Currency Crises and the Term Structure of Interest Rates

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April 1997

Abstract

The currency crisis literature has identified two possible types of crisis: fundamentals based crises and self-fulfilling crises. A fundamentals based crisis arises when some state variable, such as foreign exchange reserves, reaches a critical level and triggers the abandonment of the fixed rate. A self-fulfilling crisis is triggered by an autonomous change in the beliefs of speculators. This paper demonstrates how these two types of crises generate different behaviour in the term structure in the period before the crisis. It is suggested that term structure data may be used to classify particular historical episodes of currency crises.

Key words: Currency crises, term structure
JEL Classification: E43, F31

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1. Introduction

The currency crisis literature has identified two possible types of currency crises: fundamentals based crises and self-fulfilling crises. A fundamentals based crisis arises when some state variable, such as foreign exchange reserves or the level of unemployment, reaches a critical level and triggers the abandonment of the fixed rate. This line of literature originates from Krugman (1979). A self-fulfilling crisis is triggered by an autonomous change in the beliefs of speculators, as first modelled by Obstfeld (1986). More recent contributions to the literature have shown how these two types of crises can be consistent with optimising behaviour on the part of policymakers.[1]

The policy implications of the two types of crises are rather different, so it is important to find ways to identify the relevant model for each real-world occurrence of a currency crisis. This paper demonstrates how these two types of crises generate different behaviour in the term structure in the period before the crisis. It is therefore suggested that term structure data may provide valuable clues to the appropriate classification of particular historical episodes. This paper can thus be seen as a contribution to empirical validation of currency crisis models. However, an alternative way to think of the results presented in this paper is that they shed light on the behaviour the term structure in periods where a fixed exchange rate regime is vulnerable to attack. This paper can thus also be viewed as a contribution to the term structure literature.

The paper proceeds as follows. Section 2 presents two very simple and stylised models of currency crises. The first represents a fundamentals based crisis while the second represents a self-fulfilling crisis. Section 3 derives explicit expressions for the term structure of interest rates for pure discount bonds for the two models. Section 4 presents a detailed analysis of the term structure in the two models. Section 5 briefly considers the case of coupon paying bonds. Section 6 concludes the paper.

2. Two Stylised Models

It is assumed that the initial position is one where the exchange rate is

[1] See for instance, Obstfeld (1994) and Ozkan and Sutherland (1994).

fixed. The log of the exchange rate is denoted s and the current fixed parity is normalised such that $s=0$. A currency crisis, of whatever form, is assumed to result in the abandonment of the fixed rate and result in an immediate step devaluation of size θ. In addition, it is assumed that after the crisis monetary policy is such that the exchange rate is expected to depreciates at a constant rate μ Thus the post-crisis exchange rate can be written as

$$s(t) = \theta + \mu\left(t - \tilde{t}\right) \qquad \text{for } t \geq \tilde{t} \qquad (1)$$

where $\tilde{t}$ is the time at which the crisis occurs.[2]

In the case where the collapse of the fixed rate is the result of a fundamentals based attack it is necessary to specify a fundamental and define its driving process. The fundamental is denoted ε and is assumed to be a simple Brownian motion process of the following form

$$d\varepsilon = \eta dt + \sigma dz \qquad (2)$$

where z is a standard Wiener process with zero drift and unit variance. This fundamental can be through of as domestic credit (as in Krugman (1979)) or some measure of excess real capacity (similar to the model of Ozkan and Sutherland (1994)). In the former case domestic credit expansion eventually leads to an exhaustion of foreign exchange reserves. In the latter case excess capacity eventually reaches a level which policymakers are no longer willing to tolerate. In each case the fundamentals based collapse can be represented by assuming that there is a trigger level of ε, denoted $\bar{\varepsilon}$, and that the collapse occurs when ε makes a first passage through $\bar{\varepsilon}$ from below.[3] At the point of collapse the exchange rate switches from $s=0$ to the process specified in equation (1).

In what follows each of the parameters in equations (1) and (2) and the trigger level of ε are treated as independent. It is important to remember, however, that in a more fully specified model some of these parameters would in fact be endogenous variables. In the Ozkan and Sutherland model the trigger level, $\bar{\varepsilon}$, is endogenously determined by an interaction between the optimising behaviour of the policymaker and the

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2 The post crisis exchange rate could be made stochastic without substantially altering the results presented later in this paper.

3 With the obvious additional assumption that the initial level of ε is below $\bar{\varepsilon}$.

expectations of speculators. The size of the devaluation at the time of collapse is likewise an endogenous variable. In the Krugman model (and models based thereon) the rate of depreciation of the exchange rate in the post-collapse phase is related to the rate of domestic credit expansion (i.e. μ and η are related). The Krugman model also imposes the condition that there is no jump in the exchange rate at the time of collapse, i.e. $\theta=0$.

In the recent literature on self-fulfilling attacks, as represented by Obstfeld (1994), a self-fulfilling attack is usually represented by an autonomous switch from one rational expectations equilibrium, where the fixed rate is sustainable, to another equilibrium, where the fixed rate is not sustainable. Thus, typically, these models display multiple equilibria. The models do not, however, in themselves determine how a switch of equilibrium is triggered or how speculators co-ordinate on one equilibrium rather than another.

