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at the University of Wisconsin-Madison

Working Paper Series
La Follette School Working Paper No. 2006-008
http://www.lafollette.wisc.edu/publications/workingpapers

Expectations and Exchange Rate Policy

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January 12, 2006

Preliminary Draft

Abstract

Both empirical evidence and theoretical discussion has long emphasized the impact of `news' on exchange rates. In most exchange rate models, the exchange rate acts as an asset price, and as such responds to news about future returns on assets. But the exchange rate also plays a role in determining the relative price of non-durable goods. In this paper we argue that these two roles may conflict with one another when nominal goods prices are sticky. If news about future asset returns causes movements in current exchange rates, then when nominal prices are slow to adjust, this may cause changes in current relative goods prices that have no efficiency rationale. In this sense, anticipations of future shocks to fundamentals can cause current exchange rate misalignments. We outline a series of models in which an optimal policy eliminates news shocks on exchange rates.

Much of analysis of open economy macroeconomics in the past 30 years has been built on the foundation that exchange rates are asset prices and that some goods prices adjust more slowly than asset prices. If this is true, it means that exchange rates wear two hats: They are asset prices that determine the relative price of two monies, but they also are important in determining the relative prices of goods in international markets in the short run. For example, if export prices are sticky in the exporting currency, then nominal exchange rate movements directly change the terms of trade. While of course the literature has recognized this dual role for exchange rate movements, it has not recognized the implication for exchange-rate or monetary policy. Asset prices move primarily in response to news that alters expectations of the future. Most exchange rate movements in the short run reflect changes in expectations about future monetary or real conditions. But future expectations should not be the primary determinant of the relative price of nondurable goods. Those relative prices ought to reflect current levels of demand and supply. So, news that causes nominal exchange rates to jump may have undesirable allocational effects as the news leads to inefficient changes in the relative prices of goods. It may be that controlling exchange rates – dampening their response to news – is an important objective for monetary policy.

The "asset market" approach to exchange rates has long recognized that exchange rate movements are primarily driven by news that changes expectations. For example, the survey of the field by Frenkel and Mussa (1985, p. 726) in the Handbook of International Economics states: "These facts suggest that exchange rates should be viewed as prices of durable assets determined in organized markets (like stock and commodity exchanges) in which current prices reflect the market's expectation concerning present and future economic conditions relevant for determining the appropriate values of these durable assets, and in which price changes are

largely unpredictable and reflect primarily new information that alters expectations concerning these present and future economic conditions." In their monograph, Foundations of International Macroeconomics, Obstfeld and Rogoff (1996, p. 529) state "One very important and quite robust insight is that the nominal exchange rate must be viewed as an asset price. Like other assets, the exchange rate depends on expectations of future variables."

At the same time, a broad part of the literature has accepted, as Dornbusch (1976, pp 1161-1162) puts it, "the fact of differential adjustment speeds in goods and asset markets." Indeed, it was this difference in the speed of adjustment that led Milton Friedman (1953, p. 165) to advocate for flexible exchange rates: "If internal prices were as flexible as exchange rates, it would make little economic difference whether adjustments were brought about by changes in exchange rates or equivalent changes in internal prices. But this condition is clearly not fulfilled…At least in the modern world, internal prices are highly inflexible."

Friedman's case for flexible exchange rates was derived, however, in a world in which capital flows were absent. In his world, the exchange rate would determine the terms of trade, but it was not forward looking and did not reflect expectations of the future as would an asset price. But when the exchange rate changes are primarily driven by news, the terms of trade or other international prices may be badly misaligned in the short run.

The misalignment of relative prices is at the heart of the monetary policy analysis in modern macroeconomic models of inflation targeting. Woodford (2003, p. 12-13) explains "when prices are not constantly adjusted, instability of the general level of prices creates discrepancies between relative prices owing to the absence of perfect synchronization in the adjustment of the prices of different goods. These relative-price distortions lead in turn to an inefficient sectoral allocation of resources, even when the aggregate level of output is correct."

Here, we are focusing on possibly severe misalignments in relative prices, when large changes in exchange rates are caused by changes in expectations. This distortion would not be present if all goods prices changed flexibly. Then relative prices would not be forced to incorporate these expectations effects, and nominal goods prices would react (efficiently) to news about the future.

To help focus the central idea of this paper, it is useful to make a list of things we are not saying:

1. We are not saying that other models of monetary policy in open economies have not modeled exchange rates as asset prices. They have. But all of those models assume that the only source of news about the future is current and past shocks to the economy. Our central insight is that monetary policy must react to news that moves exchange rates. In existing models, the only news that hits the market is shocks to current economic variables. By targeting current economic variables in those models, monetary policy does effectively target the news. But in a realistic model, agents have many other sources of information than simply shocks to current macro aggregates. Targeting the aggregates does not achieve the goal of offsetting the influence of news on relative prices. Our model explicitly allows agents to have information about the future that is different than shocks to the current level of macro variables.

2. We are not looking at differences in the information set of the market and policy makers. While that may be an interesting area for study, it is not our primary concern. To make this clear, we model the market and policy makers as having the same information.

3. The problem we have pinpointed is not one of "excess volatility" in asset prices. We do not construct a model in which there is noise or bubbles in asset prices. Instead, we model the exchange rate as the no-bubble solution to a forward-looking difference equation, so it is

modeled as an efficient, rational expectations, present discounted value of expected future fundamentals. Indeed, as West (1988) has demonstrated, the more news the market has, the smaller the variance of innovations in the exchange rate. Nonetheless, it is the influence of that news on exchange rates that concerns us. Our intuition is that movements in nominal exchange rates caused by noise or bubbles would also be inefficient, but we purposely put aside that issue for others to study.

4. We are not saying that exchange rates are the only asset price that could be of concern to policy makers. We have not investigated other asset prices, such as equity prices. But our intuition is that exchange rates are different. Exchange rates are the only asset price whose movement directly causes a change in the relative price of two non-durables that have fixed nominal prices. That happens because nominal prices of different goods (or the same good sold in different locations) can be sticky in different currencies. Fluctuations in other asset prices cause a change in the price of a durable (e.g., equity prices are the price of capital) relative to the price of a non-durable. At least in some circumstances, that fluctuation is not a concern of monetary policy. As Woodford (2003, p. 13) explains, "Large movements in frequently adjusted prices – and stock prices are among the most flexible – can instead be allowed with out raising such concerns, and if allowing them to move makes possible greater stability of the sticky prices, such instability of flexible prices is desirable."

5. Our concerns about how news influences exchange rates and affects relative goods prices does not depend on whether internationally traded goods' prices are set in the producers' currencies (PCP) or the consumers' currencies (LCP). Some of our earlier work (Devereux and Engel, 2003, 2004) has focused on that issue, in models where news was not important. But we set aside that dispute here. If there is PCP, then nominal exchange rate changes (arising from

news of the future) can lead to inefficient changes in the terms of trade. If there is LCP, these nominal exchange rate changes lead to inefficient deviations from the law of one price.

6. We are not saying that a policy of fixed nominal exchange rates is optimal. First of all, in response to traditional contemporaneous disturbances (non-news shocks), exchange rate adjustment may be desirable. But even with news shocks alone, our results generally say not necessarily that exchange rates should be fixed, but that unanticipated movements in exchange rates should be eliminated. In fact, anticipated movements in exchange rates may play a vital role in facilitating relative price movements after a news shock. In general, our point is that news shocks can lead to relative price distortions that are translated through exchange rate changes, and these shocks should be a target of policy.

Technically, our model is exceedingly simple. The central idea is based on the property that efficient relative prices of non-durable goods depend only on current fundamentals, and should not be directly linked to news about future fundamentals. This property is satisfied in most recent general equilibrium exchange rate models. In fact, the clearest statement of independence of current allocations on future fundamentals is in Barro and King (1984). They show that in general equilibrium models with time-additive utility and absenting investment, current (efficient) equilibrium allocations are independent of expectations about future fundamentals. This result extends to an open economy where markets are sufficiently complete to support a time-invariant risk sharing rule. But, in the presence of sticky nominal prices, this dichotomy between current allocations and future fundamentals no longer necessarily holds. When prices cannot adjust, any news shocks that affect the current exchange rate automatically affect relative prices. But in general, this is inefficient, and the monetary authority should take action to dampen or eliminate the impact of news shocks on current allocations.

Section 1 presents some empirical evidence on the importance of news in moving exchange rates. Section 2 then explains in a general context why prices of nondurables should not act like asset prices and reflect expectations of future fundamentals. The rest of the paper demonstrates the logic of targeting shocks to exchange rates caused by news in two different models. Section 3 describes the first model, in which prices are pre-set one period in advance, and can fully adjust after one period. In this model, we find that an optimal monetary policy in face of news shocks is to maintain a fixed exchange rate. Section 4 then extends the model to allow gradual price adjustment. The extended model no longer calls for a fixed exchange rate, but implies that an optimal monetary rule eliminates the impact of news shocks on the exchange rate. In section 5, we build a more realistic model with investment. Optimal investment decisions are forward looking, so in this model it is no longer strictly true that current relative goods prices should not depend on future productivity shocks. Nonetheless, under standard parameterizations, our conclusions are not altered – optimal monetary policy should not only target inflation but also try to eliminate the effect of news on exchange rates.

