2$=0 | 40.29*** |
| Hausman Test (Fixed Effects vs. Random Effects) | $H_0$: Cov($u_i$, $x_{it}$)=0 | 0.45 |
| *F* Test (Endogeneity & Measurement Errors) | $H_0$: Cov($e_{it}$, $x_{it}$)=0 | 4.50*** |

[Regression Results]

| | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_2^d$*Dum | $\alpha_3$ | *F* (all $\alpha$'s=0) | $R^2$ |
|---|---|---|---|---|---|---|---|
| A. Pooling Model | | | | | | | |
| (i) OLS | 0.619E-04 | 0.107 | -0.473 | -0.696 | -0.544 | 3.57*** | 0.001 |
| | ( 0.461) | ( 2.394)** | (-1.310) | (-1.627) | (-2.035)** | | |
| (ii) Instrumental Variables | -0.387E-04 | 1.696 | -15.355 | 4.757 | -5.658 | ---------- | ---------- |
| | (-0.277) | ( 3.267)*** | (-3.823)*** | ( 1.114) | (-1.236) | | |
| B. Fixed Effects Model | | | | | | | |
| (i) OLS | --------- | 0.107 | -0.270 | -1.110 | -0.543 | 0.19 | 0.001 |
| | ( --------- ) | ( 1.830)* | (-0.415) | (-1.173) | (-1.188) | | |
| (ii) Instrumental Variables | --------- | 1.954 | -16.688 | 4.702 | -7.353 | ---------- | ---------- |
| | ( --------- ) | ( 2.648)*** | (-3.277)*** | ( 0.947) | (-1.013) | | |
| C. Random Effects Model | 0.6254E-04 | 0.107 | -0.468 | -0.706 | -0.544 | ---------- | ---------- |
| | ( 0.456) | ( 2.390)** | (-1.291) | (-1.632) | (-2.031)** | | |

*Notes* 1. Dum=1 if the Japanese yen depreciates against the U.S. dollar, and Dum=0 otherwise.
2. We use a linear combination of (up to 5-day) lagged 10-year government bond yield (first difference form) and each regressor as instrumental variables.
3. Figures in parentheses are *t*-values in two-tail tests.
(*: significant at 10% level **: significant at 5% level ***: significant at 1% level)
4. The *t*-values are computed based on heteroscedasticity–corrected standard error estimators obtained by the method proposed by White (1980).

## Table 3: Regression Results for the Short Sub-Periods

**(i) Appreciation Periods**

A. 30-day period (February 28-April 11: Number of Observations=2,520)

(a) Gross Measure: $\left.\frac{d\Omega_{it}^{*}}{\Omega_{it-1}^{*}}\right|_{g}=\alpha_i+\alpha_1\sum_{n\in N}\frac{A_i^n}{\Omega_{it-1}^{*}}\frac{d\Pi_t^n}{\Pi_{t-1}^n}+\alpha_2\sum_{n\in N}\frac{B_i^n}{\Omega_{it-1}^{*}}\frac{d\Pi_t^n}{\Pi_{t-1}^n}+\alpha_3\sum_{n\in N}\frac{C_i^n}{\Omega_{it-1}^{*}}\frac{d\Pi_t^{US}}{\Pi_{t-1}^{US}}+\varepsilon_{it}$

[Specification Tests]

| | Null Hypothesis | Test Statistic |
|---|---|---|
| *F* Test (Pooling vs. Fixed Effects) | $H_0$: $\alpha_i$=0 for all *i* | 0.29 |
| *LM* Test (Pooling vs. Random Effects) | $H_0$: $\sigma_u^2$=0 | 22.00*** |
| Hausman Test (Fixed Effects vs. Random Effects) | $H_0$: Cov($u_i$, $x_{it}$)=0 | 0.21 |
| *F* Test (Endogeneity & Measurement Errors) | $H_0$: Cov($e_{it}$, $x_{it}$)=0 | 15.94*** |

[Regression Results]

| | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | *F* (all α's=0) | $R^2$ |
|---|---|---|---|---|---|---|
| A. Pooling Model | | | | | | |
| (i) OLS | -0.173E-02 | -0.759E-01 | -0.660 | -2.142 | 4.63*** | 0.005 |
| | (-3.492)*** | (-0.574) | (-0.832) | (-2.846)*** | | |
| (ii) Instrumental Variables | -0.313E-02 | -0.881 | 0.255 | -4.863 | ---------- | ---------- |
| | (-5.388)*** | (-2.912)*** | ( 0.152) | (-3.155)*** | | |
| B. Fixed Effects Model | | | | | | |
| (i) OLS | --------- | -0.634E-01 | -0.900 | -2.280 | 0.43 | 0.015 |
| | ( --------- ) | (-0.404) | (-0.950) | (-1.433) | | |
| (ii) Instrumental Variables | --------- | -1.357 | -0.886 | -7.262 | ---------- | ---------- |
| | ( --------- ) | (-0.771) | (-0.012) | (-0.588) | | |
| C. Random Effects Model | -0.173E-02 | -0.736 | -0.707 | -2.169 | ---------- | ---------- |
| | (-3.083)*** | (-0.542) | (-0.867) | (-2.794)*** | | |

