About the Adjustment of Exchange rate, Interest Rate and Price Level

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About the Adjustment of Exchange Rate, Interest Rate and Price Level

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Abstract

We model the dynamics of the exchange rate of the currency of a relatively small country vis-à-vis to U.S. dollar. In order to construct a complete model for the financial system, the dynamics of interest rate and average price level are modeled too. Our results imply that the exchange rate will change due to imbalances in the part of the balance of payments of the country, charged in U.S. dollars, if the central bank does not sterilize these impulses. The simultaneous adjustment of the exchange rate, interest rate and the average price level may be stable or not, and the adjustment may be monotonic or critically damped, i.e. overshooting and financial panics may occur. The equilibrium state of the dynamic system is shown to be conditional on investors' expectations of the future exchange rate. (JEL F31, F32, G15)

Keywords: Exchange rate, interest rate, price level, nonlinear dynamics.

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1 Introduction

Meese and Rogoff (1983a) compare the empirical performance of various macro-based exchange rate models to the random-walk model. Their conclusion is that none of the asset market exchange rate models outperforms the simple random-walk model. In a later work (1983b), Meese and Rogoff found such combinations of parameter constraints that the models outperform the random-walk model for time horizons beyond twelve months. These models are, however, unstable and the evidence given is thus vague. The tested models by Koedijk and Schotman (1990) outperform the random-walk model with pooled data, and the results support the mean-reverting behavior of exchange rates toward their equilibrium values.

Flood and Taylor (1996) present the existing theories of exchange rate movements based on macro fundamentals: 1) the Purchasing Power Parity (PPP) model, 2) the flexible-price monetary model, 3) the sticky price, overshooting monetary model, 4) the portfolio balance model and 5) the equilibrium model. The authors conclude that very simple macro fundamentals — relative inflation or relative interest rates — have poor explanatory power with respect to variations in exchange rate movements even over the one-year horizon. Five-, ten-, and twenty-year averages, however, show a strong proportionality between the average exchange rate depreciation and movements in these fundamentals. A simple macro fundamentals based model thus outperforms the random-walk model at horizons of five years or longer. "Again, this suggests that there are speculative forces at work in the foreign exchange market that are not reflected in the usual menu of macro-economic fundamentals..." (ibid. p. 285-6) "...but the differences in exchange rate fundamentals change very slowly through time, while exchange rate time series show comparatively huge variation." (ibid. p. 287).

In their survey, Berben and de Jong (1999) conclude that evidence from long-horizon regressions is at best weak, but the results of Vector Error-Correction models is more convincing. The evidence seems to support the mean-reverting behavior of exchange rates toward the PPP equations, but the adjustment is slow and the PPP -theory cannot explain the short-term movements of exchange rates. Taylor concludes his survey (1995) as: "The macroeconomic fundamentals are important in setting the parameters within which the exchange rate moves in the short term, but they do not appear to tell the whole story. It is in this context that the emerging literature of foreign exchange market microstructure seems especially promising."

We can summarize this review as follows. The models of exchange rate dynamics have concentrated on the international trade of goods on the basis of price competition (the PPP theory), on investors' speculative capital flows (the Interest Rate Parity (IRP) theory and the portfolio balance models), on modeling money market behavior at macro-level (the flexible and sticky price monetary models), or on modeling general equilibrium in a two country model (the equilibrium model). Empirical evidence supports the PPP theory in the long-term determination of exchange rates, but the modeling of short-term fluctuations by the IRP and other models has been less successful.

According to the requirements for theoretical completeness and empirical success, none of the mentioned models alone fulfills the criteria for a complete theory of exchange rate movements. For that we need a theory which explains short- and long-term exchange rate movements, where international trade of goods and investments are taken into account, expectations and speculative investment flows are present as well as central bank's possible operations.

In the proposed model, we integrate short- and long-term capital flows and show how expectations and speculative demand flows affect exchange and interest rates. We operate with macro-level quantities and define their measurement units to allow the empirical testing of the model. The micro-foundations for the macro equations are not exactly specified because, for example, we apply a Keynesian type of model for the dynamics of average price level, and the micro foundations of Keynesian theory are vague. However, the proposed model is consistent with the generally assumed principles for the behavior of economic agents, that is, real consumption depends on real GDP, physical investments depend on real GDP and interest rate, the international trade of goods and financial investments are made on the basis of price and yield competition, the demand of money in circulation depends on monetary transactions in the domestic and international trading of goods and financial investments etc. The modeled 'prices' in the model — the exchange rate, interest rate and the average price level — are assumed to adjust according to excess demand in the corresponding market.

We define the economic 'forces' which act upon the three adjusting quantities, which terminology has been used by Flood and Taylor (1996 p. 286) and Park (1997 p. 478), for example. These forces contain parameters which allow the central bank to steer the adjustment process. The equilibrium values of the adjusting quantities define the steady-state of the model, the 'zero-force' situation. We define inertial factors for the adjusting quantities and study their role in the adjustment process. The exchange rate overshooting phenomena, the case of interest in Dornbush (1976), is shown to occur in special cases in our model, but contrary to the Dornbush's model, now overshooting takes place in stable cases. The model explains also financial panics and possible collapses of exchange rates.

The study in organized as follows. In sections 2 and 3 the current and capital accounts of the home country are modeled. Sections 4 and 5 present a dynamic model for the exchange rate between the currency of the home country and U.S. dollar. Section 6 contains a dynamic model for the interest rate. In section 7 the models for exchange and interest rate are analysed simultaneously. Section 8 contains a dynamic model for the average price level and in section 9 are studied simulations with the complete model. Section 10 discusses limitations of the analysis and section 11 gives a summary.

2 Modeling Current Account

We study the determination of exchange rate of the currency of a relatively small country vis-à-vis to U.S. dollar. For convenience, the home country is assumed to be Sweden, but the modeling applies to any relatively small country with an own currency. People's willingness to exchange U.S. dollars to Swedish crowns due to international trade depends on the U.S. dollar revenues of Swedish exporting firms which pay their costs in Swedish crowns. Similarly, people's willingness to exchange Swedish crowns to U.S. dollars due to international trade depends on the revenues of Swedish importing firms in Swedish crowns which pay their suppliers in U.S. dollars.

We analyze only those export revenues and import expenditures of Sweden which are charged in U.S. dollars. Only those Swedish firms are thus involved, which charge their sales or pay to their suppliers in U.S. dollars. Let us denote that part of the current account of Sweden, charged in U.S. dollars, as $R = X - M$ where X (USD/y) are the U.S. dollar export revenues and M (USD/y) the import expenditures of Swedish firms during time unit y.[1] Firms' net willingness to exchange Swedish crowns to U.S. dollars due to international trade then depends on the quantity R.

We denote the unit price of Swedish export good i by p_i (SEK/kg), and the unit U.S. dollar price of the corresponding foreign good by p_{ui} (USD/kg). The unit prices of goods are expressed as kilogram -prices to make them additive. From the point of view of good i, the international price competitiveness of Sweden can be measured by quantity: $Sp_{ui} - p_i$ (SEK/kg), where S with unit SEK/USD is the nominal exchange rate of the two currencies. The greater this quantity the better the international price competitiveness of Sweden from the point of view of good i, and vice versa.

