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Insurance Value of International Reserves: An Option Pricing Approach

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Abstract

A quantitative framework is developed to bring forward the insurance motive of holding international reserves. The insurance value of reserves is quantified as the market price of an equivalent option that provides the same insurance coverage as the reserves. This quantitative framework is applied to calculating the cost of a regional insurance arrangement (e.g., an Asian Monetary Fund) and to analyzing one leg of an optimal reserve-holding decision.

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I. INTRODUCTION

From the traditional viewpoint that regards the demand for international reserves as a hangover from the fixed exchange rate era, the observed demand for international reserves continues to be puzzlingly robust. According to Flood and Marion (2001) and Edison (2003), global reserves (in percent of world GDP) have exhibited an upward trend since the 1960s. Over the same period, however, exchange rate flexibility has increased. Although debate continues on whether de facto exchange rate flexibility has indeed increased in recent decades (Reinhart and Rogoff, 2003), no evidence has been put forward that exchange rate flexibility has decreased.

The resilience of the demand for international reserves, however, is less surprising if one notes that international reserves are held not only as an instrument of exchange rate management, but also as a cushion against an undesired shortage of international liquidity that could damage the economy. Such a *self-insurance* view, which dates back to Heller (1966), formed the undercurrent of numerous papers on the demand for international reserves that flourished until the early 1980s (see Tweedie, 2000, for references).

Recently, the latent insurance view has made its way further into policy discussions. Following the capital account driven currency crises that sent former Asian tigers into a tailspin, several proposals were floated in favor of maintaining a level of reserves high enough to provide against capital market-driven drains on international liquidity.[1] Some countries, notably Chile and Korea, appear to have followed through on such proposals by coincidence or design, and accumulated international reserves of more than 20 percent of their GDPs by late 2003. As the largest emerging market, the stock of international reserves held by China alone surpassed US$ 400 billion by end-2003, exceeding the capital of the International Monetary Fund.[2]

Despite the apparent ascent of the insurance role of reserves, both as a conceptual undercurrent and a policy option, little effort has been put into bringing the insurance perspective to the fore. This paper highlights the insurance aspect of holding reserves, and a quantitative aspect at that, by exploiting the equivalence between insurance and financial options. It starts by recognizing that holding reserves is an act of self-insurance. Once interpreted that way, the insurance value of reserves can be quantified by building upon the functional equivalence between the self-insurance aspect of reserve holding and a put option that provides identical insurance coverage.

The first discussion of the equivalence between insurance and a put option appeared in Merton's (1976) analysis of the cost of providing deposit insurance. He noted that in the United States, the Federal Deposit Insurance Corporation (FDIC) provided guarantees for the loan extended by depositors to banks. Moreover, there was a further belief that the U.S. government offered the ultimate implicit guarantees for the liabilities of the FDIC, and thus those of the banks. On the

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[1]See Mulder (2000) for references on policy proposals.

[2]The capital of the IMF, measured by the paid-in quotas of member countries, amounted to SDR 212 billion (somewhat below US $ 300 billion) at end-2002.

grounds that deposit insurance—viewed as a security—was isomorphic to a put option, he proposed calculating the cost of deposit insurance on the basis of the option pricing theory.

In the case of reserves, similarly, its self-insurance value can be approximated by the cost of obtaining equivalent insurance in the market, which can be derived from the option pricing theory. This approach offers a quantitative metric of the insurance value of reserves that is based on observable parameters. It also has the advantage of being applicable to a large variety of situations without being mired in particular theoretical settings.

That said, a caveat is in order. The market value of insurance does not fully coincide with the welfare value of insurance. As a result, this quantitative metric does not form a self-contained basis for determining the optimal level of overall insurance. Rather, this framework offers a starting point for quantifying the elusive insurance value of reserve holding. Subject to this caveat, the framework is applied in this paper to exploring the role of reserves in meeting the need for a *given* size of overall insurance.

To be more specif c, this quantitative framework advances our understanding of reserve holding on two fronts. First and straightforward, the framework can be used to calculate the cost of an insurance arrangement that provides insurance coverage of a desired size. The accuracy of this cost calculation can be enhanced by several ref nements that ref ect individual insurance situations. Next, for any desired level of overall insurance, the framework can be used to investigate how large a fraction of the total insurance need will be covered by holding reserves (self-insurance). Aided by additional working assumptions, this reserve coverage ratio can also be used to assess the amount of excessive reserves in various countries.

The rest of the paper is organized as follows. Section II reviews the existing literature on reserves, and discusses its relationship to the insurance interpretation of this paper. Section III discusses the equivalence between a f nancial option and the self-insurance role of reserves, and Section IV turns to the European option formula for a simple parameterization of the quantitative framework. Section V applies these theoretical and numerical results to two questions that have drawn much attention in relation to international reserves, including what is the cost of arranging a regional insurance, like the one much discussed in Asia, and it compares the theory-implied optimal self-insurance ratio and the stylized data from advanced and emerging markets. Section VI concludes.

II. Many Faces of Official Reserves

Though not always couched in such terms, off cial reserves are ultimately held to guard against an undesired shortfall in international liquidity and to mitigate its adverse consequences. At the same time, holding reserves entails an opportunity cost, namely the interest rate cost. This f ts a classic def nition of insurance: guarding against a downside risk at the cost of insurance premium. Despite obvious conceptual parallel, however, the traditional literature put little emphasis on the implicit insurance aspect of holding reserves—not much more than noting the parallel in abstraction. This section offers a selective survey of the literature, with a view to highlighting the latent insurance aspect that this paper brings to the fore.

Probably the most often cited motive of holding reserves is as a means of sterilized intervention, namely to manage the exchange rate without changing domestic interest rates. In this case, reserves are being held to avoid the necessity of having to adjust domestic interest rates to limit the fluctuation in the exchange rate. That is, an insurance is being taken against the risk of fluctuation in the interest rate or the exchange rate.

The insurance view fits well the literature on the demand for reserves that has developed in parallel with the theory of the demand for money. To borrow terminology from money demand, reserves were viewed to be demanded largely for two motives: transactions motive and precautionary motive.[3] Considering the role of reserves as the medium of international transactions, reserve demand was first attributed to the transactions demand (Harrod (1953)). As in money demand, the transactions demand for reserves can exist in the absence of any uncertainty, and has little overlap with the insurance view of reserves. However, the insurance view dovetails the more recent and influential viewpoint based on the precautionary demand for reserves.