(b) Net Measure: $\left.\frac{d\Omega_{it}^{*}}{\Omega_{it-1}^{*}}\right|_{n}=\alpha_i+\alpha_1\sum_{n\in N}\frac{A_i^n}{\Omega_{it-1}^{*}}\frac{d\Pi_t^n}{\Pi_{t-1}^n}+\alpha_2\sum_{n\in N}\frac{B_i^n}{\Omega_{it-1}^{*}}\frac{d\Pi_t^n}{\Pi_{t-1}^n}+\alpha_3\sum_{n\in N}\frac{C_i^n}{\Omega_{it-1}^{*}}\frac{d\Pi_t^{US}}{\Pi_{t-1}^{US}}+\varepsilon_{it}$

[Specification Tests]

| | Null Hypothesis | Test Statistic |
|---|---|---|
| *F* Test (Pooling vs. Fixed Effects) | $H_0$: $\alpha_i$=0 for all *i* | 0.43 |
| *LM* Test (Pooling vs. Random Effects) | $H_0$: $\sigma_u^2$=0 | 14.27*** |
| Hausman Test (Fixed Effects vs. Random Effects) | $H_0$: Cov($u_i$, $x_{it}$)=0 | 0.13 |
| *F* Test (Endogeneity & Measurement Errors) | $H_0$: Cov($e_{it}$, $x_{it}$)=0 | 3.19** |

[Regression Results]

| | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | *F* (all α's=0) | $R^2$ |
|---|---|---|---|---|---|---|
| A. Pooling Model | | | | | | |
| (i) OLS | -0.157E-02 | -0.188 | -0.402 | -2.317 | 9.64*** | 0.011 |
| | (-3.797)*** | (-1.696)* | (-0.605) | (-3.679)*** | | |
| (ii) Instrumental Variables | -0.199E-02 | -0.584 | 0.830 | -1.980 | ---------- | ---------- |
| | (-4.148)*** | (-2.341)** | ( 0.598) | (-1.557) | | |
| B. Fixed Effects Model | | | | | | |
| (i) OLS | --------- | -0.185 | -0.618 | -2.454 | 0.74 | 0.026 |
| | ( --------- ) | (-1.416) | (-0.715) | (-1.702)* | | |
| (ii) Instrumental Variables | --------- | -1.307 | 2.388 | -0.258 | ---------- | ---------- |
| | ( --------- ) | (-0.996) | ( 0.422) | (-0.029) | | |
| C. Random Effects Model | -0.158E-02 | -0.187 | -0.459 | -2.353 | ---------- | ---------- |
| | (-3.214)*** | (-1.643) | (-0.671) | (-3.608)*** | | |

*Notes*: 1. We use a linear combination of (up to 5-day) lagged 10-year government bond yield (first difference form) and each regressor as instrumental variables.

2. Figures in parentheses are *t*-values in two-tail tests.
(*: significant at 10% level **: significant at 5% level ***: significant at 1% level)

3. The *t*-values are computed based on heteroscedasticity–corrected standard error estimators obtained by the method proposed by White (1980).

B. 60-day period (January 24-April 18: Number of Observations=5,040)

(a) Gross Measure: $$\left.\frac{d\Omega_{it}^*}{\Omega_{it-1}^*}\right|_g = \alpha_i + \alpha_1 \sum_{n\in N} \frac{A_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_2 \sum_{n\in N} \frac{B_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_3 \sum_{n\in N} \frac{C_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^{US}}{\Pi_{t-1}^{US}} + \varepsilon_{it}$$

[Specification Tests]

| | Null Hypothesis | Test Statistic |
|---|---|---|
| *F* Test (Pooling vs. Fixed Effects) | $H_0$: $\alpha_i$=0 for all *i* | 0.27 |
| *LM* Test (Pooling vs. Random Effects) | $H_0$: $\sigma_u^2$=0 | 22.91*** |
| Hausman Test (Fixed Effects vs. Random Effects) | $H_0$: Cov($u_i$, $x_{it}$)=0 | 0.21 |
| *F* Test (Endogeneity & Measurement Errors) | $H_0$: Cov($e_{it}$, $x_{it}$)=0 | 6.44*** |

[Regression Results]

| | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | *F* (all α's=0) | $R^2$ |
|---|---|---|---|---|---|---|
| A. Pooling Model | | | | | | |
| (i) OLS | -0.233E-02 | -0.194 | -0.368 | -2.209 | 9.45*** | 0.006 |
| | (-7.320)*** | (-1.776)* | (-0.558) | (-3.529)*** | | |
| (ii) Instrumental Variables | -0.255E-02 | -0.323 | -1.130 | -2.591 | --------- | --------- |
| | (-6.531)*** | (-1.049) | (-0.682) | (-1.698)* | | |
| B. Fixed Effects Model | | | | | | |
| (i) OLS | --------- | -0.183 | -0.600 | -2.552 | 0.59 | 0.010 |
| | ( --------- ) | (-1.365) | (-0.702) | (-1.921)* | | |
| (ii) Instrumental Variables | --------- | 0.791 | -9.062 | -12.987 | --------- | --------- |
| | ( --------- ) | ( 0.215) | (-0.689) | (-0.508) | | |
| C. Random Effects Model | -0.234E-02 | -0.192 | -0.412 | -2.276 | --------- | --------- |
| | (-6.511)*** | (-1.730)* | (-0.614) | (-3.561)*** | | |

