THE JOURNAL OF THE KOREAN ECONOMY, Vol. 10, No. 3 (December 2009) 395-419

Opportunity Cost and the Demand for International Reserves: A Simultaneous Approach Incorporating the Supply Side*

Hee-Ryang Ra**

This study develops a simultaneous supply/demand model of international reserve accumulation to examine the opportunity cost effect on the demand for reserves. If the opportunity cost is also determined simultaneously by the supply side, the coefficient of the marginal opportunity cost effect obtained from OLS estimation of reserve demand equations would be biased upward. Thus, we perform system estimation methods to verify and correct for the bias. Using data for 17 developing countries from 1994 to 2002, we identify an upward bias for over half of the countries examined and for the pooled sample that provides a stronger or reinforced estimated opportunity cost effect when we incorporate the supply side. The theoretical expectation of negative opportunity cost effects is firmly supported by a simultaneous supply/demand model.

JEL Classification: E52, F31, G21

Keywords: opportunity cost, demand for international reserves,
Simultaneous supply/demand model,
System estimation methods

* Received March 3, 2009. Accepted October 20, 2009.

** Department of International Trade, College of Commerce & Business, Pusan University of Foreign Studies (PUFS), Busan, Korea, Tel.: 82-51-640-3153, Fax: 82-51-640-3563, E-mail: heeryang@pufs.ac.kr

1. INTRODUCTION

This study develops a simultaneous supply/demand model of international reserve (hereafter reserve(s)) holdings. Previous studies on reserve holdings focus on the formulation and estimation of reserve demand equations. These studies are based on the assumption that reserve supply is always elastic enough to meet the reserve demand (i.e., perfectly elastic supply). However, this assumption may not always be valid. For instance, for East Asian countries the supply of reserves fell short of the demand during the Asian financial crisis from 1997-1998 (Aizenman and Marion, 2003a and 2003b). If the supply of reserves is not elastic enough to meet the demand (implying that actual reserves are determined partially by the supply side) then the opportunity cost is determined in relation to the reserve supply as well.

Opportunity cost is regarded as one of the key factors that determine the demand for reserves. For central banks, the opportunity cost of holding current reserves is the best alternative that is forgone; for example, reserves are usually invested in U.S. treasury bonds with a yield lower than the expected return on local investments that gives a net opportunity cost of the difference between the two. The theory predicts a negative marginal effect on the demand for reserves. The higher the net opportunity cost, the less incentive a central bank would have to hold reserves. If a proper measure for opportunity cost is used for estimation, then it is expected to display a negative effect on reserve holdings. However, many empirical studies in the 1960s and 1970s were not successful in finding significant and negative opportunity cost effects. Opportunity cost measures were even intentionally dropped from analyses because of the lack of reliable measures. In the 1980s, the inadequate measurement of opportunity cost was generally blamed as the reason for the insignificant or wrong sign. This led to an ongoing effort to find an adequate opportunity cost measure (Edwards, 1985; Aizenman and Marion, 2004).[1)]

[1)] Edwards asserts that the proxy for opportunity cost of reserve holdings should be net cost, pointing out that previous studies ignore the yield on reserves. Aizenman and Marion

This study proposes another potential reason for the insignificant estimated effect (or at least bias) of opportunity costs on reserve demand — an upward bias due to the simultaneous determination of opportunity costs effect when the supply side is incorporated into the demand function. This study is regarded as the first to deal with the simultaneity problem of opportunity cost effects by taking the reserve supply side into account.

For this discussion, we discard the assumption of a perfectly elastic reserve supply and introduce a supply function. We adopt system estimation methods, such as Two-Stage Least Squares (2SLS) to verify and correct for the bias. We then compare the results from system estimation methods with those from conventional single equation methods, Ordinary Least Squares (OLS). The empirical results show the existence of the upward bias for over half of the countries examined and for the pooled sample. We take this as support for the approach of this study.

In the next section, we review relevant literature on the opportunity cost of reserve holdings and the supply side of reserves. Then, we discuss data and methodology in section 3. Section 4 presents estimation results. Finally, section 5 summarizes the main findings and the conclusion.

2. LITERATURE REVIEW

Opportunity cost plays an important role in all theoretical models for reserve holdings (Kenen and Yudin, 1965; Heller, 1966; Clark, 1970; Hamada and Ueda, 1977; Frenkel and Jovanovic, 1981; Ben-Bassat and Gottlieb, 1992). Theoretically, it is defined as the difference between the highest possible marginal productivity forgone from an alternative investment in fixed assets and the yield on reserves.

---

suggest some reasons for the ambiguous opportunity cost effects: premature capital markets that result in non-market determined interest rates, the discrepancy between currency composition and yield on reserves (because the yield is not fully captured by the rate on U.S. Treasury bonds), and the possibility of inadequacy of the standard interest differential as a measurement of the true opportunity cost of holding reserves.

In earlier studies, opportunity cost is assumed as constant over time and across countries (Heller, 1966; Hamada and Ueda, 1977). This strong assumption ignores the differences in the opportunity cost effects across countries and periods. Later studies use various proxies to measure opportunity costs. Kenen and Yudin (1965) and Kelly (1970) use per capita income as a proxy but find the wrong (positive) sign. Flanders (1971) uses the growth rate of an economy but also finds the wrong sign. Courchene and Youssef (1967) and Frenkel and Jovanovic (1981) use the domestic discount rate as a proxy. Courchene and Youssef find that the coefficients have correct (negative) signs but are insignificant in most cases, while Frenkel and Jovanovic find correct signs and significant coefficients.