The international price competitiveness of Sweden is measured by H_R,

$$H_R = \sum_{i=1}^{n} w_i[S(t)p_{ui} - p_i(t)] = S(t)\sum_{i=1}^{n} w_i p_{ui} - \sum_{i=1}^{n} w_i p_i(t) = S(t)\overline{p}_u - \overline{p}(t),$$

[1]The measurement units are denoted in braces after the quantities.

where $0 \leq w_i < 1$, $\sum_{i=1}^{n} w_i = 1$ are dimensionless weights which reflect the importance of every good in the measure, n is the number of possible export goods produced in Sweden and $\overline{p}_u, \overline{p}$ are weighted averages of the unit prices abroad and in Sweden. The exchange rate and the average domestic price level are set as functions of time t because later we model their dynamics. The greater the H_R the better the price competitiveness of Sweden.

Because the quality of various goods is difficult to measure, the international trade of goods and services is assumed to be determined according to price competitiveness. We can then write

$$X = f(H_R),\ f'(H_R) > 0,\ f(0) = 0,\ M = g(H_R),\ g'(H_R) < 0,\ g(0) = 0.$$

The model for R becomes then

$$R(H_R) = f(H_R) - g(H_R),\ R'(H_R) = f'(H_R) - g'(H_R) > 0,\ R(0) = 0. \quad (2)$$

From (2) we get the following results:

$$\begin{aligned} \frac{\partial R}{\partial \overline{p}_u} &= R'(H_R)\frac{\partial H_R}{\partial \overline{p}_u} = R'(H_R)S > 0, \\ \frac{\partial R}{\partial \overline{p}} &= R'(H_R)\frac{\partial H_R}{\partial \overline{p}} = -R'(H_R) < 0, \\ \frac{\partial R}{\partial S} &= R'(H_R)\frac{\partial H_R}{\partial S} = R'(H_R)\overline{p}_u > 0. \end{aligned}$$

Increases in foreign (domestic) unit prices thus have a positive (negative), and the devaluation of Swedish crown vis-à-vis to U.S. dollar a positive effect on the current account of Sweden.

3 Modeling Capital Account

International investments are assumed to be made according to the highest expected yield, and we study directly net investment flows. We assume uncovered interest rate parity equation in continuous time

$$E_t[S(t_1)] = S(t)e^{\int_t^{t_1}[r(s)-r_u(s)]ds}, \quad t_1 > t,$$

because later we model the dynamics of the exchange rate in continuous time. By r with unit $1/y$ is denoted the domestic interest rate, by r_u with unit $1/y$ the U.S. interest rate and $E_t[S(t_1)]$ is the investors' expectation at moment t of the spot rate at moment t_1; see Appendix 1. The net investment flow of U.S. dollars to Sweden at time moment t then depends on the quantity H_C,

$$H_C = S(t)e^{\int_t^{t_1}[r(s)-r_u(s)]ds} - E_t[S(t_1)].$$

If H_C with unit SEK/USD is positive, investors on the average consider that investing in Sweden is more profitable than in U.S. and vice versa; see Appendix 1. H_C thus measures the international competitiveness (profitability) of Swedish investment opportunities; the greater the H_C the better the competitiveness of Swedish investments, and vice versa.

We denote that part of the capital account of Sweden, charged in U.S. dollars, by C (USD/y) at moment t,

$$C = h\left(H_C\right), \quad h'(H_C) > 0, \quad h(0) = 0. \tag{4}$$

If $C > 0$, a positive net investment flow of U.S. dollars takes place to Sweden, and vice versa. From (4) we get the following results:

$$\begin{aligned}
\frac{\partial C}{\partial S} &= h'(H_C)\frac{\partial H_C}{\partial S} = h'(H_C)e^{\int_t^{t_1}[r(s)-r_u(s)]ds} > 0,\\
\frac{\partial C}{\partial r} &= h'(H_C)\frac{\partial H_C}{\partial r} = h'(H_C)Se^{\int_t^{t_1}[r(s)-r_u(s)]ds}(t_1 - t) > 0,\\
\frac{\partial C}{\partial r_u} &= h'(H_C)\frac{\partial H_C}{\partial r_u} = -h'(H_C)Se^{\int_t^{t_1}[r(s)-r_u(s)]ds}(t_1 - t) < 0,\\
\frac{\partial C}{\partial E_t[S(t_1)]} &= h'(H_C)\frac{\partial H_C}{\partial E_t[S(t_1)]} = -h'(H_C) < 0.
\end{aligned}$$

The devaluation of Swedish crown vis-à-vis to U.S. dollar and an increase in Swedish interest rate thus have a positive, and an increase in U.S. interest rate and expectations of future devaluation of the Swedish crown a negative effect on the capital account of Sweden.

4 Modeling Exchange Rate Dynamics

That part of the balance of payments of Sweden, the transactions of which are charged in U.S. dollars, can be formulated roughly by adding the corresponding current and capital accounts. The corresponding part of the balance of payments of Sweden N (USD/y) can then be expressed as

$$N = X - M + C = f(H_R) - g(H_R) + h(H_C) = R(H_R) + h(H_C).$$

Now $S'(t)$ with unit $SEK/(USD \times y)$ measures the instantaneous velocity of the exchange rate; when $S'(t) > 0$, Swedish crown is devaluing against U.S. dollar and vice versa. We can then write an equation of motion for the exchange rate as follows

$$S'(t) = \xi_S\left(F_S\right), \quad F_S = A(t) - (1-a)N(t), \quad \xi_S(0) = 0, \quad \xi_S'(F_S) > 0, \tag{5}$$

where A with unit USD/y is the Swedish central bank's net buying of Swedish crowns by U.S. dollars during time unit y (if $A > 0$, Swedish central bank buys U.S. dollars by Swedish crowns, and vice versa); $0 < a < 1$ is the share of the balance of payments of Sweden charged in U.S. dollars which is left on the currency accounts in banks and not exchanged to crowns when N is positive (from crowns to dollars when N is negative). For simplicity, a is assumed to be a constant which reflects the payment routines of the firms. According to Eq. (5), $S'(t) > 0$ if $F_S = A - (1-a)N > 0$ and vice versa. We name F_S as the 'force' acting upon the exchange rate S. Eq. (5) gives a clear policy rule for the central bank if it aims to follow a fixed exchange rate (sterilizing) policy: $S'(t) = 0$ when $F_S = 0 \Leftrightarrow A = (1-a)N$.