Heller (1966) initiated the analysis of reserve demand out of precautionary motive, thereby giving emphasis to the role of uncertainty. Since the ready availability of international liquidity would limit the extent of a downward adjustment that is needed in times of a deficit in the external balance, the monetary authorities would be inclined to hold international reserves out of precautionary motive. The optimal reserve holding would be mainly affected by the cost of adjustment in times of an external imbalance, the cost of maintaining a stock of reserves, and the probability of having to rely on international reserves.

Subsequent literature on reserves developed by elaborating on the nature of the adjustment and uncertainty that were involved. In a prime example of the line of research that purported to improve the analysis of the adjustment involved, Clark (1970) developed a general equilibrium model which illustrated the tradeoff between domestic adjustment and external financing (via reserves). The other line of research purported to analyze better the consequence of the degree of uncertainty involved. Drawing on the theory of stochastic inventory control, Frenkel and Jovanovic (1981) developed a stochastic model in which depletion of reserves was assumed to impose a discrete (fixed) adjustment cost.

The insurance interpretation of reserves came out most clearly in the literature spawned by the currency crises of the 1990s. Contemplating on the possibility of the currency crises not warranted by fundamentals, Guidotti and Greenspan remarked on maintaining reserves that are sufficiently large as to exceed short-term external liabilities (see Mulder, 2000, for details). Other economists who recognized a similar war chest motive of holding reserves include Feldstein (1999), Kletzer and Mody (2000), and Caballero (2003). Finally, in an analysis of

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[3]This section cites freely from Tweedie (2000), which offers a comprehensive survey of the traditional literature until the 1980s.

politico-economic determinants of demand for reserves, Aizenman and Marion (2002) explicitly brought out the insurance value of reserves.

Compared to existing papers that elaborate on specif c sources of the implicit insurance demand, this paper brings to the fore the quantitative implication of the insurance view of reserves while abstracting from the specif c sources of insurance need. The holding of reserves is regarded as an act of self-insurance, with the alternative arrangement being the market-based provision of a comparable insurance. The value and desirability of reserve holding—self-insurance—are then analyzed as a f nancial problem that lends itself to quantif cation.

III. Options and Reserves

A. Two Methods of Insurance

Consider an agent—which may be called a country—that desires a guaranteed cash f ow to meet its liquidity need of D at time T against an underlying asset with value V_t ($0 \leq t \leq T$). The net cash f ow from the underlying asset at maturity date T will be $V_T - D$, which is negative when the value of the asset falls short of the liquidity need D. The agent looks for an insurance with coverage D, which pays out $D - V_T$ when the value of the underlying asset falls below the liquidity need D.

Such an insurance is equivalent to a put option on the underlying asset with exercise price D, which grants the agent the right to sell its underlying asset worth V_T at the predetermined price D. When the asset value exceeds the exercise price, the agent can claim a prof t of $V_T - D$ after meeting the need for liquidity on its own and the option will not be exercised. When the asset value falls below the exercise price ($V_T < D$), the option will be exercised to meet its liquidity need.

An alternative to acquiring the put option is to self-insure by holding suff cient cash reserves to cover the discrepancy between the time-T value of the underlying asset (V_T) and the liquidity need (D). Again, when the asset value remains suff ciently high ($V_T > D$), there is no need to draw down reserves; when the asset value is not high enough ($V_T < D$), reserves will be drawn down by the amount of liquidity shortfall $D - V_T$. The agent will have self-insured fully when it holds reserves large enough to meet all the liquidity need.

In comparing the two alternatives, the underlying asset is the anchor that ensures the equivalence between a market-based insurance (put option) and the act of self-insurance inherent in reserve holding. The value of the underlying asset is also a key determinant of the market value of the self-insurance imparted by reserve holding. However, the identity and value of the underlying asset are not f xed but vary with the insurance function that is fulf lled in different instances of reserve holding.

Traditional discussions of the demand for reserves have been couched in terms of import coverage. This viewpoint can be translated into our framework by interpreting D as the more or less constant value of imports demanded by the country, and V as the highly variable value of exports. To meet its need for imports, the country desires an insurance of coverage D that can be written against an asset of value V that is highly variable—or at least much more volatile than D.

More recent discussions of the demand for reserves have often been cast in terms of the need to counteract sudden reversals in capital inflows. A canonical example would be found in a small open economy that borrowed D in the international financial market to invest in a project of value V, but that which wants to avoid a default. In this instance, value V would be the market value of the project, be it measured by the salvage value of the invested project or the present value of forthcoming revenue streams.

The underlying asset can also be interpreted more flexibly without being tied to individual projects. For commodity-rich economies, the underlying asset can be viewed as available commodity exports, with the commodity price becoming the major determinant of it.[4] From the viewpoint of sovereigns, the natural candidate for the underlying asset will be a government bond. This is not an asset in the balance sheet sense, but is a pledgeable asset from the viewpoint of transactions to obtain international liquidity.

At the most primitive level, the identity and value of the underlying asset are determined by the contractual arrangement between the insured and the insurer. The contractual arrangement can be structured in such a way that expands the base of the underlying asset beyond what is possible under typical bilateral contracts. Indeed, such arrangements turn out to be the critical factor for reducing the cost of a regional insurance arrangement, to be discussed in Section A.

B. Insurance Value of Reserves

Given the equivalence of the two methods of insurance in terms of available cash flow, payoffs to the agent under the two alternatives can be compared to derive a measure of the insurance value of holding reserves. Having $G(D, V_t, T, t)$ to denote the time-t price of a put option that matures at T with exercise price D against the underlying asset of value V_t, the period-T (net) payoff for an agent who purchases the put option—where time T can be viewed as $T - \epsilon$ for a very small ϵ—is

$$(V_T - D) + \max\{D - V_T, 0\} - G(D, V_{T-\epsilon}, T, T - \epsilon) \approx \max\{V_T - D, 0\} - G(D, V_T, T, T). \quad (1)$$

Substituting in the terminal condition for the put option price, $G(D, V_T, T, T) = \max\{D - V_T, 0\}$, the net payoff is written as follows.[5]

$$\max\{V_T - D, 0\} - \max\{D - V_T, 0\} = V_T - D. \quad (2)$$

[4]See Caballero and Panageas (2003) for an in-depth analysis of the potential role of commodity prices in hedging capital account risks for Chile.