One crude way of representing self-fulfilling attacks, for present purposes, is simply to assume that a self-fulfilling attack occurs as a Poisson process with arrival rate v. To be specific, it is assumed that the fixed rate survives for the next instant dt with probability $(1-vdt)$ or that an attack occurs with probability vdt which triggers a switch to the post attack exchange rate process given in equation (1).

Again it is assumed that the parameter v is independent of the other parameters of the model. As in the previous case, in a more fully specified model it might that the size of the devaluation when an attack occurs or the rate of depreciation after the attack are related to the probability of an attack.

The next two sections analyse the implications of these two models for the term structure of interest rates. Before turning to that task it is worth noting that, although it is assumed here that the two types of attack are mutually exclusive, this is not necessarily true in the real world and it is not true of all theoretical models. Ozkan and Sutherland (1994), for instance, show that their model can generate fundamentals attacks, of the form represented by equation (2), and self-fulfilling attacks, of the form generated by multiple equilibria. The fact that either type of crisis can occur will have implications for the term structure. However, to keep the analysis simple, in what follows the two types of attack are treated separately.

3. Solution

Consider a pure discount bond of maturity τ which pays one unit of domestic currency at the time of maturity. If agents are risk neutral, arbitrage will establish the following relationship

$$e^{i(\tau,t)\tau} = e^{i^*(\tau,t)\tau} E_t\left[e^{s(t+\tau)}\right] \quad (3)$$

where $i(\tau,t)$ is the yield on a domestic pure discount bond of maturity τ at time t, $i^*(\tau,t)$ is the yield on the corresponding foreign currency bond and E_t is the expectations operator conditional on time t information. The left hand side of (3) represents the proceeds received from an investment of one unit of domestic currency in a domestic bond. The right hand side of (3) represents the expected proceeds from an investment of one unit of domestic currency in the foreign bond. (The time t exchange rate is unity so it has been omitted from this relationship.) Risk neutral arbitrage requires that these two quantities be equal. To simplify the analysis, equation (3) is replaced by the following log linear approximation

$$i(\tau,t) = i^*(\tau,t) + \frac{E_t[s(t+\tau)]}{\tau} \quad (4)$$

Equation (3) involves an expectation of a non-linear function of a stochastic variable so equation (4) implies that some Jensen's inequality terms are being neglected. For present purposes, it is assumed that these terms are of second order importance (but it is acknowledged that a more thorough analysis of this issue would be useful).

Equation (4) shows that the main task in solving for the term structure is to find an expression for $E_t[s(t+\tau)]$. A general expression for $E_t[s(t+\tau)]$, applicable to both crisis models, can be obtained by the following steps. For both models the timing of a crisis is a stochastic event. Denote by x the time until a crisis and by $g(x)$ the probability density function of x. If x is greater than τ then at the date of maturity of a τ maturity bond the fixed rate will still be in force so $s(t+\tau)=0$. If x is less than τ the crisis will have occurred before the date of maturity of the bond so $s(t+\tau) = \theta + \mu(\tau - x)$. So the following expression is obtained

$$E_t[s(t+\tau)] = \int_0^{\tau} g(x)\left[\theta + \mu(\tau - x)\right]dx \quad (5)$$

The next stage is to obtain an expression for *g(x)*. This is where the differences between the two currency crisis models enter. In the case of the fundamentals model *g(x)* is the probability density of the first passage time of ε through $\bar{\varepsilon}$ from below. This is easily obtained from standard texts (see for instance Cox and Miller (1965)) and is the following

$$g(x,\varepsilon)=\frac{(\bar{\varepsilon}-\varepsilon)}{\sigma\sqrt{2\pi x^3}}\,Exp\left[-\frac{(\bar{\varepsilon}-\varepsilon-\eta x)^2}{2\sigma^2 x}\right] \tag{6}$$

As can be seen, in this case g is a function of both x and ε.[4]

In general, for the fundamentals model it is not possible to carry out the integration in equation (5) explicitly. But for the special case where $\eta=0$ (i.e. a driftless fundamental) it is possible to obtain the following explicit expression for $E_t[s(t+\tau)]$

$$E_t[s(t+\tau)]=(\theta+\mu\tau)P_1(\tau,\varepsilon)-\mu P_2(\tau,\varepsilon) \tag{7}$$

where

$$P_1(\tau,\varepsilon)=1-\sqrt{\frac{2(\bar{\varepsilon}-\varepsilon)^2}{\pi\sigma^2\tau}}\,M\left[\frac{1}{2},\frac{3}{2},-\frac{(\bar{\varepsilon}-\varepsilon)^2}{\pi\sigma^2\tau}\right]$$

and

$$P_2(\tau,\varepsilon)=-\frac{(\bar{\varepsilon}-\varepsilon)^2}{\sigma^2}+\sqrt{\frac{2\tau(\bar{\varepsilon}-\varepsilon)^2}{\pi\sigma^2}}\,M\left[-\frac{1}{2},\frac{1}{2},-\frac{(\bar{\varepsilon}-\varepsilon)^2}{\pi\sigma^2\tau}\right]$$

where M[.,.,.] is the Confluent Hypergeometric function.