Section 1. Empirical Evidence on the Effect of Expectations on Exchange-Rate Volatility

Several recent empirical papers have emphasized the role of news in driving exchange rates. Engel and West (2005) demonstrate that standard exchange rate models do not in fact imply that exchange rate changes should be predictable using current values of fundamental variables, or even necessarily strongly correlated with contemporaneous changes in fundamentals. Instead, they show that a testable hypothesis of the models is that the news that is incorporated in exchange rates should help the exchange rate forecast future macroeconomic variables. They find empirical evidence to support that position.

Andersen, et. al. (2003) use six years (1992-1998) of real-time quotations from the foreign exchange market to assess the impact of macroeconomic news on exchange rates. They measure "news" as the difference between announced values of macro variables (payroll employment, trade balance, retail sales, etc.) and a survey measure of the market's expectation of these announcements. They find that exchange rates react significantly to these announcements, and over 5-minute windows, a simple OLS regression of the exchange rate on the news yields high R^2 values: "often around 0.3 and sometimes approaching 0.6." While the emphasis in Andersen, et. al. is on the short-run influence of news on exchange rates, Faust, et. al. (2005) use real-time data and information from the term structure of interest rates to examine how news announcement affect expectations of long-run exchange rate changes. They find that news announcements about U.S. real or nominal activity move exchange rates and also influence longer-term interest rates, with the maximum effect 2-years. They argue that the effect on long-term rates might reflect the response of long-run changes in expected currency depreciation.

Here we provide some alternative evidence on the effect of changes in expectations on exchange rates. In particular, we consider models in which the exchange rate can be expressed as a present discounted value of current and future fundamentals. The log of the exchange rate is determined by:

$$x_{tI} = (1-b)\sum_{j=0}^{\infty} b^j E(f_{t+j} \mid I_t) \qquad 0 < b < 1. \tag{1.1}$$

Here, f_t measures the economic "fundamentals" that drive the log of the exchange rate. The discount factor is *b*. I_t represents the information set of agents. It is helpful to rewrite this as:

$$x_{tI} = f_t + (1-b)\sum_{j=1}^{\infty} b^j E(f_{t+j} - f_t \mid I_t). \tag{1.2}$$

Our models suggest that monetary policy should have as one objective the stabilization of

innovations (unexpected changes) in the second term on the right-hand-side of equation (2). That is, monetary policy should work to offset the effects of news shocks on exchange rates that work through unexpected changes in future fundamentals relative to the current fundamental.

How important is this second term in driving exchange rate innovations relative to the effect of innovations in the current fundamental? We would like to know how much of the variance of unexpected changes in x_{tI} can be attributed to innovations in the current fundamentals, f_t. That is, we would like to calculate

$$\eta_t \equiv \frac{\text{var}(f_t - E(f_t \mid I_{t-1}))}{\text{var}(x_{tI} - E(x_{tI} \mid I_{t-1}))}. \tag{1.3}$$

Our premise is that innovations in current fundamentals do not contribute much to the variance in the innovations in x_{tI}. We believe that it is mostly news about future fundamentals that causes variation in x_{tI}. If our hypothesis is correct, then η_t should be small.

However, it seems hopeless to measure the variances in the numerator and denominator of equation (1.3), because we do not have the information available to the market in forming its expectations. We can calculate a measure of the expected discounted sum of current and future fundamentals based on the information set available to the econometrician, H_t. Define

$$x_{tH} = (1-b)\sum_{j=0}^{\infty} b^j E(f_{t+j} \mid H_t). \tag{1.4}$$

But as West (1988) shows, we can only construct upper bounds for the variances in equation (1.3). That is, from West, we have

$$\text{var}(f_t - E(f_t \mid I_{t-1})) < \text{var}(f_t - E(f_t \mid H_{t-1}))$$

$$\text{var}(x_{tI} - E(x_{tI} \mid I_{t-1})) < \text{var}(x_{tI} - E(x_{tI} \mid H_{t-1})).$$

Having an upper bound on both the numerator and the denominator does not help us even

establish an upper bound on η_t.

We could follow the method of Campbell and Shiller (1987), and impose that the log of the exchange rate exactly equals x_{tI}. Their methods then allow one to extract the relevant information in I_t because that information is reflected in exchange rate movements. But as Engel and West (2005) argue, that approach requires that we have measures of all the relevant fundamentals that drive the exchange rate. While one might plausibly argue that the fundamentals for some asset prices such as equities are completely observable ex post (that is, dividends are observable), it is much less plausible to assert that we can observe all the fundamentals that drive exchange rates, which include such variables as money demand shocks, productivity shocks, etc. If the fundamentals are not ex post observable, we cannot apply the procedures of Campbell and Shiller (1987).

We can, however, rely on a result of Engel and West (2004) to get a measure of the denominator of η_t from equation (1.3). They show that as the discount factor gets large ($b \to 1$), the econometrician's measure of the variance of innovations in the present value is approximately equal to the variance based on the market's information set:

$$\text{var}(x_{tI} - E(x_{tI} \mid I_{t-1})) \approx \text{var}(x_{tI} - E(x_{tI} \mid H_{t-1})).$$

Even though the econometrician cannot replicate the information set of the market, he can accurately measure the variance of the innovation in the discounted sum when the discount factor is large. Engel and West show that in practice the discount factors implied by common empirical models are large enough that the approximation is a good one.

Engel and West (2004) proceed to show that the volatility of innovations in the actual exchange rate is approximately twice the size of $\text{var}(x_{tI} - E(x_{tI} \mid H_{t-1}))$ for U.S. exchange rates

relative to other G7 countries using two familiar models of exchange rates.[1] The first is a monetary model, in which the observed fundamental is measured as $f_t = m_t - y_t - (m_t^* - y_t^*)$, the log of the money/output ratio in the U.S. relative to another country. The fundamentals in this model correspond approximately to those in our model in section 3. The second is a model based on a Taylor rule for monetary policy, in which the fundamental can be written as either $f_t = p_t - p_t^*$, the difference in the log of U.S. versus foreign-country prices, or $f_t = p_t - p_t^* + (i_t - i_t^*)$, the sum of the log of the price level and the interest rate in the U.S. relative to another country. Engel and West (2005) demonstrate how these fundamentals are derived from the underlying model. These fundamentals correspond to the ones in our model in sections 4 and 5. The fact that exchange rates innovations are more volatile than innovations in the discounted sum of current and expected future fundamentals indicates either that there are "fundamentals" that are not included, or that exchange rates may be driven by non-fundamental sources.

Our objective here is not to ask whether economic fundamentals from traditional models can account for exchange rate volatility. Instead, we take the models as given, and simply try to measure η_t. Using the Engel-West theorem, we can approximately calculate the variance in the denominator of equation (1.3). As we have noted, we can calculate an upper bound on the variance in the numerator, and hence can calculate an upper bound for η_t.

Table 1 reports our measure of η_t for the fundamentals considered by Engel and West (2004), for various values of the discount factor, *b*. In calculating these statistics, we take the econometrician's information set to be only current and lagged values of the fundamentals, f_t.

[1] Engel and West (2004) rely on a result of Engel and West (2005) to show that innovations in the log of the exchange rate can be measured approximately by change in the log of the exchange rate when the discount factor is near one.

We estimate an autoregression with four lags (in all cases) on each measure of the fundamentals. From these, we calculate our estimates of $\text{var}(f_t - E(f_t \mid H_{t-1}))$ and $\text{var}(x_{tI} - E(x_{tI} \mid H_{t-1}))$.

We use the same data used in Engel and West (2004, 2005). It is quarterly data, 1973:1-2003:1.[2] The US is the home country, and we measure the fundamentals relative to the other G7 countries. The money supplies are seasonally adjusted M1 (except for UK, for which we use M4) from the *OECD Main Economic Indicators*. The US money supply data is corrected for "sweeps", as described in Engel and West (2004), using data from the Federal Reserve Bank of St. Louis. We use seasonally adjusted GDP from the same source (except for Germany, which combines data from the IMF's *International Financial Statistics* (*IFS*) with the OECD data.) The interest rates are 3-month Eurocurrency returns taken from *Datastream*. The consumer prices are from the *IFS*.

While the estimated value of η_t varies from country to country, typically we find that it is around 0.20. More precisely, the average across all countries and all measures of the fundamentals, in the case of $b = 0.99$ is 0.215. The average is slightly higher for lower values of b and lower for higher values of b. That is, most of the surprise movement in the discounted sum that is supposed to determine exchange rates comes from innovations in expected future values of fundamentals rather than unexpected changes in current values.

It is important to note that the upper bounds for η_t reported in Table 1 might be crude upper bounds. That is, innovations in the current fundamentals might contribute much less to innovations in x_{tI} than the numbers reported in this Table. For example, during 2005, the Federal Reserve raised the Fed Funds rate by 25 basis points all seven times that the FOMC has met (so far.) Fed Funds futures indicated before each meeting that there was virtual certainty

[2] In a few cases, the time span differs because of data availability. See Engel and West (2005) for data spans.

that the Fed would raise rates. That is, there was essentially no innovation in the current fundamental – the interest rate – on the FOMC meeting days. But clearly the Fed's policy decisions are important for exchange rates, and that is reflected in movements in the exchange rates on those FOMC days. The exchange rate, however, was not changing because of any surprise in the current fundamental. The news that hit the market came in the announcements of the Fed's assessment of market conditions, which in turn imparted news about future interest rate changes. Our measure of the variance in the innovations in the current fundamental, $\text{var}(f_t - E(f_t \mid H_{t-1}))$, is a crude one because the market uses much more information than four quarterly lags of the fundamentals to form its expectations. For example, it does not even use the Fed funds future rates to help capture the market's information about future interest rates, and so we tend to overestimate the variance of innovations in current fundamentals.