Iyoha (1976) uses the estimated discount rate of each country as a proxy for the yield on reserves (not for the rate of return of capital) and finds the correct (positive) sign. The study postulates that the higher the domestic interest rate, the greater the optimal level of reserves, because the higher domestic interest rate implies a lower opportunity cost of holding reserves. However, Hipple (1979) and Shinkai (1979) argue that Iyoha misinterprets the significant positive relationship between the domestic interest rate and the reserve demand, because reserves are usually invested abroad in the form of short-term interest bearing assets, i.e., U.S. Treasury bills.

Several studies argue that previous studies ignore the yield on reserves and estimate the opportunity cost effects only using the proxy for the rate of return on capital (Shinkai, 1979; Edward, 1985; Landell-Mills, 1989; Grimes, 1993). These studies emphasize the importance of net opportunity cost and attempt to measure the yield differential for it. Other studies (Clark, 1970; Frenkel, 1974, 1980; Bilson and Frenkel, 1979; Heller and Kahn, 1978; Edwards, 1983) simply drop the opportunity cost measure from the analysis because reliable opportunity cost measures for estimation are not available.

Many empirical studies fail to find a significant opportunity cost effect or even exclude the opportunity cost measure from estimation despite its important role in theory. This may be due to the failure to measure opportunity cost in accordance with the theoretical definition. It may also be due to the lack of reliable data on the real rate of return to capital and alternative yields on reserves, because in many developing countries the domestic capital market is not fully developed (Edward, 1985; Landell-Mills, 1989; Aizenman and Marion, 2004).

Recent studies in the 1980s and 1990s continue to find that demand for reserves is significantly related to the measures of the opportunity costs (Edwards, 1985; Landell-Mills, 1989; Ben-Bassat and Gottlieb, 1992; Islam and Khan, 1994; Huang, 1995). These studies search for an adequate measure for opportunity cost, because it is thought that the insignificant results of opportunity cost effects are due to inadequate measurements. Although early studies in 1960s and 1970s were not successful in finding significant and negative opportunity cost effects on reserve demand, studies in the 1980s and 1990s show that reserve holdings are significantly related to the measures of opportunity cost. Therefore, it is now standard to include opportunity cost measures in reserve demand equations.

Previous studies on reserve demand generally assume that the supply of reserves is elastic enough to meet the demand. However, the supply of reserves need not keep pace with demand growth. Triffin (1961) warns of the possibility of a shortage of reserve supply because there is no official international control on gold and foreign exchange, this indicates that the shortage of reserves would be compensated by the sustained balance of payments deficit of the U.S. Aizenman and Marion (2003a and 2003b) also suggest that during and immediately after the crisis, emerging Asian economies had limited access to global markets and could not immediately adjust stocks to the higher level it chose to maintain because of the lack of a reserve supply. Ra (2007) also shows the empirical results that may provide evidence that the Korean reserve demand became more sensitive to the adjustment cost and the openness, but less sensitive to the opportunity cost after the Asian financial crisis.

Under the possibility of the lack of reserve supply, Bahmani-Oskooee (1985) first deals with the simultaneous bias issue by formulating a simultaneous model of the demand for and supply of reserves. The study indicates that if the assumption of an elastic supply of reserves might not be valid, the estimation of reserve demand equations without considering the supply side would result in a simultaneous equation bias. In the study, the endogenous variables are reserve quantities (R^D and R^S) and the price of gold (P_g).

The estimation of reserve demand equations, including the investigation of opportunity cost effects on reserve holdings has been innovated by (in most of the cases) devising more adequate measures for opportunity cost. However, a study that considers system estimation methods as a means to correct for the simultaneous bias in opportunity cost effects has not yet been conducted. We contribute by modeling and estimating a simultaneous system.

3. MODEL AND DATA

3.1. Reserve Demand Equation

Most previous theoretical and empirical studies on the demand for reserves rely on the buffer stock model (Heller, 1966; Frenkel and Jovanovic, 1981; Flood and Marion, 2002; Aizenman and Marion, 2004). This model is based on the inventory management principle that optimizes the trade-off between flow holding costs and fixed restocking costs. It assumes that the central bank chooses an initial level of reserves that minimizes the total expected costs. Two costs are considered: the opportunity cost of holding reserves, and the adjustment cost that is incurred when reserves reach some lower bound. The two costs are interrelated because a higher stock of reserves reduces the probability of having to adjust that reduces the expected cost of adjustment, but at the cost of higher forgone earnings. In addition, the size of transactions and the openness of the economy are suggested as arguments to influence reserve demand.

The basic model of demand for reserves is a stable function of adjustment cost, opportunity cost, scale variables, and the degree of openness. Using a log-linear specification, the conventional reserve demand equation follows:

$$\log R_{it}^{D} = \alpha_0 + \alpha_1 \log \sigma_{it} + \alpha_2 \log(\rho - r^{*})_{it} + \alpha_3 \log Y_{it} + \alpha_4 \left(\frac{IM}{Y} \right)_{it} + \varepsilon_{it}, \quad (1)$$

where, R_{it}^{D} is the demand for reserves, σ_{it} is the variable of country *i* adjustment cost at time *t*, $(\rho - r^{*})_{it}$ is the net opportunity cost of holding reserves for country *i* at time *t* (ρ denotes the real rate of return on capital, and r^{*} denotes the yield on reserves), Y_{it} is the income for country *i* at time *t* (a scale variable), and $(IM / Y)_{it}$ is the average propensity to import of country *i* at time *t* (the degree of openness). Variables are assumed to be determined exogenously. Here, we expect that $\alpha_1 > 0$, $\alpha_2 < 0$, $\alpha_3 > 0$, and $\alpha_4 > 0$.