Because of the number of variables in Eq. (5), the assumed general functional forms and the non-specification of the expectation formation mechanism for the exchange rate, we do not try to solve the equation. Rather we study its economic implications. The following results are obtained:

$$\begin{aligned}
\frac{\partial S'(t)}{\partial S} &= -\xi_S'(F_S)(1-a)\Big[R'(H_R)\frac{\partial H_R}{\partial S} + h'(H_C)\frac{\partial H_C}{\partial S}\Big] < 0,\\
\frac{\partial S'(t)}{\partial r} &= -\xi_S'(F_S)(1-a)h'(H_C)\frac{\partial H_C}{\partial r} < 0,\\
\frac{\partial S'(t)}{\partial r_u} &= -\xi_S'(F_S)(1-a)h'(H_C)\frac{\partial H_C}{\partial r_u} > 0,\\
\frac{\partial S'(t)}{\partial \overline{p}_u} &= -\xi_S'(F_S)(1-a)R'(H_R)\frac{\partial H_R}{\partial \overline{p}_u} < 0,\\
\frac{\partial S'(t)}{\partial \overline{p}} &= -\xi_S'(F_S)(1-a)R'(H_R)\frac{\partial H_R}{\partial \overline{p}} > 0,\\
\frac{\partial S'(t)}{\partial E_t[S(t_1)]} &= -\xi_S'(F_S)(1-a)h'(H_C)\frac{\partial H_C}{\partial E_t[S(t_1)]} > 0,\\
\frac{\partial S'(t)}{\partial A} &= \xi_S'(F_S) > 0.
\end{aligned}$$

The first result implies that the process is stable; the devaluation of the Swedish crown vis-à-vis to U.S. dollar has a positive effect on those parts of the current and capital accounts of Sweden, which are charged in U.S. dollars, and vice versa. This negative relation must be strong enough for stability, however; $S'(t)$ must change its sign with large enough changes in S. An increase in Swedish (U.S.) interest rate decreases (increases) the speed of devaluation of Swedish crown; these effects come via capital account. Increases in Swedish (foreign) unit prices increase (decrease) the speed of devaluation of Swedish crown; these effects come via current account. Investors' expectations of the future devaluation of Swedish crown vis-à-vis to U.S. dollar increase its current speed of devaluation via international investment flows, and if Swedish central bank increases its buying of U.S. dollars by Swedish crowns, this increases the speed of devaluation of Swedish crown.

It is quite widely accepted that the short-term fluctuations in exchange rates are caused by speculative investment flows, and in the long-run exchange rates obey a converging tendency toward the PPP -equations. The latter can be understood because PPP -equations express an equality between the purchasing powers of the corresponding currencies. A PPP -equation is a direct consequence of the 'law of one price'. Suppose that the law of one price holds between all n goods, $Sp_{ui} = p_i$, $i = 1, \ldots, n$, and let us assume that all foreign goods are produced in U.S. We can then write

$$S \sum_{i=1}^{n} w_i p_{ui} = \sum_{i=1}^{n} w_i p_i \quad \Rightarrow \quad S\overline{p}_u = \overline{p}_i \quad \Rightarrow \quad \frac{1}{S\overline{p}_u} = \frac{1}{\overline{p}_i},$$

where $\overline{p}_u$ and $\overline{p}$ are weighted averages of unit prices in U.S. and Sweden. The last form of the equation shows an equality between the purchasing powers of the two currencies in units kg/SEK. If this equality does not hold, the more powerful currency is more wanted and people began to exchange these two currencies until the exchange rate changes to balance the purchasing powers. This explains the long-term convergence of exchange rates toward the PPP -equations, that is, the long-term equilibrium exchange rates of currencies balance their 'internal' purchasing powers. In normal circumstances goods' prices change relatively slowly, however, and so we need other explanations for short-term fluctuations in exchange rates.

The daily changes in exchange rates occur due to people's daily willingness to exchange currencies. We do not know, however, whether these daily excess demands or supplies are caused by monetary transactions at goods or financial markets. Due to this, both these reasons to exchange any two currencies must be contained in a theory attempted as a complete description for the determination of exchange rates. The role of the central bank as a policy-maker in the currency market must also be included in a complete model. In the proposed model, the central bank has two parameters by which it can affect the force $F_S = A-(1-a)N$, namely A and r, the latter of which the bank can affect by its discount rate.

5 Equilibrium Exchange Rate

The equilibrium exchange rate between Swedish crown and U.S. dollar is obtained from Eq. (5) setting $F_S = 0 \;\Leftrightarrow\; S'(t) = 0$. This gives the equation

$$A(t) = (1-a)[R(H_R) + h(H_C)]. \tag{6}$$

Denoting the equilibrium exchange rate by S^*, by implicit differentiation we get the following results from (6):

$$\begin{aligned}
\frac{\partial S^*}{\partial r} &= -\frac{h'(H_C)\frac{\partial H_C}{\partial r}}{R'(H_R)\frac{\partial H_R}{\partial S} + h'(H_C)\frac{\partial H_C}{\partial S}} < 0, \\
\frac{\partial S^*}{\partial r_u} &= -\frac{h'(H_C)\frac{\partial H_C}{\partial r_u}}{R'(H_R)\frac{\partial H_R}{\partial S} + h'(H_C)\frac{\partial H_C}{\partial S}} > 0, \\
\frac{\partial S^*}{\partial \overline{p}} &= -\frac{R'(H_R)\frac{\partial H_R}{\partial \overline{p}}}{R'(H_R)\frac{\partial H_R}{\partial S} + h'(H_C)\frac{\partial H_C}{\partial S}} > 0, \\
\frac{\partial S^*}{\partial \overline{p}_u} &= -\frac{R'(H_R)\frac{\partial H_R}{\partial \overline{p}_u}}{R'(H_R)\frac{\partial H_R}{\partial S} + h'(H_C)\frac{\partial H_C}{\partial S}} < 0, \\
\frac{\partial S^*}{\partial E_t[S(t_1)]} &= -\frac{h'(H_C)\frac{\partial H_C}{\partial E_t[S(t_1)]}}{R'(H_R)\frac{\partial H_R}{\partial S} + h'(H_C)\frac{\partial H_C}{\partial S}} > 0, \\
\frac{\partial S^*}{\partial A} &= \frac{1}{(1-a)\left(R'(H_R)\frac{\partial H_R}{\partial S} + h'(H_C)\frac{\partial H_C}{\partial S}\right)} > 0.
\end{aligned}$$

The results verify the common assumptions of factors affecting the equilibrium exchange rates of currencies. The result $\partial S^*/\partial E_t[S(t_1)]$ shows how expectations fulfill themselves, that is, the expected future devaluation of Swedish crown vis-à-vis to U.S. dollar has an immediate devaluing effect on the crown via the capital account. The Swedish central bank can affect the equilibrium exchange rate directly by A and indirectly via its discount rate.

To get a preliminary formula for the equilibrium exchange rate, we assume all behavioral functions in (5) linear and passing through the origin. The argument behind this assumption is the first order Taylor series approximation of a possible more general relationship. Eq. (5) then becomes

$$m_S S'(t) = A(t) - (1-a)\Big[\alpha[S(t)\overline{p}_u - \overline{p}] + \beta\big[S(t)e^{\int_t^{t_1}[r(s)-r_u(s)]ds} - E_t[S(t_1)]\big]\Big], \tag{7}$$

where $R(H_R) = \alpha \times H_R$, $h(H_C) = \beta \times H_C$, and α, β are positive constants with units $(kg \times USD)/(SEK \times y)$ and $USD^2/(SEK \times y)$, respectively. The interpretation of the positive constant m_S with unit USD^2/SEK is the same as inertial mass has in Newtonian mechanics, $m_S = F_S/S'(t)$, $F_S = A - (1-a)N$. The greater the numerical value of m_S, the slower the adjustment in $S(t)$ with fixed F_S, that is, the less sensitive $S(t)$ is to imbalances in $A-(1-a)N$. Notice that the parameters α, β, respectively, measure the consumers' and investors' consumption and investment sensitivity with respect to differences in goods' prices and expected yields of investments.