[5]Inclusive of opportunity cost of holding the option, the agent's net cash payoff does not change with the purchase of option.

Now consider the payoff of an agent who has been holding, since time $T-\epsilon$, reserves C that is large enough to cover the whole liquidity need if necessary ($C = D$). The agent's net payoff is

$$(V_T - D) + \max\{D - V_T, 0\} + [e^{r\epsilon}C - \max\{D - V_T, 0\}] - e^{r\epsilon}C. \tag{3}$$

If the value of the asset falls short of the liquidity need, the agent can draw down the discrepancy ($\max\{D - V_T, 0\}$) from the cash reserves, and the level of remaining cash reserves declines by the corresponding amount ($-\max\{D - V_T, 0\}$ within the bracket). To calculate net payoff, the opportunity cost of obtaining and maintaining reserves under interest rate r ($e^{r\epsilon}C$ in the last term) is subtracted from the gross cash revenue of holding reserves ($e^{r\epsilon}C$ within the bracket).[6] The net payoff is then simplif ed as $V_T - D$, showing that the period-T net payoff of holding an option with exercise price D is equivalent to the period-T net payoff of holding reserves of level D. Comparison of equations (1) and (3) implies that the time-T market value of self-insurance (reserves) can be viewed as:

$$\max\{D - V_T, 0\} = G(D, V_T, T, T), \tag{4}$$

which is the terminal condition for the option price as already stated.

The ex-ante (at time $t < T$) benef t of holding reserves would then be the present value of the time-T option value in equation (4), denoted as $G(D, V_t, T, t)$ when an insurance of D is being provided by holding reserves of the same amount. More generally, when the reserves of level C—possibly different from the overall liquidity need (D)—are held against the underlying asset of value V_t, the time-t insurance value of holding reserves corresponds to the time-t price of a put option with an exercise price as large as the amount of cash reserves: $G(C, V_t, T, t)$. This will be called the insurance value of reserves.

$$I(C, V_t) \equiv G(C, V_t, T, t). \tag{5}$$

This insurance value is also the implicit cost of obtaining equivalent insurance coverage through the market, if available. If an insurance arrangement is not already available, this framework provides one method of calculating the cost of setting up a market-based arrangement that f lls in the gap.

C. Optimal Reserve Coverage

In addition to offering a quantitative measure of the insurance value of reserves, the equivalence between insurance and a put option can be called upon to analyze the optimal reserve coverage, viewed as the optimal choice of self-insurance. When an agent has an overall insurance need of D that can be satisf ed by either market-based insurance or self-insurance (reserves), the agent

[6]In this calculation, liquidity discount—the lower interest on liquid investment—is not considered, for it is secondary to the calculation of the insurance value. A positive liquidity discount is allowed in the next section where self-insurance (reserves) is compared with generic market-based insurance.

will choose an optimal mix between the two methods of insurance.[7] Ceteris paribus, holding reserves reduces the need for market-based insurance, and the tradeoff between the two alternatives can be quantified by calculating the combined cost of all forms of market-based insurance on the basis of option prices.

Consider an agent that provides for its liquidity need D by combining reserves and market-based insurance (put option). If the agent chooses to hold reserves of level C, its reserve coverage ratio λ is defined as $\lambda = C/D$, and the agent can meet its total liquidity (insurance) need by acquiring a put option with exercise price $\widetilde{D} \equiv (1-\lambda)D$ on its underlying asset of value V_t. Without the reserves, the agent would have acquired a put option with exercise price D. Holding the reserves of $C = \lambda D$ enables the agent to lower the market-based insurance cost by an amount equal to

$$G(D, V_t, T, t) - G(\widetilde{D}, V_t, T, t). \tag{6}$$

In the optimal self-insurance decision, this is the insurance benefit of holding reserves, namely the effect of holding reserves C on the cost of the market-based insurance that has to be obtained to meet the overall insurance need. This insurance benefit is distinct from the insurance value (or cost) of reserves in equation (5) of the previous subsection, which measures the direct cost of obtaining an insurance that provides the same coverage as the level of reserves.

Holding reserves entails a cost of its own, too, owing to the liquidity premium. Reserves are kept in liquid assets that offer a lower return than is available from investment in less-liquid assets. Let investment interest rate R denote the risk-adjusted rate of return from a less-liquid investment. The investment interest rate R would be larger than the riskless interest rate r of liquid assets in which reserves are kept invested, ultimately by as much as the liquidity premium. The cost of holding cash reserves of level C is the present value of the foregone investment income and can be written as:

$$e^{-r(T-t)}\left[e^{R(T-t)} - e^{r(T-t)}\right]C = \left[e^{(R-r)(T-t)} - 1\right]C = (R-r)(T-t)C, \tag{7}$$

using the approximation $e^{xt} - 1 \approx xt$.

In countries that replenish their international reserves by long-term borrowing, the investment interest rate is better interpreted as the borrowing interest rate, and the difference between the borrowing interest rate and the riskless interest rate captures the opportunity cost of maintaining reserves. This interpretation amounts to assuming a differential access to financial markets by the writer and the purchaser of an option. While the writer of an option can lend and borrow at interest rate r, the purchaser of the option can borrow only at interest rate R. In this instance, the

[7] A concern may be raised that the agent will select not only the optimal mix between market-based insurance and self-insurance but also the optimal level of overall insurance coverage—which is taken as given in this paper. However, for each level of overall insurance, it will be most efficient to maintain the optimal mix between market-based insurance and self-insurance. In other words, the optimal self-insurance choice will be a necessary condition for the overall optimality of insurance decision.

purchaser can be forced to pay a higher price for the option, but this possibility is assumed away in this paper.