In the case of the model of self-fulfilling crises, where the crisis is driven by a Poisson arrival process, *g(x)* is given by the following

$$g(x)=ve^{-vx} \tag{8}$$

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[4] Svensson (1991) shows how a partial differential equation can be obtained which defines the behaviour of *E[s]* when fundamentals follow a Brownian motion. It is straightforward to show that expression for *E[s]* given in (5), with *g(x)* given by (6), solves Svensson's PDE and satisfies appropriate boundary conditions.

In this case the integration in (5) can easily be carried out, and yields the following expression for $E_t[s(t+\tau)]$

$$E_t[s(t+\tau)] = \mu\tau + \left[1 - e^{-\nu\tau}\right]\left(\theta - \frac{\mu}{\nu}\right) \tag{9}$$

The expressions given in (7) and (9) will be used in the analysis of the term structure presented in the next section.

4. Analysis of the Term Structure

In this section the implications for the term structure of the two currency crises model will be compared and the effects of the various parameters of the models will be analysed. Given the complexity of equation (7) the analysis is best accomplished by considering numerical examples. These are presented in Figures 1-6 which plot the term structure for different cases. Most of the plots are in pairs. For each pair the upper panel shows the effect of varying a particular parameter in the case of the fundamentals attack model, while the lower panel shows the effect of the same (or equivalent) parameter in the self-fulfilling attack model.

In the benchmark case the size of the devaluation at the time of the crisis is set at 10%, i.e. $\theta=0.1$, and the rate of depreciation after the crisis is set at 5%, i.e. $\mu=0.05$. In the fundamentals attack model the initial level of ε is set at zero and the trigger level of ε is set at 0.8, i.e. $\bar{\varepsilon} = 0.8$. The drift in the fundamental is set to zero and the noise parameter is set at unity, i.e. $\eta=0$, $\sigma=1$. Notice from equation (6) that the absolute level of the fundamental variable is irrelevant for the determination of interest rates. It is the difference between ε and $\bar{\varepsilon}$ that matters. Notice also that when there is no drift in the fundamental (as is the case in the benchmark parameter set) the noise parameter, σ, only enters through the term $(\bar{\varepsilon} - \varepsilon)/\sigma$, hence the effects of changes in σ can be inferred from the effects of changes in $(\bar{\varepsilon} - \varepsilon)$.

In order to create a point of comparison between the fundamentals model and the self-fulfilling attacks model it is useful to consider the probability of a collapse implied by the parameter set just described. The benchmark parameter for the fundamentals model implies a probability of 0.26 that there will be a collapse within one period (i.e. within the time interval $t=0$ to $t=1$). In the self-fulfilling attack model this same probability is obtained by setting $v=0.3$. This is therefore used as the benchmark value of v.

All the figures show $i(\tau,t)-i^*(\tau,t)$ on the vertical axis and τ on the horizontal axis. In other words the main focus is on the term structure of interest differentials, rather than on the term structure of interest rates. The terms structure of foreign interest rates is taken as exogenous in this analysis.

Figure 1 shows the term structure for the benchmark parameter sets for the two models. Some of the important features of the two cases are apparent from this figure. Notice firstly that both plots are converging on a value of 0.05 as the maturity increases. This fact is readily apparent from equation (9) for the self-fulfilling attack case, but is less apparent from equation (7) for the fundamentals case. However, in both cases the explanation for this feature is simple. At very long maturities it is almost certain that a crisis will occur within the lifetime of the bond, whichever form of attack model is being considered. So the long run expected behaviour of the exchange rate is dominated by the rate of depreciation after the crisis, i.e. it is dominated by μ. The benchmark value of μ is 0.05 hence this forms the asymptote for the term structure in both models.

The two models, however, differ greatly in the behaviour of the term structure at the short end of the maturity range. For the fundamentals model the term structure tends to zero as the maturity tends to zero, while for the self-fulfilling attack model the term structure tends to a value of 0.03 as the maturity tends to zero. This reflects one of the most important differences between the two models (at least in the form they are being represented in this paper). In the fundamentals based model a crisis occurs only once the fundamental has travelled the distance $\bar{\varepsilon}-\varepsilon$. The probability of this occurring in the next instant is effectively zero, so very short term interest rates are unaffected by the prospect of a crisis. On the other hand, in the self-fulfilling attack model a crisis can occur in any instance dt with probability vdt. The expected movement of the exchange rate over dt is therefore θvdt, so the instantaneous interest rate is $\theta vdt/dt=\theta v$ (and in the benchmark case θv=0.03).