The equilibrium exchange rate S^* is the following

$$S'(t) = 0 \quad \Rightarrow \quad S^* = \frac{A(t) + (1-a)\left(\alpha\overline{p} + \beta E_t[S(t_1)]\right)}{(1-a)[\alpha\overline{p}_u + \beta e^{\int_t^{t_1}[r(s)-r_u(s)]ds}]}.$$

S^* is thus a time-dependent random variable which depends on investors' expectations of its future value. This explains the observed vulnerability of exchange rates as compared with goods' prices, which are less affected by consumers' expectations of their future values. Eq. (7) can be presented in an Error-Correction form as

$$S'(t) = -z[S(t) - S^*], \quad z = \frac{(1-a)}{m_S}\left(\alpha\overline{p}_u + \beta e^{\int_t^{t_1}[r(s)-r_u(s)]ds}\right) > 0. \qquad (8)$$

According to (8), $S'(t) > 0$ when $S(t) < S^*$ and vice versa. The Error-Correction coefficient z depends on the difference in the interest rates, the average foreign price level, constants m_S, a, α, β and time.

6 Dynamics of Interest Rate

Above we studied reasons causing the dynamics of exchange rates. The obtained adjustment was monotonic, however, although we have evidence that exchange rates may adjust in a cyclic (overshooting) manner. To model this kind of behavior, we assume the adjustment period short enough for the price level to stay fixed (i.e. less than one month). In the short-run, the adjusting variables in money and currency markets are the exchange and interest rates while the adjustment in goods' prices takes longer.

We assume the domestic interest rate to be determined in the money market according to the demand and supply of Swedish crowns in circulation. A stable demand function for Swedish crowns, which does not depend on the international trade of goods and investments, is assumed and called the 'domestic' component of the demand. This part of the demand positively depends on the Swedish nominal GDP (the transaction motive) denoted by $Y(t) = \overline{p}(t)Q$ (SEK/y), where real GDP Q (kg/y) is valued by the average price level $\overline{p}$ (SEK/kg). For simplicity, Q is assumed constant. The domestic demand component of Swedish crowns still negatively depends on the interest rate (the alternative costs from holding wealth in liquid form). The 'international' demand component of Swedish crowns depends on the surplus in the balance of payments of Sweden, of which N is a part (in the case $N > 0$). We denote the balance of payments of Sweden as $N_T = N + N_R$ with N_R denoting the rest of the balance of payments of Sweden charged in other currencies than U.S. dollar (although N_R is expressed in U.S. dollars with unit USD/y). For simplicity, N_R is assumed constant.

The demand of Swedish crowns M_d with unit SEK at moment t is then

$$M_d(t) = \Big[l\,(Y(t), r(t)) + (1-a)S(t)[N(t) + N_R]\Big]\Delta t, \quad \frac{\partial l}{\partial Y} > 0, \quad \frac{\partial l}{\partial r} < 0,$$

where $l(Y(t), r(t))$ is the domestic component of the demand, $\Delta t = y$ is the length of the studied time interval — which transforms the measurement units to those required — and constant $0 < a < 1$ was defined above.

If $A > 0$, Swedish central bank supplies Swedish crowns to the market, and vice versa. The amount of Swedish crowns circulating in the economy at moment t, the supply of Swedish crowns $M_s(t)$ with unit SEK, is then

$$M_s(t) = M_s(t-y) + S(t)A(t)\Delta t,$$

where by $M_s(t-y)$ is denoted the money circulating at moment $t-y$. The net demand of Swedish crowns at moment t is then

$$M_d - M_s = \Big[l(Y(t), r(t)) + (1-a)S(t)[N(t) + N_R] - A(t)S(t)\Big]\Delta t - M_s(t-y).$$

We can remark here that N and A may be negative too. In these cases people buy U.S. dollars with Swedish crowns, and the Swedish central bank buys Swedish crowns with U.S. dollars more than they do the opposite. When $N < 0$, the term $(1-a)SN\Delta t < 0$ is actually a part of supply of Swedish crowns, and when $A < 0$, the term $AS\Delta t < 0$ is a part of demand of Swedish crowns. These cases thus do not affect the above net demand formula.

The money market in Sweden is dynamized as follows

$$r'(t) = \xi_r(F_r), \quad \xi_r(0) = 0, \quad \xi_r'(F_r) > 0, \quad F_r = M_d - M_s. \tag{9}$$

We name the quantity F_r as the 'force' acting upon the interest rate. This force contains the central bank's policy variable A; setting $A = (1-a)[N + N_R]$ the central bank can eliminate the 'international component' of the force, and it can affect the 'domestic component' $l(Y(t), r)$ by its discount rate.

From (9) we get the following results:

$$\begin{aligned}
\frac{\partial r'(t)}{\partial r} &= \xi_r'(F_r)\left(\frac{\partial l}{\partial r} + (1-a)S\frac{\partial N}{\partial r}\right)\Delta t,\\
\frac{\partial r'(t)}{\partial Q} &= \xi_r'(F_r)\frac{\partial l}{\partial Y}\overline{p}\Delta t > 0,\\
\frac{\partial r'(t)}{\partial A} &= -\xi_r'(F_r)S\Delta t < 0,
\end{aligned}$$

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\begin{aligned}
\frac{\partial r'(t)}{\partial M_s(t-y)} &= -\xi_r'(F_r) < 0, \\
\frac{\partial r'(t)}{\partial S} &= \xi_r'(F_r)\left((1-a)[N+N_R] - A + (1-a)S\frac{\partial N}{\partial S}\right)\Delta t, \\
\frac{\partial r'(t)}{\partial \overline{p}} &= \xi_r'(F_r)\left(\frac{\partial l}{\partial Y}Q + (1-a)S\frac{\partial N}{\partial \overline{p}}\right)\Delta t, \\
\frac{\partial r'(t)}{\partial \overline{p}_u} &= \xi_r'(F_r)(1-a)S\frac{\partial N}{\partial \overline{p}_u}\Delta t > 0, \\
\frac{\partial r'(t)}{\partial r_u} &= \xi_r'(F_r)(1-a)S\frac{\partial N}{\partial r_u}\Delta t < 0, \\
\frac{\partial r'(t)}{\partial E_t[S(t_1)]} &= \xi_r'(F_r)(1-a)S\frac{\partial N}{\partial E_t[S(t_1)]}\Delta t < 0.
\end{aligned}
$$

To save space we analyse here only the ambiguous results. An increase in the domestic price level may either increase or decrease the velocity of the domestic interest rate. The positive effect comes via the domestic demand component (higher price level raises the need of money in circulation), and the negative effect comes via the international demand component (increasing price level reduces the current account of Sweden). The effect an increase in Swedish interest rate has on its velocity depends on whether the negative effect on the domestic demand component dominates the positive effect on the international demand component via capital account. The devaluation of Swedish crown with respect to U.S. dollar improves the balance of payments of Sweden, which negatively affects the velocity of the interest rate. However, $(1-a)[N+N_R]-A$ may be positive or negative, and only when this quantity is positive, we can uniquely sign the partial as $\partial r'(t)/\partial S > 0$.