3.2. Reserve Supply Equation

The reserve supply comes mainly from two routes, current account surpluses and capital inflows. Current account includes the exports and imports of goods and services plus private remittances and governments grants. The last item is usually regarded to be trivial and insensitive to economic factors. Current account surplus or net exports (exports minus imports), depends primarily on relative income levels of the domestic and foreign countries, and on the relative prices of domestic and foreign goods (Obstfeld and Rogoff, 1999; Yarbrough and Yarbrough, 2003). Higher domestic relative income levels imply higher levels of domestic spending on goods and services that include imports from foreign countries. Net exports also depend on prices of the domestically produced goods and services relative to the prices of foreign produced counterparts. We define the relative price, *R* as:

$$R = \frac{P}{eP^*}, \quad (2)$$

where, P, P^*, and e are the domestic price level, foreign price level, and foreign exchange rate, respectively. The higher the relative price, R, the more expensive domestic goods are relative to foreign goods, then the lower the exports and vice versa. Net exports depend negatively on relative income levels, and the relative price of domestic goods and services, R. In addition, R is composed of two terms: $1/e$ and P/P^*. We can say that net exports depend positively on the foreign exchange rate (e) and negatively on the relative price level (P/P^*). This study assumes that the current account surplus (net exports) is determined by the relative income levels, foreign exchange rate, and relative price levels between the home country and the foreign country (in this study the U.S.) as in the conventional way (Bahmani-Oskooee, 1985).

This study also assumes that capital movements (portfolio and direct investment) are determined by the real rate of return on investment in the home country (ρ) compared to the same rate in the foreign country (ρ^*). The higher the relative real rate of return, then the greater inflow of portfolio or direct investment in the domestic country that results in an increase in the reserve supply. We can then formulate a log-linear reserve supply equation as below:

$$\log R_{it}^S = \delta_0 + \delta_1 \log(\rho - \rho^*)_{it} + \delta_2 \log e_{it} + \delta_3 \left(\frac{P}{P^*}\right)_{it} + \delta_4 \left(\frac{Y}{Y^*}\right)_{it} + \upsilon_{it}. \quad (3)$$

The supply of reserves, R^S, depends on four factors: $(\rho - \rho^*)_{it}$, the differential between the real rates of return on investment in the home country $i(\rho_{it})$ and in the foreign country (ρ_{it}^*) at time t; e_{it}, the foreign exchange rate of the home country i currency in terms of that of the foreign country at time t; $(P/P^*)_{it}$, the ratio of the price levels; and $(Y/Y^*)_{it}$, the ratio of real income levels. Here, it is expected that $\delta_1 > 0$, $\delta_2 > 0$, $\delta_3 < 0$, and $\delta_4 < 0$.

3.3. System Estimation

The system estimations along the simultaneity issue of this study are based on Bahmani-Oskooee (1985). The study first deals with the simultaneity issue by formulating a system that is specified as follows:

$$\log R_{it}^{D} = \gamma_0 + \gamma_1 \log M_{it} + \gamma_2 \log\left(\frac{M}{Y}\right)_{it} + \gamma_3 \log P_{git} + \upsilon_{it}^{1}, \tag{4}$$

$$\log R_{it}^{S} = \delta_0 + \delta_1 \log P_{git} + \delta_2 \log\left(\frac{r^{US}}{r^{Other}}\right)_{it} + \delta_3 \log\left(\frac{P^{US}}{P^{Other}}\right)_{it} + \delta_4 \log\left(\frac{y^{US}}{y^{Other}}\right)_{it} + \upsilon_{it}^{2}, \tag{5}$$

and

$$\log R_{it}^{D} = \log R_{it}^{S}, \tag{6}$$

where, R_{it}^{D} and R_{it}^{S} are the reserve demand and supply of country *i* at time *t*, M_{it} is the imports of country *i* at time *t*, $(M/Y)_{it}$ is the average propensity to import of country *i* at time *t*, $P_{g_{it}}$ is the market price of gold of country *i* at time *t*, $(r^{US}/r^{Other})_{it}$ is the ratio of real rate of return in the U.S. to that of country *i* at time *t*, $(P^{US}/P^{Other})_{it}$ is the ratio of price level, and $(y^{US}/y^{Other})_{it}$ is the ratio of real income.

Regarding the supply equation, this study assumes that the supply of reserves is determined by the U.S. balance of payments deficit. The U.S. balance of payments is composed of two major accounts: the capital account and the current account. Capital movements (portfolio or direct investment) are sensitive to the real rate of return on these investments in the U.S. (r) compared to the same rate in the rest of the world (r^{*}). The current account is mainly composed of the exports and imports of goods and services. Since imports are usually assumed as a function of the price and the income level, the relative price and the income level of the U.S. would be the determinants of the reserve supply. In addition, a higher market price of gold (relative to the official price) would allow the central bank to sell gold in exchange for convertible foreign currencies. Thus, a higher market price of gold will cause the official supply of reserves to increase. Here, we would expect $\gamma_1 > 0$, $\gamma_2 > 0$, $\gamma_3 < 0$, $\delta_1 > 0$, $\delta_2 < 0$, $\delta_3 > 0$, and $\delta_4 > 0$. This study uses 2SLS to estimate the reserve demand equation while taking the supply side into account. By pooling cross-sectional quarterly data from 19 developed countries from 1972-1977, this study finds that the gold price-elasticity of the demand for reserves is significantly negative.