The two models also differ in the behaviour of the middle range of the term structure. The self-fulfilling attack model produces a gently rising term structure from θv at the short end to μ at the long end. The fundamentals based model has a much more complicated structure. In this case, at first yields rise rapidly and reach a peak of nearly 0.06 at a maturity of about 6 months, and then gently decline. It is not readily apparent from the plot, but the term structure actually dips below 0.05 and then is asymptotic to 0.05 from below as maturity rises. The steady rise in the term structure in the self-fulfilling attack case reflects the steadily growing importance of the post attack depreciation rate as maturity increases. The hump shape of the term structure in the fundamentals based model reflects the interaction of two offsetting effects that arise as maturity increases. At relatively short maturities the probability of a crisis rises rapidly as τ increases. A high probability of a step change in the exchange rate requires a relatively large interest differential at short maturities, hence the rapid rise in the term structure. But at longer maturities the step change in the exchange rate (measured by θ) is spread out over a longer horizon so the required interest differential declines.

The effects of varying the main parameters of the two models will now be considered.

The upper panel in Figure 2 shows the effects of varying $\bar{\varepsilon} - \varepsilon$ in the fundamentals based model. It shows that, as $\bar{\varepsilon} - \varepsilon$ falls, the hump in the term structure increases, and the peak of the hump moves towards the short maturity end. This reflects the higher probability of the fundamental travelling the distance $\bar{\varepsilon} - \varepsilon$. (When $\bar{\varepsilon} - \varepsilon$=0.6, for instance, the probability of a crisis within one period is 0.4.) Conversely, when $\bar{\varepsilon} - \varepsilon$ rises the hump flattens out and eventually disappears, leaving a uniformly rising term structure. However, even for relatively large values of $\bar{\varepsilon} - \varepsilon$, the term structure retains the feature that it is steeper at the short end than at the long end. For all values of $\bar{\varepsilon} - \varepsilon$ it remains the case that the term structure is asymptotic to μ as at the long end (although this is not apparent in the figure).

The lower panel of Figure 2 shows the effect of varying v in the self-fulfilling attack model. It shows that increasing v raises the term structure along its entire length. For values of v less than about 0.5 the term structure remains relatively flat. Indeed for $v=0.5$ the term structure is horizontal at 0.05. The term structure is however pivoting as v rises and for values of v above 0.5 the term structure becomes downward sloping and can become very steeply downward sloping for high values of v.[5]

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[5] The values of v used to generate the lower panel of Figure 2 are chosen to match the values of ε used to generate the upper panel of Figure 2 in the sense that they produce the same probability of an attack occurring within 1 period. Thus v=0.095 yields the

Increasing v in the self-fulfilling attack model is in a sense equivalent to decreasing $\bar{\varepsilon} - \varepsilon$ in the fundamentals model. In each case the change has the effect of increasing the probability of a crisis happening in the near future, and it therefore raises the importance of the step devaluation for short maturities. In the self-fulfilling attack model this raises all short maturity rates, including the instantaneous rate. This contrasts with the fundamentals model where raising the probability of an attack raises medium maturity rates.

Figure 3 shows the effects of varying the size of the step devaluation, i.e. the effects of varying θ. To a great extent the effects shown in Figure 3 are similar to those shown in Figure 2. For the fundamentals based model, varying θ affects the height of the hump in the term structure. While in the self-fulfilling attack model, varying θ affects the intersection of the term structure with the vertical axis.

Figure 4 shows the effects of varying μ. The main effect of varying μ is on the long end of the term structure. In both models a reduction in μ tends to pivot the long end of the term structure downwards, and vice verse for an increase in μ.

Finally, Figure 5 shows the effects of varying the degree of drift in the fundamental in the fundamentals based model, i.e. the effects of varying η.[6] A positive drift obviously increases the probability that a crisis will occur. This tends to raise the term structure over all but the very short and the very long ends.

5. Coupon Paying Bonds

All of the analysis so far has concentrated on pure discount bonds. The term structure of yields on coupon paying bonds can behave rather differently from that of pure discount bonds, so it is useful briefly to consider coupon paying bonds.

Consider a domestic currency bond which pays a flow coupon of c and has a value of unity when it matures at time τ. The market price of this bond, denoted $p(\tau, t)$, is given by the following expression

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same probability of an attack as ε=-0.4, v=0.17 yields the same probability of an attack as ε=-0.2, v=0.3 yields the same probability as ε=0, and v=0.5 yields the same probability as ε=0.2. Plots corresponding to two further values of v are shown to illustrate the effects of values of v greater than 0.5.

[6] In this case it is necessary to use numerical integration to evaluate the integral in (5).

$$p(\tau,t)=\int_0^{\tau} ce^{-i(x,t)x}dx+e^{-i(\tau,t)\tau} \tag{10}$$

where *i(x,t)* is the yield on a pure discount bond of maturity *x*, as derived and analysed in previous sections of this paper. If the yield on the coupon paying bond is denoted *r(τ,t)*, then the following relationship must hold

$$\int_0^{\tau} ce^{-r(\tau,t)x}dx+e^{-r(\tau,t)\tau}=p(\tau,t)=\int_0^{\tau} ce^{-i(x,t)x}dx+e^{-i(\tau,t)\tau} \tag{11}$$

The integration on the right hand side can be carried out explicitly to yield

$$\frac{c}{r(\tau,t)}\left[1-e^{-r(\tau,t)\tau}\right]+e^{-r(\tau,t)\tau}=\int_0^{\tau} ce^{-i(x,t)x}dx+e^{-i(\tau,t)\tau} \tag{12}$$

r(τ,t) is the solution to this equation.