Section 2. A General Result

The technical result of the paper rests on an insight into dynamic general equilibrium models first discussed by Barro and King (1984). In a closed economy model with time-additive utility and without endogenous investment, they show that all real allocations and relative prices are determined solely by contemporaneous fundamentals. That is, there are no intrinsic inter-temporal links between periods, and no persistence in the effects of shocks, apart from that due to persistence in the shocks themselves. An equilibrium allocation in their model is Pareto efficient, since there is a representative individual and all prices are fully flexible. It follows that, in an economy with sticky prices, if an optimal monetary policy is designed to replicate the flexible price equilibrium, it should insulate current allocations and relative prices against shocks that come in the form of announcements about future fundamentals.

We develop this basic intuition within the standard two-country environment of recent open economy macroeconomic models. We first set out a general version of the model, to illustrate the logic of Barro and King within our framework. We then apply this model to two particular types of price setting environments – one where prices are pre-set one period ahead, for just one period, and then to an environment of Calvo-type staggered pricing. In each case, we identify one or more optimal monetary policy rules to deal with news shocks.

Although the analytical results rely on the strict separation across periods, we do not argue that it be taken literally. There are a number of factors that give rise to efficient links between current allocations or relative prices and future fundamentals shocks. One obvious channel is investment. But we argue that even once we allow for this linkage, our central result, that the current exchange rate response to announcements about future fundamentals should be dampened, will still hold in a quantitative sense. An extension of the model to allow for endogenous investment establishes this point.

The Basic Model

Take a general example of an open economy macro model. Say that there are two equally sized countries: home and foreign, where in each country, the measure of households is normalized to one. In each country, households maximize expected lifetime utility taking prices and wages as given. Households consume traded goods, constituting a mix of home and foreign goods, and a non-traded good, produced and consumed only in the domestic country. Firms are monopolistic and maximize utility for their owners. Say that consumer preferences are:

$$\Upsilon = E_0 \sum_{t=0}^{\infty} \beta^t \upsilon_t , \qquad 0 < \beta < 1,$$

where $\upsilon_t = U(C_t, L_t) + V(M_t / P_t)$, with $U_1 > 0, U_2 < 0, U_{11} < 0, U_{22} < 0.$ Here C represents aggregate consumption, L is labor supply, and M / P are real money balances. Aggregate

consumption C is a function of non-traded consumption and traded consumption; $C = C(C_N, C_T)$. Traded consumption is also a function of home and foreign traded good consumption; $C_T = C(C_H, C_F)$. Each function is homogenous of degree 1, and each argument of these functions is a homogenous of degree 1 function of a continuum of differentiated individual goods, with constant elasticity of substitution λ across varieties. The price index *P* reflects the weights implied by the consumption aggregator, and $P = P(P_N, P_T) = P(P_N, P_T(P_H, P_F))$, where again each function is homogenous of degree 1.

Firms are monopolistic competitors, and set prices as a markup over marginal cost. Assume first that all prices are fully flexible. In addition, let the production technologies of typical firms in the traded and non-traded sectors of the economy be (ignoring firm specific notation):

$$Y_N = \theta L_N, \quad Y_H = \theta L_H.$$

Thus, there is a common technology shock to both sectors, and the only input to production is labor. Finally, we assume that there exists a full set of state contingent assets for sharing consumption risk across countries. There is only one type of fundamental shock in this model, a shock to the country specific technologies. But the argument may be easily generalized to other shocks.

It is straightforward to show that the equilibrium of this economy, where all households within a country and all firms within a sector are identical, may be represented by the following conditions (letting foreign variables be denoted with an asterisk).

(2.1) $$\frac{P_{Ht}}{P_t} = \frac{\lambda}{\lambda - 1} \frac{U_1(C_t, L_t)\theta_t}{U_2(C_t, L_t)},$$

(2.2) $$\theta L_{Nt} = P_1(P_{Nt}, P_{Tt}) C_t,$$

(2.3) $$\theta L_{Ht} = P_1(P_{Nt}, P_{Tt}) P_{T1t}(P_{Ht}, P_{Ft}) C_t + P_{1t}^*(P_{Nt}^*, P_{Tt}^*) P_{T1t}^*(P_{Ht}^*, P_{Ft}^*) C_t^*,$$

(2.4) $$U_1(C_t, L_t) = \Lambda U_1^*(C_t^*, L_t^*) \frac{S_t P_t^*}{P_t}.$$

Equation (2.1) relates the equilibrium real price for home goods to the price-cost markup times the firm's marginal cost, represented by the ratio of the real wage to the technology variable. Since non-traded and traded goods share the same technology, and labor is mobile across sectors, this condition is the same for both sectors (so that $P_{Nt} = P_{Ht}$). Equations (2.2) and (2.3) represent market clearing in the home non-traded and traded goods market, respectively, where the notation $P_1(P_N, P_T)$ represents the first derivative of the price index with respect to the first argument, etc. Finally, (2.4) represents the risk-sharing condition across countries, relating marginal utilities to the real exchange rate (where S_t is the nominal exchange rate), for a time-invariant constant Λ.

Equations (2.1)-(2.3), their analogues for the foreign economy, and equation (2.4) represent a general equilibrium in seven equations that determine the endogenous variables (where tildes denote equilibrium values); $\tilde{C}_t, \tilde{C}_t^*, \tilde{L}_{Nt}, \tilde{L}_{Ht}, \tilde{L}_{Nt}^*, \tilde{L}_{Ht}^*,$ and $\tilde{\tau}_t = \frac{S_t P_{Ft}^*}{P_{Ht}}$, the terms of trade.

The key feature of this solution is that it represents a mapping from contemporaneous technology shocks θ_t and θ_t^* to the equilibrium values of endogenous variables. More particularly, future technology shocks have no impact on allocations or the terms of trade. In fact, the system (2.1)-(2.4) contains no past or future variables at all. The following result then immediately follows. If nominal prices P_H and P_F^* are sticky, and the monetary authority follows a rule aimed to sustain the flexible price equilibrium of the model described by (2.2)-

(2.4), then it must necessarily choose a value of the nominal exchange rate that is independent of unanticipated current announcements about future technology shocks (or news shocks). If this were not the case, then news shocks would affect the current terms of trade, and allocations would be pushed away from the flexible price equilibrium of the model.

We now explore the implication of this result in a number of settings where prices are sticky.

Section 3. A Model with One-period Price Setting.

We now apply this result to a model where prices are pre-set for one period. The model is a simple extension of Devereux and Engel (2003) (henceforth DE) and is based also on Duarte and Obtsfeld (2005). We let:

$$\upsilon_t = \frac{1}{1-\rho} C_t^{1-\rho} + \frac{\chi}{1-\varepsilon}\left(\frac{M_t}{P_t}\right)^{1-\varepsilon} - \eta L_t, \qquad \rho > 0,\ \varepsilon > 0,$$

and $C = \dfrac{C_T^{\gamma} C_N^{1-\gamma}}{\gamma^{\gamma}(1-\gamma)^{(1-\gamma)}}$, $C_T = 2C_H^{.5}C_F^{.5}$. The parameter γ represents the share of non-traded goods in consumption. The price indices P are defined by $P = P_T^{\gamma} P_N^{1-\gamma}$, $P_T = P_H^{0.5} P_F^{0.5}$.

Following Beaudry and Portier (2003), we assume that technology shocks have a component that is known one period in advance of the shock. Thus, for the home country, we assume that the technology shock is

$$\theta_t = \theta_{1t}\theta_{2t}, \quad \theta_{1t} = \exp(v_{t-1}), \quad \theta_{2t} = \exp(u_t),$$

where v_t and u_t are normally distributed, with mean zero, and variance σ_v^2 and σ_u^2 respectively. The critical feature of the technology process is that the innovation in θ_{1t} becomes known one period in advance, i.e. at time t-1. On the other hand, the component θ_{2t}, is realized at the same

time as it becomes known[3]. The implication of this assumption is that households and firms will know, one period in advance, part of future technology innovations. Hence, since, in this version of the model, prices are pre-set for only one period, prices for future periods can fully adjust to a forecast in the technology shock. But prices for the current period, based on period t-1 information, cannot adjust to the shock.

The solution to the model follows closely that of DE. An approximation to the money market equilibrium may be written as:

$$m_t - p_t = \frac{\rho}{\varepsilon} c_t - \frac{1}{i\varepsilon}(E_t p_{t+1} + \rho E_t c_{t+1} - p_t - \rho c_t) + \Gamma_m \tag{3.1}$$

where Γ_m is a constant, and lower-case letters refer to logs of the respective variables. An analogous condition may be derived for the foreign country.

The optimal trade-off between consumption and leisure implies:

$$\frac{W_t}{P_t C_t^{\rho}} = \eta . \tag{3.2}$$

The risk sharing condition implies:

$$\frac{S_t P_t^*}{P_t} = \Gamma_0 \left(\frac{C_t}{C_t^*} \right)^{\rho} . \tag{3.3}$$

[3] Beaudry and Portier (2003) assume that the forecastable component of technology is permanent. Here we assume that it is transitory. This makes little difference to the results of this section. In section 4, some of details of the results are altered in the presence of a permanent forecastable technology shock, although the central result (eliminating surprise exchange rate changes) is unchanged.