(b) Net Measure: $$\left.\frac{d\Omega_{it}^*}{\Omega_{it-1}^*}\right|_n = \alpha_i + \alpha_1 \sum_{n\in N} \frac{A_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_2 \sum_{n\in N} \frac{B_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_3 \sum_{n\in N} \frac{C_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^{US}}{\Pi_{t-1}^{US}} + \varepsilon_{it}$$

[Specification Tests]

| | Null Hypothesis | Test Statistic |
|---|---|---|
| *F* Test (Pooling vs. Fixed Effects) | $H_0$: $\alpha_i$=0 for all *i* | 0.34 |
| *LM* Test (Pooling vs. Random Effects) | $H_0$: $\sigma_u^2$=0 | 18.78*** |
| Hausman Test (Fixed Effects vs. Random Effects) | $H_0$: Cov($u_i$, $x_{it}$)=0 | 0.23 |
| *F* Test (Endogeneity & Measurement Errors) | $H_0$: Cov($e_{it}$, $x_{it}$)=0 | 2.22* |

[Regression Results]

| | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | *F* (all α's=0) | $R^2$ |
|---|---|---|---|---|---|---|
| A. Pooling Model | | | | | | |
| (i) OLS | -0.134E-02 | -0.995E-01 | -0.549 | -1.977 | 7.93*** | 0.005 |
| | (-4.737)*** | (-1.026) | (-0.936) | (-3.551)*** | | |
| (ii) Instrumental Variables | -0.162E-02 | -0.547 | 0.898 | -1.124 | --------- | --------- |
| | (-4.652)*** | (-1.995)** | ( 0.609) | (-0.827) | | |
| B. Fixed Effects Model | | | | | | |
| (i) OLS | --------- | -0.705E-01 | -0.810 | -2.286 | 0.60 | 0.010 |
| | ( --------- ) | (-0.599) | (-1.014) | (-1.832)* | | |
| (ii) Instrumental Variables | --------- | -1.029 | 0.643 | -1.446 | --------- | --------- |
| | ( --------- ) | (-0.359) | ( 0.061) | (-0.075) | | |
| C. Random Effects Model | -0.135E-02 | -0.930E-01 | -0.609 | -2.048 | --------- | --------- |
| | (-4.112)*** | (-0.941) | (-1.017) | (-3.594)*** | | |

*Notes*: 1. We use a linear combination of (up to 5-day) lagged 10-year government bond yield (first difference form) and each regressor as instrumental variables.

2. Figures in parentheses are *t*-values in two-tail tests. (*: significant at 10% level **: significant at 5% level ***: significant at 1% level)

3. The *t*-values are computed based on heteroscedasticity–corrected standard error estimators obtained by the method proposed by White (1980).

C. 90-day period (February 1-June 12: Number of Observations=7,560)

(a) Gross Measure: $$\left.\frac{d\Omega_{it}^{*}}{\Omega_{it-1}^{*}}\right|_{g} = \alpha_i + \alpha_1 \sum_{n\in N} \frac{A_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_2 \sum_{n\in N} \frac{B_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_3 \sum_{n\in N} \frac{C_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^{US}}{\Pi_{t-1}^{US}} + \varepsilon_{it}$$

[Specification Tests]

| | Null Hypothesis | Test Statistic |
|---|---|---|
| *F* Test (Pooling vs. Fixed Effects) | $H_0$: $\alpha_i$=0 for all *i* | 0.26 |
| *LM* Test (Pooling vs. Random Effects) | $H_0$: $\sigma_u^2$=0 | 23.39*** |
| Hausman Test (Fixed Effects vs. Random Effects) | $H_0$: Cov($u_i$, $x_{it}$)=0 | 0.19 |
| *F* Test (Endogeneity & Measurement Errors) | $H_0$: Cov($e_{it}$, $x_{it}$)=0 | 1.28 |

[Regression Results]

| | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | *F* (all α's=0) | $R^2$ |
|---|---|---|---|---|---|---|
| A. Pooling Model | | | | | | |
| (i) OLS | -0.233E-02 | -0.276E-01 | -0.679 | -1.536 | 8.07*** | 0.003 |
| | (-9.995)*** | (-0.385) | (-1.529) | (-3.666)*** | | |
| (ii) Instrumental Variables | -0.230E-02 | -0.189 | -2.507 | -1.944 | --------- | --------- |
| | (-9.139)*** | (-0.664) | (-1.133) | (-1.050) | | |
| B. Fixed Effects Model | | | | | | |
| (i) OLS | --------- | -0.421E-01 | -0.672 | -1.537 | 0.53 | 0.006 |
| | ( --------- ) | (-0.516) | (-1.302) | (-2.329)** | | |
| (ii) Instrumental Variables | --------- | -0.335 | -7.364 | -1.459 | --------- | --------- |
| | ( --------- ) | (-0.479) | (-0.822) | (-0.202) | | |
| C. Random Effects Model | -0.233E-02 | -0.305 | -0.678 | -1.536 | --------- | --------- |
| | (-8.897)*** | (-0.423) | (-1.516) | (-3.641)*** | | |