Figure 6 plots the term structure of coupon paying bonds for the two currency crisis models. To generate these plots *c* is set to unity. This is actually a very high value for *c* relative to the maturity value of the bonds and it is chosen to highlight the differences with the case of pure discount bonds. For comparison the benchmark pure discount term structure is also plotted in each panel of Figure 6.

It is immediately apparent that the general shape of the term structure for coupon paying bonds is very similar to pure discount bonds for both currency crisis models. There are just two differences between the coupon paying and pure discount cases. Firstly, the coupon paying term structure is marginally smoother than the pure discount term structure. This is true for both currency crisis models. This is because coupon paying bonds are effectively composite bonds, consisting of a combination of pure discount bonds, so the yield on a coupon paying bond is effectively a form of weighted average of the yields on pure discount bonds. Secondly, the coupon paying term structure is not asymptotic to μ as maturity rises. This is because the weight attached to pure discount yields, in forming the yield of the coupon paying bond, declines exponentially as maturity rises. Short dated pure discount yields therefore always tend to dominate the yield on coupon paying bonds, even for infinite maturity coupon paying bonds (i.e. consols).

6. Discussion and Conclusions

The results presented in Figures 1-5 highlight a number of important differences between the two forms of currency crisis model. The self-fulfilling attack model tends to produce a relatively flat term structure, while the fundamentals model tends to produce a hump shaped term structure with very low rates at the short end. These are features which relate to the term structure at a point in time. The dynamic behaviour of the term structure can be inferred from the results presented above and this will also display important differences between the models. In the self-fulfilling attack model a collapse can occur at any moment. The term structure may change as speculators change their views about the probability of an attack or receive news which alters their beliefs about the post attack regime, but there need be no relationship between the receipt of such news and the occurrence of an attack. There need not, therefore, be any systematic pattern of changes in the term structure before an attack takes place. On the other hand, in the fundamentals based model, a crisis only occurs when the fundamental reaches the trigger level. As Figure 2 shows, the term structure evolves in a systematic way as the fundamental rises towards the crisis level. As a crisis approaches, the hump in the term structure increases in height and moves towards the short end of the maturity range. It is suggested that these results may provide some clues which will be useful in classifying particular historical episodes.

Of course, there are a number of reasons for doubting the power of these results in providing a clear empirical distinction between currency crisis models. Firstly, there are situations, even given the narrow definitions of the models used in this paper, where the two models may yield very similar behaviour for the term structure. For instance, if a self-fulfilling attack is preceded by a period where speculators steadily revise upwards their views about the probability of a crisis (i.e. v increases) this will produce an increase in short rates which may look very similar to the effects of a fundamentals attack. Secondly, this paper has used very stylised definitions of the two currency crisis models which have some implications for the resulting behaviour of the term structure. In particular the fundamentals model is based on a stochastic process which rules out discrete jumps in the fundamental. This is crucial for determining the behaviour of very short term interest rates. For these two reasons it can be said that the results in this paper are open to the criticisms raised by Krugman (1997), namely that an empirical distinction between the two alternative models is being achieved by considering excessively narrow definitions of the models.

The results presented in this paper do, however, have other potential uses. There is a large theoretical and empirical literature which is directed at understanding the behaviour of the term structure. This paper shows that currency crises have very significant effects on the term structure. Currency crisis models, and the links with term structure behaviour as outlined in this paper, may therefore provide useful insights for the study of the term structure more generally.