Putting together the benefit and cost of holding reserves, the net benefit of self-insurance—for the overall insurance cost—is

$$G(D, V_t, T, t) - G(\widetilde{D}, V_t, T, t) - (R - r)(T - t)(D - \widetilde{D}). \quad (8)$$

Since the option price depends on time only through the time left until expiration, we simplify notation by defining $\tau \equiv T - t$ and dropping t from all other variables. The net benefit of holding reserves is written as

$$B(\lambda) = G(D, V, \tau) - G(\widetilde{D}, V, \tau) - (R - r)\tau(D - \widetilde{D}). \quad (9)$$

As the need for market-based insurance, $\widetilde{D}$, declines with the increase in reserve holding, the net benefit (cost-saving) of holding reserves rises with λ. This marginal benefit of increasing reserve coverage λ is:

$$MB(\lambda) \equiv \frac{\partial B(\lambda)}{\partial \lambda} = D\left[\frac{\partial G(\widetilde{D}, V, \tau)}{\partial \widetilde{D}} - (R - r)\tau\right], \quad (10)$$

using $\frac{\partial \widetilde{D}}{\partial \lambda} = -D$. The optimal reserve coverage (self-insurance) ratio will satisfy $MB(\lambda) = 0$:

$$\frac{\partial G(\widetilde{D}, V, \tau)}{\partial \widetilde{D}} = (R - r)\tau \quad (11)$$

By the monotonicity of the put option price in its exercise price,

$$\frac{\partial G(\widetilde{D}, V, \tau)}{\partial \widetilde{D}} \geq 0,$$

and thus a meaningful solution will exist for equation (11).[8] From equations (9) and (11), we can see that a full self-insurance ($\lambda = 1$ and $\widetilde{D} = 0$) is optimal when $R - r = 0$. In this case, we have $MB(1) \geq 0$ by the monotonicity of the put option price in its exercise price. Since the opportunity cost of holding reserves is zero, the agent may just as well self-insure fully.

The first-order condition for the optimal reserve coverage ratio (equation (11)) provides an implicit function that links the optimal coverage ratio λ^*, the value of the overall insurance need D, the interest rate spread $R - r$, the value of the underlying asset V, and its volatility σ.

$$H(\lambda^*, D, R - r, V, \sigma) = 0. \quad (12)$$

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[8]In particular, if the option price is convex (which is the case for the European option), $B(\lambda)$ is a concave function of λ, and equation (11) is also the sufficient condition for the optimal reserve coverage ratio.

In addition, each pair of λ^* and D would satisfy

$$C = \lambda^* D. \tag{13}$$

Equations (12) and (13) determine the optimal reserve coverage ratio and the implied demand for reserves, for a given level of desired overall insurance D. We can also investigate the response of reserve coverage to changes in parameters, including the volatility and interest rate spread. Given the desired level of overall insurance D, the optimal reserve coverage ratio can be solved numerically as a function of the volatility (σ) and spread ($R - r$).

$$\lambda^* = \lambda^*(\sigma, R - r \mid D) \tag{14}$$

For any level of D, we can track simultaneously the locus of $(\lambda^*, \sigma, R - r)$ and $(C^*, \sigma, R - r)$ by using $C^* = \lambda^* D$ in equation (13).

IV. Parameterization by European Option

To explore the quantitative implication of the framework developed so far, we turn to the Black-Scholes formula (Black and Scholes (1973) and Merton (1992)). The availability of a closed-form solution makes it easy to derive indicative ratios that serve as quick reference points. In particular, under the Black-Scholes formula, the insurance value and the optimal reserve coverage ratio depend on the ratio of D (or C) to V, independent of the level of V.

From the viewpoint of quantitative accuracy, the parameterization by a European option leaves several loose ends. Indeed, financial markets offer a variety of instruments that provide richer insurance possibilities than a European option. First, an American option allows an early exercise prior to the expiration date, and thus can be used to quantify the value of insurance that can be exercised any time before expiration. Next, the financial market has nurtured several new instruments of insurance. Credit derivatives, which have grown rapidly in recent years, offer insurance against credit events of both private and sovereign debts. The most popular instrument, credit default swap provides a means of insurance against the default of associated private or sovereign debt (Duffie and Singleton 2003). Finally, in the most general form, the full market equivalent of credit protection will be provided by the likes of macroeconomic insurance espoused by Shiller (2003). The development of these instruments will expand the set of market-based alternatives to self-insurance, and can lessen the reliance on it. However, the European option price captures the lion's share of the market value of insurance, and offers a flexible apparatus for an illustrative analysis of the quantitative framework proposed in this paper.

A. Simple Calculus of Self-Insurance

When the value of the underlying asset follows a log-normal process $\frac{dV_t}{V_t} = \mu dt + \sigma d\omega(t)$, with $\omega(t)$ denoting a standard Brownian motion, the price of a put option with exercise price D is:

$$G(D, V, \tau) = De^{-r\tau}N(x_2) - VN(x_1) \tag{15}$$

$$\text{where} \quad x_1 = \frac{\log(D/V) - (r + \frac{\sigma^2}{2})\tau}{\sigma\sqrt{\tau}} \quad \text{and} \quad x_2 = x_1 + \sigma\sqrt{\tau},$$

where N denotes the standard normal distribution function. Substituting the formula into equation (5), we can write the average insurance value per unit of reserves as

$$\frac{I(C,V)}{C} = e^{-r\tau}N(x_2) - \frac{V}{C}N(x_1)\tau \equiv I^A(C/V) \tag{16}$$

where x_1 and x_2 are defned using C in place of D in equation (15). Several properties of the average insurance value follow from this expression.

- The average insurance value of reserves depends on the ratio of C to V, independent of the level of V.
- The average insurance value of reserves increases in the C/V ratio. Differentiating equation (16) and rearranging it,

  $$\frac{\partial I^A(C/V)}{\partial\left(\frac{C}{V}\right)} = \left(\frac{V}{C}\right)^2 N(x_1) > 0.$$

  For the same level of reserves (C), a lower value of the underlying asset raises the C/V ratio, and thus increases the market value (cost) of self-insurance provided by holding reserves.
- The average insurance value increases in the volatility of the value of the underlying asset, for the same reason as the option price increases in the volatility.