(b) Net Measure: $$\left.\frac{d\Omega_{it}^{*}}{\Omega_{it-1}^{*}}\right|_{n} = \alpha_i + \alpha_1 \sum_{n\in N} \frac{A_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_2 \sum_{n\in N} \frac{B_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_3 \sum_{n\in N} \frac{C_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^{US}}{\Pi_{t-1}^{US}} + \varepsilon_{it}$$

[Specification Tests]

| | Null Hypothesis | Test Statistic |
|---|---|---|
| *F* Test (Pooling vs. Fixed Effects) | $H_0$: $\alpha_i$=0 for all *i* | 0.34 |
| *LM* Test (Pooling vs. Random Effects) | $H_0$: $\sigma_u^2$=0 | 18.38*** |
| Hausman Test (Fixed Effects vs. Random Effects) | $H_0$: Cov($u_i$, $x_{it}$)=0 | 0.04 |
| *F* Test (Endogeneity & Measurement Errors) | $H_0$: Cov($e_{it}$, $x_{it}$)=0 | 0.59 |

[Regression Results]

| | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | *F* (all α's=0) | $R^2$ |
|---|---|---|---|---|---|---|
| A. Pooling Model | | | | | | |
| (i) OLS | -0.723E-03 | -0.105E-01 | -0.657 | -1.340 | 7.74*** | 0.003 |
| | (-3.515)*** | (-0.166) | (-1.676)* | (-3.623)*** | | |
| (ii) Instrumental Variables | -0.668E-02 | 0.262 | -1.726 | -2.433 | --------- | --------- |
| | (-3.000)*** | ( 1.042) | (-0.884) | (-1.488) | | |
| B. Fixed Effects Model | | | | | | |
| (i) OLS | --------- | -0.180E-01 | -0.659 | -1.323 | 0.60 | 0.007 |
| | ( --------- ) | (-0.242) | (-1.370) | (-2.135)** | | |
| (ii) Instrumental Variables | --------- | 0.443 | -4.339 | -3.143 | --------- | --------- |
| | ( --------- ) | ( 0.589) | (-0.552) | (-0.494) | | |
| C. Random Effects Model | -0.724E-03 | -0.124E-01 | -0.658 | -1.336 | --------- | --------- |
| | (-3.035)*** | (-0.194) | (-1.666)* | (-3.555)*** | | |

*Notes*: 1. We use a linear combination of (up to 5-day) lagged 10-year government bond yield (first difference form) and each regressor as instrumental variables.
2. Figures in parentheses are *t*-values in two-tail tests.
(*: significant at 10% level **: significant at 5% level ***: significant at 1% level)
3. The *t*-values are computed based on heteroscedasticity–corrected standard error estimators obtained by the method proposed by White (1980).

## (ii) Depreciation Periods

A. 30-day period (July 6-Aug 16: Number of Observations=2,520)

(a) Gross Measure: $$\left.\frac{d\Omega_{it}^{*}}{\Omega_{it-1}^{*}}\right|_{g} = \alpha_i + \alpha_1 \sum_{n\in N} \frac{A_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_2 \sum_{n\in N} \frac{B_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_3 \sum_{n\in N} \frac{C_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^{US}}{\Pi_{t-1}^{US}} + \varepsilon_{it}$$

[Specification Tests]

| | Null Hypothesis | Test Statistic |
|---|---|---|
| *F* Test (Pooling vs. Fixed Effects) | $H_0$: $\alpha_i$=0 for all *i* | 0.49 |
| *LM* Test (Pooling vs. Random Effects) | $H_0$: $\sigma_u^2$=0 | 13.14*** |
| Hausman Test (Fixed Effects vs. Random Effects) | $H_0$: Cov($u_i$, $x_{it}$)=0 | 0.02 |
| *F* Test (Endogeneity & Measurement Errors) | $H_0$: Cov($e_{it}$, $x_{it}$)=0 | 25.40*** |

[Regression Results]

| | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | *F* (all α's=0) | $R^2$ |
|---|---|---|---|---|---|---|
| A. Pooling Model | | | | | | |
| (i) OLS | 0.520E-02 | 0.913 | -2.540 | 1.246 | 25.88*** | 0.030 |
| | (10.639)*** | ( 7.527)*** | (-3.274)*** | ( 1.763)* | | |
| (ii) Instrumental Variables | 0.642E-02 | 0.883 | -6.472 | -5.525 | --------- | --------- |
| | (10.472)*** | ( 2.648)*** | (-3.583)*** | (-3.530)*** | | |
| B. Fixed Effects Model | | | | | | |
| (i) OLS | --------- | 0.877 | -2.351 | 1.571 | 1.32 | 0.045 |
| | ( --------- ) | ( 4.247)*** | (-2.317)** | ( 0.903) | | |
| (ii) Instrumental Variables | --------- | 2.232 | -14.687 | -16.959 | --------- | --------- |
| | ( --------- ) | ( 0.725) | (-1.102) | (-1.307) | | |
| C. Random Effects Model | 0.520E-02 | 0.903 | -2.488 | 1.335 | --------- | --------- |
| | ( 8.865)*** | ( 7.244)*** | (-3.114)*** | ( 1.827)* | | |