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Figure 1: Benchmark cases

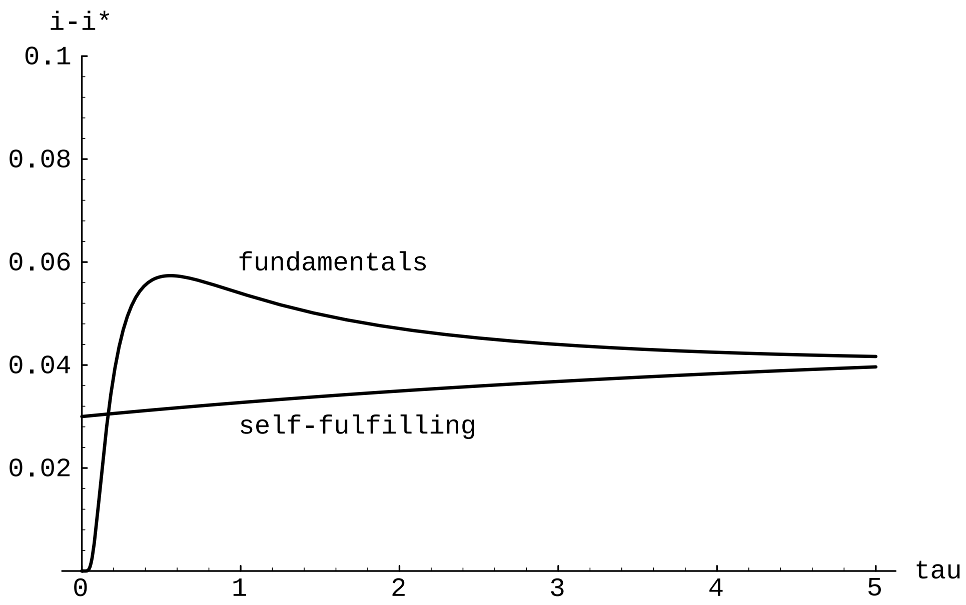
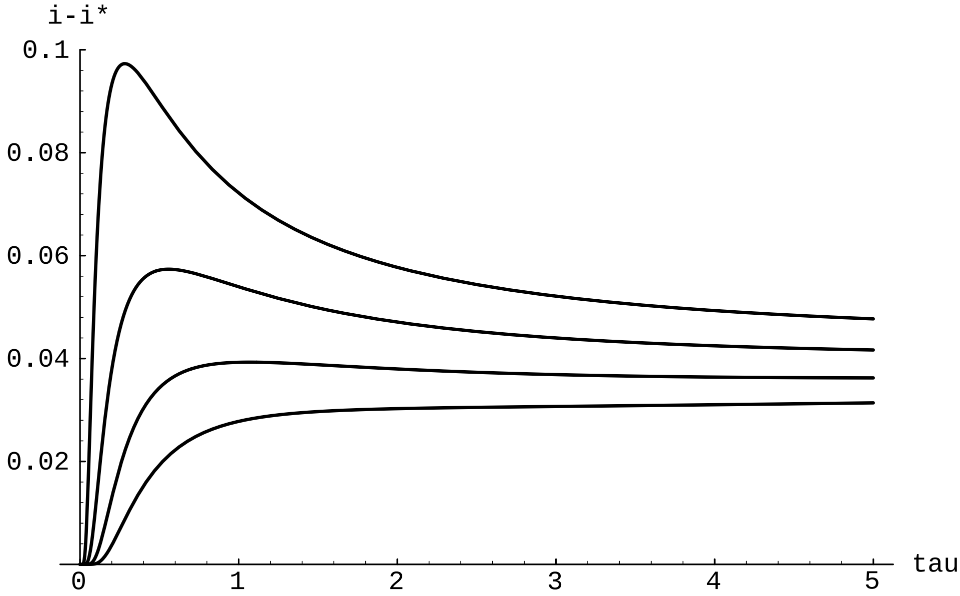
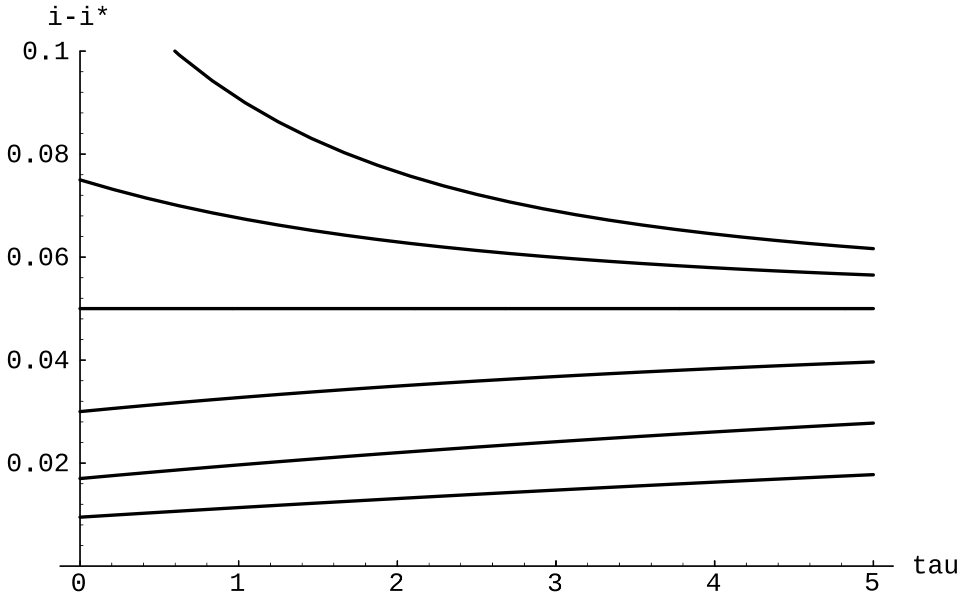