The model needs modification for the purposes of this study. The current proportion of gold in reserves is so small that the specification for incorporating the price of gold in the system seems outdated.[2)] Furthermore, even though the study deals with the simultaneous determination of reserve demand and supply by incorporating gold prices, the study does not consider opportunity cost for estimating reserve demand. In this study, the opportunity cost measure is used for the endogenous variable instead of the gold price. We put two equations of reserve demand, reserve supply into the system to address the simultaneous determination of the opportunity cost parameters. We seek to obtain unbiased coefficients of the opportunity cost by incorporating the supply side into the reserve demand equation.

We consider home country *i*, a small open economy, which trades with a foreign country (the U.S.). Only the foreign country issues the currency that is used for the exchange of goods and services, and investment worldwide. In addition, for simplicity, we assume free capital movement in the international capital market, and we assume that the yield on reserves (r^*) is equal to the real rate of return on investment in the foreign country (ρ^*). This assumption follows the principle that a country borrows from abroad as long as the cost of borrowing is lower than or equal to the domestic marginal productivity of capital. As well, we assume that actual reserves are always at equilibrium

---

[2)] Only 2.3% by the end of 2005 (International Financial Statistics).

level, meaning that demand for reserves is equal to supply of reserves.

In this case, it is not possible to ascertain the true demand and supply slopes given only the equilibrium data. Furthermore, based on these propositions, we find the problem of single equation estimation on either reserve demand equations or supply equations, without considering the other side. For instance, concerning the demand equation, OLS results in an upward bias in the estimated coefficient of opportunity cost.[3] As a result, we put two equations into one system and formulate a simultaneous model in which the parameters of the variables are determined simultaneously in the system. The system follows as: [4]

$$\log R_{it}^{D} = \alpha_0 + \alpha_1 \log \sigma_{git} + \alpha_2 S_{it} + \alpha_3 \log Y_{it} + \alpha_4 \left(\frac{IM}{Y}\right)_{it} + \omega_{it}^{1}, \tag{7}$$

---

[3] If we assume typical structural equations (7) and (8) considering the simultaneity as below:

$$Y_{1t} = \beta_0 + \beta_1 Y_{2t} + \beta_2 X_t + \varepsilon_{1t,} \tag{10}$$

$$Y_{2t} = \alpha_0 + \alpha_1 Y_{1t} + \alpha_2 Z_t + \varepsilon_{2t}. \tag{11}$$

Here, if we consider equation (10) and (11) as reserve demand and supply equations. Y_1 and Y_2 are reserve holdings and opportunity costs (spreads) respectively. Then, the expected value of $\hat{\beta}$ (coefficient of opportunity costs) from OLS simplifies to:

$$E(\hat{\beta}_1) = \beta_1 + E\left[\sum (Y_{2t} - \bar{Y}_2)(\varepsilon_{1t}) / \sum (Y_{2t} - \bar{Y}_2)^2\right]. \tag{12}$$

In a non-simultaneous equation, where, Y_2 and ε_1 are not correlated, the expected value of $\hat{\beta}$ equals the true β_1 because the expected value of the term $\sum (Y_{2t} - \bar{Y}_2)(\varepsilon_{1t})$ is zero. If Y_2 and ε_1 are positively correlated (α_1 is positive), then the expected value of $\hat{\beta}$ is greater than the true β_1 because the expected value of the term $\sum (Y_{2t} - \bar{Y}_2)(\varepsilon_{1t})$ is positive. Here, we assume that Y_2 and ε_1 are positively correlated because α_1 is positive. Then, the expected value of $\hat{\beta}$ is greater than the true β_1 which results in overestimation or upward bias.

[4] We do not take log form for the variable of (*IM/Y*), (*P/P**), (*Y/Y**) to avoid the problem of negative value of the log form.

$$\log R_{it}^{S} = \beta_0 + \beta_1 \log S_{it} + \beta_2 \log e_{it} + \beta_3 \log\left(\frac{P}{P^*}\right)_{it} + \beta_4 \log\left(\frac{Y}{Y^*}\right)_{it} + \omega_{it}^2, \quad (8)$$

and

$$\log R_{it}^{D} = \log R_{it}^{S}. \quad (9)$$

The focus of this study is to estimate the demand equation and opportunity cost effects by incorporating the supply side, we first introduce 2SLS to get the unbiased estimated coefficient of the opportunity cost effect.[5)] Then, we expand the empirical work to the other system estimation methods, using SUR, 3SLS, and GMM as a robustness test. In the system, we follow the model for the parameters as shown by the equation (1), defining $\sigma_{g\,it}$ as the volatility of the change in reserves from a Generalized Autoregressive Conditional Heteroskedasticity (GARCH) process,[6)] S_{it} as the differential (spread) between the yield the home country pays on its own debt and the yield it receives on the reserve assets of foreign country, and $(IM\,/\,Y)_{it}$ as import ratio of country i at time t. In addition, (regarding the reserve supply

---

5) In this case, both the demand and the supply equations are overidentified. 2SLS provides a useful estimation procedure for obtaining parameters in the case of overidentification.