(b) Net Measure: $$\left.\frac{d\Omega_{it}^{*}}{\Omega_{it-1}^{*}}\right|_{n} = \alpha_i + \alpha_1 \sum_{n\in N} \frac{A_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_2 \sum_{n\in N} \frac{B_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_3 \sum_{n\in N} \frac{C_i^n}{\Omega_{it-1}^{*}} \frac{d\Pi_t^{US}}{\Pi_{t-1}^{US}} + \varepsilon_{it}$$

[Specification Tests]

| | Null Hypothesis | Test Statistic |
|---|---|---|
| *F* Test (Pooling vs. Fixed Effects) | $H_0$: $\alpha_i$=0 for all *i* | 0.563 |
| *LM* Test (Pooling vs. Random Effects) | $H_0$: $\sigma_u^2$=0 | 8.71*** |
| Hausman Test (Fixed Effects vs. Random Effects) | $H_0$: Cov($u_i$, $x_{it}$)=0 | 0.08 |
| *F* Test (Endogeneity & Measurement Errors) | $H_0$: Cov($e_{it}$, $x_{it}$)=0 | 5.68*** |

[Regression Results]

| | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | *F* (all α's=0) | $R^2$ |
|---|---|---|---|---|---|---|
| A. Pooling Model | | | | | | |
| (i) OLS | 0.215E-02 | 0.986E-01 | -0.814 | -0.793 | 0.94 | 0.001 |
| | ( 4.964)*** | ( 0.915) | (-1.182) | (-1.263) | | |
| (ii) Instrumental Variables | 0.216E-02 | 0.574 | -3.915 | -4.100 | --------- | --------- |
| | ( 4.070)*** | ( 1.984)** | (-2.498)** | (-3.019)*** | | |
| B. Fixed Effects Model | | | | | | |
| (i) OLS | --------- | 0.241E-01 | -0.515 | -0.550 | 0.57 | 0.020 |
| | ( --------- ) | ( 0.122) | (-0.555) | (-0.391) | | |
| (ii) Instrumental Variables | --------- | 1.298 | -7.731 | -10.100 | --------- | --------- |
| | ( --------- ) | ( 0.481) | (-0.681) | (-1.016) | | |
| C. Random Effects Model | 0.217E-02 | 0.743 | -0.717 | -0.717 | --------- | --------- |
| | ( 4.036)*** | ( 0.670) | (-1.009) | (-1.103) | | |

*Notes*: 1. We use a linear combination of (up to 5-day) lagged 10-year government bond yield (first difference form) and each regressor as instrumental variables.

2. Figures in parentheses are *t*-values in two-tail tests.
(*: significant at 10% level **: significant at 5% level ***: significant at 1% level)

3. The *t*-values are computed based on heteroscedasticity–corrected standard error estimators obtained by the method proposed by White (1980).

B. 60-day period (June 26-September 13: Number of Observations=5,040)

(a) Gross Measure : $\left.\frac{d\Omega_{it}^{*}}{\Omega_{it-1}^{*}}\right|_{g}=\alpha_i+\alpha_1\sum_{n\in N}\frac{A_i^n}{\Omega_{it-1}^{*}}\frac{d\Pi_t^n}{\Pi_{t-1}^n}+\alpha_2\sum_{n\in N}\frac{B_i^n}{\Omega_{it-1}^{*}}\frac{d\Pi_t^n}{\Pi_{t-1}^n}+\alpha_3\sum_{n\in N}\frac{C_i^n}{\Omega_{it-1}^{*}}\frac{d\Pi_t^{US}}{\Pi_{t-1}^{US}}+\varepsilon_{it}$

[Specification Tests]

| | Null Hypothesis | Test Statistic |
|---|---|---|
| *F* Test (Pooling vs. Fixed Effects) | $H_0$: $\alpha_i$=0 for all *i* | 0.40 |
| *LM* Test (Pooling vs. Random Effects) | $H_0$: $\sigma_u^2$=0 | 15.44*** |
| Hausman Test (Fixed Effects vs. Random Effects) | $H_0$: Cov($u_i$, $x_{it}$)=0 | 0.15 |
| *F* Test (Endogeneity & Measurement Errors) | $H_0$: Cov($e_{it}$, $x_{it}$)=0 | 35.68*** |