Price Setting

Prices for period *t* are set one period in advance, based on period *t*-1 information sets. Firms choose prices to maximize profits using the stochastic discount factor of their owners. We allow for exported goods prices to be set either in the firm's own currency (producer currency pricing, or PCP) or in foreign currency (local currency pricing, or LCP).

Equilibrium

The goods market equilibrium in the home country non-traded goods sector is:

$$\theta_t L_{Nt} = (1-\gamma)\frac{P_t C_t}{P_{Nt}}, \tag{3.4}$$

where L_{Nt} represents employment in the non-traded goods sector. In the traded goods sector, for the PCP pricing environment, the equilibrium condition is (L_{Ht} is employment in the home traded goods sector):

$$\theta_t L_{Ht} = \gamma\frac{1}{2}\left(\frac{P_t C_t}{P_{Ht}} + \frac{S_t P_t^* C_t^*}{P_{Ht}}\right). \tag{3.5}$$

With LCP the goods-market equilibrium in the home traded goods sector is written as:

$$\theta_t L_{Ht} = \gamma\frac{1}{2}\left(\frac{P_t C_t}{P_{Ht}} + \frac{P_t^* C_t^*}{P_{Ht}^*}\right). \tag{3.6}$$

The difference between (3.5) and (3.6) is due to the fact that in the latter case there are separate pre-set prices of home goods in domestic currency (for domestic sales) and foreign currency (for export).

Flexible-Price Solution

With flexible prices, we may apply the conditions (2.1)-(2.4) to solve for consumption and the terms of trade as:

(3.7) $$C_t = \left(\frac{\lambda\eta}{\lambda-1}\right)^{-\frac{1}{\rho}} \left(\theta_t^{.5\gamma+1-\gamma}\theta_t^{*.5\gamma}\right)^{\frac{1}{\rho}}$$

(3.8) $$\tau_t = \Gamma_0^{\frac{1}{1-\gamma}} \frac{\theta_t}{\theta_t^*}$$

Without non-traded goods, consumption would be equalized across countries. Generally however, with $\gamma<1$, home consumption is more sensitive to a home technology shock than to a foreign technology shock.

Monetary Policy Rules

Money supply of each country is given by:

(3.9) $$m_t = m_{t-1} + \mu_t + \delta_{t-1}$$

(3.10) $$m_t^* = m_{t-1}^* + \mu_t^* + \delta_{t-1}^*.$$

Monetary policy rules are designed to respond to unanticipated shocks, so $E_{t-1}(\mu_t) = E_{t-1}(\mu_t^*) = 0$, and $E_{t-2}(\delta_{t-1}) = E_{t-2}(\delta_{t-1}^*) = 0$ will hold. Here μ_t (μ_t^*) is an addition to the time *t* information set, while δ_{t-1} (δ_{t-1}^*) is an addition to the time *t-1* information set. Note that this assumption means that conditionally (on time t information) expected money growth will vary over time, although the unconditional expectation of money growth is zero. This monetary rule is designed so that the μ_t component reacts to current u_t shocks, while the δ_t component reacts to future v_t shocks, which are announced today.

Exchange Rate and Consumption under PCP

With PCP pricing, the law of one price holds for traded goods. Hence, from (2.4):

(3.11) $$(c_t - E_{t-1}c_t) = (c_t^* - E_{t-1}c_t^*) + \frac{(1-\gamma)}{\rho}(s_t - E_{t-1}s_t).$$

Unanticipated changes in the exchange rate will affect the real exchange rate, and therefore

relative consumption levels, to the extent that they alter the international relative price of non-traded goods, which in this model, is also equal to the terms of trade.

Since prices fully adjust after one period, the expected real allocations from next period on will be governed by (3.7) and (3.8). Therefore:

$$E_t c_{t+1} - E_{t-1} c_{t+1} = \frac{1}{\rho}\left[(1-0.5\gamma)v_t + .5\gamma v_t^*\right]. \tag{3.12}$$

There are no expected changes in nominal interest rates from time period *t+2* onwards, since the news shock is then dissipated, and in expectation, the money stock is constant. We can then use this property and the period *t+1* version of (3.1), to obtain:

$$\begin{aligned} E_t p_{t+1} - E_{t-1} p_{t+1} &= E_t m_{t+1} - E_{t-1} m_{t+1} - \frac{\rho}{\varepsilon}(E_t c_{t+1} - E_{t-1} c_{t+1}) \\ &= \delta_t + E_t m_t - E_{t-1} m_t - \frac{\rho(1+i)}{(1+\varepsilon i)}(E_t c_{t+1} - E_{t-1} c_{t+1}) \end{aligned} \tag{3.13}$$

.

Now, putting (3.11), (3.12), and (3.13) together with (3.1), and using the analogous equations for the foreign country, leads to the exchange rate

$$s_t - E_{t-1} s_t = \frac{(1+i\varepsilon)\left[(m_t - E_{t-1} m_t) - (m_t^* - E_{t-1} m_t^*)\right]}{1+i(1-\gamma(1-\varepsilon))} + \frac{\frac{(\varepsilon-1)i}{(1+i\varepsilon)}\left[(1-\gamma)(v_t - v_t^*)\right] + \delta_t - \delta_t^*}{1+i(1-\gamma(1-\varepsilon))} \tag{3.14}$$

The exchange rate is the sum of two elements. First, there are revisions to current fundamentals, i.e. unanticipated movements in relative money growth across the home and foreign country. The second element is future fundamentals, captured by the second term in (3.14). This is explained as follows. When $v_t > v_t^*$, there is a shock to future home productivity that exceeds that to future foreign productivity. If in addition $\gamma < 1$, this must increase anticipated consumption at home more than in the foreign country, since home residents' consumption is more sensitive to home productivity in the presence of a non-traded goods sector. From (3.1),

holding the current monetary innovation constant, a rise in expected future home relative consumption will increase the home nominal interest rate, relative to the foreign nominal interest rate, when $\varepsilon > 1$. This will reduce demand for money at home relative to the foreign country, and as a result there is an unanticipated home currency depreciation. Finally, future fundamentals also incorporate future changes in the relative money supplies, $\delta_t - \delta_t^*$, which can be forecasted based on announcements of future relative technology growth rates.

Note that the key feature of this mechanism is that the exchange rate responds to future fundamentals, rather than current fundamentals. That is, the time t+1 productivity shock becomes known at time t, and generates `news', which leads the current exchange rate to move, and the resulting changes in the expected future money supply have a similar effect. There are no changes in current supply or demand variables, however.

How do home and foreign consumption rates respond to future productivity shocks? Again from the money market clearing condition (3.1), we can derive the expression for the unexpected response of home and foreign consumption, respectively, as:

$$(3.15)\quad c_t - E_{t-1}c_t = \phi\left[(m_t - E_{t-1}m_t) - \frac{\gamma}{2}(s_t - E_{t-1}s_t)\right] + \frac{1}{(1+i)}\left(\frac{(\varepsilon-1)i}{(1+i\varepsilon)}\left(E_t c_{t+1} - E_{t-1}c_{t+1}\right) + \frac{\delta_t}{\rho}\right)$$

$$(3.16)\quad c_t^* - E_{t-1}c_t^* = \phi\left[(m_t^* - E_{t-1}m_t^*) + \frac{\gamma}{2}(s_t - E_{t-1}s_t)\right] + \frac{1}{(1+i)}\left(\frac{(\varepsilon-1)i}{(1+i\varepsilon)}\left(E_t c_{t+1}^* - E_{t-1}c_{t+1}^*\right) + \frac{\delta_t^*}{\rho}\right)$$

where $\phi = \frac{1}{\rho}\left(\frac{1+i\varepsilon}{1+i}\right)$.

We may explain these expressions as follows. Take equation (3.15), and imagine that there is an anticipated positive home country productivity shock. Then there is a rise in expected future home consumption, which will tend to raise nominal interest rates when $\varepsilon > 1$. This causes an excess supply of home money, and would lead to an unanticipated rise in current home

consumption. Against this, however, is the fact that the anticipated home productivity shock causes an exchange rate depreciation, when $\varepsilon > 1$. This reduces real money supply, and tends to reduce home consumption. The net effect on current period home consumption may be positive or negative. When $\varepsilon < 1$ the reasoning goes the other way.

The impact of future money supply changes are straightforward – a positive δ_t represents an expected future monetary expansion, which raises nominal interest rates and raises current consumption.

Local-Currency Pricing (LCP)

Under local-currency pricing, the law of one price will not generally hold. Since with LCP all domestic and foreign nominal goods prices are pre-determined, the CPI's of each country are also predetermined. Then, from (3.3), we get:

(3.17) $$(c_t - E_{t-1}c_t) = (c_t^* - E_{t-1}c_t^*) + \frac{1}{\rho}(s_t - E_{t-1}s_t)$$

The behavior of expected period t+1 consumption is the same as in (3.7), since LCP and PCP are equivalent to one another after prices have fully adjusted. For the same reason, equation (3.13) is the same as before. Then, using (3.17), (3.7), (3.13), and the money market equilibrium conditions (3.1) for each country, gives:

(3.18)

$$s_t - E_{t-1}s_t = \left(\frac{1+i\varepsilon}{1+i}\right)\left[(m_t - E_{t-1}m_t) - (m_t^* - E_{t-1}m_t^*)\right] + \frac{1}{(1+i)}\left(\frac{(\varepsilon-1)i}{(1+i\varepsilon)}\left[(1-\gamma)(v_t - v_t^*)\right] + \delta_t - \delta_t^*\right)$$

This differs from expression (3.14) due to the fact that price levels are predetermined under LCP. But qualitatively, we get a similar message. The exchange rate is a function of current and future fundamentals. A future productivity shock, which becomes known today, represents `news', which impacts on the current exchange rate. The size of this effect depends on the size of the

non-traded goods sector, as well as the size of ε.