6) We model the volatility by the GARCH process because the change in reserves is related to its variance, which is not constant over any period of time (Engel, 1982; Bollerslev, 1986). It is preferred to the conventional standard deviation in payments and receipts (Flood and Marion, 2002). Assuming that the conditional variance depends on an infinite number of lags of reserve changes, we test various GARCH (p, q) specifications. To measure the volatility, we estimate the following basic regressions:

$$\Delta R_t = \omega_t + \sqrt{\sigma_t^2 \upsilon_t}, \quad (13)$$

$$\sigma_t^2 = \alpha_0 + \alpha(L)\varepsilon_t^2 + \phi(L)\sigma_t^2, \quad (14)$$

where, ΔR is the change in reserves, ω is the constant term, σ^2 is the conditional variance, υ is normally distributed, L is the lag operator, and $\alpha(L)$ and $\phi(L)$ are the lag polynomials with orders p and q, respectively. Then, the conditional standard deviation, σ_{git}, can be used for the volatility of payments and receipts. Due to the massive quantity of output, the results are not reported but are available from the author of this study upon request.

equation) we define S_{it} as the differential between the real rate of return on investment in home country (ρ_{it}) and that in the foreign country (ρ_{it}^{*}), e_{it} as the foreign exchange rate of the home country currency in terms of the currency of the foreign country, $(P/P^{*})_{it}$ as the ratio of price level of the home country to that of the foreign country, and $(Y/Y^{*})_{it}$ as the ratio of real income levels, of country *i* at time *t*, respectively. Finally, we compare the results that are obtained from the system estimation methods with the results from the conventional regression equations, and evaluate the opportunity cost effects in relation to the simultaneous determination of reserve demand and supply.

3.4. Data

We use the JP Morgan Emerging Market Bond Index (EMBI) Global Composite of 19 emerging economies during 1994-2002 for the opportunity cost measures (spreads) for the demand equation, and the differential between the real rate of return on investment in the home country (ρ) and that in the foreign country (ρ^{*}) for the supply equation.[7] Since the EMBI is daily data, we calculate the monthly average of the spread for estimation. We exclude Egypt and the Ukraine because of a lack of sufficient data for an individual country analysis.[8] The data for the other explanatory variables are obtained or manipulated from the International Financial Statistics (IFS) of the IMF. Here, we transform the quarterly GDP data to monthly data by dividing the quarterly GDP by 3.[9] Table 1 is the description of the data.

---

[7] The data for 2003 and after would be added to future research.

[8] Only the annual GDP data is available for Egypt, and we have only 12 observations for the Ukraine.

[9] It is acknowledged that this transformation could lead to a bias in the estimation results.

Table 1 Description of the Data Set for the Reserve Demand and Supply Equations

Variables	Definition	Measure of	Data Source	Frequency
Reserve Demand Equation				
R^D	Demand for Reserves	Reserve Holdings	IFS	Monthly
σ_g	Volatility of Reserves	Adjustment Cost	Derived from GARCH process	Monthly
S	Spread	Opportunity Cost	EMBI	Monthly
Y	Income	Scale	IFS	Monthly
$\frac{IM}{Y}$	Imports to GDP Ratio	Openness	IFS	Monthly
Reserve Supply Equation				
R^S	Supply of Reserves	Reserve Supply	IFS	Monthly
S	Spread	Capital Inflow	EMBI	Monthly
e	Foreign exchange rate of home country currency in terms of the currency of foreign country (U.S.)	Price Level	IFS	Monthly
$\frac{P}{P^*}$	Ratio of price level to that of foreign country (U.S.)	Price Level	IFS	Monthly
$\frac{Y}{Y^*}$	Ratio of real income level to that of foreign country (U.S.)	Income Level	IFS	Monthly

4. EMPIRICAL RESULTS

4.1. Estimation in Levels and Differenced Form

ADF unit root tests demonstrate that $\log R$, $\log S$, and $\log Y$ are non-stationary; log σ_g and (IM/Y) are stationary.[10] Therefore, estimating the empirical reserve demand equations in levels using OLS that are consistent with theory, may result in spurious regression.[11] To address this problem, we estimate the model in differenced form. We may lose information about a possible long-run relationship in levels when we use differenced data. However, the estimation using the first-differenced data may be applicable since the purpose of this study is to examine the parameter of opportunity cost by comparing OLS with system estimations.[12] The ADF statistics for all the differenced variables reject the unit roots and imply that they are stationary.[13]

Table 2 presents the estimation results from OLS, 2SLS, and GMM in the differenced form of the variables for each individual country. For 2SLS and GMM, we identify the downward bias in 10 and 9 out of 15 countries, respectively. The reason why some countries such as Columbia, Ecuador, and Peru do not show the bias would be due to the differences of the exchange rate system. Especially, in these Latin American countries the dollarization are more deeply processed than other countries.[14] If US dollar are used as domestic currency, the opportunity cost effects would be marginal. In addition, it may be simply due to the lack of data.

---

[10] For $\log R$, $\log S$, and $\log Y$, 3, 7, and 5 countries out of 17 show stationary time series; for $\log \sigma_g$ and (IM/Y), 16 and 11 countries present stationary time series.