[Regression Results]

| | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | *F* (all α's=0) | $R^2$ |
|---|---|---|---|---|---|---|
| A. Pooling Model | | | | | | |
| (i) OLS | 0.380E-02 | 0.751 | -2.091 | 0.826 | 27.71*** | 0.016 |
| | (11.734)*** | ( 7.902)*** | (-3.382)*** | ( 1.460) | | |
| (ii) Instrumental Variables | 0.472E-02 | 0.604 | -5.332 | -6.025 | ---------- | ---------- |
| | (11.400)*** | ( 1.846)* | (-3.046)*** | (-3.939)*** | | |
| B. Fixed Effects Model | | | | | | |
| (i) OLS | --------- | 0.763 | -2.215 | 0.920 | 1.34 | 0.023 |
| | ( --------- ) | ( 4.870)*** | (-2.745)*** | ( 0.776) | | |
| (ii) Instrumental Variables | --------- | 4.922 | -26.576 | -25.611 | ---------- | ---------- |
| | ( --------- ) | ( 0.915) | (-1.176) | (-1.488) | | |
| C. Random Effects Model | 0.380E-02 | 0.754 | -2.124 | 0.851 | ---------- | ---------- |
| | ( 9.948)*** | ( 7.810)*** | (-3.375)*** | ( 1.476) | | |

(b) Net Measure: $\left.\frac{d\Omega_{it}^{*}}{\Omega_{it-1}^{*}}\right|_{n}=\alpha_i+\alpha_1\sum_{n\in N}\frac{A_i^n}{\Omega_{it-1}^{*}}\frac{d\Pi_t^n}{\Pi_{t-1}^n}+\alpha_2\sum_{n\in N}\frac{B_i^n}{\Omega_{it-1}^{*}}\frac{d\Pi_t^n}{\Pi_{t-1}^n}+\alpha_3\sum_{n\in N}\frac{C_i^n}{\Omega_{it-1}^{*}}\frac{d\Pi_t^{US}}{\Pi_{t-1}^{US}}+\varepsilon_{it}$

[Specification Tests]

| | Null Hypothesis | Test Statistic |
|---|---|---|
| *F* Test (Pooling vs. Fixed Effects) | $H_0$: $\alpha_i$=0 for all *i* | 0.42 |
| *LM* Test (Pooling vs. Random Effects) | $H_0$: $\sigma_u^2$=0 | 14.70*** |
| Hausman Test (Fixed Effects vs. Random Effects) | $H_0$: Cov($u_i$, $x_{it}$)=0 | 1.02 |
| *F* Test (Endogeneity & Measurement Errors) | $H_0$: Cov($e_{it}$, $x_{it}$)=0 | 6.67*** |

[Regression Results]

| | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | *F* (all α's=0) | $R^2$ |
|---|---|---|---|---|---|---|
| A. Pooling Model | | | | | | |
| (i) OLS | 0.219E-02 | 0.862E-01 | -0.704 | -0.925 | 1.52*** | 0.001 |
| | ( 7.397)*** | ( 0.994) | (-1.246) | (-1.791)* | | |
| (ii) Instrumental Variables | 0.237E-02 | 0.226 | -2.341 | -3.588 | ---------- | ---------- |
| | ( 6.420)*** | ( 0.774) | (-1.498) | (-2.628)*** | | |
| B. Fixed Effects Model | | | | | | |
| (i) OLS | --------- | 0.774E-01 | -0.766 | -0.881 | 0.45 | 0.008 |
| | ( --------- ) | ( 0.542) | (-1.061) | (-0.881) | | |
| (ii) Instrumental Variables | --------- | 1.989 | -11.364 | -11.800 | ---------- | ---------- |
| | ( --------- ) | ( 0.460) | (-0.626) | (-0.892) | | |
| C. Random Effects Model | 0.219E-02 | 0.838E-01 | -0.720 | -0.913 | ---------- | ---------- |
| | ( 6.254)*** | ( 0.950) | (-1.253) | (-1.734) | | |

*Notes*: 1. We use a linear combination of (up to 5-day) lagged 10-year government bond yield (first difference form) and each regressor as instrumental variables.

2. Figures in parentheses are *t*-values in two-tail tests.
(*: significant at 10% level **: significant at 5% level ***: significant at 1% level)

3. The *t*-values are computed based on heteroscedasticity–corrected standard error estimators obtained by the method proposed by White (1980).

C. 90-day period (June 29-November 2: Number of Observations=7,560)

(a) Gross Measure: $$\left.\frac{d\Omega_{it}^*}{\Omega_{it-1}^*}\right|_g = \alpha_i + \alpha_1 \sum_{n\in N} \frac{A_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_2 \sum_{n\in N} \frac{B_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_3 \sum_{n\in N} \frac{C_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^{US}}{\Pi_{t-1}^{US}} + \varepsilon_{it}$$

[Specification Tests]

| | Null Hypothesis | Test Statistic |
|---|---|---|
| *F* Test (Pooling vs. Fixed Effects) | $H_0$: $\alpha_i$=0 for all *i* | 0.28 |
| *LM* Test (Pooling vs. Random Effects) | $H_0$: $\sigma_u^2$=0 | 22.11*** |
| Hausman Test (Fixed Effects vs. Random Effects) | $H_0$: Cov($u_i$, $x_{it}$)=0 | 0.03 |
| *F* Test (Endogeneity & Measurement Errors) | $H_0$: Cov($e_{it}$, $x_{it}$)=0 | 30.06*** |