Equilibrium state in the money market, $F_r = 0 \;\Leftrightarrow\; r'(t) = 0$, gives

$$
\Big[l\left(Y(t), r(t)\right) + \big[(1-a)[N(t)+N_R] - A(t)\big]S(t)\Big]\Delta t = M_s(t-y).
$$

From this equation we can derive results concerning the equilibrium interest rate r^*. All these partials turn out to be of ambiguous sign, however, because their denominator $\partial l/\partial r + (1-a)S(t)\partial N/\partial r$ cannot be uniquely signed as was explained above. For this reason these results are omitted.

7 Dynamics of Money and Currency Markets

Due to the assumed general functional forms in Equations (5) and (9), we analyze the dynamic behavior of the system by phase diagrams, see Appendix 2. We obtain six cases depending on whether $\partial r'(t)/\partial r$ is positive or negative, and whether the slope of the curve $r'(t) = 0$ is positive or negative, or steeper than that of $S'(t) = 0$ in the coordinates (r, S). The non-plausible cases of exactly horizontal and vertical slope are omitted. The results in section 6 imply that $\partial r'(t)/\partial r < 0$ when $|\partial l/\partial r| > |(1-a)S\partial N/\partial r|$ and vice versa.

The slope of the curve $r'(t) = 0$ in the coordinates (r, S) is

$$\frac{\partial r^*}{\partial S} = \frac{A - (1-a)[N + N_R] - (1-a)S\frac{\partial N}{\partial S}}{\frac{\partial l}{\partial r} + (1-a)S\frac{\partial N}{\partial r}}, \tag{10}$$

We can assume that the central bank never overreacts when it tries to stabilize the balance of payments, i.e. $|A| \leq |(1-a)[N + N_R]|$. Then $\partial r^*/\partial S$ is positive, if a relatively large deficit in the balance of payments exists together with relatively small values of terms $\partial N/\partial S$, $|\partial l/\partial r|$ and a relatively large value of $\partial N/\partial r$. However, $\partial r^*/\partial S$ may also be positive if the balance of payments is positive and $|\partial l/\partial r| > (1-a)S\partial N/\partial r$.

The system is stable in Diagrams 1-3 and unstable in Diagrams 4-6. In stable cases the adjustment is cyclic in Diagrams 1 and 2 and monotonic in Diagram 3 (the initial points are assumed on the demarcation lines). The overshooting phenomena, the case of interest in Dornbush (1976) among others, takes place in Diagrams 1, 2. Contrary to the Dornbush's and Lyons' (1990) models, in our model overshooting takes place in stable situations. We thus do not have to make the strong assumptions of these authors, namely that every investor in the market rightly guesses the location of the saddle-path in the diagram, and that they operate together so that the exchange rate exactly jumps on the path. These information requirements question the reliability of these models concerning real-world phenomena.

The proposed model raises also another critical comment concerning the strong form of rational expectations hypothesis applied in economics. Suppose that the model (5) is the true one for the exchange rate behavior. Then none of the agents in the market has enough information to accurately forecast the exchange rate, because the model contains various unspecified functional forms. The lesson from this is that we should not use an exactly specified form of any theory in the modeling of expectations in economics, unless we are sure that the theory is the correct one and a clear majority of agents in the market are aware of the theory and believe a certain form of it. Rather we should use various theories in specifying the relevant variables (and the directions these variables affect the studied quantity) people should concentrate on when they make expectations of the corresponding quantity. We believe that the weak form of the rational expectations hypothesis together with the above assumption is a more realistic framework for expectation formation in economics.

In the proposed model, any of the quantities $A, Q, E_t[S(t_1)], M_s(t-y), r_u$, $\overline{p}, \overline{p}_u$ may be the source of an impulse into the system, and the exchange and interest rates either converge toward their equilibrium values (Diagrams 1-3), or diverge away from them (Diagrams 4-6). The adjustment critically depends on the partials $\partial N/\partial S$, $\partial N/\partial r$, $\partial l/\partial r$. An impulse into the system may start a self-sustaining unstable process, which represent financial panics. One such case goes as follows. Suppose that the domestic interest rate decreases due to some exogenous reason. Possible such nominal reasons are expectations of a future devaluation of the Swedish crown ($\Delta E_t[S(t_1)] > 0$), or the central bank's extra supply of Swedish crowns ($\Delta A > 0$). A similar real reason could be a decrease in Swedish real GDP ($\Delta Q < 0$).

A decrease in the domestic interest rate decreases the capital account of Sweden, which decreases the international demand component of Swedish crowns; this further decreases the interest rate. Decreasing capital account has a devaluing effect on Swedish crown, which may stop this process by stabilizing the balance of payments (a stable case). However, if the devaluation of the Swedish crown is not strong enough to turn the balance of payments positive, the international demand component of Swedish crowns continues to decrease which further decreases the interest rate. The process continues with decreasing interest rate, balance of payments deficit and the devaluation of Swedish crown vis-à-vis to U.S. dollar. Due to the same reasons, we may observe an increasing interest rate, a surplus in the balance of payments and a continuous revaluation of Swedish crown, if the revaluation is not strong enough to stabilize the balance of payments.

8 Dynamics of Price Level

In order to study the longer term adjustment of the financial system in the home country, we introduce a dynamic model for the price level. The average domestic price level $\overline{p}$ is assumed to adjust according to the excess demand in the goods' market, and we assume a Keynesian type of model for the market. The domestic demand of goods is split to real consumption $C(Q)$, real investment $I(Q, r)$ and real public demand G; these all have unit kg/y. The international demand of Swedish goods consists of real exports $S \times X/\overline{p} = S \times f(H_R)/\overline{p}$ with unit kg/y. The supply at the goods' market consists of domestic real GDP Q (kg/y) and real imports $M/\overline{p}_u = g(H_R)/\overline{p}_u$ with unit kg/y. The equation of motion for the price level is then

$$\overline{p}'(t) = \xi_{\overline{p}}\left(F_{\overline{p}}\right),\ F_{\overline{p}} = C(Q) + I(Q, r(t)) + G + \frac{S(t)f(H_R)}{\overline{p}(t)} - \frac{g(H_R)}{\overline{p}_u} - Q, \quad (11)$$

where $\xi_{\overline{p}}(0) = 0$ and $\xi'_{\overline{p}}(F_{\overline{p}}) > 0$. $F_{\overline{p}}$ measures the excess demand of goods in the Swedish goods' market, and we name it as the 'force acting upon the price level $\overline{p}$'. Eq. (11) is the macro-level analogue to the law of demand and supply for a single good introduced by Samuelson (1941). Eq. (11) gives

$$\begin{aligned}
\frac{\partial \overline{p}'(t)}{\partial \overline{p}} &= \xi'_{\overline{p}}(F_{\overline{p}}) \left(\left(\frac{Sf'(H_R)}{\overline{p}} - \frac{g'(H_R)}{\overline{p}_u} \right) \frac{\partial H_R}{\partial \overline{p}} - \frac{Sf(H_R)}{\overline{p}^2} \right) < 0, \\
\frac{\partial \overline{p}'(t)}{\partial r} &= \xi'_{\overline{p}}(F_{\overline{p}}) \frac{\partial I}{\partial r} < 0, \\
\frac{\partial \overline{p}'(t)}{\partial S} &= \xi'_{\overline{p}}(F_{\overline{p}}) \left(\frac{f(H_R)}{\overline{p}} + \left(\frac{Sf'(H_R)}{\overline{p}} - \frac{g'(H_R)}{\overline{p}_u} \right) \frac{\partial H_R}{\partial S} \right) > 0, \\
\frac{\partial \overline{p}'(t)}{\partial \overline{p}_u} &= \xi'_{\overline{p}}(F_{\overline{p}}) \left(\left(\frac{Sf'(H_R)}{\overline{p}} - \frac{g'(H_R)}{\overline{p}_u} \right) \frac{\partial H_R}{\partial \overline{p}_u} + \frac{g(H_R)}{{\overline{p}_u}^2} \right) > 0, \\
\frac{\partial \overline{p}'(t)}{\partial Q} &= \xi'_{\overline{p}}(F_{\overline{p}}) \left(\frac{\partial C}{\partial Q} + \frac{\partial I}{\partial Q} - 1 \right), \\
\frac{\partial \overline{p}'(t)}{\partial G} &= \xi'_{\overline{p}}(F_{\overline{p}}) > 0.
\end{aligned}$$

The only ambiguous result depends on whether the marginal consumption and investment propensities with respect to real GDP, together, exceed 1.