Figure 2: Effects of epsilon and v

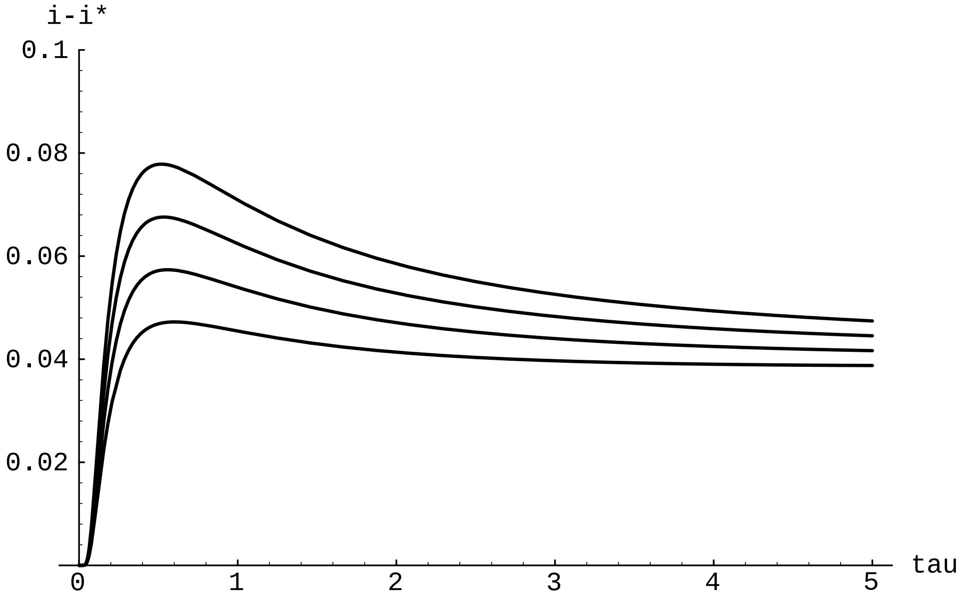


Starting with the lowest plot, epsilon=-0.4, -0.2, 0.0, 0.2

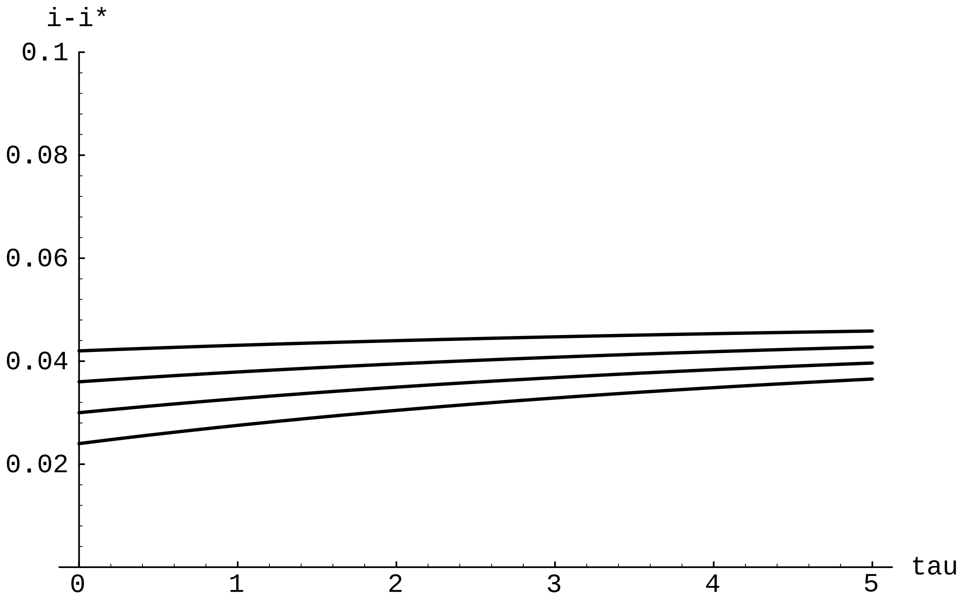


Starting with the lowest plot, v=0.095, 0.17, 0.3, 0.5, 0.75, 1.2

Figure 3: Effects of theta

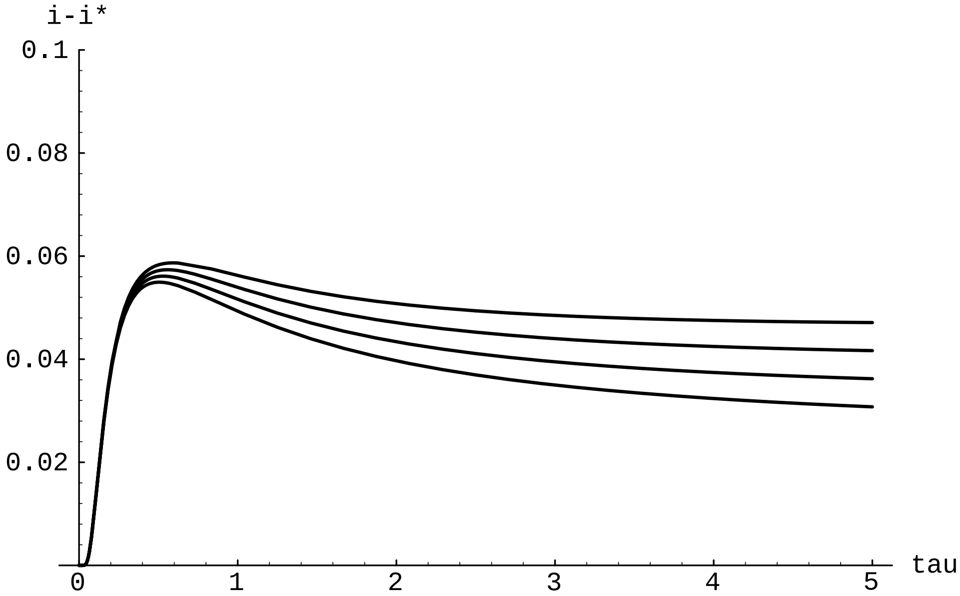


Starting with the lowest plot, theta=0.08, 0.10, 0.12, 0.14