The impact of future productivity shocks on consumption is given by:

$$(3.19)\quad c_t - E_{t-1}c_t = \phi(m_t - E_{t-1}m_t) + \frac{1}{(1+i)}\left(\frac{(\varepsilon-1)i}{(1+i\varepsilon)}\left(E_t c_{t+1} - E_{t-1}c_{t+1}\right) + \frac{\delta_t}{\rho}\right)$$

$$(3.20)\quad c_t^* - E_{t-1}c_t^* = \phi(m_t^* - E_{t-1}m_t^*) + \frac{1}{(1+i)}\left(\frac{(\varepsilon-1)i}{(1+i\varepsilon)}\left(E_t c_{t+1}^* - E_{t-1}c_{t+1}^*\right) + \frac{\delta_t^*}{\rho}\right)$$

These effects are equivalent to the PCP case, save for the absence of the exchange rate from (3.19) and (3.20), since movements in the exchange rate no longer directly impact on CPI values. But again, as in the PCP case, we have announcements effects of future productivity shocks influencing current consumption. This case also allows us to be more precise regarding the impact of future productivity shocks. Whenever $\varepsilon > 1$, a rise in future home or foreign productivity will lead to a rise in current consumption. This happens because there is no secondary channel of the initial interest rate increase arising from the future productivity shock, as exists in the PCP case.

Optimal Monetary Policy with News Shocks

So far we have not been specific about the monetary policy response to current or anticipated future productivity shocks. Implicit in the analysis above is that *current* productivity shocks (i.e. shocks to θ_{2t}) have no impact on either the exchange rate or consumption, independent of the endogenous response of monetary policy. But, following the analysis of DE, there are clear welfare reasons why monetary policy should be designed to ensure the efficient response of the real economy to current productivity shocks in the presence of sticky prices. The optimal values for the monetary policy response to *current* productivity shocks are similar to those analyzed in DE and Duarte and Obstfeld (2005). For the PCP model, the monetary policy responses in the home and foreign currency can perfectly replicate the flexible price equilibrium.

For the LCP model, given the absence of exchange rate pass-through, the flexible price equilibrium cannot be sustained. The optimal monetary policy response ensures that consumption responds to current productivity shocks as in the flexible price equilibrium, but the exchange rate responds by less than in the flexible price equilibrium.

In face of anticipated *future* productivity shocks however, the rationale for an optimal policy response becomes less clear. When there is a shock to θ_{1t+1}, which by assumption is observed at time t, then prices have the chance to respond fully before the shock takes effect. In that case, there is no reason for monetary policy to be used in order to ensure the efficient adjustment of the period t+1 allocations to the productivity shock. But the key feature of our examples above, and the central message of the paper, is that these anticipated future shocks will affect the economy in the *present*. That is, by impacting on interest rates and exchange rates, current consumption will be moved away from its flexible price equilibrium, given by (2.9). The reason is that, while future prices have time to adjust to the shock that occurs in period t+1, current prices cannot react to the announcement. To the extent that the announcement effects shift current allocations away from their flexible price equilibrium, they are undesirable, and an optimal monetary policy can be devised to deal with this.

The nature of the optimal monetary policy for future productivity shocks turns out to be the same, for both types of pricing. Thus, we can state:

Result 1:

Let the monetary policy rules be defined as

$$\delta_t = a_0 v_t + a_1 v_t^* \qquad\qquad \delta_t^* = a_0^* v_t + a_1^* v_t^* .$$

Then for both LCP and PCP, the optimal monetary rule is described by

$$a_0 = a_1^* = -\frac{(\varepsilon - 1)i}{(1+i\varepsilon)}(1-\frac{\gamma}{2}) \qquad\qquad a_1 = a_0^* = -\frac{(\varepsilon - 1)i}{(1+i\varepsilon)}\frac{\gamma}{2}.$$

Proof:

These rules eliminate the impact of future productivity shocks on current consumption in both countries. Therefore, employment is also unchanged. Therefore the rules sustain the flexible price equilibrium, in face of announced future productivity shocks.

Result 2:

The optimal monetary rules from Result 1 prevent the exchange rate from responding to future productivity shocks.

Proof: By inspection.

Result 2 is in a sense the more interesting one. Standard Optimal Currency Area (OCA) reasoning suggests that it is efficient to allow the exchange rate to respond to country specific productivity shocks. We find, in the absence of a monetary response, that indeed the exchange rate will respond to announcements of country specific productivity shocks. The direction of movement depends on the size of ε. For $\varepsilon > 1$, the exchange rate will depreciate in response to an announced future home productivity expansion. It is tempting to interpret this movement along efficiency (or OCA) lines – the future home productivity expansion should cause a home country terms of trade deterioration. Hence, the response of agents in financial markets, forecasting this, leads to an immediate nominal exchange rate depreciation.

But the problem with this reasoning is that the immediate response of the current nominal exchange rate causes a change in the current real exchange rate (by different degrees in the PCP and LCP environments), because current nominal prices cannot respond to the announced future shock. In the absence of a *current* (as opposed to future) productivity shock, however, there is no efficiency reason for the real exchange rate to move at all. In fact, movements in the real

exchange rate are associated with welfare losses since they push consumption and employment away from their efficient levels.

Thus, in a sticky price environment, when the exchange rate responds to `news', there is no guarantee that it will do so in an efficient manner. Indeed, in our model, the optimal monetary rule should prevent the exchange rate from responding to news shocks at all. The critical requirement is that there not be any *unanticipated* movements in the exchange rate. That is the time *t* exchange rate will be known in time *t-1*. Given the form of the monetary rules defined here, we can actually go beyond this, and establish that under these rules the exchange rate is fixed over time (when all shocks are observed in advance). To see this, note that

$$
\begin{aligned}
s_{t+1} &= \rho(c_{t+1} - c^*_{t+1}) + p_{t+1} - p^*_{t+1} \\
&= \frac{\rho(\varepsilon - 1)i}{(1 + i\varepsilon)}(c_{t+1} - c^*_{t+1}) + m_{t+1} - m^*_{t+1} \\
&= \frac{\rho(\varepsilon - 1)i}{(1 + i\varepsilon)}(c_t - c^*_t) + m_t - m^*_t + \frac{(\varepsilon - 1)i(1-\gamma)}{(1 + i\varepsilon)}(v_t - v^*_t) + \delta_t - \delta^*_t \\
&= \frac{\rho(\varepsilon - 1)i}{(1 + i\varepsilon)}(c_t - c^*_t) + m_t - m^*_t \\
&= s_t
\end{aligned}
$$

The first equality comes directly from the risk sharing condition (2.5). The second comes from the solutions for period *t+1* prices discussed before equation (3.13). The third equality comes from a decomposition of money growth and consumption growth, while the fourth uses the optimal money rule of Result 1.

Hence, the monetary authority follows a rule in which next period's money supply responds to future productivity shocks letting, nominal price levels take the full burden of adjusting the future real exchange rate to the productivity shocks, and keeping the exchange rate fixed over time. From a welfare perspective however, this is not necessary. The efficient allocation could just as easily be attained by a policy which prevents the *current* exchange rate

from reacting to news shocks, but allowing part of the real exchange rate adjustment to occur via movements in the future nominal exchange rate. Thus, there could be expected changes in the exchange rate over time. These changes would not be costly, because prices can adjust over the same time frame. The critical ingredient in the analysis is that future productivity shocks do not generate surprise movements in the current nominal exchange rate.

Of course the model is quite stylized, since we have assumed that all prices can adjust before the news takes effect. But this is not necessarily unrealistic. At an anecdotal level, we see the exchange rate responding to all types of potential events (e.g. effects of Social Security changes that may affect the budget deficit in 5 or more years' time) that may occur much further in the future than would be relevant for business cycle frequencies. These exchange rate movements are not necessarily desirable, because we have to recognize that the response to future shocks may not be consistent with the currently desired structure of relative prices. Nevertheless, we now turn to an extended version of the model, which assumes that nominal prices must be adjusted gradually rather than all at once.

Section 4. Extension to Gradual Price Adjustment

We now extend the model to allow gradual price adjustment using the Calvo specification where only a given fraction of firms may adjust their prices within a period, and ex ante, all firms have an equal chance of price adjustment. The specification for households and firms is unchanged except for the price setting rule. For simplicity, we focus only on the PCP pricing case. In addition, to make the analysis comparable to the previous model, we follow Rotemberg and Woodford (1997) in assuming that a firm that has an opportunity to change its price must set its price for period t with information based on period t-1. That is, prices that are

adjusted are set one period in advance, as in the previous model. Unlike the previous model however, not all prices are adjusted in every period.