[Regression Results]

| | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | *F* (all $\alpha$'s=0) | $R^2$ |
|---|---|---|---|---|---|---|
| A. Pooling Model | | | | | | |
| (i) OLS | 0.230E-02 | 0.667 | -1.907 | 1.150 | 37.04*** | 0.014 |
| | ( 9.255)*** | ( 8.773)*** | (-3.779)*** | ( 2.535)** | | |
| (ii) Instrumental Variables | 0.308E-02 | 0.352 | -5.836 | -5.522 | --------- | --------- |
| | ( 9.557)*** | ( 1.002) | (-3.106)*** | (-3.118)*** | | |
| B. Fixed Effects Model | | | | | | |
| (i) OLS | --------- | 0.681 | -1.978 | 1.163 | 1.55*** | 0.018 |
| | ( --------- ) | ( 5.945)*** | (-3.158)*** | ( 1.315) | | |
| (ii) Instrumental Variables | --------- | 2.745 | -19.537 | -22.361 | --------- | --------- |
| | ( --------- ) | ( 0.937) | (-1.604) | (-1.664)* | | |
| C. Random Effects Model | 0.230E-02 | 0.670 | -1.922 | 1.153 | --------- | --------- |
| | ( 8.178)*** | ( 8.735)*** | (-3.773)*** | ( 2.517)** | | |

(b) Net Measure: $$\left.\frac{d\Omega_{it}^*}{\Omega_{it-1}^*}\right|_n = \alpha_i + \alpha_1 \sum_{n\in N} \frac{A_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_2 \sum_{n\in N} \frac{B_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^n}{\Pi_{t-1}^n} + \alpha_3 \sum_{n\in N} \frac{C_i^n}{\Omega_{it-1}^*}\frac{d\Pi_t^{US}}{\Pi_{t-1}^{US}} + \varepsilon_{it}$$

[Specification Tests]

| | Null Hypothesis | Test Statistic |
|---|---|---|
| *F* Test (Pooling vs. Fixed Effects) | $H_0$: $\alpha_i$=0 for all *i* | 0.28 |
| *LM* Test (Pooling vs. Random Effects) | $H_0$: $\sigma_u^2$=0 | 22.05*** |
| Hausman Test (Fixed Effects vs. Random Effects) | $H_0$: Cov($u_i$, $x_{it}$)=0 | 0.02 |
| *F* Test (Endogeneity & Measurement Errors) | $H_0$: Cov($e_{it}$, $x_{it}$)=0 | 6.31*** |

[Regression Results]

| | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | *F* (all $\alpha$'s=0) | $R^2$ |
|---|---|---|---|---|---|---|
| A. Pooling Model | | | | | | |
| (i) OLS | 0.138E-02 | 0.139 | -0.852 | -0.255 | 1.50 | 0.001 |
| | ( 6.046)*** | ( 1.995)** | (-1.842)* | (-0.612) | | |
| (ii) Instrumental Variables | 0.130E-02 | 0.515 | -3.488 | -1.381 | --------- | --------- |
| | ( 4.538)*** | ( 1.685)* | (-2.091)** | (-0.878) | | |
| B. Fixed Effects Model | | | | | | |
| (i) OLS | --------- | 0.144 | -0.899 | -0.258 | 0.32 | 0.004 |
| | ( --------- ) | ( 1.401) | (-1.552) | (-0.317) | | |
| (ii) Instrumental Variables | --------- | 2.845 | -14.283 | -9.823 | --------- | --------- |
| | ( --------- ) | ( 1.073) | (-1.301) | (-0.793) | | |
| C. Random Effects Model | 0.138E-02 | 0.140 | -0.861 | -0.255 | --------- | --------- |
| | ( 5.344)** | ( 1.992)** | (-1.845)* | (-0.608) | | |

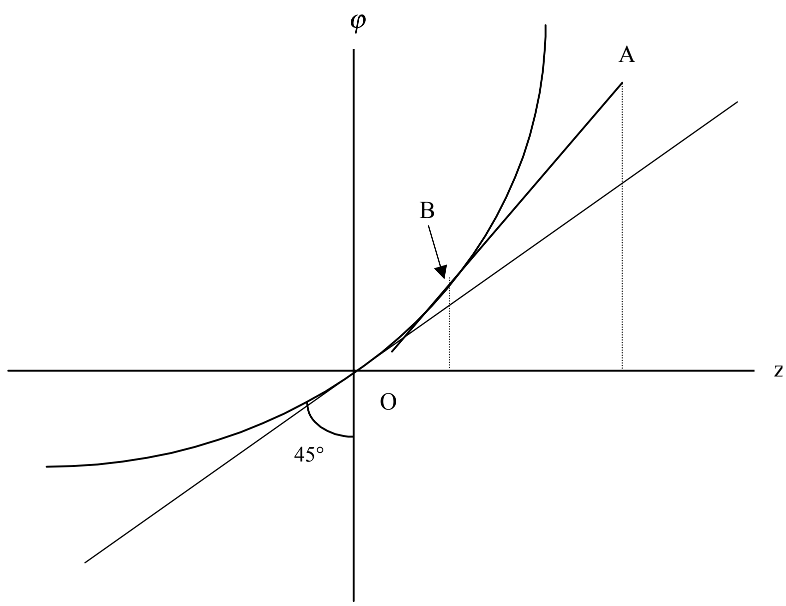
*Notes*: 1. We use a linear combination of (up to 5-day) lagged 10-year government bond yield (first difference form) and each regressor as instrumental variables.