The equilibrium average price level $\overline{p}^*$ is obtained from (11) setting $F_{\overline{p}} = 0 \Leftrightarrow \overline{p}'(t) = 0$. From the resulting equation we get

$$\begin{aligned}
\frac{\partial \overline{p}^*}{\partial S} &= -\frac{\frac{f(H_R)}{\overline{p}} + \left(\frac{Sf'(H_R)}{\overline{p}} - \frac{g'(H_R)}{\overline{p}_u} \right) \frac{\partial H_R}{\partial S}}{\left(\frac{Sf'(H_R)}{\overline{p}} - \frac{g'(H_R)}{\overline{p}_u} \right) \frac{\partial H_R}{\partial \overline{p}} - \frac{Sf(H_R)}{\overline{p}^2}} > 0, \\
\frac{\partial \overline{p}^*}{\partial r} &= -\frac{\frac{\partial I}{\partial r}}{\left(\frac{Sf'(H_R)}{\overline{p}} - \frac{g'(H_R)}{\overline{p}_u} \right) \frac{\partial H_R}{\partial \overline{p}} - \frac{Sf(H_R)}{\overline{p}^2}} < 0, \\
\frac{\partial \overline{p}^*}{\partial \overline{p}_u} &= -\frac{\frac{g(H_R)}{{\overline{p}_u}^2} + \left(\frac{Sf'(H_R)}{\overline{p}} - \frac{g'(H_R)}{\overline{p}_u} \right) \frac{\partial H_R}{\partial \overline{p}_u}}{\left(\frac{Sf'(H_R)}{\overline{p}} - \frac{g'(H_R)}{\overline{p}_u} \right) \frac{\partial H_R}{\partial \overline{p}} - \frac{Sf(H_R)}{\overline{p}^2}} > 0, \\
\frac{\partial \overline{p}^*}{\partial Q} &= -\frac{\frac{\partial C}{\partial Q} + \frac{\partial I}{\partial Q} - 1}{\left(\frac{Sf'(H_R)}{\overline{p}} - \frac{g'(H_R)}{\overline{p}_u} \right) \frac{\partial H_R}{\partial \overline{p}} - \frac{Sf(H_R)}{\overline{p}^2}}, \\
\frac{\partial \overline{p}^*}{\partial G} &= -\frac{1}{\left(\frac{Sf'(H_R)}{\overline{p}} - \frac{g'(H_R)}{\overline{p}_u} \right) \frac{\partial H_R}{\partial \overline{p}} - \frac{Sf(H_R)}{\overline{p}^2}} > 0,
\end{aligned}$$

which results are consistent with the previous ones.

9 Simulations with the Model

In order to study the behavior of the financial system of the home country, we linearize the dynamic model by taking the first order Taylor approximation of the system in the neighborhood of the equilibrium point $(S^*, r^*, \overline{p}^*)$. This assumption is supported by Meese and Rose (1991) who report no evidence of non-linearities in exchange rate models from their testing of the five theories. We introduce three nonnegative inertial factors: $m_S = 1/\xi'_S(F_S)$ with unit USD^2/SEK (already discussed in the context of Eq. (7)), $m_r = 1/\xi'_r(F_r)$ with unit $SEK \times y$ and $m_{\overline{p}} = 1/\xi'_{\overline{p}}(F_{\overline{p}})$ with unit $(SEK \times y)/kg^2$; $F_S, F_r, F_{\overline{p}}$ are functions of B^*, $B^* = (S^*, r^*, \overline{p}^*, Z_0)$ where Z_0 is a fixed vector of the exogenous quantities $A, Q, \overline{p}_u, r_u,\ E_t[S(t_1)], M(t-y), a, G$. For example, $m_{\overline{p}}$ measures the sensitivity of $\overline{p}'(t)$ with respect to the force $F_{\overline{p}}$ similarly as the mass of a body measures its inertia in Newton's equation $ma = F$. This way we can study the role of the inertial factors in the adjustment. Because $F_S(B^*) = F_r(B^*) = F_{\overline{p}}(B^*) = 0$, the linearized form of the model is

$$\begin{pmatrix} m_S S'(t) \\ m_r r'(t) \\ m_{\overline{p}} \overline{p}'(t) \end{pmatrix} = \begin{pmatrix} \frac{\partial F_S}{\partial S}(B^*) & \frac{\partial F_S}{\partial r}(B^*) & \frac{\partial F_S}{\partial \overline{p}}(B^*) \\ \frac{\partial F_r}{\partial S}(B^*) & \frac{\partial F_r}{\partial r}(B^*) & \frac{\partial F_r}{\partial \overline{p}}(B^*) \\ \frac{\partial F_{\overline{p}}}{\partial S}(B^*) & \frac{\partial F_{\overline{p}}}{\partial r}(B^*) & \frac{\partial F_{\overline{p}}}{\partial \overline{p}}(B^*) \end{pmatrix} \begin{pmatrix} S(t) - S^* \\ r(t) - r^* \\ \overline{p}(t) - \overline{p}^* \end{pmatrix} + \begin{pmatrix} \epsilon_1 \\ \epsilon_2 \\ \epsilon_3 \end{pmatrix},$$

where ϵ_i, $i = 1, 2, 3$ are constants the numerical values of which depend on the degree of nonlinearity of the functional forms of ξ_i, $i = S, r, \overline{p}$, and the values of the exogenous variables.

For the simulations we assume $\epsilon_i = 0$, $i = 1, 2, 3$ and set $S^*, r^*, \overline{p}^*$ equal to 10. The interest rate is thus expressed in per cent, the average price level is expressed in units to match this value and 10 (SEK/USD) is close to the prevailing spot rate. For the parameters, $\partial F_S/\partial S$ etc., we assume suitable values the signs of which match the results derived; for those with ambiguous sign we apply different values. For the inertial factors we assume that $m_{\overline{p}}$ is clearly greater than m_S, m_r; producers and consumers at the goods' market are thus assumed to behave in a more rigid manner than investors, depositors and borrowers at the currency and money market.