[11] For OLS results in levels show that the magnitudes of the opportunity cost effects get stronger or reinforced under the system estimation methods for both individual country case and the pooled sample case.

[12] Cointegration regression, such as dynamic ordinary least squares and Johansen's method, can be adopted to examine the long-run relationship. We leave cointegration estimation for future research.

[13] The statistics are not reported.

[14] Dollarization refers to the phenomenon where US dollars are preferred instead of the domestic currency.

Table 2 Coefficients of the Opportunity Cost from OLS, 2SLS, and GMM (Differenced Form, Individual Country)

	OLS	2SLS		GMM		Sample Size
Argentina	–0.186**	–0.346**	√	–0.510***	√	106
Brazil	–0.177***	–0.229***	√	0.135		106
Bulgaria	–0.140	–0.780*	√	–0.586***	√	95
Columbia	0.018	0.029		0.029		42
Ecuador	–0.119	–0.068		–0.082		83
Korea	–0.003	–0.015	√	–0.005	√	50
Mexico	–0.201**	–0.323**	√	0.031		104
Morocco	0.042	–0.034	√	0.135**		59
Nigeria	–0.113	0.169		–0.313***	√	71
Panama	–0.313*	–0.320	√	–0.413**	√	69
Peru	0.014	0.078		0.030		44
Philippines	–0.046	–0.136**	√	–0.108	√	82
Poland	–0.061*	–0.092*	√	–0.073**	√	92
Russia	–0.303***	–0.223**		–0.330***	√	58
Venezuela	–0.022	–0.054	√	–0.038	√	87

Notes: Significance levels are 10% *, 5% **, and 1% ***. √ indicates the identification of downward bias or reinforcement of the negative opportunity cost effects.

Table 3 and table 4 present the results from the estimations in the differenced form of the variables for the pooled sample. Overall, the results of the opportunity cost effects are consistent with the previous results: upward bias. In table 3, the magnitude of the opportunity cost effects become stronger, from –0.018 to –0.105, when we use 2SLS. The other coefficients of the variables present the expected signs (positive), except for the adjustment cost, and remain similar across the estimations. These results support the upward bias in estimates of the opportunity cost effects when we perform OLS again.

In table 4, we add fixed effects for each country. The results are not

Table 3 Results of OLS and 2SLS on the Reserve Demand Equations (Differenced Form, Pooled Sample without Fixed Effect)

	OLS	2SLS
	Δ log R^D	Δ log R^D
C	–0.032 (0.032)	–0.012 (0.040)
$\Delta \log \sigma_g$	-0.012^{**} (0.006)	–0.012 (0.008)
$\Delta \log S$	-0.018^{***} (0.006)	-0.105^{***} (0.032)
$\Delta \log Y$	0.013^{**} (0.005)	0.012^{*} (0.007)
$\Delta \frac{IM}{Y}$	0.011^{***} (0.003)	0.010^{**} (0.005)
Adjusted R^2	0.134	0.179
Durbin-Watson	1.964	1.814
Observations	643	641

Notes: Significance levels are 10% *, 5% **, and 1% ***. Δ denotes the first difference.

significantly different from the results in table 3. We get reinforced negative opportunity cost effects on the reserve demand when we perform 2SLS. When we compare the results of OLS with those of 2SLS, the magnitude of the negative opportunity cost effects becomes larger, from –0.014 to –0.121. This again confirms the upward bias in the estimated coefficients of opportunity cost. The other coefficients of the variables present the expected signs (positive) and remain similar across the estimations.[15] In addition, we

[15] At table 3 the adjusted R^2 increases to 0.256 and 0.278 for OLS and 2SLS respectively when we exclude the countries which do not demonstrate bias. The signs and coefficients of the variables are similar to the previous results. For example the coefficients of opportunity cost are –0.028 and –0.114 respectively. In addition, at table 4 the adjusted R^2 increases to 0.289 and 0.376 for OLS and 2SLS respectively and the signs and coefficients of the variables are similar to the previous results. For example the coefficients of opportunity cost are –0.036 and –0.168 respectively.

Table 4 Results of OLS and 2SLS on the Reserve Demand Equations (Differenced Form, Pooled Sample with Fixed Effect)

	OLS	2SLS
	Δ log R^D	Δ log R^D
C	0.548*** (0.165)	0.347 (0.227)
$\Delta \log \sigma_g$	0.071*** (0.105)	0.067*** (0.019)
$\Delta \log S$	–0.014** (0.006)	–0.121*** (0.038)
$\Delta \log Y$	0.012 (0.013)	0.010 (0.019)
$\Delta \frac{IM}{Y}$	0.011 (0.008)	0.003 (0.015)
Fixed Effect		
Argentina	–0.024	0.024
Brazil	0.134	0.098
Bulgaria	–0.213	–0.102
Columbia	–0.066	–0.056
Ecuador	–0.150	–0.066
Korea	0.121	0.165
Malaysia	0.042	0.030
Mexico	0.082	–0.062
Morocco	–0.066	–0.078
Nigeria	–0.140	–0.106
Panama	–0.141	–0.086
Peru	–0.105	0.095
Philippines	0.018	0.004

Poland	0.040	0.092
Russia	0.081	0.018
Turkey	–0.032	0.008
Ukraine	0.000	0.024
Venezuela	–0.044	0.098
Adjusted R^2	0.173	0.241
Durbin-Watson	1.977	1.795
Observations	643	641

Notes: Significance levels are 10% *, 5% **, and 1% ***. Δ denotes the first difference.

find the individual effect term for Korea (0.121) is relatively large in comparison with other countries. It would be due to the huge accumulation of the international reserves of Korea after the Asian financial crisis.