Assume that all firms in both countries have a probability $1-\kappa$ of receiving an opportunity to change their price in any period. Then the newly set price for any home country firm in the non-traded goods sector that can change its price for period t is given by

$$(4.1) \qquad \tilde{P}_{Nt} = \frac{\lambda}{\lambda - 1} \frac{E_{t-1} \sum_{i=0}^{\infty} (\beta\kappa)^i \frac{W_{t+i}}{\theta_{t+i}} P_{Nt+i}^{\lambda} Y_{Nt+i} \frac{C_{t+i}^{-\rho}}{P_{t+i}}}{E_{t-1} \sum_{i=0}^{\infty} (\beta\kappa)^i P_{Nt+i}^{\lambda} Y_{Nt+i} \frac{C_{t+i}^{-\rho}}{P_{t+i}}}$$

Using standard properties of the Calvo price setting scheme, we may write the non-traded goods price index as

$$(4.2) \qquad P_{Nt}^{1-\lambda} = \kappa P_{Nt-1}^{1-\lambda} + (1-\kappa)\tilde{P}_{Nt}^{1-\lambda}$$

Now, taking a linear approximation of (4.1) and (4.2) around a zero-inflation steady state, and putting the two conditions together, we may obtain the conventional forward looking inflation equation, given by

$$(4.3) \qquad \pi_{Nt} = \varphi E_{t-1}(w_t - p_{Nt} - u_t - v_{t-1}) + \beta E_{t-1}\pi_{Nt+1}$$

Since the marginal cost facing firms in the home country traded goods sector is identical to that of the non-traded good firm, to a linear approximation the price inflation equation for traded goods will be identical to (4.3). We then follow the convention of referring to inflation in the home goods price (either traded or non-traded) as π_t.

To conform to the standard in the literature, we assume now that the monetary authorities follow an interest rate rule rather than a rule for the money supply. The gross nominal interest rate in the home economy may be read off the Euler equation as:

(4.4) $$R_t = \frac{1}{\beta} \frac{\frac{C_t^{-\rho}}{P_t}}{E_t \frac{C_{t+1}^{-\rho}}{P_{t+1}}}$$

Again, taking a linear approximation around a steady state, gives us:

(4.5) $$r_t = \bar{r} + \rho E_t(c_{t+1} - c_t) + E_t \pi_{t+1} + \frac{\gamma}{2} E_t(\tau_{t+1} - \tau_t)$$

Where $\tau_t = p_{ft}^* + s_t - p_{ht}$ is the home country terms of trade.

Assume that the monetary authority follows an interest rate rule given by:

(4.6) $$r_t = \bar{r} + \sigma \pi_t + \delta_t$$

where $E_{t-1}\delta_t = 0$. Different assumptions regarding δ_t will be examined below.

Table 2 describes the full model.

Table 2

The model with gradual price adjustment

Home inflation	$\pi_t = \varphi E_{t-1}(\rho c_t + \frac{\gamma}{2}\tau_t - u_t - v_{t-1}) + \beta E_{t-1}\pi_{t+1}$
Foreign inflation	$\pi_t^* = \varphi E_{t-1}(\rho c_t^* - \frac{\gamma}{2}\tau_t - u_t^* - v_{t-1}^*) + \beta E_{t-1}\pi_{t+1}^*$
Risk sharing	$\rho(c_t - c_t^*) = (1-\gamma)\tau_t$
Home interest rate	$\sigma\pi_t + \delta_t = \rho E_t(c_{t+1} - c_t) + E_t\pi_{t+1} + \frac{\gamma}{2}E_t(\tau_{t+1} - \tau_t)$
Foreign interest rate	$\sigma\pi_t^* + \delta_t^* = \rho E_t(c_{t+1}^* - c_t^*) + E_t\pi_{t+1}^* - \frac{\gamma}{2}E_t(\tau_{t+1} - \tau_t)$

For simplicity, we deal for now only with the case where all shocks are `news shocks', so

that $u_t = 0$. [4] Note that the flexible price solution to the model is identical to (3.7) and (3.8) above, so that $c_t = \frac{1}{\rho}\left[(1-\frac{\gamma}{2})v_{t-1} + \frac{\gamma}{2}v^*_{t-1}\right]$, $c^*_t = \frac{1}{\rho}\left[(1-\frac{\gamma}{2})v^*_{t-1} + \frac{\gamma}{2}v_{t-1}\right]$, and $\tau_t = v_{t-1} - v^*_{t-1}$. Efficient consumption and the terms of trade are independent of anticipated future productivity shocks.

The objective of monetary policy, as in the previous section, should be to replicate the response of the flexible price economy. But in contrast to the previous section, there is an independent welfare cost of inflation, even if it is perfectly anticipated. This is because in an environment of gradual price adjustment, inflation generates price dispersion, since not all firms may change their prices simultaneously. By setting inflation to zero, firms will never wish to adjust their prices, and thus price dispersion will be eliminated. As in Woodford (2003), an optimal monetary policy should therefore replicate the response of the flexible price economy, while achieving a zero rate of price change.

Note that so long as the monetary authority follows a rule in which $\sigma > 1$, the system in Table 2 is saddle path stable, and there is a unique solution for bounded shock processes.

Case 1. Simple Inflation Targeting

Assume that the monetary authorities follow a simple inflation targeting policy, setting $\sigma > 1$, but not adjusting interest rates to ex-post information, so that $\delta_t = 0$. We may write the general solutions for the terms of trade as $\tau_t = a_0 v_{t-1} + a^*_0 v^*_{t-1} + a_1 v_t + a^*_1 v^*_t$. Note that, since all prices are pre-set, the unanticipated component of the terms of trade; $\tau_t - E_{t-1}\tau_t = a_1 v_t + a^*_1 v^*_t$, is equivalent to the movement in the nominal exchange rate.

It is easy to verify that:

[4] Since the inflation rate is predetermined, an optimal policy response to a current productivity disturbance will require an interest rate adjustment - δ_t will need to fall in response to a positive u_t shock.

(4.7) $$a_0 = -a_0^* = \frac{\sigma\varphi}{1+\sigma\varphi},\ a_1 = -a_1^* = \frac{(\sigma-1)\varphi}{1+\sigma\varphi}.$$

The solution for home country inflation is written as:

(4.8) $$\pi_t = -\frac{\varphi}{1+\sigma\varphi} v_{t-1}.$$

The consumption responses may be written as:

(4.9) $$c_t = \frac{\varphi\sigma}{(\sigma\varphi+1)\rho}\left[\left(1-\frac{\gamma}{2}\right)v_{t-1} + \frac{\gamma}{2}v_{t-1}^*\right] + \frac{\varphi(\sigma-1)}{(\sigma\varphi+1)\rho}\left[\left(1-\frac{\gamma}{2}\right)v_t + \frac{\gamma}{2}v_t^*\right]$$

(4.10) $$c_t^* = \frac{\varphi\sigma}{(\sigma\varphi+1)\rho}\left[\left(1-\frac{\gamma}{2}\right)v_{t-1}^* + \frac{\gamma}{2}v_{t-1}\right] + \frac{\varphi(\sigma-1)}{(\sigma\varphi+1)\rho}\left[\left(1-\frac{\gamma}{2}\right)v_t^* + \frac{\gamma}{2}v_t\right]$$

As we increase the `tightness' of the monetary policy rule (i.e. setting $\sigma \to \infty$), the variance of inflation falls to zero. This also ensures that the anticipated component of the terms of trade and consumption responds as in the flexible price equilibrium. But this fails to support the full flexible price equilibrium, because it does not generate the appropriate response of the terms of trade to contemporaneous news shocks. In fact, a tight money rule exacerbates the inefficiency of news shocks. As σ increases, the response of the nominal exchange rate movement to news shocks is increased, generating a larger (inefficient) terms of trade and consumption movement.

The intuitive explanation for the relationship between the stance of monetary policy (as described by the parameter σ) and the response to news shocks can be understood as follows. Since a positive news shock will raise future consumption, it will tend to raise real interest rates in both countries. But with advance price setting and the interest rate rule (6.6), the nominal interest rate is pre-determined with respect to current news shocks. Moreover, the higher is σ, the smaller is the impact of news shocks on anticipated inflation. Given that both the nominal interest rate and anticipated inflation are smoothed, the upshot is that the equilibrium real interest

rate is prevented from responding the news shock, and more-so, the higher is σ. This makes the news shock more expansionary in the current period, raising consumption in both countries.

A similar explanation lies behind the terms of trade response to the news shock. Combining the two interest rate equations in Table 2, we have an equation in the terms of trade and inflation differentials, given by:

$$\sigma\Delta\pi_t = E_t\tau_{t+1} - \tau_t + E_t\Delta\pi_{t+1}, \tag{4.11}$$

where $\Delta\pi_t \equiv \pi_t - \pi_t^*$. Again, a news shock will tend to increase the anticipated future terms of trade, as it increases home relative to foreign productivity. With perfectly flexible prices, the impact would be offset by a fall in anticipated future relative inflation. But when inflation targeting stabilizes expected inflation, the change in the anticipated future terms of trade spills over into the current terms of trade.

Case 2. Targeting news shocks.

Now extend the interest rate rule so that $\delta_t = c_0 v_{t-1} + c_1 v_t$ for the home authorities, and $\delta_t^* = c_0 v_{t-1}^* + c_1 v_t^*$ for the foreign monetary authorities. Setting $c_0 = -1$ and $c_1 = 1$ jointly ensures that inflation is zero (for any value of $\sigma > 1$) and the terms of trade (and consumption) respond as in the fully flexible price equilibrium. Note that this implies that the nominal exchange rate is insulated against news shocks. But it does not mean that the exchange rate is fixed over time. The efficient monetary rule ensures that the inflation rate of domestic goods prices is zero in each country. Hence all terms of trade movement must involve exchange rate changes. But the key feature of this rule is that it eliminates any *unanticipated* exchange rate changes. The exchange rate will change in response to contemporaneous productivity shocks. But this change is anticipated one period in advance.