2. Figures in parentheses are *t*-values in two-tail tests.
(*: significant at 10% level **: significant at 5% level ***: significant at 1% level)

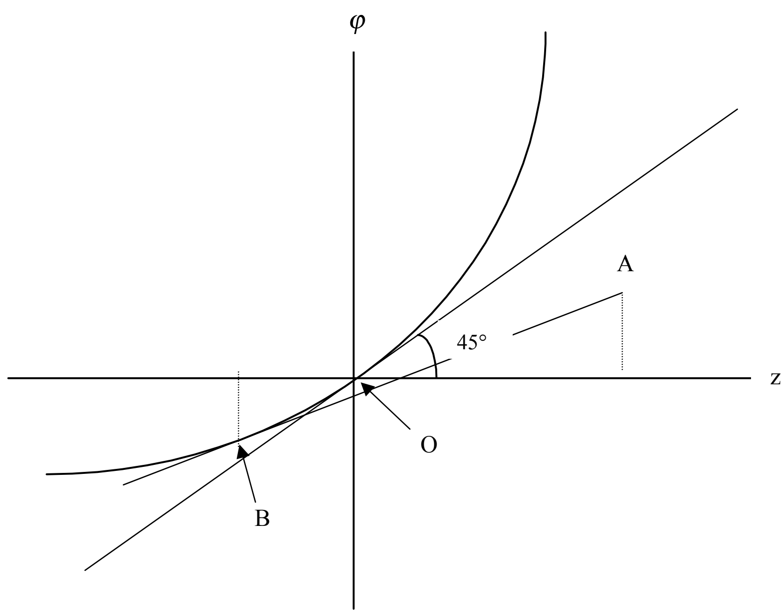
3. The *t*-values are computed based on heteroscedasticity–corrected standard error estimators obtained by the method proposed by White (1980).

**Figure: Penrose Curve and the Optimal Investment-Capital Stock Ratio**

**A: The Case of Expansion**




**B: The Case of Withdrawal**



## Appendix: Currency Weights in the Effective Exchange Rate of the Japanese Yen

We obtained the data below from *White Paper on Trade 1995* (Ministry of International Trade and Industry) and daily nominal exchange rates of each country from Dow Jones Telerate.

| | Amount of exports of electrical machinery (thousand yen) | Weight |
|---|---|---|
| American Continent | | |
| United States (U.S. dollar) | 26,071,952 | 0.89 |
| Canada (Canadian dollar) | 899,797 | 0.03 |
| Argentina (peso) | 177,489 | 0.01 |
| Mexico (Mexican peso) | 1,502,210 | 0.05 |
| Brazil (cruzado) | 544,189 | 0.02 |
| Venezuela (bolivar) | 89,212 | 0.00 |
| Total | 28,834,849 | 1.00 |
| European Continent | | |
| Austria (Austrian schilling) | 325,000 | 0.02 |
| Belgium (Belgium franc) | 941,705 | 0.06 |
| Denmark (krone) | 139,074 | 0.01 |
| Germany (deutch mark) | 4,980,124 | 0.31 |
| France (Franc) | 1,296,604 | 0.08 |
| Finland (markka) | 559,361 | 0.04 |
| Greece (drachma) | 48,021 | 0.00 |
| The Netherland (guilder) | 1,514,167 | 0.09 |
| Ireland (Irish pound) | 240,164 | 0.02 |
| Italy (lira) | 858,978 | 0.05 |
| Norway (Norwegian krone) | 82,693 | 0.01 |
| Portugal (escudo) | 122,296 | 0.01 |
| Sweden (Swedish krona) | 551,645 | 0.03 |
| Spain (peseta) | 360,380 | 0.02 |
| The United Kingdom (pound) | 3,611,087 | 0.23 |
| Switzerland (Swiss franc) | 341,171 | 0.02 |
| Total | 15,972,470 | 1.00 |
| Asian, Oceanic, and African Region | | |
| Hong Kong (dollar) | 8,517,262 | 0.19 |
| Indonesia (rupiah) | 1,158,071 | 0.03 |
| India (rupee) | 412,037 | 0.01 |
| Korea (won) | 6,251,771 | 0.14 |
| Australia (Australia dollar) | 1,061,468 | 0.02 |
| Malaysia (Malaysian dollar) | 5,372,365 | 0.12 |
| New Zealand (New Zealand dollar) | 154,945 | 0.00 |
| Philippines (Philippine peso) | 1,703,763 | 0.04 |
| South Africa (rand) | 267,197 | 0.01 |
| Saudi Arabia (Saudi riyal) | 463,694 | 0.01 |
| Singapore (Singapore dollar) | 8,910,384 | 0.20 |
| Thai (baht) | 3,229,972 | 0.07 |
| Turkey (Turkish lira) | 136,750 | 0.00 |
| Taiwan (Taiwan dollar) | 6,722,145 | 0.15 |
| Total | 37,639,679 | 1.00 |