The derivation of the optimal reserve-coverage (self-insurance) ratio starts with calculating the costs of market insurance under different degrees of self-insurance. When self-insurance accounts for λ of the overall insurance need, the cost of the market-based insurance of level $\widetilde{D}$ $(= (1-\lambda)D)$ is estimated by substituting $\widetilde{D}$ into D in equation (15):

$$G(\widetilde{D}, V, \tau) = \widetilde{D}e^{-r\tau}N(\widetilde{x}_2) - VN(\widetilde{x}_1)$$

$$\text{where} \quad \widetilde{x}_1 = \frac{\log(\widetilde{D}/V) - (r + \frac{\sigma^2}{2})\tau}{\sigma\sqrt{\tau}} \quad \text{and} \quad \widetilde{x}_2 = \widetilde{x}_1 + \sigma\sqrt{\tau}.$$

Differentiation and some rearrangement lead to: $\frac{\partial G(\widetilde{D})}{\partial \widetilde{D}} = e^{-r\tau} N(\widetilde{x}_2)$. Substituting this into equation (10), the marginal benef t of increasing reserve coverage λ is obtained as:

$$MB(\lambda) = D\left[e^{-r\tau} N(\widetilde{x}_2) - (R-r)\tau\right]. \tag{17}$$

The optimal reserve coverage (self-insurance) is determined by:

$$MB(\lambda^*) = 0$$

This expression implies the following properties of the optimal reserve coverage ratio.

- The optimal reserve coverage ratio depends on the ratio of D (or C) to V, independent of the level of V. Equation (17) shows that the optimal coverage ratio is determined by the expression within the bracket, which depends only on the ratio of $\widetilde{D}$ to V where $\widetilde{D} = D - C$.
- The marginal benef t in equation (17) is a decreasing function of λ, as a higher value of λ would lower $\widetilde{x}_2$. This property ref ects the convexity of the European option price and algebraically, $\frac{\partial MB}{\partial \lambda} = De^{-r\tau} N'(\widetilde{x}_2) \frac{-1}{\sigma\sqrt{\tau}} \frac{1}{1-\lambda} < 0$.
- The optimal reserve coverage ratio is determined as an internal solution when $0 < (R-r)\tau < 1$. Since the marginal benef t function decreases in λ, we have only to show that $MB(0) > 0 > MB(1)$. It is easy to see that $MB(0) > 0$ under $(R-r)\tau < 1$, which is likely to hold true in most conceivable cases. To see $MB(1) < 0$ when $R > r$, note that $\lim_{\lambda \to 1} \widetilde{x}_2 = -\infty$. We can verify that $\lim_{\lambda \to 1} MB(\lambda) = D[e^{-r\tau} N(-\infty) - (R-r)\tau] = -(R-r)\tau < 0$ when $R > r$.

B. Numerical Calculations

The average insurance value and optimal reserve coverage ratio are driven by the values of the volatility, spread, and ratio of the asset value to reserves (or to the desired overall insurance). With enough econometric investigation, many of these values can be estimated from data of individual countries, but that path is not pursued here. Instead, the insurance value and the optimal reserve coverage ratio are calculated for a variety of parameter values, to assess the sensitivity of calculation results to changes in parameter values and to deduce a number of results that are more likely to emerge under a broad range of circumstances.

The f rst group of calculations is the average insurance value of reserves for various combinations of volatility σ and ratio C/V (Table 1). The C/V ratio was varied from 0.5 to 3, while the volatility was varied from 0.05 to 0.5 (i.e. from 5 percent to 50 percent). Except in cases with $C = V$, the volatility is found to have little effect on the average insurance value. In contrast, the average insurance value responds sensitively to the C/V ratio, indicating the importance of the value of the underlying asset in determining the insurance value of reserves. Table 2 repeats the same calculation for smaller values of the C/V ratio, and will be revisited when the cost of regional insurance arrangement is discussed in Section A.

The next group of numerical calculations relates to the optimal reserve coverage ratio. The volatility and the spread are varied, but the D/V ratio is kept at 1. If the D/V ratio is larger than 1, it amounts to seeking an insurance coverage larger than the current value of the underlying asset. Such a situation may arise when economic fundamentals deteriorate, thereby reducing the value of the underlying asset while the need for insurance becomes more acute. By keeping the D/V ratio equal to 1, this paper considers a normal situation where the desired overall insurance can be backed up by the value of the underlying asset.

Figure 1 illustrates the effect of the volatility and spread on the optimal reserve coverage ratio, for the D/V ratio equal to 1. The lower panel is the equi-λ^* contour, which is a cross section of the 3D plot in the upper panel. Table 3 presents numerical values of the optimal reserve coverage ratios that are plotted in Figure 1. As can be expected, the optimal reserve coverage ratio decreases in the spread, and increases in the volatility. Accordingly, the iso-λ^* contour in the lower panel of Figure 1 is upward sloping.

The elasticity of the optimal reserve coverage ratio to the spread varies with the volatility. In Figure 1 and Table 3, for lower values of the volatility ($\sigma = 0.05$ and 0.1), the optimal reserve coverage ratio falls by about a half as the spread rises ten-fold from 100 to 1,000 basis points. The decline in reserve coverage ratio is less sharp for higher values of the volatility ($\sigma = 0.5$, for example). In turn, the elasticity of the optimal reserve coverage ratio to the volatility varies with the spread. For lower values of the spread (1 or 2 percent), the reserve coverage ratio rises nearly tenfold as the volatility increases from 0.05 to 0.5. The corresponding rise in the reserve coverage ratio is much more than tenfold for higher values of the spread (9 or 10 percent).

In terms of the level of reserve coverage, a full coverage hardly appears to be optimal. In Table 3, numerical values of reserve coverage ratios are less than 0.5 for most parameter values, except for the upper right-hand corner. Considering that the rise in the volatility will be accompanied by the rise in the spread, the reserve coverage ratio below 0.5 appears to be a more likely outcome when $D = V$. In Table 4, spreads are kept at extremely low values that range from 1 to 10 *basis* points. Even then, optimal reserve coverage ratios maintain a good distance from 1, a full coverage. On the low end of the optimal reserve coverage ratios, the likely ratios seem to often exceed 0.2, except under combinations of a low volatility and a high spread. Again considering that a low spread is likely to be accompanied by a low volatility, the lower left-hand corner of the table is less likely to occur. To focus on the middle section, by picturing a thick diagonal bloc that runs from the upper left-hand corner to the lower right-hand corner, the range for more likely values of the optimal reserve coverage ratios appears to be 20-50 percent.