The results are presented in Figures 1-3 with certain initial conditions; the thinnest curve represents $S(t)$ and the thickest $\overline{p}(t)$. In all cases we have $m_S = m_r = 1$ and $m_{\overline{p}} = 3$; other parameters are as follows. Figure 1: $\partial F_S/\partial S = -1$, $\partial F_S/\partial r = -0.5$, $\partial F_S/\partial \overline{p} = 0.5$, $\partial F_r/\partial S = 0.5$, $\partial F_r/\partial r = -1$, $\partial F_r/\partial \overline{p} = 0.5$, $\partial F_{\overline{p}}/\partial S = 0.5$, $\partial F_{\overline{p}}/\partial r = -0.5$, $\partial F_{\overline{p}}/\partial \overline{p} = -1$. Figure 2: $\partial F_S/\partial S = -2$, $\partial F_S/\partial r = -1$, $\partial F_S/\partial \overline{p} = 0.5$, $\partial F_r/\partial S = 2$, $\partial F_r/\partial r = -2$, $\partial F_r/\partial \overline{p} = -0.2$, $\partial F_{\overline{p}}/\partial S = -0.3$, $\partial F_{\overline{p}}/\partial r = -0.3$, $\partial F_{\overline{p}}/\partial \overline{p} = -1$. Figure 3: $\partial F_S/\partial S = -1$, $\partial F_S/\partial r = -0.5$, $\partial F_S/\partial \overline{p} = 0.5$, $\partial F_r/\partial S = 1$, $\partial F_r/\partial r = 1$, $\partial F_r/\partial \overline{p} = -0.2$, $\partial F_{\overline{p}}/\partial S = 0.5$, $\partial F_{\overline{p}}/\partial r = -0.5$, $\partial F_{\overline{p}}/\partial \overline{p} = -1$.

In Figure 1, the adjustment is relatively smooth while in Figure 2 the exchange and interest rate overshoot their equilibrium values. Figure 3 shows an unstable case where the money and currency markets collapse: crown devalues, interest rate decreases and hyperinflation takes place in the goods' market. In real economies, the exogenous variables in the model change frequently, and these changes create an adjustment process to the endogenous variables. Figures 1-3 each demonstrate one such adjustment, but because in real economies these impulses occur frequently, a continuous adjustment takes place in real financial systems. This explains the highly fluctuating behavior of exchange and interest rates in real economics.

10 Extensions and Limitations of the Model

The proposed model can be extended according to the following lines. First, the expectation formation process of the exchange rate can be made explicit. Second, exact functional forms can be specified for the behavioral functions. Third, the sterilization policy of the central bank can be assumed conditional on its reserves of foreign currencies. This element can be added to the model so that the exchange rate becomes freely floating by the 'force' $-(1-a)N$ in the case the central bank likes to support the home currency but is lacking the required reserves. Fourth, the micro foundations for the macro equations can be made explicit. When the first and second additions are made to the model, its performance can be tested empirically. However, because the expectation formation process can be made in various ways, the model allows differing testable descriptions for the adjustment of the studied quantities.

11 Conclusions

We modeled those parts of the current and capital accounts of a small country, which are charged in a certain foreign currency. We based our modeling on the international competitiveness of the home country in terms of the relative prices and expected yields of financial investments. The dynamics of the corresponding exchange rate was modeled on the basis of imbalance in these parts of the balance of payments. By the proposed model we studied possibilities for the central bank to steer the adjustment process of the exchange rate. The model produces the common forecasts concerning the effects various macro variables have on the equilibrium exchange rate, it gives an explanation for the observed mean-reverting behavior of exchange rates, and it explains the observed vulnerability of exchange rates: the equilibrium exchange rate was shown to be a time-dependent random variable which depends on investors' expectations of its future value.

In order to model the observed nonlinear behavior of exchange rates, money market was added to the model. By the dynamic model of two equations, overshooting and currency crises were shown to occur in certain circumstances. To complete the financial system, an equation for price dynamics was introduced. The results from the simultaneous adjustment of the three quantities imply that the adjustment of the exchange and interest rate is essentially cyclic, while price level adjusts in a more monotonic way.

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Appendix 1

We denote by $x(t)$ the amount of Swedish crowns to be invested in Sweden, and by $z(t)$ the amount of U.S. dollars to be invested U.S. at moment t. The continuous time interest rates in both countries are defined as

$$\frac{x'(t)}{x(t)} = r(t), \quad \frac{z'(t)}{z(t)} = r_u(t);$$

on the left hand side are the growth rates of the invested capitals and on the right hand side the corresponding interest rates. The interest rates are assumed to be the publicly known highest risk-free rates of return for investments in these two countries. The left hand sides of the equations are measured in units $1/y$ (SEK/y divided by SEK and USD/y divided by USD) and so are the right hand sides. Solving the equations, we get

$$x(t_1) = x(t)e^{\int_t^{t_1} r(s)ds}, \quad z(t_1) = z(t)e^{\int_t^{t_1} r_u(s)ds}, \quad t \leq s \leq t_1$$

where by $x(t_1), z(t_1)$ are denoted the Swedish crowns and U.S. dollars to be obtained at moment t_1. Let $S(t)$ with unit SEK/USD be the spot exchange rate at moment t and $E_t[S(t_1)]$ the expectation of the spot rate at moment t_1 made by investors at moment t. Investing in Sweden is expected to be more profitable if $E_t[S(t_1)]z(t_1) < x(t_1)$ holds together with $x(t) = S(t)z(t)$ (equal amounts are invested and more crowns are expected from the Swedish investment), and vice versa. Capital is thus flowing to Sweden, if

$$\frac{x(t_1)}{z(t_1)} > E_t[S(t_1)] \quad \Leftrightarrow \quad \frac{S(t)z(t)e^{\int_t^{t_1} r(s)ds}}{z(t)e^{\int_t^{t_1} r_u(s)ds}} > E_t[S(t_1)] \quad \Leftrightarrow$$
$$S(t)e^{\int_t^{t_1}[r(s)-r_u(s)]ds} - E_t[S(t_1)] > 0, \quad \text{and vice versa.}$$

Figure 1

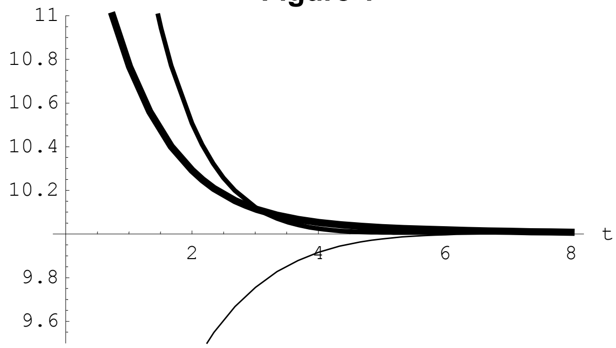


Figure 2

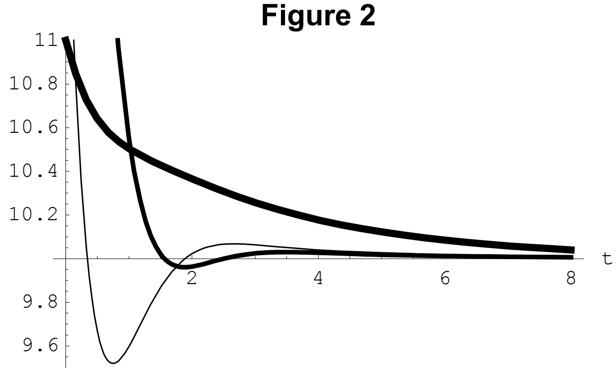
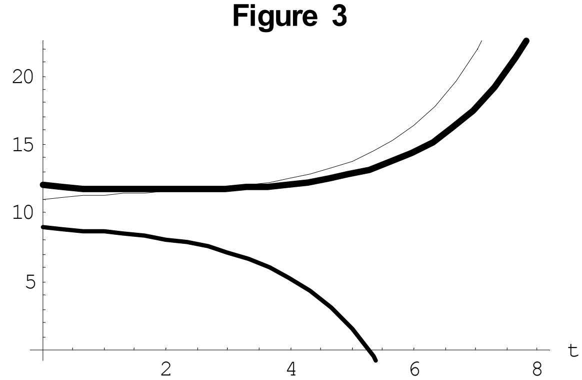