Case 3. Targeting exchange rates.

Since the optimal monetary policy eliminates exchange rate surprises, is there a case for including the exchange rate directly in the interest rate rule? Say now that the state-contingent component of interest rate rules for the home and foreign country are given by

$$\delta_t = \frac{\omega}{2}(\tau_t - E_{t-1}\tau_t),\ \ \delta_t^* = -\frac{\omega}{2}(\tau_t - E_{t-1}\tau_t) \tag{4.12}$$

We may solve the model under this specification. The solution for the terms of trade is given by:

$$\tau_t = \frac{\sigma\varphi}{1+\sigma\varphi}(v_{t-1} - v_{t-1}^*) + \frac{1}{1+\omega}\frac{(\sigma-1)\varphi}{1+\sigma\varphi}(v_t - v_t^*) \tag{4.13}$$

This differs from case 1 only due to the presence of the ω expression. But this difference is crucial, for it allows the policy maker to jointly ensure that the terms of trade responds appropriately to contemporaneous productivity shocks through an ex-ante `tight money rule' (i.e. setting σ very high) raising interest rates in response to anticipated inflation shocks, while at the same time eliminating the effects of news shocks on the terms of trade through an ex-post interest rate rule which raises interest rates in response to an unanticipated nominal exchange rate depreciation (setting ω very high). Hence, in the presence of news shocks, the standard inflation targeting prescription for an optimal monetary rule is not adequate. It can be improved by an explicit inclusion of the exchange rate in the interest rate rule. More precisely, the policy-maker should target a low expected rate of inflation, and dampen any unexpected movements in the nominal exchange rate.

Of course, this analysis pertains only to the response to news shocks. As pointed out in footnote 3 above, to the extent that there are unanticipated current productivity shocks, the optimal monetary policy should allow the exchange rate to respond immediately. Then, the extent to which monetary policy should accommodate surprise movements in the exchange rate

depends on the importance of news shocks in total exchange rate variability. The empirical evidence in section 1 above, however, suggests that most of the variance in exchange rate changes that can be attributed to fundamentals is accounted for by non-contemporaneous movements in fundamentals.

Section 5. Extension to a Model with Investment.

In the models we have analyzed up until now, efficient relative prices (and all other real allocations) are independent of future productivity realizations. This serves to highlight the inefficiency generated by having exchange rates change in response to announcements about future productivity shocks. But it might be argued that a more realistic economic model would allow for inter-temporal linkages between periods. A natural way to do this is by introducing capital into the production process and exploring the role of physical investment in linking relative prices and allocations between periods. We now extend the model to allow for physical investment, and in particular we allow current investment to respond to news shocks about future productivity. We show however that under a conventional calibration of the model, the results described above hold effectively without any change at all.

Amending the model to allow for investment requires only a few alterations. We assume that investment within each country is defined by an aggregator over non-traded and traded home and foreign goods using the same weights as the consumption aggregator. Each sector has specific capital which is immobile within a period, but may be augmented by investment, over time. Thus, defining $K_{Ht}(i)$ and $K_{Nt}(i)$ as capital of firm *i* in the home traded good and non-traded good sector, respectively, assuming capital is held as an asset by national residents, we model the evolution of the aggregate capital stock in the standard way as:

(5.1) $$K_{Nt+1} = \phi\left(\frac{I_{Nt}}{K_{Nt}}\right)K_{Nt} + (1-\delta)K_{Nt},$$

(5.2) $$K_{Ht+1} = \phi\left(\frac{I_{Ht}}{K_{Ht}}\right)K_{Ht} + (1-\delta)K_{Ht},$$

Where, in each case, we assume that $\phi'(.) > 0, \quad \phi''(.) < 0, \quad \phi(\delta) = \delta.$

Production functions for the two sectors are defined as:

(5.3) $$Y_{Nt}(i) = \theta_t K_{Ht}^{\alpha}(i) L_{Ht}^{1-\alpha}(i), \quad Y_{Nt}(i) = \theta_t K_{Nt}^{\alpha}(i) L_{Nt}^{1-\alpha}(i).$$

Again, the productivity shock is assumed to affect both sectors equally.

The previous optimization conditions for the household and firms are augmented in that a) households choose how much capital to hold, and b) firms' marginal cost functions now depend on the rental rate for capital. As before, we explore the impact of a news shock in the same form as above; i.e. a productivity expansion which is announced one period ahead. In this case, we assume that $\theta_{1t} = \theta_{1t-1}^{\mu}\exp(v_{t-1})$, where $0 < \mu < 1$.

Figures 1 to 4 illustrate the impact on a news shock in the home country on the terms of trade, aggregate home consumption, employment and investment under alternative monetary policy rules. Unlike the previous sections, even in the flexible price equilibrium a news shock impacts upon contemporaneous allocations through affecting optimal investment. The positive future productivity shock raises the return on investment today. But at the same time, the rise in future consumption arising from the future productivity increase raises the current real interest rate. This tends to depress investment today. The first locus in the Figures illustrates that, if prices are fully flexible, these two forces tend to offset each-other almost exactly. Investment and employment fall very slightly, but consumption and the terms of trade are effectively unchanged. This indicates that the central requirement of the previous model – that the efficient

level of the current relative prices should be insulated against news shock, carries over to the extended model with investment, in a quantitative sense.

Figures 1-4 also show the response of the terms of trade, consumption, employment and investment when prices are sticky (and set according to PCP), under different monetary rules. First, we look at inflation targeting as in (6.6), assuming that $\sigma = 1.5$. In this case, there is a noticeable difference both in the contemporaneous and the subsequent response to a news shock relative to that of the flexible price equilibrium. With sticky prices, the news shock has only a small impact on future output and consumption. This is because, absent a direct monetary policy response, the productivity increase can only affect output to the extent that prices adjust, and in this model, prices cannot adjust enough within one period to facilitate an efficient response to the productivity shock. This implies that the real interest rate increase is considerably less in the initial period. Consumption and investment therefore increase immediately. Likewise, the terms of trade increases immediately, but the terms of trade increase in the period in which the shock occurs is less than in the flexible price equilibrium.

Under strict inflation targeting (i.e. setting σ very high), the results are very much as before. Strict inflation targeting ensures that the economy responds efficiently to the productivity shock in the period in which it occurs. Intuitively, when the news shock pertaining to productivity in period t+1 is announced, there is a tendency for inflation for period t+1 to fall, as adjusting firms will revise their period t+1 prices downwards. This generates a large downward response in the nominal interest rate for period t+1, facilitating an efficient (flexible price equilibrium) response to the shock during period t+1. But strict inflation targeting again magnifies the immediate (time t) response of the terms of trade, consumption, and home country output to a home news shock, as in the previous section.

Finally, the Figures illustrate the effect of allowing interest rates to respond to unanticipated exchange rate changes in addition to anticipated inflation. That is, we allow a direct response of the interest rate rule to the surprise change in the exchange rate. As before, this policy effectively replicates the response of the flexible price equilibrium to news shocks. Again, it is efficient to prevent the current terms of trade from responding to news shocks, and this is done by eliminating unanticipated movements in the exchange rate.

In summary, this section illustrates that our results are not at all dependent on the properties of the simple model of earlier sections, that efficient allocations and relative prices are functions of contemporaneous productivity shocks alone. Even with an efficient response of investment to anticipated future shocks, both the results and the policy conclusions carry over essentially unchanged.

Section 6. Conclusions

The examples in the two models of the paper all imply that the exchange rate should be insulated against the impact of shocks to expectations over future productivity. This is because, with sticky nominal goods prices, exchange rate movements affect relative prices, and in the models we analyze, efficient relative prices are independent of future productivity. Even when we allow for efficient contemporaneous response of investment to news shocks, our numerical results indicate that unanticipated exchange rate movements generated by news shocks should be eliminated.

The model as formulated makes an assumption of complete markets. When market are incomplete, news shocks may generate wealth effects that alter current relative prices, even when all nominal prices are fully flexible. This makes the optimal policy response to news shocks less

clear. But it is still not self-evident that under a policy that ignores news shocks, the exchange rate will move in a manner consistent with efficient adjustment. More generally, an optimal cooperative monetary policy may wish to eliminate these wealth effects in any case, and this would be likely to involve dampening the exchange rate impacts of news shocks.