V. Two Illustrative Applications

The discussion so far tried to distill broad patterns that emerge from various combinations of parameter values, without zooming in on particular parameter values that apply to specif c countries or situations. While limiting the extent to which the results can be applied to specif c countries, this approach illustrates the logic of this framework. As the next step, this section applies the broad patterns identif ed thus far to several issues that are much discussed in relation to international reserves. The comparison of theory and data are similarly illustrative, with emphasis placed on drawing out overall patterns rather than exact estimates for particular countries.[9]

A. Cost of an Asian Monetary Fund

Several emerging-market economies have accumulated a large amount of reserves, as can be seen in Table 5. This tendency has been particularly strong in Asia, leading some economists to diagnose overaccumulation of reserves for several Asian countries (Edison (2003)). One cause of this apparent overaccumulation would be the absence of insurance arrangement that can substitute for reserve accumulation. Partly in an attempt to f ll the gap, several Asian countries signed on to a mutual swap agreement under the Chiang Mai Initiative (CMI). With the cumulative total of 35 billion dollars, however, its size pales by the scale of reserves being held by several countries in the region.

What then would be the cost of arranging a larger-scale regional insurance scheme, which may be called the Asian Monetary Fund (AMF)? Numerical results presented in Table 1 offer suggestive estimates of the cost of an insurance arrangement at a scale comparable to the reserves being held by several Asian countries.[10] The critical parameter in this calculation is the ratio of the underlying asset value to the insurance coverage that is currently provided by reserves. Different values of this ratio correspond to different institutional arrangements. We focus on two sets of values: $C/V = 1$ and $C/V \leq 0.5$, each of which can be interpreted as representing certain types of institutional arrangement that we observe.

First consider the case with $C/V = 1$. This comes close to an insurance arrangement in the form of a mutual company. Each country entrusts its reserves to the insurance pool, which can manage it more eff ciently than individual countries, thereby reducing the opportunity cost of maintaining reserves. The mutual can then purchase put options. The results of Table 1 indicate that the average cost of insurance—per unit of reserves—ranges between 0.01 and 0.1 when $C/V = 1$. Applying these cost estimates, the insurance cost of reserves amounting to 10 percent of GDP would be between 0.1 and 1 percents of GDP. Several countries whose excess reserve holdings are about 20 percent of GDP—China and Korea in Asia, and Chile in Latin America—are carrying an insurance with a market value (cost) that ranges between 0.2 and 2.0 percents of GDP. Even on the low side of the range, this is probably too expensive to be a cost-effective alternative to holding international reserves, especially for countries like Chile, China, and Korea. With their sovereign spreads around 100 basis points, the opportunity cost of holding reserves amounting to 20 percent of GDP would be about 0.2 percent of GDP, near the lower end of the insurance cost estimates.

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[9]Such estimation requires further econometric and theoretical investigation which tailor the framework to the country or situation in question.

[10]The cost estimate based on the European option will be, if any, lower than the cost estimate based on the American option or other more customized derivative arrangements.

The insurance cost can be lowered substantially if the arrangement can be based on an underlying asset with a larger value.[11] Consider $C/V = 0.5$, which corresponds to the f rst row of Table 1. The cost of insurance is less than 0.01 for most parameter values, and the cost of insurance amounting to 10 percent of GDP would thus be less than 0.1 percent of GDP. This calculation is carried on further in Table 2, where the cost of insurance for even smaller values of the C/V ratio is reported in units of thousandths. If the C/V ratio can be lowered to 0.1, the cost of insurance falls below 10^{-5} per unit, implying that the cost of insurance amounting to 10 percent of GDP would be less than a one-thousandth percent of GDP.

The value of the underlying asset can be raised and the C/V ratio be lowered in two ways. First, the option can be arranged for use by a subgroup of members, rather than for simultaneous use by all members. By basing a small number of option arrangements on the pooled asset that exceeds the combined notional value of the underlying assets, the effective value of the underlying asset rises, lowering the cost of insurance. This the pure benef t of pooling.

The other way of raising the value of the underlying asset requires more than the pledging of external assets. It can take the form of a mutual commitment to emergency loan accompanied by conditionality—much like the existing structure of the IMF crisis lending. The cost of insurance can be paid in the form of the forgone investment income on the capital (quota) that is pledged to the insurance pool (e.g. the AMF). Agreeing to abide by the conditionality to be imposed at the time of an emergency loan has the effect of expanding the scope and value of the underlying asset on the basis of which an (effective) option contract can be purchased.

Viewed in this light, conditionality is not only a way of ensuring repayment to the lending agency ex post, but also a method of lowering the cost of ex-ante insurance arrangement. The latter role has one immediate implication on the appropriate scope of conditionality. The scope of conditionality has to be adjusted in accordance with the source of risks for which de-facto insurance is provided by emergency lending arrangement. To the extent that the source of an ex-ante insurance is structural issues inherent in the private sector, structural conditionality that goes beyond the traditional arena of macroeconomic policy is the coherent and necessary apparatus for expanding the base of the underlying asset to structural aspects where the insurance need originated in the f rst place.

The most cost-effective arrangement is made possible if all participants subscribe to conditionality and, in addition, if the number of participants is large enough to have a near-perfect pooling of insurance need within the AMF. Insurance can then be provided internally without having to purchase options from the market. This combines both ways of raising the value of the underlying asset, and is not too different from the current arrangement of

[11] One possibility is to pool individual contributions and purchase an option with a strike price of smaller value. This is the traditional pooling arrangement, but has limited insurance value when only a small number of participants are involved as in the hypothesized case of an Asian Monetary Fund.

the IMF. In this instance, economies of scale would render the IMF, a larger pooling, to be a strictly more eff cient arrangement than the AMF, a smaller pooling.[12]

B. Excess Reserves—Advanced versus Emerging Markets

To confront theory-implied optimal self-insurance ratios (λ^*) with data, we make auxiliary working assumptions on the desired level (D) of overall insurance. Had we constructed a complete model that includes both the preference and cost sides of insurance decision, the desired level (D) of overall insurance will naturally follow. Without such a model, we adopt the working assumption that the desired level of overall insurance is equal to the amount of the short-term external debt, consistent with policy guidelines recently offered.[13]

According to Table 6, actual reserve coverage ratios for advanced economies most often fall in the 20-40 percent range, not very far from the calculated optimal reserve coverage ratios in the 20-50 percent range (Tables 3 and 4). Considering that advanced markets have better access to f nancial markets, it is to be expected that their observed ratios are closer to theoretically calculated optimal ratios. With ample availability of insurance opportunities—both implicit and explicit—individual agents can avail themselves of suitable insurance arrangements. The authorities have little need to arrange an explicit aggregate insurance, beyond the holding of reserves by central banks at a near-optimal level. The actual amount of reserves is near-optimal in that the level is consistent with the optimal reserve coverage (self-insurance) ratio that would have prevailed, had a central bank made an explicit optimal choice between self-insurance and market-based insurance for the whole economy.