4.2. An alternative Estimation for Just Differencing the Data

In section 4.1, we examined the opportunity cost effect for both individual countries and the pooled data with all variables in the differenced form to deal with the spurious regression problem in levels.

Because all variables are not clearly non-stationary, we may consider an alternative specification that difference only those series that show $I(1)$. Recent literature suggests that panel-based unit root tests have a higher power than unit root tests based on individual time series because they increase the sample size (Maddala and Kim, 1998).

The results of the panel unit root tests show that log R and log Y are non-stationary; on the other hand, $\log\sigma_g$, $\log S$, and (IM/Y) are stationary.[16)] Thus, we use the first differenced data for log R and log Y to make the data stationary and to re-estimate the reserve demand to examine the opportunity cost effects.

[16)] The statistics are not reported.

Table 5 Results of OLS and 2SLS on the Reserve Demand Equations (Pooled Sample without Fixed Effect)

	OLS	2SLS
	$\Delta \log R^D$	$\Delta \log R^D$
C	0.593 (0.640)	1.763 (1.500)
$\Delta \log \sigma_g$	0.882*** (0.106)	0.854*** (0.115)
$\Delta \log S$	–0.115* (0.061)	–0.371 (0.301)
$\Delta \log Y$	0.024 (0.049)	0.074 (0.078)
$\Delta \frac{IM}{Y}$	–0.328 (0.498)	0.225 (0.803)
Adjusted R^2	0.358	0.298
Durbin-Watson	2.011	1.869
Observations	1239	1234

Notes: Significance levels are 10% *, 5% **, and 1% ***. Δ denotes the first difference.

The results of the reinforcement of the opportunity cost effects are consistent with the previous results: upward bias. Table 5 shows the results without fixed effects. The magnitude of the opportunity cost for 2SLS (–0.371) is larger than that for OLS (–0.115). The other coefficients of adjustment cost, scale variable, and the openness present the expected signs (positive). Adjusted R^2s are around 0.30-0.36, and Durbin-Watson statistics do not demonstrate an autocorrelation problem. These results support the upward bias in the estimates of the opportunity cost effects when we perform OLS that avoids the fatal problem.

In table 6, we add fixed effects for each country. The results are not significantly different from the results in table 5. We get reinforced negative opportunity cost effects on reserve demand when we perform 2SLS. This

Table 6 Results of OLS and 2SLS on the Reserve Demand Equations (Pooled Sample with Fixed Effect)

	OLS	2SLS
	$\Delta \log R^D$	$\Delta \log R^D$
C	2.375 (2.275)	1.013 (2.679)
$\Delta \log \sigma_g$	0.578* (0.342)	0.484 (0.367)
$\Delta \log S$	–0.069 (0.113)	–0.338 (0.397)
$\Delta \log Y$	0.019 (0.053)	0.001 (0.057)
$\Delta \frac{IM}{Y}$	–0.335 (0.809)	–1.527 (1.396)
Fixed Effect		
Argentina	–0.703	–0.108
Brazil	0.179	–0.203
Bulgaria	–0.500	–0.262
Columbia	–0.403	–0.974
Ecuador	–0.097	0.384
Korea	0.826	2.259
Malaysia	–1.642	–1.554
Mexico	0.487	0.188
Morocco	–0.322	–0.859
Nigeria	–0.256	–0.728
Panama	–0.704	–1.247
Peru	–0.876	–1.382
Philippines	–0.054	0.618
Poland	–0.105	0.123
Russia	0.592	0.917

Turkey	0.704	0.913
Ukraine	0.841	1.038
Venezuela	-	-
Adjusted R^2	0.364	0.315
Durbin-Watson	2.113	2.015
Observations	1239	1234

Notes: Significance levels are 10% *, 5% **, and 1% ***. Δ denotes the first difference.

again confirms the downward bias in the estimated coefficients of opportunity cost.[17)]

5. CONCLUSION

This study develops a simultaneous demand/supply model of reserve accumulation to correct for the bias in the estimated opportunity cost effects on the demand for reserves from the conventional OLS method. If the opportunity cost (which is regarded as one of the key arguments for the reserve demand) is determined simultaneously in relation to the reserve supply, the coefficient would be biased upward. We examine the estimated opportunity cost effects of the simultaneous model.

The empirical results from OLS and 2SLS demonstrate that for over half of the individual countries out of 15 and for the pooled sample that there are stronger and reinforced opportunity cost effects on reserve demand when we incorporate the supply side. Furthermore, we extend the analysis of this study to other system estimation methods (SUR, 3SLS, and GMM) as a

[17)] At table 5 the adjusted R^2 increases to 0.409 and 0.389 for OLS and 2SLS respectively when we exclude the countries which do not demonstrate bias. The signs and coefficients of the variables are similar to the previous results. For example the coefficients of opportunity cost are –0.128 and –0.391 respectively. In addition, at table 6 the adjusted R^2 increases to 0.402 and 0.365 for OLS and 2SLS respectively and the signs and coefficients of the variables are similar to the previous results. For example the coefficients of opportunity cost are –0.089 and –0.392 respectively.

robustness test. Overall, the results are similar to the previous ones.