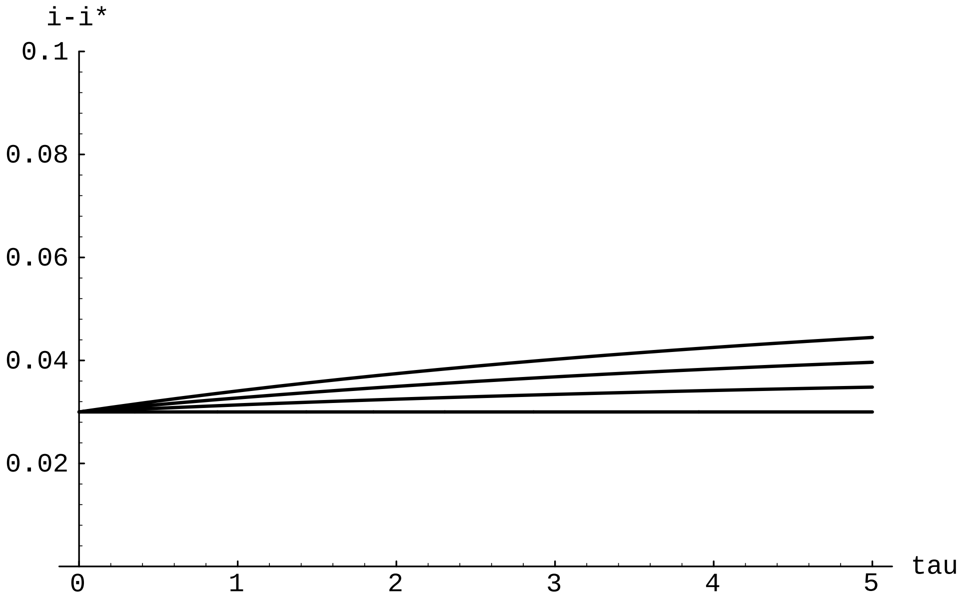


Starting with the lowest plot, theta=0.08, 0.10, 0.12, 0.14

Figure 4: Effects of mu

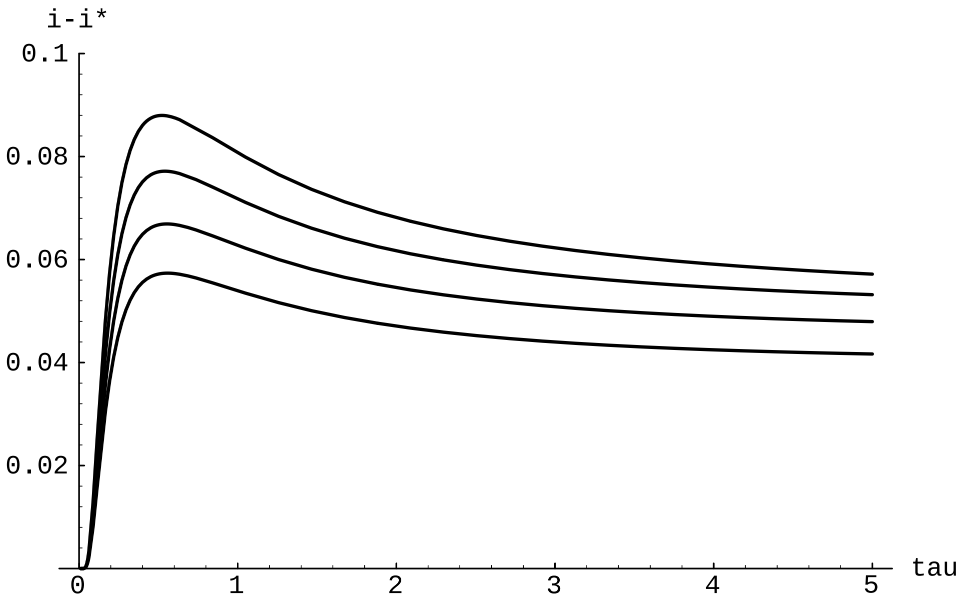


Starting with the lowest plot, mu=0.03, 0.04, 0.05, 0.06



Starting with the lowest plot, mu=0.03, 0.04, 0.05, 0.06

Figure 5: Effects of eta



Starting from the lowest plot, eta=0.0, 0.2, 0.4, 0.6

Figure 6: Coupon paying bonds