On the other hand, Table 7 shows that the observed ratios of reserves to the short-term debt are much higher in emerging markets, except in years prior to the outbreak of a currency crisis—e.g. Korea and Thailand in 1997—when the levels of reserves were likely to have been constrained by external factors. For most emerging markets, the ratios used to be close to or higher than 100 percent, and have picked up sharply in several Asian countries following the Asian crisis.

On the basis of this clear contrast between advanced and emerging-market economies, a particular measure of excess reserves can be constructed by asking the following question. How large is the excess holding of reserves by emerging markets, relative to the advanced-country norm, which appears to be quite close to theory-implied optimal ratios? To approximate this excess reserve ratio, we assume that about a half of the short-term external debt is the optimal amount of reserve coverage (self-insurance). This is a relatively high ratio, in light of the

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[12]The rationale for a regional arrangement like the AMF comprises both economic and geo-political factors (Henning, 2002). The calculation here shows the ineff ciency of one economic factor, namely the cost of insurance, and does not constitute a recommendation for or against the regional arrangement.

[13]In contrast to existing policy guidelines, this framework can assess how much of the desired insurance should be covered in the form of self-insurance (reserves) rather than suggesting it to be covered fully by self-insurance.

numerical calculations and the actual ratios for advanced economies. On the basis of this assumption, Table 8 shows the average reserve holding by emerging markets over 2000-2002 period (based on Table 5), the optimal reserve holding implied by the average short-term external debt over the same period, and the implied amount of excess reserves, all measured in percent of GDP. Most emerging markets have large excess reserves, presented in the third column as the sizeable gaps between their reserve holdings and what would have been held by advanced economies under the same levels of external short-term debt.

This measure of excess reserves—the gap between advanced and emerging-market economies—can be viewed as a quantitative indicator of financial-market limitations that confront emerging markets. Not having the first-best access to financial markets that is available to advanced economies, many emerging-market economies are led to accumulate a much larger amount of reserves—relative to a common benchmark—than advanced economies.[14] This gap reflects, as often argued, the weakness in institutional development and policy credibility on the part of emerging markets, and can hardly be expected to be narrowed quickly. Fostering institutional development and establishing credibility appear to require time-tested proofs of their resilience, rather than an ostensible adoption of cutting-edge institutions (Caballero and others (2004); Mauro and others (2004)).

Given the inevitably slow pace of developing institutions and establishing the first-best market access, a pragmatic short-term solution can indeed be to maintain reserves at a level no less than the short-term external debt. Some have even argued for expanding the target of reserve coverage to the potential amount of capital outflow originating in the domestic market (Wijnholds and others, 2001). The fact remains, however, that the long-term solution should lie in narrowing the gap between advanced and emerging markets, that is, the gap between the best possible outcome—the near optimal practice of advanced economies—and the current reality facing emerging markets.

Two potential aids in bridging the gap are the Contingent Credit Line (CCL) facilities that were offered by the IMF for a short duration, and Precautionary Arrangements that are being considered for a broader use by the IMF. Under these arrangements, the optimal ratio of the reserves to the size of the credit line would correspond to λ^* (Table 3). In the CCL, the ratio most comparable to optimal reserve coverage would be the ratio of member country's quota to the size of the CCL, which was recommended to range between 1/5 and 1/3. In comparison to numerical calculations in this paper, these ratios come on the low side; for most parameter values, the self-insurance ratio exceeds 1/3. The low value of the implied self-insurance ratio under the CCL, however, was accompanied by very stringent requirements for qualification. The stringency may have been the critical reason for the limited interest that was expressed for the CCL, which led to its eventual abandonment. No comparable ratios have yet been developed for Precautionary Arrangements, which might replace some of the functions that had been intended

[14]Of course, this is not a perfect measure. In particular, the excess-reserve measures in Table 8 are higher for emerging-market economies that are viewed less vulnerable, implying that highly vulnerable ones are even constrained from accumulating reserves.

for the CCL. The framework of this paper can facilitate a quantitative analysis of the tradeoff between the size of access and the stringency of requirements.

VI. Conclusion

This paper proposes quantifying the unobservable insurance value of holding external reserves by the price of a put option with equivalent insurance coverage. Using the specific parameterization based on European options, several numerical guidelines were derived and compared with stylized statistics associated with reserve holdings.

Applied to the calculation of international insurance arrangement costs, it showed that pure regional swapping arrangements are too costly to be implemented on a large scale (10 or 20 percent of GDP). In contrast, an arrangement similar to the IMF—adopting conditionality as a device to increase the effective value of the underlying asset—can greatly reduce the cost of an insurance arrangement at both regional and global levels.

Next, under the auxiliary assumption that countries desire an implicit insurance coverage equivalent to the level of the short-term external debt, the theoretically derived optimal reserve coverage (self-insurance) ratio was shown to be close to the actual reserve holdings of advanced economies. In contrast, the reserve holdings of emerging markets exceed the optimal ratio by wide margins, offering a quantitative measure of the gap in financial market access between the two groups of countries. In moving toward the long-term goal of closing the gap, the quantitative framework proposed in this paper can play an instrumental role.