Figure 3



Appendix 2

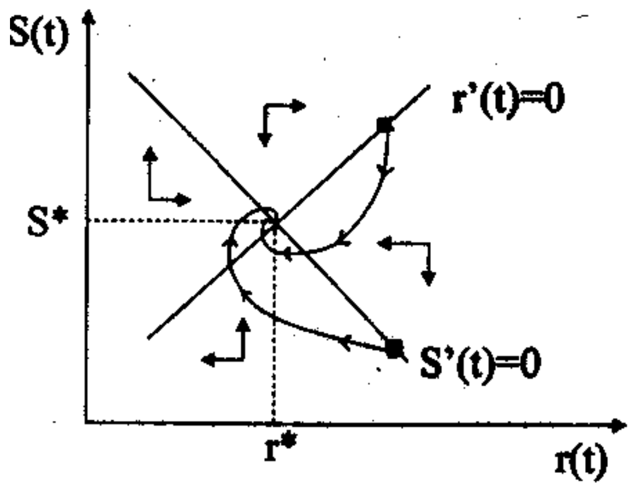


Diagram 1.

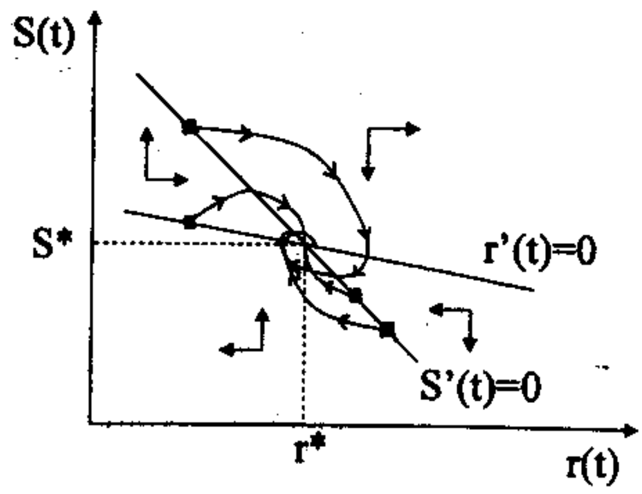
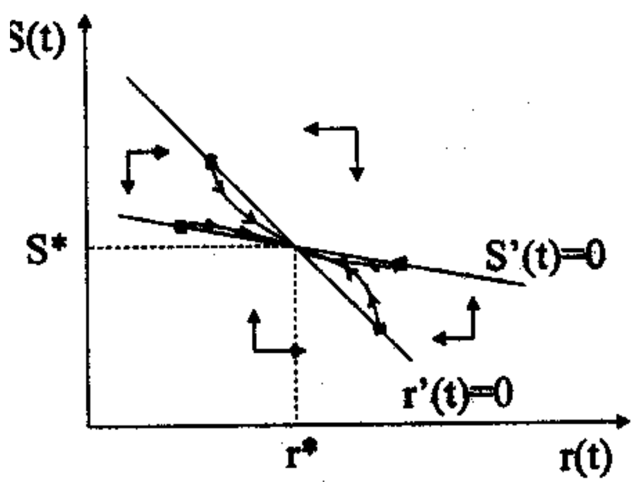


Diagram 2.



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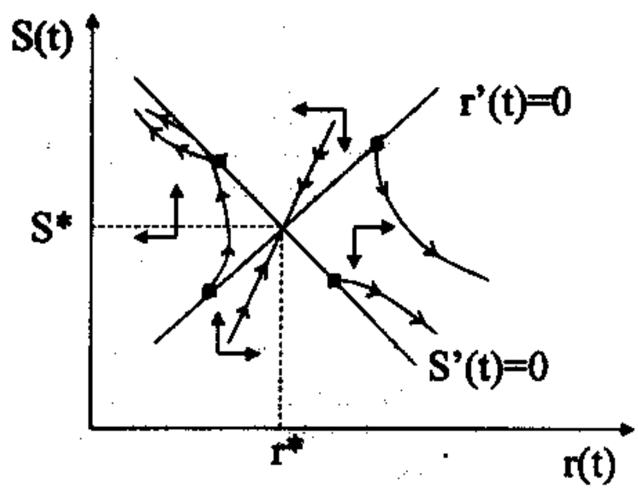

Diagram 4.

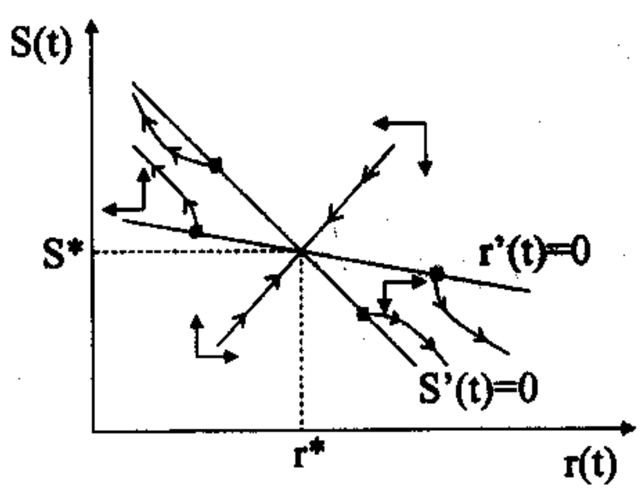

Diagram 5.

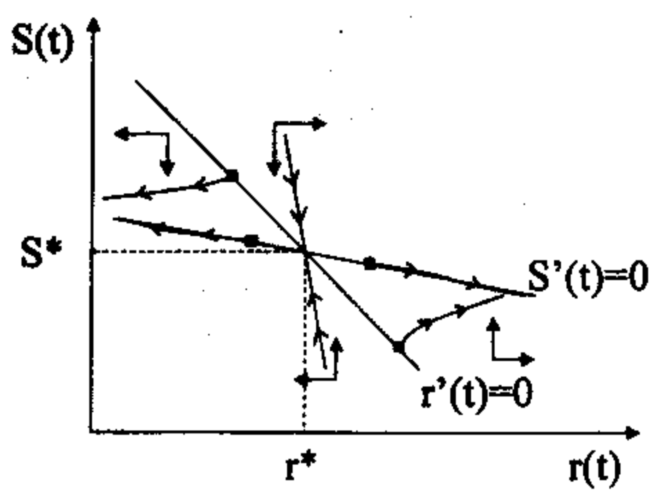

Diagram 6.