The empirical results of a simultaneous supply/demand model support that if we consider the simultaneity in estimation of the opportunity cost effects, the estimated effects increase and are reinforced. The theoretical expectation of negative opportunity cost effects is firmly supported by a simultaneous supply/demand model.

REFERENCES

Aizenman, J. and N. P. Marion, "Foreign exchange reserves in East Asia: why the high demand?," *FRBSF Economic Letter*, 2003-11, April 2003a.

____________, "The high demand for international reserves in the far east: what is going on?," *Journal of the Japanese and International Economies*, 17, 2003b, pp. 370-400.

____________, "International reserve holdings with sovereign risk and costly tax collection," *The Economic Journal*, 114, 2004, pp. 569-591.

Bahmani-Oskooee, M., "Demand of and supply of international reserves: a simultaneous approach," *Journal of Post Keynesian Economics*, Summer 1985.

Bilson, J. F. and J. A. Frenkel, "Dynamic adjustment and the demand for international reserves," NBER Working Paper, No. 403, 1979.

Ben-Bassat, A. and D. Gottlieb, "Optimal international reserves and sovereign risk," *Journal of International Economics,* 33, 1992, pp. 345-362.

Bollerslev, T., "Generalized autoregressive conditional heteroskedasticity," *Journal of Econometrics*, 31, 1986, pp. 307-327.

Clark, P. B., "Optimum international reserves and the speed of adjustment," *Journal of Political Economy*, 78, 1970, pp. 356-376.

Couchene, T. J. and G. M. Youssef, "The demand for international reserves, *Journal of Political Economy*," 75, 1967, pp. 404-413.

Edwards, S., "The demand for international reserves and exchange rate adjustments: the case of the LDCs, 1964-1972," *Economica*, 50, 1983, pp. 269-280.

____________, "On the interest rate elasticity of the demand for international reserves: some evidence from developing countries," *Journal of International Money and Finance*, 4, 1985, pp. 287-295.

Engle, R. F., "Autoregressive conditional heteroskedasticity with estimates of the variance of United Kingdom inflation," *Econometrica*, 50, 1982, pp. 987-1006.

Flanders, M. J., "The demand for international reserves," *Princeton Studies in International Finance*, 27, Princeton, 1971.

Flood, R. and N. P. Marion, "Holding international reserves in an era of high capital mobility," in S. M. Collins and D. Rodrik, eds., *Brookings Trade Forum 2001*, Washington, D.C.: Brookings Institution Press, 2002, pp. 1-68.

Frenkel, J. A., "The demand for international reserves by developed and less developed countries," *Economica*, 41, 1974, pp. 14-24.

____________, "International reserves under pegged exchange rates and managed float: corrections and extensions," *Journal of Monetary Economics*, 6, 1980, pp. 295-302.

Frenkel, J. A. and B. Jovanovic, "Optimal international reserves: a stochastic framework," *The Economic Journal*, 91, 1981, pp. 507-514.

Grimes, A., "International reserves under floating exchange rates: two paradoxes explained," *The Economic Record*, 69, 1993, pp. 411-415.

Hamada, K. and K. Ueda, "Random walks and the theory of optimal international reserves," *Economic Journal*, 87, 1977, pp. 722-742.

Heller, R., "Optimal international reserves," *The Economic Journal*, 76, 1966, pp. 296-311.

Heller, R. and M. Khan, "The demand for international reserves under fixed and floating exchange rates," *IMF Staff Papers*, 25, 1978, pp. 623-649.

Hipple, F. S., "A note on the measurement of the holding cost of international reserves," *Review of Economics and Statistics*, 56, 1979, pp. 612-614.

Huang, G., "Modeling China's demand for international reserves," *Applied Financial Economics*, 5, 1995, pp. 357-366.

Ioyah, M. A., "Demand for international reserves in less developed countries: a distributed lag specification," *Review of Economics and Statistics*, 58(3), 1976, pp. 351-355.

Islam, M. and M. Khan, "An empirical test of the demand for international reserves," in D. Ghosh and E. Oritz, eds., *The Changing Environment of International Financial Markets; Issues and Analysis*, St. Martin's Press, 1994, pp. 83-94.

Kelly, M. G., "The demand for international reserves," *American Economic Review*, 60, 1970, pp. 655-667.

Kenen, P. B. and E. B. Yudin, "The demand for international reserve," *Review of Economics and Statistics*, 47, 1965, pp. 242-250.

Landell-Mills, J. M., "The demand for international reserves and their opportunity cost," *IMF Staff Papers*, 36, 1989, pp. 708-732.

Obstfeld, M. and K. Rogoff, *Foundation of International Macroeconomics* 4e, Cambridge, Mass.: MIT Press, 1999.

Ra, Hee-Ryang, "Demand for International Reserves: A Case Study for Korea," *The Journal of the Korean Economy*, 8, 2007, pp. 147-175.

Shinkai, Y., "Demand for international reserves in less developed countries: a comment," *Reviews of Economics and Statistics*, 56, 1979, pp. 614-615.

Triffin, R., *Gold and the Dollar Crisis*, 2e, New Haven: Yale University Press, 1961.

Yarbrouhg, B. and R. Yarbrouhg, *The world economy: Trade and finance*, 6e, South-Western, 2003.