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Table 1. Average Insurance Value

$C/V \setminus$ volatility	0.050	0.100	0.150	0.200	0.300	0.400	0.500
0.5	0.000	0.000	0.000	0.000	0.001	0.008	0.023
1.0	0.008	0.026	0.045	0.065	0.103	0.142	0.180
1.5	0.304	0.304	0.304	0.306	0.316	0.333	0.356
2.0	0.470	0.470	0.470	0.470	0.471	0.476	0.485
3.0	0.637	0.637	0.637	0.637	0.637	0.637	0.639

Table 2. Average Insurance Value–Further Calculations
(in thousandths)

$C/V \setminus$ volatility	0.050	0.100	0.150	0.200	0.300	0.400	0.500
0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.15
0.3	0.00	0.00	0.00	0.00	0.00	0.20	1.94
0.4	0.00	0.00	0.00	0.00	0.10	1.85	8.57
0.5	0.00	0.00	0.00	0.01	1.09	7.68	22.54

Table 3. Self-Insurance Ratios with $D/V = 1$

spread \ volatility	0.050	0.100	0.150	0.200	0.300	0.400	0.500
0.010	0.083	0.187	0.280	0.364	0.508	0.623	0.714
0.020	0.071	0.164	0.250	0.329	0.466	0.580	0.672
0.030	0.063	0.149	0.230	0.305	0.437	0.549	0.643
0.040	0.056	0.138	0.215	0.286	0.415	0.525	0.618
0.050	0.051	0.129	0.202	0.271	0.396	0.504	0.598
0.060	0.047	0.121	0.191	0.258	0.379	0.486	0.579
0.070	0.043	0.114	0.181	0.246	0.364	0.470	0.562
0.080	0.040	0.108	0.173	0.235	0.351	0.454	0.546
0.090	0.037	0.102	0.165	0.225	0.338	0.440	0.531
0.100	0.034	0.096	0.157	0.216	0.326	0.426	0.517

Table 4. Self-Insurance Ratios with $D/V = 1$

spread \ volatility	0.050	0.100	0.150	0.200	0.300	0.400	0.500
0.0001	0.167	0.328	0.458	0.566	0.728	0.821	0.885
0.0002	0.144	0.291	0.414	0.517	0.675	0.781	0.858
0.0003	0.137	0.280	0.400	0.501	0.658	0.768	0.843
0.0004	0.133	0.272	0.390	0.491	0.646	0.758	0.835
0.0005	0.129	0.265	0.383	0.481	0.638	0.750	0.829
0.0006	0.126	0.261	0.376	0.475	0.632	0.744	0.824
0.0007	0.124	0.258	0.372	0.470	0.626	0.739	0.819
0.0008	0.122	0.254	0.368	0.466	0.621	0.733	0.815
0.0009	0.121	0.251	0.364	0.462	0.617	0.729	0.811
0.0010	0.119	0.249	0.361	0.458	0.613	0.726	0.808

Table 5. Ratios of Reserves to GDP
(in percent)

country \ year	1995	1996	1997	1998	1999	2000	2001	2002
Argentina	6	7	8	8	9	9	5	3
Brazil	7	8	6	6	7	6	7	9
Chile	23	21	22	20	21	20	22	24
China	11	14	16	16	16	16	18	23
Colombia	9	10	9	9	10	12	12	15
Czech Rep.	28	23	19	22	24	26	25	34
Hong Kong	39	41	53	54	60	65	68	69
Hungary	27	22	18	20	23	24	21	16
India	6	6	7	7	8	9	10	14
Indonesia	7	9	8	25	20	19	19	18
Korea	7	7	4	16	18	21	24	26
Malaysia	28	28	21	36	39	33	35	36
Mexico	6	6	7	8	7	6	7	8
Philippines	10	14	11	17	20	20	22	21
Poland	12	13	14	18	18	17	15	16
Russia	5	4	4	4	6	11	12	14
Singapore	83	84	75	91	93	86	88	93
Thailand	22	21	18	26	28	27	29	31
Turkey	8	10	10	10	13	12	14	16
Venezuela	14	23	20	15	15	13	10	13

Table 6. Ratios of Reserves to Short-term External Debt I
(in percent)

country \ year	1995	1996	1997	1998	1999	2000	2001	2002
Australia	59	66	67	47	65	55	48	55
Austria	...	...	...	...	40	36	28	27
Belgium	...	...	...	...	10	11	11	11
Canada	...	...	...	...	41	43	39	33
Denmark	...	...	...	...	54	37	41	50
Finland	...	...	...	...	58	31	30	70
France	...	...	...	...	27	25	23	20
Germany	...	...	...	...	28	25	22	19
Iceland	51	64	52	38	29	20	17	17
Italy	...	...	...	...	27	26	30	36
Japan	...	...	...	...	41	43	39	33
Netherlands	...	...	...	...	146	187	215	190
New Zealand	98	143	68	60	86	62	47	58
Norway	...	...	...	...	108	91	53	43
Spain	...	...	...	...	48	58	63	53
Sweden	...	...	...	...	38	27	25	26
Switzerland	...	...	...	...	31	18	18	19
United Kingdom	...	...	...	...	6	7	5	4
United States	...	...	...	...	28	24	23	29

Table 7. Ratios of Reserves to Short-term External Debt II
(in percent)

country \ year	1995	1996	1997	1998	1999	2000	2001	2002
Argentina	74	94	92	73	70	65	52	80
Brazil	180	164	115	82	101	98	112	163
Chile	244	201	238	162	161	155	172	151
China	464	457	486	503	666	890	1134	1508
Colombia	155	180	148	133	133	214	236	299
Czech Rep.	493	328	165	200	254	232	252	437
Hong Kong	24	36	51	71	110	153	183	226
Hungary	396	330	210	167	262	211	196	155
India	329	349	366	459	428	458	758	1127
Indonesia	59	66	50	90	126	146	166	240
Korea	64	55	29	161	217	293	332	324
Malaysia	340	279	132	239	394	427	394	515
Mexico	58	72	102	114	121	159	169	217
Philippines	228	197	99	109	185	228	236	264
Poland	759	785	525	534	386	367	265	245
Russia	83	71	46	35	87	261	250	335
Singapore	34	44	36	64	80	124	116	145
Thailand	97	81	59	107	183	317	320	538
Turkey	167	176	151	103	128	80	92	156
Venezuela	347	643	498	303	277	337	314	289

Table 8. Excess Reserves
(in percent of GDP; average over 2000-2002)

	Total Reserves	External ST Debt	Excess Reserves
Argentina	6	9	1
Brazil	7	6	4
Chile	22	14	15
China	19	2	18
Colombia	13	5	10
Czech Rep.	28	10	23
Hong Kong	67	37	49
Hungary	20	11	15
India	11	1	10
Indonesia	19	11	13
Korea	24	8	20
Malaysia	35	8	31
Mexico	7	4	5
Philippines	21	9	17
Poland	16	6	13
Russia	12	4	10
Singapore	89	70	54
Thailand	29	8	25
Turkey	14	13	7
Venezuela	12	4	10