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Table 1

Upper Bounds for η_t from Equation (1.3)

Fundamentals:		*msw-y*	*p*	*i+p*
Country	*b*	η	η	η
Canada	0.9	0.780	0.258	0.352
	0.95	0.755	0.225	0.315
	0.99	0.735	0.200	0.287
	1	0.730	0.194	0.280
France	0.9	0.516	0.117	0.268
	0.95	0.449	0.067	0.188
	0.99	0.394	0.034	0.130
	1	0.380	0.027	0.116
Germany	0.9	0.460	0.184	0.289
	0.95	0.394	0.119	0.219
	0.99	0.339	0.072	0.165
	1	0.325	0.062	0.151
Italy	0.9	0.422	0.130	0.194
	0.95	0.369	0.078	0.123
	0.99	0.327	0.042	0.074
	1	0.316	0.035	0.063
Japan	0.9	0.361	0.243	0.624
	0.95	0.324	0.164	0.546
	0.99	0.294	0.106	0.480
	1	0.287	0.093	0.463
U.K.	0.9	0.239	0.236	0.260
	0.95	0.196	0.164	0.191
	0.99	0.164	0.110	0.139
	1	0.156	0.098	0.126

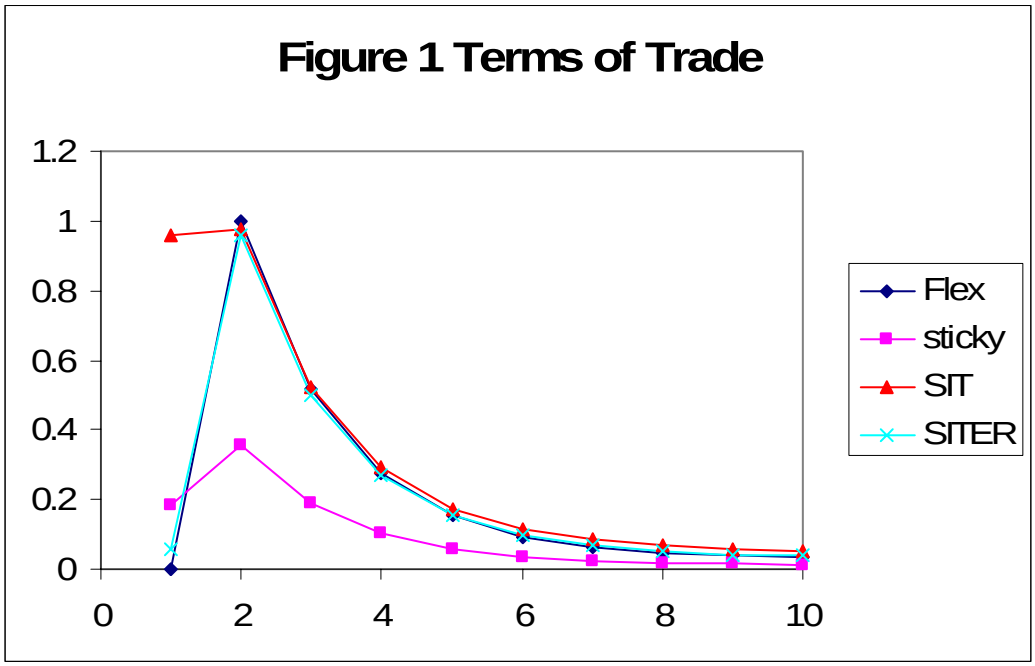
Figure 1 Terms of Trade
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
Flex
sticky
SIT
SITER

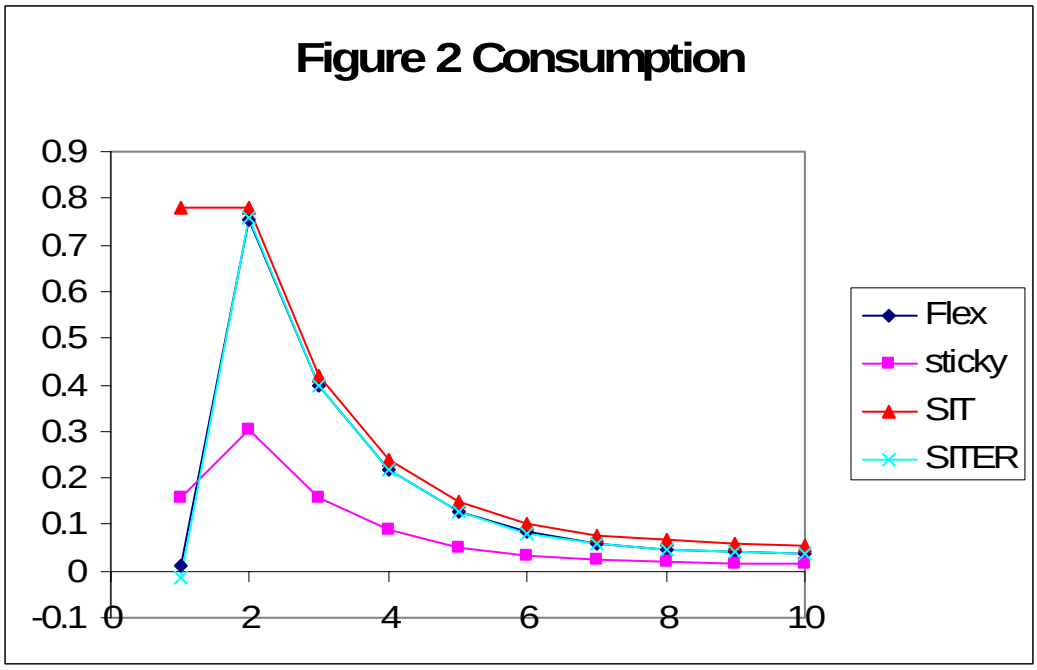
Figure 2 Consumption
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
2
4
6
8
10
Flex
sticky
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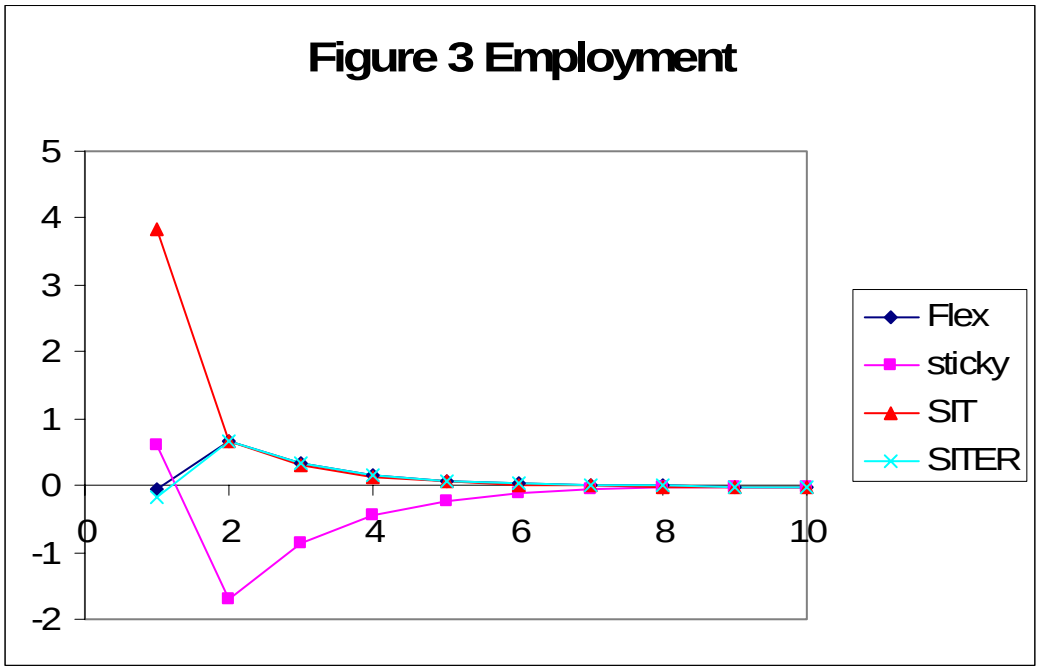
Figure 3 Employment
5
4
3
2
1
0
-1
-2
0
2
4
6
8
10
Flex
sticky
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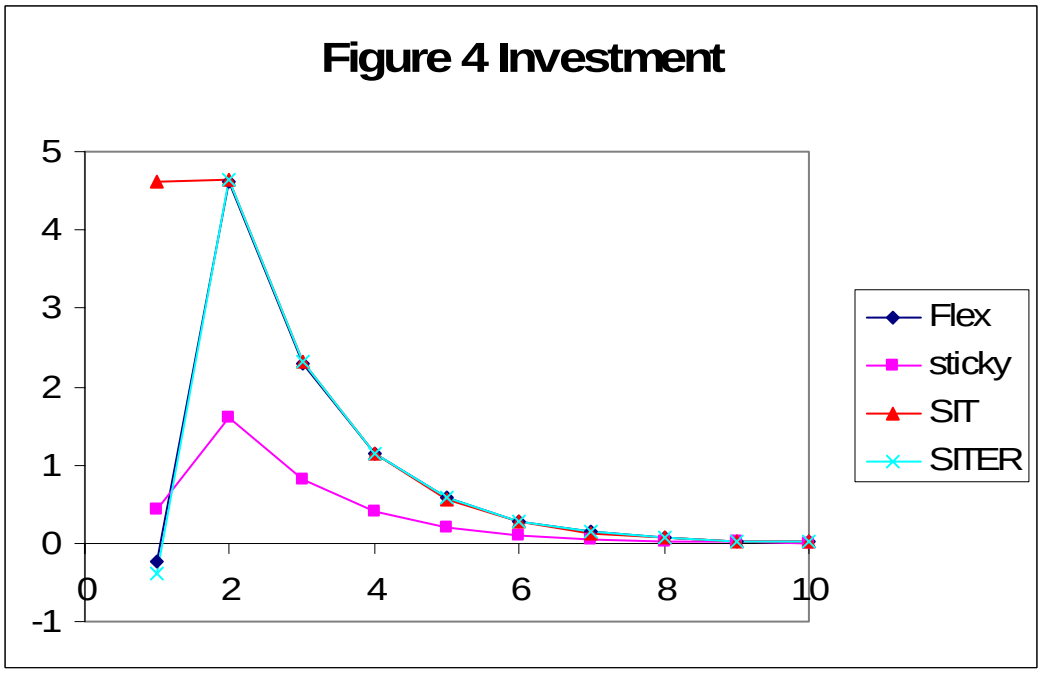
Figure 4 Investment
5
4
3
2
1
0
-1
0
2
4
6
8
10
Flex
sticky
SIT
SITER